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REVISION OF ENVIRONMENTAL FACTORS FOR MIL-HDBK-217B

Martin Marietta Corporation

B. F. Kremp
E. W. Kimball

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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APPROVED: Lester J. Gubbins

LESTER J. GUBBINS
Project Engineer

APPROVED: David C. Luke

DAVID C. LUKE, Colonel, USAF
Chief, Reliability & Compatibility Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

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This study revised and updated the appropriate sections of Military Handbook 217C, "Reliability Prediction of Electronic Equipment", pertaining to Environmental Factor (π_E) Tables. More than 1.79 x 10^{12} part hours of field data were collected and analyzed during the study effort. The quantity of environments was expanded from the present 11 to a new total of 21, thus facilitating prediction accuracy.

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EVALUATION

This contractual effort is part of the broad RADC Reliability Program intended to provide reliability prediction, control and demonstration procedures for military electronic systems and equipment. The prediction procedures are contained in MIL-HDBK-217C for which RADC is the Preparing Activity. The new environmental factors developed in this effort for both operating and nonoperating modes will expand the applicability of the reliability prediction procedures and will be included in the next issue of MIL-HDBK-217. This effort is responsive to TPO IV F2, Equipment/System R&M.

LESTER J. GUBBINS
Project Engineer

SUMMARY

This report comprises the results of a 19-month program conducted by Martin Marietta Aerospace to revise the environmental factors for MIL-HDBK-217. This report summarizes the data collected and the data analysis methodology used. The revisions to the failure rate models and the environmental factor tables are provided separately in Appendix F.

A total of more than 1.39×10^{12} part hours of operating data and 3.98×10^{11} part hours of nonoperating data were collected. This gave a grand total of 1.79×10^{12} part hours of new information. The data were amassed as a result of an extensive collection program that included all major contractors, government facilities, and research organizations throughout the aerospace industry.

The list of environments was expanded from the present total of 11 to a new total of 21, thus facilitating improved prediction accuracy in both old and new applications for military electronic equipment.

PREFACE

This final technical report on Revision of Environmental Factors for MIL-HDBK-217B was prepared for Rome Air Development Center, Air Force Systems Command, Griffiss Air Force Base, New York by the Product Support and Logistics Division, Martin Marietta Aerospace, Orlando, Florida under contract F30602-78-C-0227. The objective of the study was to evaluate the environmental factors presently used in MIL-HDBK-217B and to determine what changes were needed concerning the environmental categorization, their definitions, their application level and their numerical values.

The contract was issued by Rome Air Development Center on 22 August 1978. Mr. Lester Gubbins (RBRT) was the RADC Project Engineer. This study was performed during the period August 1978 through March 1980.

Study team members included Edwin Kimball, Gloria Isler, Julie Gallassini, Marianne Sweeney, Peter Golding, John Keppel, Earle Kirkley, Nancy Thomson, Shelley Kujawa, Richard Long and others.

Technical consultation, and assistance in the collection of data was provided by George Guth, Thomas Kirejczyk, Donald Cottrell and others.

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1.0 INTRODUCTION

The reliability prediction procedure in MIL-HDBK-217B contained a series of nine equipment use environments. Each environment had associated π_E factors for each device model which adjust the predicted failure rate to account for the expected environmental severities that are not explicitly treated in the device models. Information received from users of the Handbook indicated that the method of accounting for environmental field conditions was overly simplistic, poorly defined, and inaccurate. Also, some equipment applications are omitted, for example helicopter and submarine. The study was initiated to correct these deficiencies.

Initially, the objective of the study consisted of revising and updating the appropriate environmental factors in MIL-HDBK-217B. However, during the course of the 19-month program, MIL-HDBK-217C was released and Proposed Change Notice 1 was circulated. Accordingly, appropriate revision of these later documents was included in the scope of the study.

It was necessary to determine what changes were required in the environmental categorization, definitions, application levels and numerical values of π_E that would result in more accurate reliability predictions that properly reflect field environments and equipment usage. The nuclear radiation environment and the effects of field conditions on avionics electronic equipment mounted on-board, or in pods for winged aircraft were specifically excluded from the study. It is anticipated that a contract will be awarded during 1980 to revise and update the Avionics Environmental Factors for MIL-HDBK-217.

The present study methodology consisted of 8 clearly defined tasks which are listed below:

1 Conducting environmental factors survey

2 Collection of data

3 Evaluation of alternate prediction techniques

4 Analysis of data

5 Determination of new environmental modes

6 Formulation of new mathematical models

7 Calculation of π_E values

8 Preparation of final report.

In the performance of this contract, Martin Marietta has developed procedures which more realistically describe how military environmental stress and field use conditions affect electronic equipment reliability. Data was collected from a wide range of recent vintage equipments being used in a variety of field environments. The data analysis resulted in all the necessary numerical factors required for reliability prediction. Clear definitions of these factors and directions for application have been included. Appropriate revision sheets to MIL-HDBK-217 have been provided as an appendix to the final report.

2.0 ENVIRONMENTAL FACTORS SURVEY

In accomplishing the evaluation and revision of the π_E environmental factors in MIL-HDBK-217B, efforts were constrained by a circumstance common to reliability engineering; there is no centrally organized collection and statistical analysis of historical data. Collection of "classical data," i.e., records of part and system failures with respect to part hours and operating conditions, has been erratic for electronic equipment in the field, dependent upon the military user and the responsible contractor. Data is held by both government agencies and private industry with access often restricted. There are environments for which little or no field data has been gathered. The difficulties involved with collecting statistically significant quantities of usable data in all field environments was recognized at the outset of this study. In anticipation of insufficient data for direct statistical analysis in all categories of the study, it was determined that expert opinion should be sought from the industry and used in conjunction with other results.

Since any single individual would have limited influence on the decisions and outcomes of this study, a technique that incorporated the concensus of the participating experts was established for use as an aid in decision making. A survey, consisting of two questionnaires, was conducted. The first questionnaire was distributed and the responses collected. Results of the first questionnaire were used to establish the content and format of the second questionnaire, which was then distributed to the participants. This feedback of the answers into the second questionnaire served to stimulate the experts to consider points which they might have neglected on first thought. The idea of tapping a wide spectrum of expert opinion is quite appealing on face value. This strategy appears even more attractive when participants are permitted to interact with each other's ideas in an anonymous atmosphere.

It was expected that the experts opinions would be valuable during data analysis and model formulation. The analysis for those environments for which little or no data is available could be supported by the experts opinion. The need for additional environments was addressed in the questionnaire and their responses were helpful in determining which ones were needed by the users of MIL-HDBK-217B. Of course, data availability was another determining factor in making these decisions.

Participants in the survey were selected: 1) because of association with the reliability department of a government contractor; 2) on the basis of a connection with a Navy, Army, Air Force, or NASA operation; 3) due to involvement in preparation of earlier versions of MIL-HDBK-217, or related investigations. The initial questionnaire was distributed to 102 people. The second questionnaire was distributed to those people responding to the first survey. However, all 102 people received feedback from the first survey.

2.1 First Survey

The first survey asked for evaluation of the MIL-HDBK-217 π_E factors from two different aspects. First there were questions designed to generate a broad critique of the handbook as it presently exists, its organization at the part level, the accuracy of the factors, the defined environments, etc. Secondly, the problem of evaluation of the handbook factors specifically, in terms of environmental categories and influences within those categories, was addressed. The participants were provided with definitions for nineteen different environments (or utilization modes). MIL-HDBK-217C lists eleven of these nineteen environments. A matrix with the environments down the left side and twenty-three influence factors across the top was provided. Participants were asked to indicate with an "x" in the appropriate box the influence factors they believed to be of major importance to environments with which they are familiar. Additional environments and/or influence factors could be added.

The initial survey, (see Appendix A) was distributed to 102 persons over the period November 21, 1978 through January 4, 1979. Seventy-four surveys (73.5% of total sent) were returned and a list of these participants is contained in Appendix B. The following conclusions were made by survey experts.

A majority of those responding to question 1 regarding improvements to environmental factors in MIL-HDBK-217 suggested:

1 A range of stress factors (or stress levels) be shown so that the user can know the effects of single factors.

2 Air to surface missiles, surface to air missiles, ICBM, MRBM, and shipboard launch missiles should be included as environmental categories.

3 Power on/off, cycling, dormancy, nonoperating and temperature-humidity-altitude should be included among the influence factors.

4 Forty-five percent of all those responding felt the environmental model for MIL-HDBK-217 should be at the part level; 30% felt it should be at the systems level; 25% wanted the model at both systems and parts levels.

A matrix summary, Figure 2.1-1 was prepared showing the total number of respondents that gave a positive response for each block in the matrix of survey one. As of January 19, 1979, there had been 49 responses. This matrix summary was sent to all survey participants. Through this summary a participant could measure his own judgements against those of the group. This allows reconsideration by the individual of his judgements and contributes to a convergence of expert response. Such convergence is desired as it generally tends towards a correct answer.

DATA SURVEY #1 RESULTS

CONTRACT F30602-78-C-0227 MIL-HDBK-217B ENVIRONMENTAL FACTORS

INFLUENCE MATRIX

**	ENVIRONMENT \ INFLUENCE FACTORS	ALTITUDE	HIGH TEMPERATURE	LOW TEMPERATURE	TEMP SHOCK/CYCLING	TEMPERATURE-ALTITUDE	SOLAR RADIATION	PYROTECHNIC SHOCK (HIGH FREQUENCY)	LOADS SHOCK	FUNGUS	SALT FOG	HUMIDITY	EXPLOSIVE ATMOSPHERE	LEAKAGE (IMMERSION)	ACCELERATION	RANDOM VIBRATION	SINE VIBRATION	ACOUSTICAL NOISE	PRESSURE SHOCK	SPACE SIMULATION	TEMPERATURE-HUMIDITY-ALTITUDE	EME
	***	23	41	37	35	23	21	28	26	20	27	39	14	20	27	41	29	24	17	10	23	27
21	GROUND, BENIGN	0	9	3	8	0	1	0	4	4	1	7	0	1	0	0	2	1	0	1	2	10
29	GROUND, FIXED	0	18	18	11	0	6	0	4	9	6	24	1	2	0	7	2	4	1	0	1	13
26	GROUND, MOBILE, WHEELED	0	20	[illegible]	12	0	5	1	14	13	11	23	4	7	5	22	10	10	1	0	4	11
23	GROUND, MOBILE, TRACKED	0	17	17	9	0	5	2	12	12	9	18	3	6	4	19	9	9	3	0	2	9
20	MANPACK	2	13	13	9	0	4	0	10	14	7	16	0	8	1	6	8	1	1	0	3	9
19	NAVAL, SHELTERED*	0	8	6	5	0	0	2	6	7	9	14	4	1	4	14	6	7	3	0	2	10
18	NAVAL, UNSHELTERED*	0	11	11	8	0	5	2	8	8	16	16	4	11	4	13	13	4	5	0	2	8
16	NAVAL, UNDERSEA, UNSHELTERED	1	3	9	6	0	0	1	4	6	8	11	0	12	3	9	9	3	9	0	2	4
18	NAVAL, BENIGN, SUBMARINE	1	7	5	1	0	0	1	4	6	6	15	4	3	1	12	9	5	3	0	1	10
14	NAVAL, HYDROFOIL	0	4	4	4	0	3	[illegible]	[illegible]	5	[illegible]	13	2	6	5	13	7	5	4	0	3	7
26	AIRBORNE, INHABITED, TRANSPORT	6	15	14	11	8	2	1	12	7	3	15	2	0	12	23	13	7	1	0	10	13
26	AIRBORNE, INHABITED, FIGHTER	8	17	14	11	9	4	2	14	7	3	15	2	1	17	23	12	8	3	0	13	14
24	AIRBORNE, UNINHABITED, TRANSPORT	17	23	19	17	18	5	1	13	7	8	17	5	1	13	23	13	8	4	1	17	13
28	AIRBORNE, UNINHABITED, FIGHTER	17	26	22	20	17	6	4	17	9	10	18	6	1	17	25	13	10	9	1	18	15
25	AIRBORNE, ROTARY WING	6	17	15	14	7	5	3	14	9	8	17	4	2	11	18	17	11	5	0	11	14
24	MISSILE LAUNCH	8	16	13	14	9	4	15	13	2	2	10	5	1	17	19	8	11	10	4	7	12
13	CANNON LAUNCH	1	7	5	6	3	1	10	9	3	2	7	2	1	13	10	5	5	7	0	3	7
20	MISSILE, FREE FLIGHT	12	14	11	8	10	4	0	7	2	1	7	2	0	8	14	6	5	5	8	7	9
19	SPACE FLIGHT	10	14	16	9	6	13	1	3	2	1	3	0	0	2	5	2	1	1	8	1	6
1	FIELD MAINTENANCE	0	0	1	0	0	0	0	0	1	0	2	0	1	0	0	0	0	0	0	1	0
1	MISSILE FREE FLIGHT (CRUISE)	1	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1
1	IMPACT PENETRATION	0	0	0	0	0	0	1	1	0	0	0	1	0	1	1	1	1	1	0	0	0
4	NON-OPERATING	2	4	4	3	3	2	1	2	3	2	4	0	1	1	3	3	3	2	0	1	4

ENVIRONMENT \ INFLUENCE FACTORS		IGNITION SHOCK (IGN @ ROCKET MOTOR)	IMPACT	CORROSION	DUST AND SAND	STATIC ELECTRICITY	GUNFIRE VIBRATION	VIBRATION-TEMP	TEMP HOT SPOTS	ICE/SNOW/RAIN	VACUUM-THERMAL	VACUUM-VIBRATION	RADIATION	ELECTRICAL ENERGIZING	ON-OFF CYCLING	MAINT SKILL LEVEL	TEMP HUMIDITY
***		1	1	2	4	1	1	1	1	3	1	1	1	1	3	1	1
GROUND, BENIGN		0	0	0	0	1	0	0	1	0	0	0	1	0	1	1	0
GROUND, FIXED		0	0	0	2	0	0	0	0	2	0	0	1	0	2	1	1
GROUND, MOBILE, WHEELED		0	0	0	3	0	0	0	1	2	0	0	1	0	2	0	1
GROUND, MOBILE, TRACKED		0	0	0	3	0	0	0	0	2	0	0	1	0	2	0	1
MANPACK		0	1	0	1	0	0	0	0	0	0	0	1	0	2	0	1
NAVAL, SHELTERED*		0	0	0	0	0	0	0	1	0	0	0	1	0	2	0	0
NAVAL, UNSHELTERED*		0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0
NAVAL, UNDERSEA, UNSHELTERED		0	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0
NAVAL, BENIGN, SUBMARINE		0	0	0	0	0	0	0	1	0	0	0	1	0	2	0	0
NAVAL, HYDROFOIL		0	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0
AIRBORNE, INHABITED, TRANSPORT		0	0	0	1	0	0	0	0	0	0	0	1	0	3	1	0
AIRBORNE, INHABITED, FIGHTER		0	0	0	1	0	0	0	0	0	0	0	1	0	2	1	0
AIRBORNE, UNINHABITED, TRANSPORT		0	0	0	3	0	1	1	0	1	0	0	1	1	2	1	0
AIRBORNE, UNINHABITED, FIGHTER		0	0	2	3	0	0	0	0	2	0	0	1	0	2	1	0
AIRBORNE, ROTARY WING		0	0	0	4	0	1	1	0	2	0	0	1	0	2	1	0
MISSILE LAUNCH		1	0	0	2	0	0	0	0	1	0	0	1	0	2	0	0
CANNON LAUNCH		0	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0
MISSILE, FREE FLIGHT		0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0
SPACE FLIGHT		0	0	0	0	0	0	0	0	0	1	1	1	0	2	0	0
FIELD MAINTENANCE		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MISSILE FREE FLIGHT (CRUISE)		0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
IMPACT PENETRATION		0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
NON-OPERATING		0	0	0	1	0	0	0	0	1	2	0	0	0	1	0	0

*ENVIRONMENTS SIGNIFICANTLY DIFFERENT FROM DEFINITION IN MIL-HDBK-217

**SHOWS THE NUMBER OF RESPONDENTS WHO INDICATED THE IMPORTANCE OF EACH ENVIRONMENT FOR AT LEAST ONE INFLUENCE FACTOR.

***SHOWS THE NUMBER OF RESPONDENTS WHO INDICATED THE IMPORTANCE OF EACH INFLUENCE FACTOR FOR AT LEAST ONE ENVIRONMENT.

INDIVIDUAL BLOCKS SHOW THE TOTAL NUMBER OF RESPONDENTS THAT GAVE A POSITIVE RESPONSE BY INDICATING THEIR BELIEF THAT THE BLOCK IN QUESTION IS OF MAJOR IMPORTANCE TO A PARTICULAR ENVIRONMENT. THERE HAVE BEEN 49 RESPONDENTS TO DATE.

Figure 2.1-1. Matrix Summary

2.2 Second Survey

In preparing the second survey, the matrix summary from the first survey was reviewed for insignificant blocks. An insignificant block was determined to be one in which less than twenty percent of the respondents for the environment felt that the influence factor was of major importance. These insignificant blocks were crossed out on a blank matrix. Also the blank matrix was modified in the following ways:

1 The list of environments was expanded to twenty-three by the addition of tactical missile launch, undersea launch, airbreathing missile flight, and nonoperating.

2 The missile launch environment was redefined as missile launch/reentry.

3 The influence factor of high temperature was deleted.

4 The three electromagnetic environments were combined under EME.

5 Dust/sand was added to the list of influence factors.

In the second survey, the participants were requested to establish an order of significance between influence factors in each environment for which they are familiar. The influence factors that are not crossed-out for that environment should be ranked on a scale of 1 to 10 with 10 being the most significant.

A participant was requested to rank their level of expertise for the environmental categories they responded to. A column on the left side was added to this modified matrix. The respondent was requested to rank their expertise on a scale of 1 to 3, 3 being a high level of expertise based on recorded failure rate data for that particular environment. For this reason, the survey was both intuitive and factual in content.

In addition, a column was added to the left side of the environment names to allow the participants to rank the overall severity of each environment to ground benign, which was given a severity ranking of 1.

The second survey is contained in Appendix C. Seventy-four second surveys were distributed. Fifty-two (70.3%) of the second surveys were returned. The average number of responses to any one environment was 25. This provided a sufficient sample size for statistical analysis.

2.3 Analysis

The 1 to 10 rankings of influence factors for each environment were analyzed by two methods: calculation of means and histograms. For ranking for each influence factor, an overall mean and the standard deviation for responses were calculated. In addition, a mean and standard deviation were calculated for the responses within each of the three groups of expertise. Bartlett's test for variance and the F-test of difference between means were run between the statistics for the three groups of expertise in each influence factor. There are a total of 301 influence factors. For 263 of these, the overall mean of the ranking values was an acceptable index of significance for that influence factor. In order to resolve the problem of finding a ranking for those 38 influence factors where the overall mean was not acceptable, and in order to reveal any clusters of opinion at one ranking which reasonably should override the overall mean as representative of the opinion of the survey sample, histograms were constructed for each influence factor. The objective of the statistical analyses was to establish a ranking and degree of significance between influence factors in each environment. To determine the appropriate number for each factor, the correlation between the overall mean and the histogram mode was tested by a visual scan. The overall mean was chosen as a factor's ranking when the histogram upheld its validity as the best representation of the opinion of the respondents. However, if the mode indicated the mean was a distorted indicator of the opinion of a majority of respondents, a number which was more representative of that opinion was determined from the histogram.

Rankings of severity between the environments were determined on the basis of the overall mean of the ratios suggested in the surveys. Outliers as determined by the Dixon Criterion Procedure with a 5% probability of risk were eliminated in calculating the means.

The resulting means for both influence factors and environmental severity ratios appear in the ranking matrix, Figure 2.3-1.

2.4 Survey Conclusions

Analysis of the survey results revealed several interesting conclusions. Worthy of note is the severity ranking for space flight being twice that of ground benign. Currently, MIL-HDBK-217C assigns space flight the same π_E factor as ground benign. Actual data collected in this study indicates that several of the part failure rates in space flight are lower than the rates in the ground benign modes.

Another survey observation is that nonoperating has approximately the same severity ratio as ground benign which is contrary to a previous study which showed that the average nonoperating part failure rate was about 1/100 of the average ground benign operating failure rate.

The new categories of missile launch were, on average, given significantly higher severity ratios than any π_E factors currently in MIL-HDBK-217. However the distributions of the U_{SL} (undersea launch), M_{FF} (missile free flight), M_{FA} (airbreathing missile, flight) and M_L (missile launch) rankings were bimodal. The lower mode was used in the analysis because it correlated with existing field data.

ENVIRONMENTAL SEVERITY RATIO	RANK	ENVIRONMENT \ INFLUENCE FACTORS	ALTITUDE	DUST/SAND	LOW TEMPERATURE	TEMPERATURE SHOCK/CYCLING	TEMPERATURE-ALTITUDE	SOLAR RADIATION	PYROTECHNIC SHOCK (HIGH FREQUENCY)	LOADS SHOCK	FUNGUS/MICROBES	SALT FOG	HUMIDITY	EXPLOSIVE ATMOSPHERE	LEAKAGE (IMMERSION)	ACCELERATION	RANDOM VIBRATION	SINE VIBRATION	ACOUSTICAL NOISE	PRESSURE SHOCK	SPACE SIMULATION	TEMPERATURE-HUMIDITY-ALTITUDE	ELECTROMAGNETIC ENVIRONMENT - EME
1	1	GROUND, BENIGN	X	X	X	1	X	X	X	1.5	1	X	3.94	X	X	X	X	X	X	X	X	X	4.11
2.7	4	GROUND, FIXED	X	X	3	3	X	1	X	X	2.64	1.5	5.64	X	X	X	1	X	X	X	X	X	4.0
11.5	8	GROUND, MOBILE, WHEELED	X	5.3	5.42	5.88	X	X	X	5.74	1	2	5	X	4.83	X	3.5	4.77	1	X	X	X	3.83
11.5	8	GROUND, MOBILE, TRACKED	X	8	5	5.96	X	2.62	X	6.30	1	2	5.45	X	4.87	X	10	5.09	4.16	X	X	X	3.9
12.5	9	MANPACK	X	X	5.61	7	X	X	X	5.74	2	1	6.07	X	7	X	5	1.5	X	X	X	X	1
7.3	6	NAVAL, SHELTERED	X	X	X	2	X	X	X	3	1	3	5.94	3.8	X	1.59	3.52	3.45	1	X	X	X	3.5
16.8	11	NAVAL, UNSHELTERED	X	X	5.52	4	X	3.2	X	8	4.23	10	10	1.5	10	2	5	4.14	2	3.32	X	X	3.94
20.6	15	NAVAL, UNDERSEA, UNSHELTERED	X	X	3	3.94	X	X	X	5.16	1	10	10	X	10	X	2	4.47	X	8	X	X	1
6.0	5	NAVAL, BENIGN, SUBMARINE	X	X	1	X	X	X	X	4.26	2.58	6	5.75	1	X	X	2.5	6	2	X	X	X	2
19.2	13	NAVAL, HYDROFOIL	X	X	3	3	X	2	X	6.31	3.53	8	7.12	X	7.5	1.5	6.62	5.18	4.93	3.29	X	2.23	3
10.2	7	AIRBORNE, INHABITED, TRANSPORT	1	X	3	6.59	5.19	X	X	4.35	1	X	4.62	X	X	2	6.33	4.62	3.59	X	X	[illegible]	4.61
19.5	14	AIRBORNE, INHABITED, FIGHTER	2	X	5.0	8	6.00	X	X	3	1	X	6	X	X	7	10	4.31	4.19	X	X	5.24	4.76
23.1	16	AIRBORNE, UNINHABITED, TRANSPORT	6	X	6.31	7.83	8	2	X	5.21	1	2	4.71	1	X	2	6.69	4.68	5	X	X	7	4.75
33.5	18	AIRBORNE, UNINHABITED, FIGHTER	8	X	6.65	10	6.87	2.78	X	6.03	1	2	6	1	X	7	10	4.81	4.53	4	X	8	4.71
27.6	17	AIRBORNE, ROTARY WING	2	5.23	6.11	8	5.56	X	X	5.80	1.5	2	5.35	X	X	3.64	10	8	5.37	X	X	5	4.92
42.7	20	MISSILE, LAUNCH/REENTRY	6.38	X	5.07	7.07	6.65	X	8.5	8	X	X	3.22	1	X	8	10	5.35	9	7	X	7.5	1
287.9	21	TACTICAL MISSILE, LAUNCH	1.5	X	3	7.12	5	X	10	7.34	X	X	4.05	1	X	9	10	4.77	5.84	2.5	1.5	8	4.90
720.6	22	CANNON, LAUNCH	X	X	3	5.40	3.94	X	10	10	1	X	4.32	X	X	10	8	1	1	7.0	X	1	2.57
37.1	19	UNDERSEA, LAUNCH	X	X	3.44	5.81	1	X	7	7.17	1	5	6.44	X	10	5	6.53	4.23	5.13	6.37	X	1	1
12.6	10	MISSILE, FREE FLIGHT	10	X	4.77	5.20	5	X	X	1	X	X	2.22	X	X	2	5	2.51	1	2	1.5	3	4.68
17.6	12	AIRBREATHING MISSILE, FLIGHT	5.85	X	5.10	5	5.84	2.89	X	5	X	X	3.33	X	X	8	8	4.81	5.05	4.58	1	4.61	1
2.1	3	SPACE, FLIGHT	1	X	5.88	5	8	10	X	X	X	X	X	X	X	X	1	X	X	X	10	X	5.14
1.1	2	NONOPERATING	1	3.88	3	2	1	1	1	1	3	3	5	1	1	1	1	1	1	1	1	1	1

NOTE: THE NUMBERS INSIDE THE MATRIX REPRESENT THE IMPORTANCE OF EACH FACTOR USING A SCALE OF 1 TO 10 WITH 10 BEING THE HIGHEST SEVERITY LEVEL.

Figure 2.3-1. Influence Matrix

For environments in which little or no data could be collected, the severity ratio rankings provided an insight to the relative rank of the environmental utilization mode and was of assistance in making a realistic estimate of a π_E factor.

The rankings of influence factors also proved helpful in defining the environments being evaluated by this study contract.

3.0 LITERATURE SEARCH

A search for information on the effects of environments on electronic equipments was conducted. All data available from past RADC reliability studies, conducted by Martin Marietta, were reviewed for environmental data. This existing data base consisted of 512 documents that were gathered as a result of past reliability studies and were available for review. By using the facilities of the Technical Information Center (TIC), The Defense Documentation Center's data base was researched so that appropriate new documents could be ordered.

The Martin Marietta Technical Information Center is a computerized information research laboratory. The company designed information storage and retrieval system provided documents to environmental project personnel in various fields of interest. The literature research staff conducted searches to support specific tasks and prepare computerized bibliographies, using the internal data base, commercial data bases and the Defense Documentation Center data base. The research capability includes:

1 100,000 records in an IBM370 computerized storage and retrieval system

2 On-line access to Defense Documentation Centers data base.

3 On-line entry to commercial data bases via DIALOG and ORBIT systems

4 31,000 technical volumes and more than 900 military manuals

5 Current issues and back copies of over 300 technical journals

6 An additional 53,000 reports stored on microfiche.

All of the above facilities were utilized to produce a master bibliography with abstracts. The master bibliography was reviewed in detail and copies of all pertinent documents were ordered from their respective sources. The documents received were further analyzed and reduced to the bibliography included in this report (see Section 10.0). The final bibliography represents all the formal manuals and reports reviewed during the update of MIL-HDBK-217C environmental factors. A large part of the failure rate data was obtained from informal reports and information gathered from outside contractors and government agencies as well as from Martin Marietta's various military projects under development and production.

4.0 DATA COLLECTION

After the survey was completed, attention was turned to the collection of failure rate data from fielded systems in the several environmental utilization modes. A list of potential data contributors was derived from several sources, the primary source being contributors of data for past reliability studies. Other potential data sources were obtained from the list of survey participants, their recommendations for contacts, suggestions from in-house personnel, from RADC, and from the literature search.

4.1 Planning

From the list of potential data contributors, a telephone canvas was made. In these calls, the objectives of the study were discussed so the potential data contributor would understand the use of the contributed data. The type of data and the desired formats for data were described to each potential contributor. From this initial dialogue, a determination was made whether there was a reasonable possibility that the organization had usable data or not, if contact had been made with the proper person in the organization, and if they knew of any other person/organization who might have data meeting our requirements. Other suggested sources were added to the primary list to be contacted. More than one hundred and eighty-five organizations were called during this telephone canvas.

As a result of the telephone canvas, a list of eighty-three potential data sources of military and governmental agencies, private companies and non-profit organizations was used for making follow-up calls. Before making the follow-up call, the source to be called was researched. The more information that was known about each potential data contributor, the better the chance of successfully suggesting the presence of usable data that may be available from that source. This is true especially concerning updates of data received from the organization for previous studies.

During the follow-up call, the objectives and data requirements of the study were reiterated. A discussion of that source data and its format usually ensued. If it was felt that the data would fit the needs of the study, and they were willing to donate it, a visit was scheduled to their plant to discuss and pick up their data. After itineraries had been established, appointment confirmation letters were sent to the parties to be visited and clearances transferred where necessary. A total of thirty-five organizations were scheduled for visits.

4.2 Presentation to Potential Data Contributors

Two different formats were used in the presentations given during the data collection trips. A formal, stand up presentation with visual aids was used if the grouping being addressed was large and there was a projector available. Appendix D contains the discussion and slides used in the formal presentation.

In some cases the situation lent itself to a more informal presentation. It was soon discovered that this informal, more personal approach yielded better results. Basically, the data collection team sat down and discussed in detail the study, its objectives, problems envisioned, plans and data requirements with the organization's representatives. The data collection team then listened to any suggestions that were made and expressed their views of these suggestions with useful dialogue often ensuing. The organization's representatives were then questioned about data they had which would fit the study's requirements. Part quality levels, derating guidelines, temperature stress, environment and other factors affecting the failure rates were discussed.

4.3 Data Collection

A total of six trips, three short and three extended trips, were taken to collect environmental failure rate data for this study. Two of the major trips were covered by a team of two persons and the remaining four trips were taken by a single person.

The first major trip covered the Northeastern United States. Six private companies, six military agencies and one non-profit research organization under contract with the military, in seven different areas from Boston, Massachusetts to Washington, D.C. were covered in two weeks.

The second major data collection trip included visits to fourteen private companies and two military organizations in the Los Angeles, San Francisco, and San Diego areas. Due to the number of scheduled visits and the limited time, the team split up for the second week of the trip in order to keep all of the appointments. One person covered the San Diego appointments while the other person kept the San Francisco appointments.

The third trip covered the central part of the country. One military organization, three private companies, and one governmental agency were visited during this trip. Facilities in Louisville, Kentucky, Crane, Indiana, St. Paul, Minnesota, Dallas, Texas and Albuquerque, New Mexico were visted during this trip.

Three shorter data collection trips were also taken. Mr. Earl Kirkley attended the 1978 Institute of Environmental Studies Seminar in Chicago to obtain information and advice pertaining to the Environmental Factors Study with a special emphasis on learning potential failure rate data sources. An announcement was made at the start of the seminar regarding the efforts to revise the application of environmental factors to reliability prediction in accordance with MIL-HDBK-217B. Private discussions were held between Mr. Kirkley and representatives from

Westinghouse Defense and Electronics Center, Sperry Univac, and Wright-Patterson Air Force Base in which the Program Plan was reviewed and inquiries made on any ideas the participants had pertaining to methods of revising the application of the π_E factors in reliability prediction.

Mr. Edwin Kimball traveled to Aberdeen, Maryland for the purpose of securing failure rate data for tracked versus wheeled vehicles. Problems with predicting failure rates for the above environments were also discussed.

Mr. Lee Mirth collected missile launch data from the Denver Division of Martin Marietta Aerospace. A major topic of discussion was Centaur Program data.

5.0 DATA ANALYSIS

The data analysis methodology used to update and revise the MIL-HDBK-217 environmental factor (π_E) tables conformed to the flow chart, Figure 5.0-1. The methods and equations employed during the analysis are described in detail in the following sections.

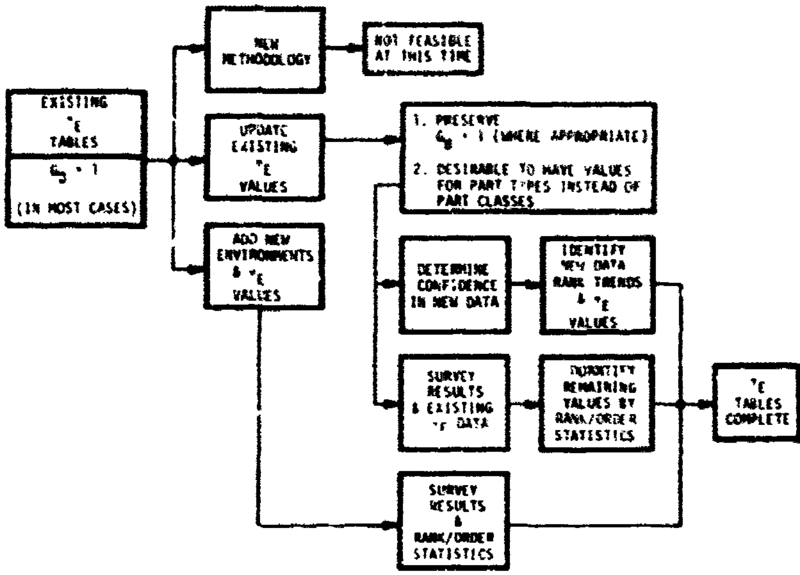


Figure 5.0-1. Data Analysis Methodology Flow Chart

5.1 Investigation of New Methodology

Several alternate methods for calculating the environmental effects on electronic equipment were investigated during the course of this study. New techniques, such as the environmental stress method described in Section 8.0 and the matrix approach discussed in Section 5.6 were considered and were found not feasible. Average part failure rates were calculated for the various environmental modes and this data was used to test the systems method for reliability prediction. Multiplying the total systems electronics part count by the segmented mission average part failure rates for a system with known field reliability, resulted in gross inaccuracies so this method was abandoned. The resulting system failure rates were too low by a factor of approximately 30 to 1. System type π_E factors were then calculated from the average part failure rates for each environmental mode. Conventional electronic part level predictions were then evaluated for 2 different complex systems in the benign mode. These failure rates were summed and the total was multiplied by appropriate system π_E factors for modes in which the true system reliability was already known. The resulting mode failure rates were too low by a factor of about 8 to 1. This method was more accurate than the average part failure rate approach but still considerably less accurate than the standard analytical procedure. It was therefore decided to retain the existing MIL-Handbook-217 methodology and data analysis proceeded as shown in the flow chart Figure 5.0-1 and described in subsequent sections of this report.

5.2 Analytical Methods

The collected failure rate data were categorized by the part types contained in MIL-HDBK-217. For the purpose of this analysis, a part type is defined to be that group of parts for which a separate model is shown in MIL-HDBK-217. For example, the discrete semiconductor part types are Group I conventional transistors, Group II FET transistors, etc.

The collected failure rate data for each part type contained a mix of quality levels, operating temperatures, stress ratios, and other influence factors that are contained in the part failure rate models of MIL-HDBK-217.

In order to isolate the effects of the environmental modes on failure rate, it was necessary to normalize the data to selected reference levels. The reference levels for the quality level, operating temperature and stress ratio were those which are representative of the largest quantity of collected part hours of data within each part type. The method used for normalization is shown below and is based on using modified part hours to calculate a normalized failure rate:

$$H_i = \lambda \text{ factor} \times Q \text{ factor} \times h_i$$

where:

H_i = modified part hours

h_i = collected part hours for each part type

$$\lambda \text{ factor} = \frac{\lambda_{bi}}{\lambda_{b\ ref}}$$

$$Q \text{ factor} = \frac{\pi_{Qi}}{\pi_{Q\ ref}}$$

λ_{bi} = the MIL-HDBK-217 tabular value of base failure rate (λ_b) for the temperature and stress ratio of the collected data

$\lambda_{b\ ref}$ = the MIL-HDBK-217 tabular value of base failure rate for the reference temperature and stress ratio

π_{Qi} = the MIL-HDBK-217 tabular value for the quality level (π_Q) of the collected data

$\pi_{Q\ ref}$ = the MIL-HDBK-217 tabular value for the reference quality level.

The other influence factors which were represented in the collected failure rate data were considered individually to determine if normalization was necessary. In some cases the value of the factor was equal to (or near) unity and normalization was not required. In some cases, the range of the factor value was small and a nominal value was used to normalize the data. In a few cases, the failure rate data were analyzed to select appropriate values for normalization.

The modified part hours (H_i) and the associated number of failures for the line entries were summed by environments for each part type. The failure rates were then calculated at the upper single-sided 60 percent confidence level. Prior to calculating the confidence levels, it had to be determined whether the component data were time or failure truncated. Since no known instances of failure truncated information were reported, received, or documented, it was assumed that the data were time truncated. The upper 60 percent confidence level failure rate can be calculated by using the component part hours and the Chi square (χ^2) value at 2r + 2 degrees of freedom at the 40 percent level of significance point. If the data had been failure truncated, the value would be obtained at 2r degrees of freedom. The following general equation was used for calculating the failure rate:

$$\frac{\chi^2(\alpha,\ 2r + 2)}{2H_i} = \lambda_{r.60}$$

where:

r = Number of failures and determines the degree of freedom coordinate used in determining χ^2

2r + 2 = Total number of degrees of freedom

α = Acceptable risk of error (40 percent in this study)

1-α = Confidence level (60 percent in this study)

H_i = Total number of modified part hours for the part type.

Since the statistical tables used were limited to χ^2 values up to 100 degrees of freedom, it was necessary to calculate an estimate of the χ^2 percentile points whenever more than 49 failures were observed in the data. Therefore, with degrees of freedom >100, the Chi Square Approximation equation was used:

$$\chi_p^2 = 1/2\ (Z_p + \sqrt{2f - 1})^2$$

where:

χ_p^2 = Approximated χ^2 value f = Total number of degrees of freedom

Z_p = 0.25335 and is the value of the standard normal variable at the 60 percent significance level

and

$$\lambda_{p.60} = \frac{\chi_p^2}{2H_1} .$$

The ground benign failure rates resulting from the analysis of the raw data showed good agreement with the reference level base failure rates (λ_b) in most of the existing MIL-HDBK-217 tables. The exceptions to this rule were the ground benign failure rates for transistors, Group I, silicon, NPN; transistors, Group I, silicon, PNP; diodes, Group IV, silicon; and zener diodes, Group V (MIL-HDBK-217 Tables 2.2.1-7, 2.2.1-8, 2.2.4-7, and 2.2.5-4 respectively). Accordingly, these tables were updated to reflect the latest "state-of-the-art" and are contained in Appendix E to this report.

5.3 Computation Procedure

When a failure rate for an environmental mode ($\lambda_{p.60}$) was calculated from a statistically significant quantity of part hours (typically > 100 x 10^6) it was ratioed to the ground benign reference failure rate to determine a revised π_E value for the mode:

$$\pi_E = \frac{\lambda_{p.60}}{\lambda_{bref_{GB}}}$$

The quantity of part hours collected for some part types in environmental modes presently considered by MIL-HDBK-217C was not adequate for this calculation. In this case, new environmental factors were computed by averaging the value from the survey (see Section 2.0) and the present MIL-HDBK-217C factor. The rationale behind this method is as follows. The old tables were based on data. The survey numbers reflect new experience, both intuitive and factual. The average was taken to provide equal weight to the old data and the survey which was based partly on judgement and partly on new data. Had the survey reflected all new data, it would have received greater weight.

The Fleet Reliability Assessment Program (FRAP) provided one of the few sources of controlled data from identical equipment which had been operated in more than one environment. The close correlation between this information and the survey results can be seen in Table 5.3-I below.

TABLE 5.3-1 COMPARISON OF FRAP VERSUS SURVEY DATA

FRAP SYSTEMS	ENVIRON-MENT	FAILURES	SYSTEM HOURS	FAILURE RATE
URC-62, WSC-3, UYK-20 and WRR-7	N_S	68	155852	0.000436
URC-62, WSC-3, UYK-20 and WRR-7	N_{SB}	24	64476	0.000372

$$\frac{\lambda_{N_{SB}}}{\lambda_{N_S}} = \frac{0.000372}{0.000436} = 0.85$$

$$\frac{\text{Survey } \pi_{E_{N_{SB}}}}{\text{Survey } \pi_{E_{N_S}}} = \frac{6.042}{7.300} = 0.83$$

Systems Used

URC-62 = AN/URC-62 VLF Fleet Broadcast System
WSC-3 = AN/WSC-3 Satellite Communication Set
UYK-20 = AN/UYK-20 Computer, Digital Data, Combat System
WRR-7 = AN/WRR-7 VERDIN Receiver

In some cases, an inadequate quantity of part hours was collected for part types in new environmental modes not presently included in MIL-HDBK-217C. The predominant information available was the π_E suggested by the survey, all of which are scaled to a Ground Benign (G_B) factor of 1.0. However, the survey yielded general environmental factors which are not tailored to any specific part type. Therefore, a formula was derived to adjust the range of these survey factors to the range of factors for specific part types as given in MIL-HDBK-217C, Notice 1. The Missile Launch (M_L) environment, which is the most severe environment in the existing handbook was selected as the ranging parameter in the formula:

$$\pi_E = \text{Survey } \pi_E \cdot \frac{\hat{\pi}_E (M_L)}{\text{Survey } \pi_E (M_L)}$$

where:

Survey π_E = Survey value for environment of interest

Survey $\pi_{E(M_L)}$ = Survey value for M_L mode

$\hat{\pi}_E (M_L)$ = Average of the survey value and existing MIL-HDBK-217C value for M_L

The M_L values were used for ordering within the range because this mode has the highest numbers in the MIL-HDBK-217C π_E tables. The synthesizing procedure assumes a constant survey bias which results in slightly conservative predictions.

In some instances, the operating π_E values for space flight, which had been calculated from data with large quantities of part hours (>100 x 10^6) were in the range of 0.1 to 1.0. It would have been possible to equate this value to the base 1 and ratio the remaining π_E's accordingly. This approach was not used because the base failure rate (λ_b) tables reflect ground benign conditions. Revision of some of these tables to reflect space flight conditions would have resulted in M_L π_E's some 5 to 10 times higher than the present values. In the interests of consistency the space flight π_E values were therefore allowed to drop below 1 when calculated from a large data base and the corresponding λ_b tables were not changed so they continue to reflect ground benign conditions.

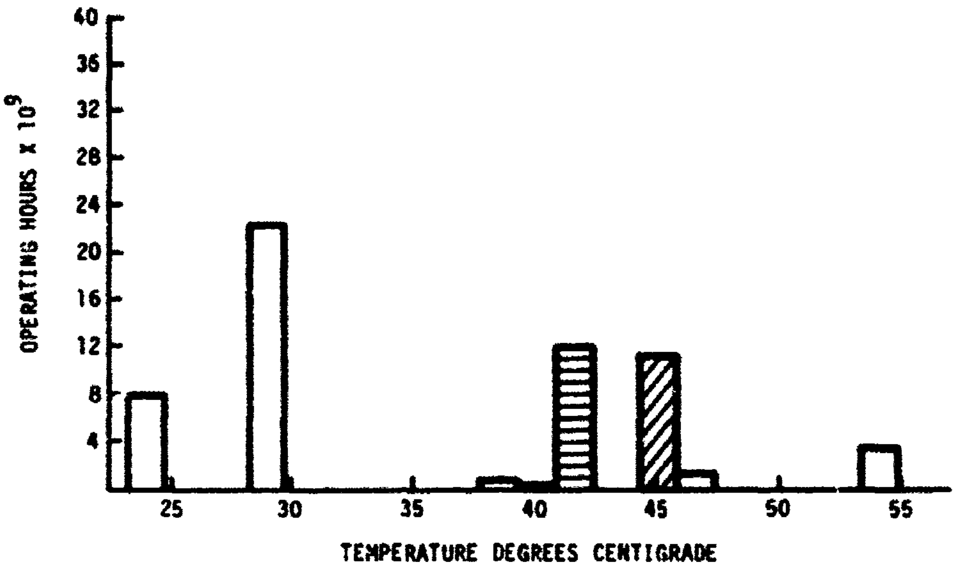
Nonoperating failure data were collected analyzed in a manner similar to the operating failure data. Since no electrical stress is applied in the nonoperating mode and most of the collected data reflected ground conditions approximately 25°C, it was not necessary to normalize the nonoperating data for stress. The operating mathematical model for each part was revised as necessary by deleting terms which were not appropriate for the nonoperating mode. The model was then evaluated and solved for nonoperating environmental factors (π_{ENO}) by substituting the appropriate π's and the table value for λ_b at 25°C and 10 percent stress ratio since that value most closely approximated the nonoperating fixed ground conditions. The nonoperating failure rate calculated from the collected new data provided the λ_{PNO} term. In most cases, the π_{ENO} calculated for each part type was recorded under the ground fixed (G_F) mode since this was the environment from which the majority of the nonoperating data were collected. The remaining π_{ENO} factors for the other modes were synthesized from the relationship between the operating π_E factors.

The nonoperating failure rates are used in reliability calculations to reflect stability degradation during periods of dormancy or storage. The ground benign (G_B) and ground fixed (G_F) π_{ENO} factors are applied when the equipment is either in storage or assembled into an all-up system but not operating. When the equipment is stored, or otherwise in a non-operating mode, in an environment that experiences relatively nominal conditions or controlled environments, the π_{ENO} factors for ground benign (G_B) are appropriate. Storage in a factory or air conditioned storeroom would be examples of ground benign conditions. Uncontrolled or "field" conditions are appropriate for ground fixed π_{ENO} conditions. The remaining π_{ENO} factors are utilized primarily when equipment is involved in a mission, but is not operating, such as aircraft captive carry to and from the target.

The data base used for this study is contained in the Collected Failure Data Summary, Appendix G. Line items for certain environmental utilization modes such as M_L, A_{RW}, and N_U have numerous entries with relatively small quantities of part hours and zero failures. These entries should not be used for analytical studies unless they are supplemented with enough additional data to obtain statistically significant results.

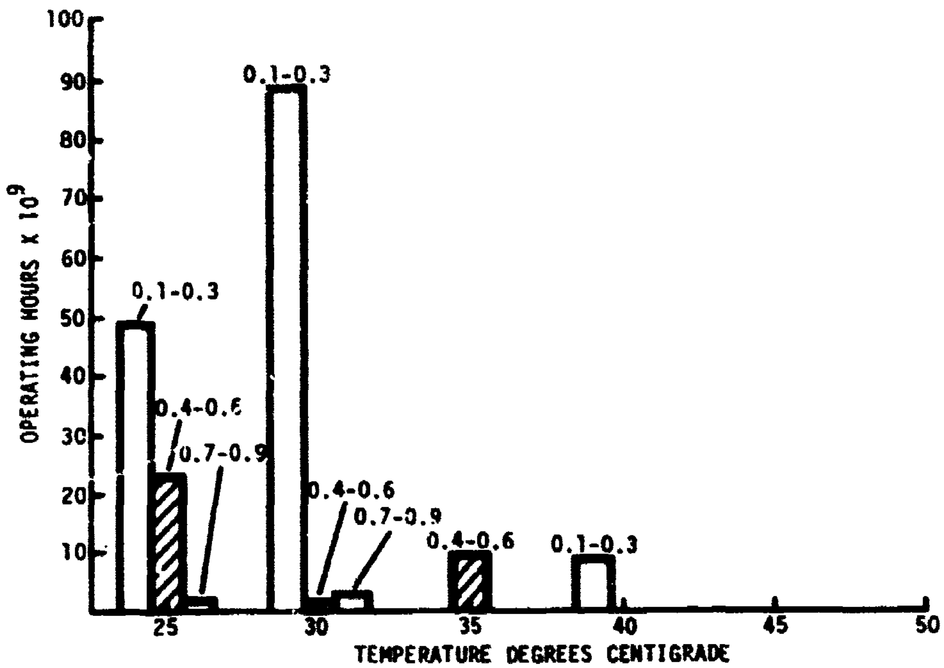
5.4 Histograms

The collected operating data was analyzed in histogram form to study the distribution of temperature and quality level within each group of parts. This was necessary to select the reference levels that represent the largest quantity of data as discussed in Section 5.2. These histograms for the major portion of the data base are shown in Figures 5.4-1 through 5.4-17.



REFERENCE LEVEL: 30°C

Figure 5.4-1. Microelectronic Devices Temperature Histogram



REFERENCE LEVEL: 30°C/STRESS RATIO = 0.2

F e 5.4-2. Discrete Semiconductors Temperature/Stress Histogram

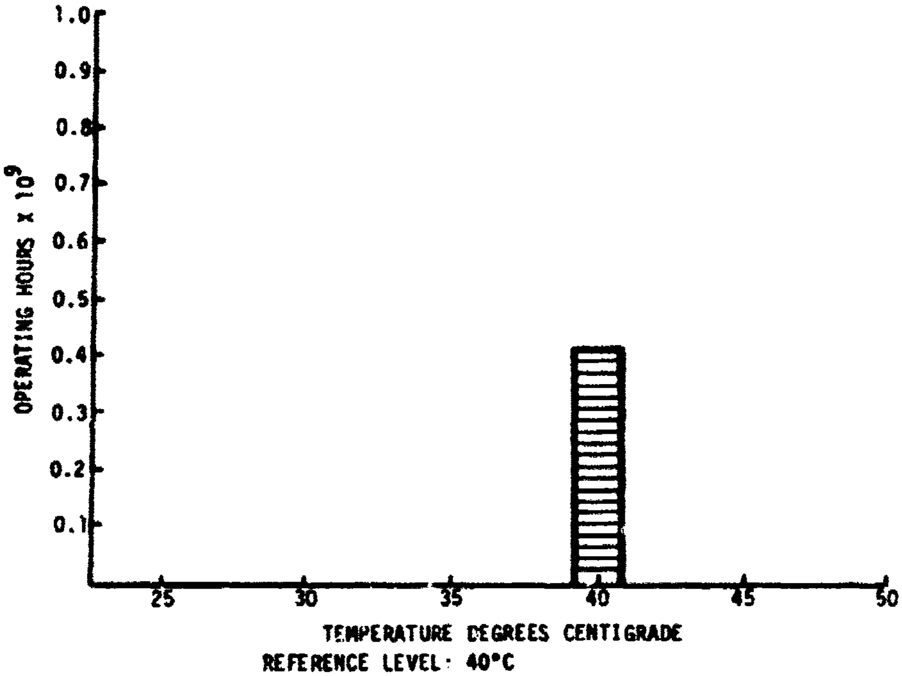


Figure 5.4-3. Tubes Temperature Histogram

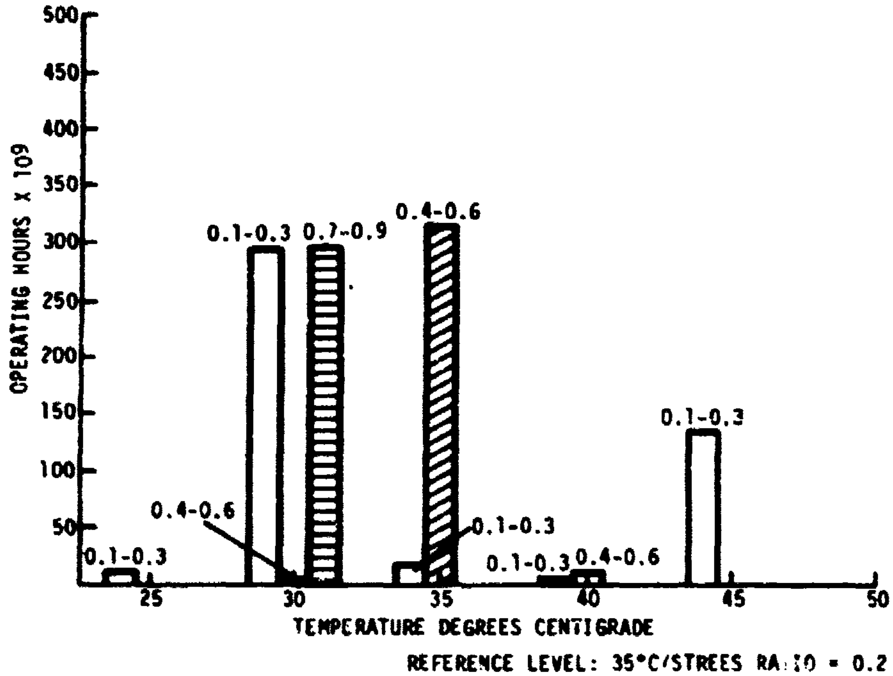


Figure 5.4-4. Resistors Temperature/Stress Histogram

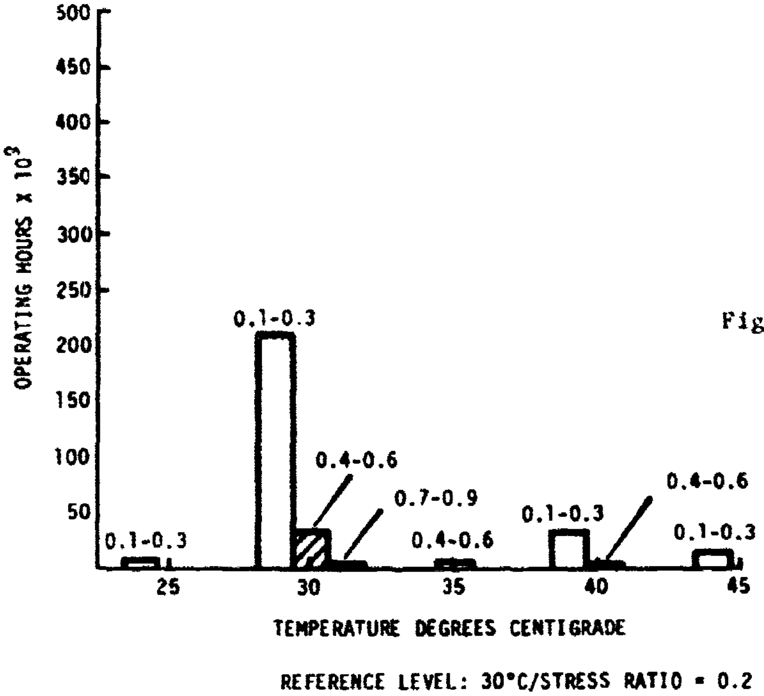


Figure 5.4-5. Capacitors Temperature/Stress Histogram

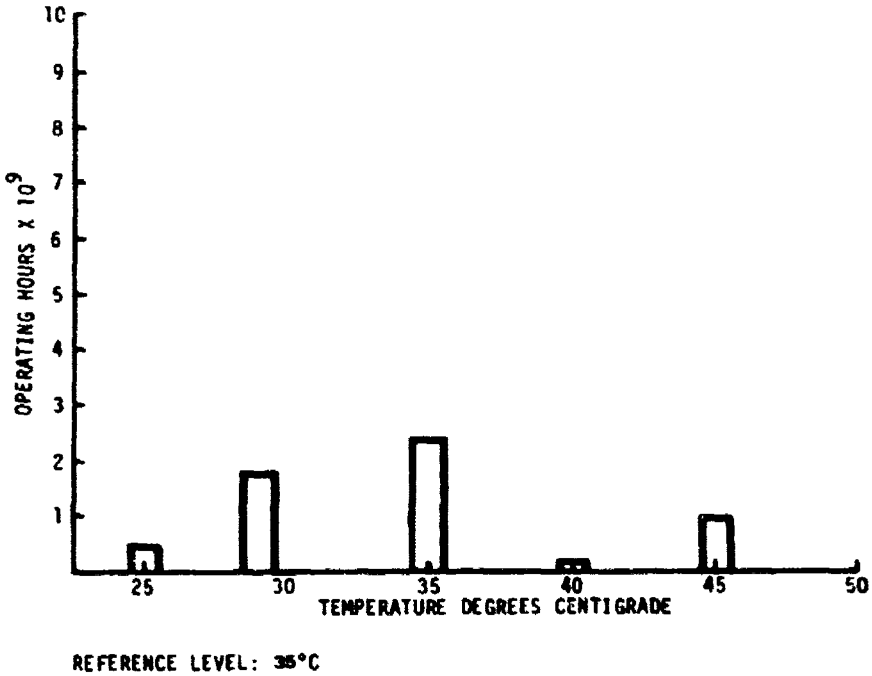


Figure 5.4-6. Inductive Devices Temperature Histogram

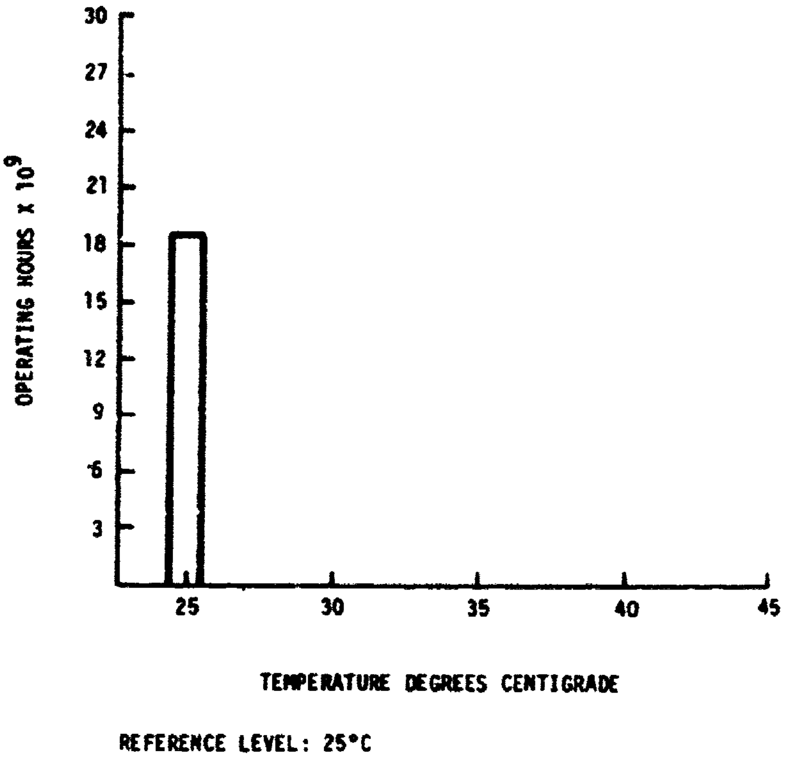


Figure 5.4-7. Rotating Devices Temperature Histogram

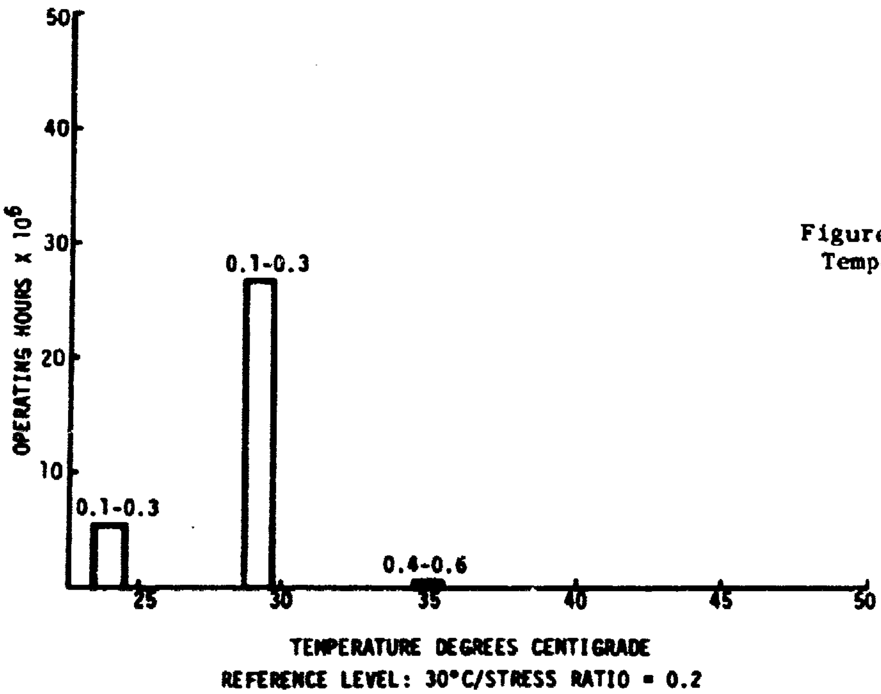
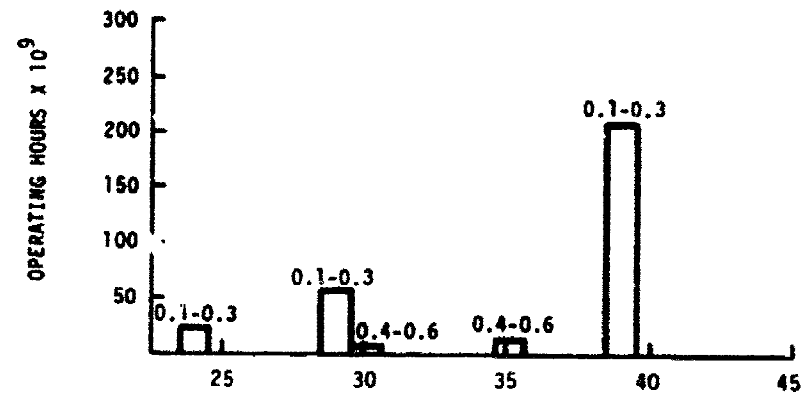


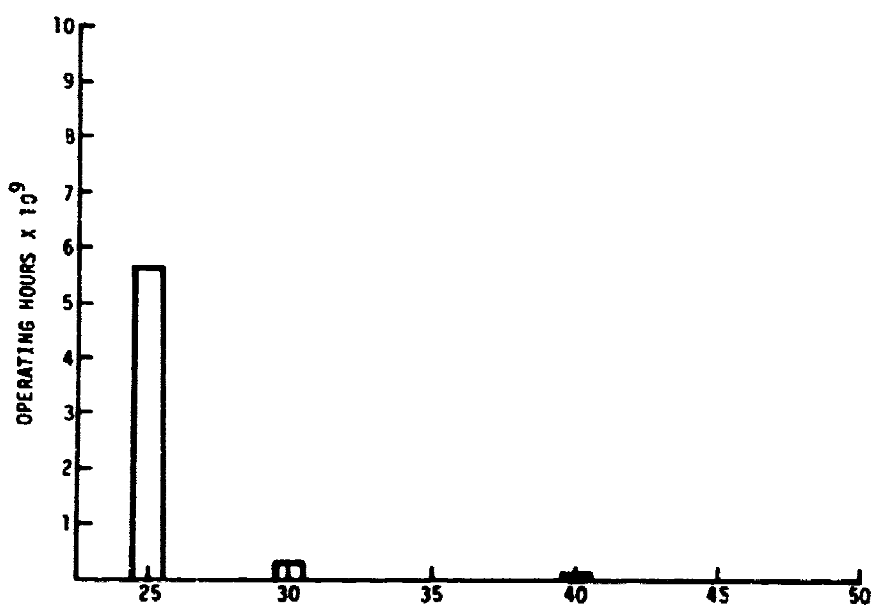
Figure 5.4-8. Relays Temperature/Stress Histogram



TEMPERATURE DEGREES CENTIGRADE

REFERENCE LEVEL: 40°C/STRESS RATIO = 0.2

Figure 5.4-9. Switches Temperature/Stress Histogram



TEMPERATURE DEGREES CENTIGRADE

REFERENCE LEVEL: 25°C

Figure 5.4-10. Connectors Temperature Histogram

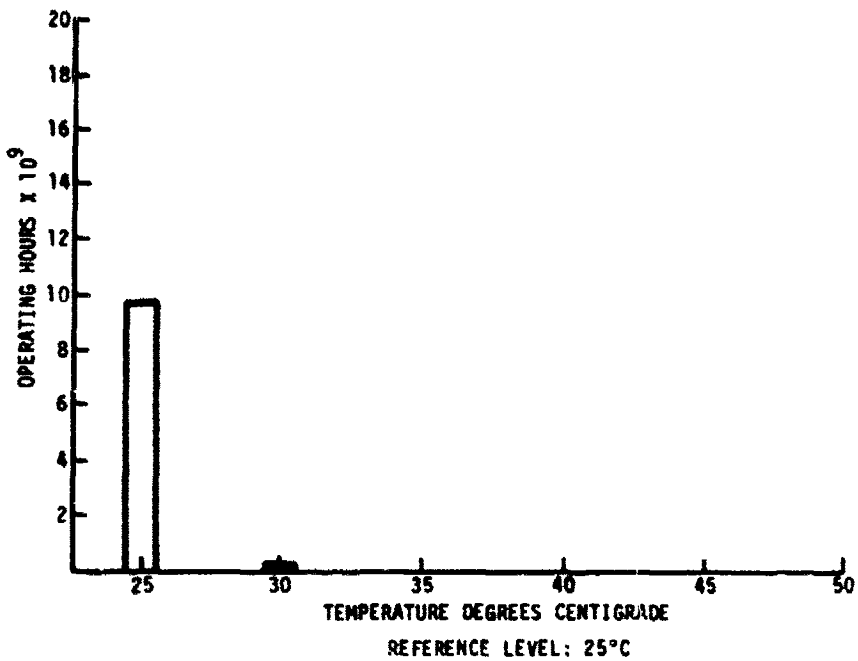


Figure 5.4-11. Printed Wiring Boards Temperature Histogram

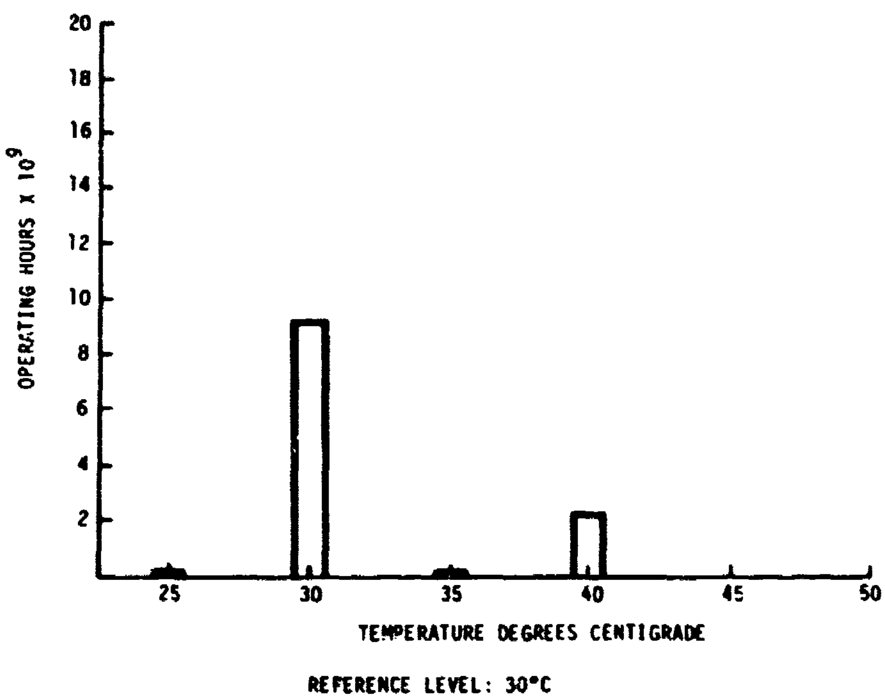


Figure 5.4-12. Connection Temperature Histogram

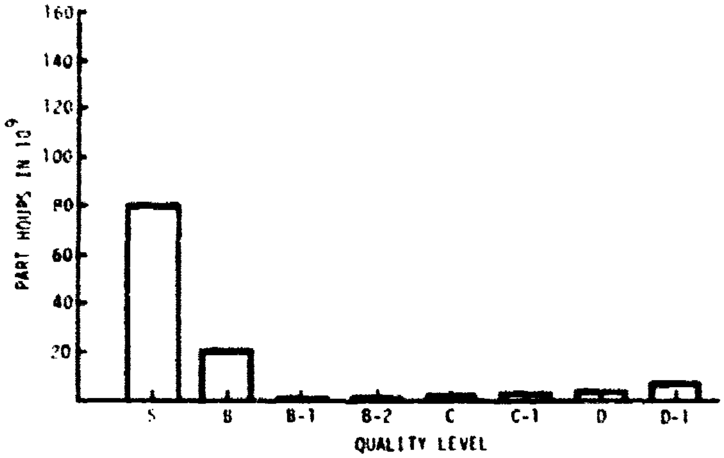


Figure 5.4-13. Micro-electronic Devices Quality Level Histogram

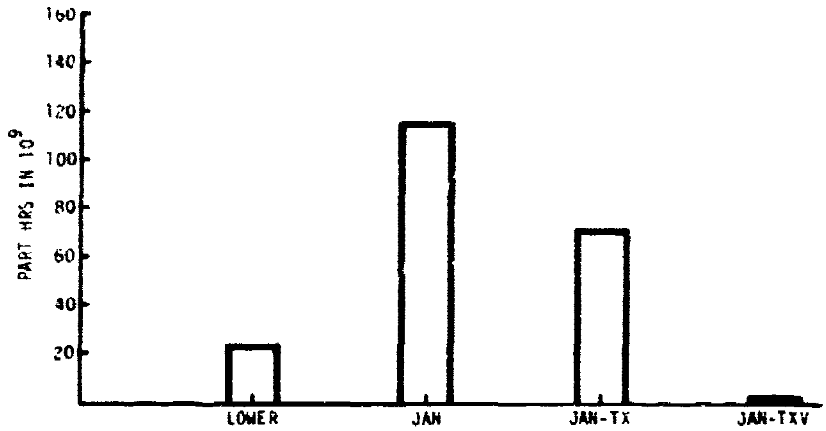


Figure 5.4-14. Discrete Semiconductors Quality Level Histogram

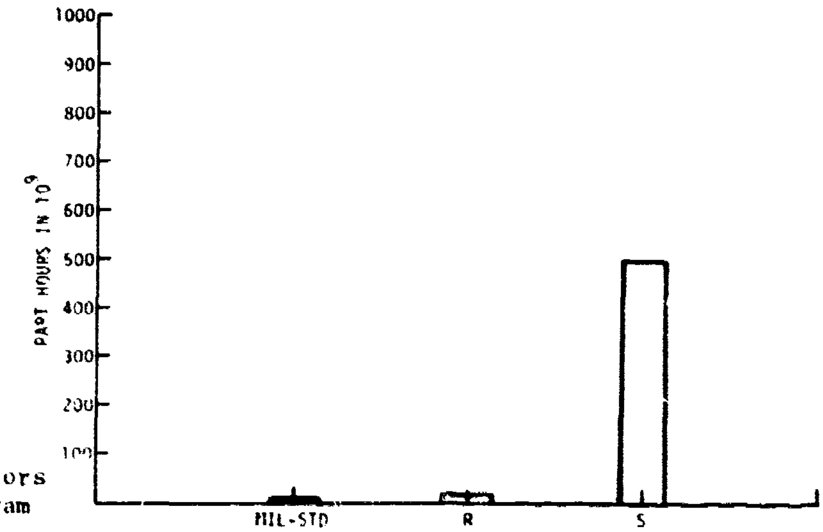


Figure 5.4-15. Resistors Quality Level Histogram

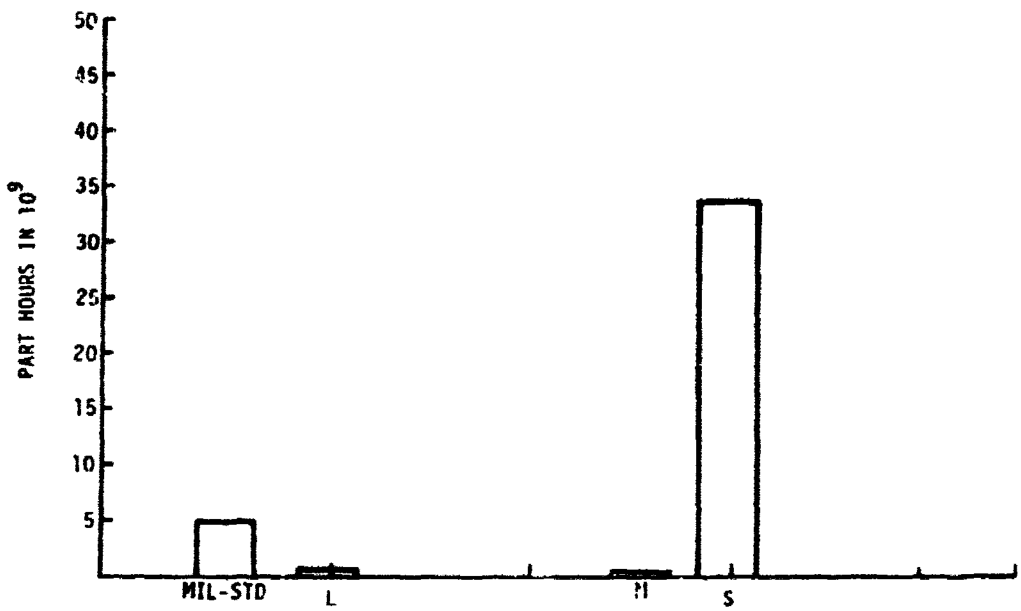


Figure 5.4-16. Capacitors Quality Level Histogram

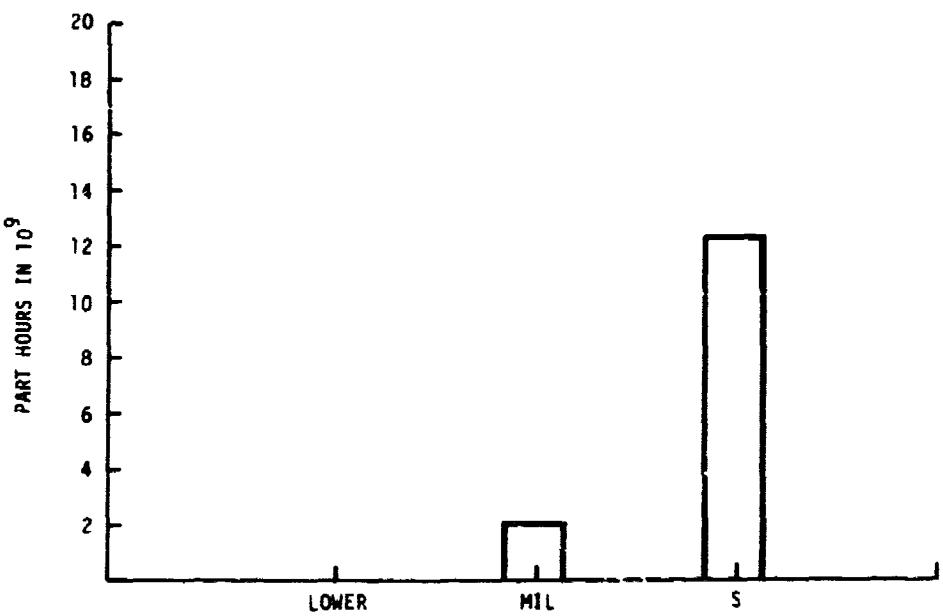


Figure 5.4-17. Inductive Devices Quality Level Histogram

5.5 Special Techniques for Microelectronics

The general equation for microelectronics failure rates (per MIL-HDBK-217C, proposed Notice I) is

$$\lambda_p = \pi_Q \, \pi_L \, (C_1 \pi_t \pi_V + (C_2 + C_3) \, \pi_E).$$

The π_L term is a learning factor. π_V is a voltage derating stress factor. For purposes of this study, π_V and π_L are assumed to be 1. Solving for π_E, the environmental factor, the equation becomes

$$\pi_E = \frac{\frac{\lambda_p}{\pi_Q} - C_1 \, \pi_T}{C_2 + C_3}$$

The part failure rate, λ_p, is the number of failures divided by the part hours. For purposes of this study, the failure rates calculated at 60 percent confidence level were used for λ_p. C_1 and C_2 are factors which are dependent upon device complexity and technology. C_3 is a packaging factor. π_T is dependent upon device technology and junction temperature. Therefore, an estimate of λ_p requires knowledge of complexity, packaging and other device characteristics. π_Q is the quality factor for the device.

Approximately 39 percent of the operating hours utilized for microelectronic devices were detailed by device complexity and technology. There were 103 different classifications comprising the detail data. Five of these classes had operating hours greater than 75 x 10^6 part hours. Eighty-nine classes had operating hours less than 10 x 10^6 part hours, and 70 percent of these had no failures reported. Low hours combined with no reported failures, when used in the above equation, results in poor estimates of π_E.

The other 61 percent of the operating hours were classified as digital, linear, LSI, or memory, with quality ratings and junction temperature provided. To obtain more realistic π_E's, the data for which device complexity and technology data was available was grouped into the classes of digital, linear, LSI, or memory. This provided a larger quantity of part hours for analysis purposes. Table 5.5-1 displays the microelectronic field data which was utilized in this study. The data is divided into the environments of ground benign (G_B) , space flight (S_F), ground fixed (G_F), Naval submarine (N_{SB}), and nonoperating ground fixed (G_F-Nonoperating). The source of the data is indicated by a number. (Note: Source 1 for G_B is the same source as source 1 for G_F, etc.) The total operating hours collected for each environment is indicated. Ground benign had the largest number of operating hours collected, more than 79 billion part hours. The total number of microelectronic hours collected for all environments is more than 102 billion part hours.

TABLE 5.9-1 MICROELECTRONICS FIELD DATA

ENVIRONMENT	SOURCE	TYPE	PART HOURS $\times 10^6$	QUALITY ADJUSTED PART HOURS $\times 10^6$	FAILURES	π_E
G_B	1	Digital	63.693	1473.578	19	2.400
		LSI	69.318	2127.265	95	5.823
		Memory	1982.505	51123.835	1148	2.172
	2	Digital	57707.211	28853.605	84	0.412
		Linear	19403.618	38807.236	35	0.076
Total			79226.345			0.380
S_F	3	Digital	505.050	505.050	0	0.199
		Linear	101.530	101.530	0	0.296
	4	Digital	193.000	193.000	2	2.748
		Linear	5.610	5.610	0	11.638
Total			805.190			0.902
G_F	1	Digital	738.509	15744.171	315	3.265
		Memory	108.074	5073.315	124	2.561
		LSI	25.370	579.950	20	4.754
	5	Digital	450.833	450.833	6	2.749
		Linear	90.740	90.740	2	1.946
		Memory	19.601	19.601	0	3.373
	6	Digital	7977.363	11017.246	164	2.473
		Linear	712.941	1163.165	45	2.151
Total			10195.431			2.506
N_{SB}	1	Digital	272.294	2476.981	0	0.028
		Memory	17.549	52.647	0	3.141
	7	Digital	2637.022	2637.022	72	4.924
		Linear	8.808	8.808	1	16.495
Total			2935.673			4.494
G_F – Nonoperating	3	Digital	945.040	945.040	1	0.237
		Linear	200.340	200.340	3	1.165
	8	Digital	5863.763	3199.635	6	0.285
		Linear	2505.254	1370.394	7	0.083
Total			9514.370			0.248

Total Hours: 102677.009×10^6

The mathematical model for microelectronic device failure rate does not allow the same procedure to be employed in solving for π_E as in other sections of MIL-HDBK-217. The other sections have an equation for π_E that is totally multiplicative. Therefore, summations of all operating hours for that section can be used to obtain an overall π_E for that section. For microelectronics, however, the hours cannot be added, due to the additive nature of the complexity factors. A π_E must be obtained for each entry in Table 5.5-1.

A median value π_T, C_1, C_2, and C_3, was calculated for each device type (i.e., digital, linear, LSI, memory) at the junction temperature for each entry. The part hours for each quality level was adjusted to the quality level for Class B devices. The method for quality factor adjustment is the same as that described in section 5.2. For each entry a π_E can be calculated, using the adjusted part hours.

After these calculations have been done for each entry in Table 5.5-1, there exists a range of π_E terms for each environment. For example; for ground benign there is a range of .076 to 5.823 for π_E. An overall π_E must be calculated for each environment that gives the appropriate weighing to each individual π_E. The original part hours for each π_E is used to weight the π_E according to actual experience data in calculating an overall π_E.

$$\pi_E = \frac{\Sigma (\pi_{E_i} \cdot h_i)}{\Sigma h_i}$$

This equation was applied to each environment which had adequate data. The resulting π_E appears in Table 5.5-1.

These new π_E's for each environment were used as the actual environmental factors derived from field data. These π_E's are for four of the sixteen operating environments (excluding airborne fixed wing environments). There was very little data for the other twelve environments. A method of calculating a synthesized π_E for these environments was devised.

There were four environments (N_S, G_M, N_U and M_L) being analyzed which appeared in the MIL-HDBK-217C. The π_E's for these environments, as in the proposed Notice 1 to MIL-HDBK-217C, are listed in Table 5.5-2. During the course of this study surveys were sent to various individuals throughout government and industry, (see Section 2.0). The resultant overall factors for each environment are listed in Table 5.5-2 in the survey column.

The four environments (N_S, G_M, N_U and M_L) which appear in MIL-HDBK-217 had new environmental factors calculated by averaging the adjusted survey number and the present MIL-HDBK-217C, Notice 1, factor. The original survey numbers were adjusted to the newly calculated ground benign base of 0.38. These new factors are listed in Table 5.5-2 in the calculated column. The rationale behind this method is as follows. The old tables were based on data. The survey factors reflect new

TABLE 5.5-2 ENVIRONMENTAL FACTORS FOR MICROELECTRONICS

ENVIRONMENT	π_E OPERATING			π_E NONOPERATING
	217C NOTICE 1	ADJUSTED SURVEY	CALCULATED	
G_B	1	0.380	0.380*	0.038
S_F	1	0.828	0.902*	0.089
G_F	2.5	1.054	2.506*	0.248*
N_{SB}	-	2.296	4.494*	0.445
N_S	4	2.774	3.387	0.335
G_M	4	4.370	4.185	0.414
M_P	-	4.750	3.838	0.380
M_{FF}	-	4.788	3.[illegible]	0.383
N_U	5	6.410	5.[illegible]	0.565
M_{FA}	-	6.688	5.404	0.535
N_H	-	7.296	5.895	0.583
N_{UU}	-	7.853	6.345	0.628
A_{RW}	-	10.495	8.480	0.839
U_{SL}	-	14.098	11.391	1.127
M_L	10	16.234	13.117	1.298
C_L	-	273.853	221.272	21.897
A_{IT}	3.5	-	-	-
A_{UT}	4	-	-	-
A_{IF}	7	-	-	-
A_{UF}	8	-	-	-

*Based on Field Failure data. See Table 5.5-1.

experience, both intuitive and factual. The average was taken to provide equal weight to the old data and the survey which was based partly on judgement and partly on new data. Had the survey reflected all new data it would have received greater weight.

There are eight environments (M_P, M_{FF}, M_{FA}, N_H, A_{RW}, U_L, N_{UU}, and C_L) for which inadequate data were collected and which had not previously appeared in MIL-HDBK-217. The predominant information available was the π_E's suggested by the survey, which are scaled to a ground benign (G_B) factor of 0.38 in Table 5.5-2. The formula described in section 5.3 was used to adjust the range of the survey factors to the range of microelectronics factors given in MIL-HDBK-217C, Notice 1. The missile launch (M_L) environment, which is the most severe environment in the existing handbook, was selected as the ranging parameter in the formula:

$$\pi_E = \text{Survey } \pi_E \quad \frac{\hat{\pi}_E(M_L)}{\text{Survey } \pi_E(M_L)} .$$

Table 5.5-2 shows the π_E for M_L is calculated as the average of the adjusted survey and the handbook π_E, or 13.117. The survey number for M_L is 16.234. Therefore, π_E's for the eight "new" environments are equal to 13.117 times the survey number for each environment divided by 16.234 or $\pi_E = 0.808 \cdot \text{Survey } \pi_E$. Table 5.5-2 lists, in the calculated column, the π_E factors for these eight environments as calculated by the above formula.

The nonoperating field data was analyzed in much the same way as the operating data. There was only one environment for which adequate nonoperating data was obtained, and that is ground fixed. The data collected for the G_F environment is tabulated in Table 5.5-1. More than 9.5 billion part hours were collected in this effort. The overall nonoperating π_E factor for G_F environment determined from this data was 0.248.

The ratio of the operating π_E for GF to the nonoperating π_E for G_F is 10.105. This ratio is applied to all other environments' operating π_E's to obtain nonoperating π_E's for these environments for which insufficient data was collected. The following equation is used:

$$\pi_E \text{ Nonop} = \frac{\pi_E \text{ Oper}}{10.105}$$

The numbers calculated in this operation are listed in Table 5.5-2 in the column titled "π_E Nonoperating."

The environmental factors for hybrids, which are given in Table 2.1.7-5 in Appendix F, were calculated in the same manner as those for microcircuits.

5.6 Environmental Matrix Approach

An early approach was investigated which would have taken advantage of the vast experience that has been accumulated in the many released military specifications defining environmental design requirements. This approach would have addressed the establishment of π_E factors for the black box level since that is the lowest level of environment most widely described in the specifications. The intent was that the predicted failure rates of parts would be established as in the past except that π_E influences would not be applied. After the part failure rates were summed to establish the black box failure rate, a new π_E factor established by this new approach, covering the overall influence of environment on the prediction, would be applied. The reasons for taking this approach were as follows:

1 It was felt that the majority of data available where environmental severity could be directly related to field operations utilization modes was available from existing specifications.

2 There is almost no readily available data on the actual level of environments seen by the parts in the field operational utilization modes.

3 If an approach was taken to establish the part environment in a particular utilization mode, an insurmountable problem could be anticipated. This problem was that if a large number of the same types of parts were used in the same black box in a particular utilization environment, the number of physical transfer functions pertinent to each of the same type of parts would be quite diverse. This would have created a confounding of the ultimately derived π_E factor for that part in the mode of use which would have created a lack of confidence in the derived factor.

The black box π_E approach considered the establishment of a weighing matrix such as is shown in Figure 5.6-1. The row vectors represented an expanded breakdown of the various service environmental modes deemed applicable. The column vectors represented the influence factors considered pertinent to failure rates of military equipment. The establishment of the environments and associated influence factors were supported by industry and government agency information expressed in the results of the survey (see Section 2.0).

Once the matrix structure was established, it was intended that each matrix element would have initially been filled with a numerical value of the applicable military specification design or test level appropriate to the environment and influence factor of concern. An abbreviated example would be:

	VIBRATION
GROUND BENIGN	N/A
GROUND MOBILE WHEELED	ACCEL ±2g peak Δf 200 Hz Δt 6 Hours V_N = 400*
AIRBORNE INHABITED FIGHTER	ACCEL ±5g peak Δf 2000 Hz Δt 6 Hours V_N = 10,000**

VIBRATION ENVIRONMENT WEIGHING FACTORS

ACCEL = 1.0

Δf = 3.0

Δt = 0.5

$$*V_N = \frac{2}{1} \times \frac{200}{3} \times \frac{6}{0.5} = 400$$

$$**V_N = \frac{5}{1} \times \frac{2000}{3} \times \frac{6}{0.5} = 10{,}000$$

Figure 5.6-1. Weighing Matrix

The value of the numerical quantity would involve one or more parameters depending on the nature of the influence factor stress as it affects the box reliability. For example, vibration would involve frequency bandwidth, acceleration level, and time of exposure. These three parameters would be weighed and combined to arrive at the specific numerical value (V_N) for the matrix element in question. The parametric values would be derived from direct reference to specifications such as MIL-STD-810, MIL-E-16400, MIL-STD-210, AR 78-35, etc. In cases such as the submarine environment, direct contact would be made with past and present developing agencies and firms to ferret out the appropriate data.

After extensive specification research to complete the matrix element entries, the influence factor stress column vectors would be normalized with respect to the highest numerical value entered. This would then provide for each influence factor a rank by stress severity for each of the environments.

At this point, the results of the survey would be melded into the matrix to incorporate the present day line of thought as expressed in the results of the industry/government survey. The survey addressed in part a determination of the relative severity of the influence factors for the various environments, i.e., matrix row vectors. This information is statistically analyzed and consolidated to derive what is essentially a field experience weighing value for the severity of individual influence factors as they pertain to a specific environment. It was intended that this weighing value be multiplied by the normalized environmental stress numerical values to reflect present experience obtained from industry/government respondents to the survey. An example is shown below: (Figure 5.6-2)

	TEMPERATURE	HUMIDITY	VIBRATION
GROUND BENIGN	0.02	0.03	N/A
SURVEY	2	3	1
NORMALIZED ENVIRONMENT	0.01	0.01	N/A
GROUND MOBILE WHEELED	0.32	6	0.12
SURVEY	4	6	3
NORMALIZED ENVIRONMENT	0.8	1	0.04
AIRBORNE INHABITED FIGHTER	5	0.24	8
SURVEY	5	3	8
NORMALIZED ENVIRONMENT	1	0.8	1

Figure 5.6-2. Composite Matrix

Once the matrix was completed with the influence factor stress value resulting from combining the survey and normalized specification criteria, the row elements (environments) would be added to obtain a combined stress value for each mode that represented the combined effect of the influence factors encountered. These combined stress values would then be normallized to the ground benign environment to rank the list of modes by order of stress severity. See example below: (Figure 5.6-3)

	TEMPERATURE	HUMIDITY	VIBRATION	ROW Σ	NORMALIZED COMBINED STRESS SURVEY
GROUND BENIGN	0.02	0.03	N/A	1.8	1
GROUND MOBILE WHEELED	0.32	6	0.12	10.0	5.6
AIRBORNE INHABITED FIGHTER	5	0.24	8	50.0	27.8

Figure 5.6-3. Rank Order Matrix

Using field data on black box environmentally induced failure rates for the various environmental modes, it was intended that an attempt be made to crosscorrelate the matrix results with the reported field results. If such a correlation was verified, it would be assumed that the newly derived normalized combined stress severity factors were in fact a good approximation to the π_E factors desired for the black box level of failure rate prediction.

The feasibility of the systems level environmental matrix approach was investigated during this study but it was not implemented for the reasons advanced in Section 5.1.

6.0 ENVIRONMENTAL MODES

Eleven different nominal environmental conditions were previously identified and quantified in MIL-HDBK-217C. This list has been expanded by adding 10 new modes for a grand total of 21. However, consideration of avionics was beyond the scope of the present study so four modes, airborne inhabited transport (A_{IT}), airborne inhabited fighter (A_{IF}), airborne uninhabited transport (A_{UT}) and airborne uninhabited fighter, (A_{UF}) were not evaluated. As a result, field failure rate data were collected and data survey results were analyzed to determine new π_E factors for the 17 environmental modes described in more detail in the following sections. Appendix F contains a complete list of the definitions for each mode and typical equipment types which fall into each mode category.

Table 6.0-1 compares the averages of the environmental factors contained in MIL-HDBK-217C Notice 1 with the average factors from this study survey and from the recommended revised factors for the Handbook. As indicated by the table, the averages of the recommended revisions do not markedly differ from those of the existing Handbook. The greatest change is the Naval sheltered average which increases from 5.4 to 6.5.

6.1 Ground Benign

MIL-HDBK-217A made no attempt to distinguish between the ground benign and ground fixed environments. Data analysis which was conducted to prepare the "B" revision indicated that a breakout was required and a new category called laboratory zero (L_O) was added. The nominal environmental conditions for this category was nearly zero environmental stress with optimum engineering operation and maintenance. When MIL-HDBK-217B was released, the identification laboratory zero was changed to ground benign (G_B) but the description has been carried over into MIL-HDBK-217C. To avoid misconceptions, it is proposed to change the definition to "non-mobile, laboratory environment readily accessible to maintenance". Typical examples of hardware which would fall into the ground benign environmental utilization mode are laboratory instruments, test equipment used in laboratories, medical electronic equipment used in hospitals, and most large business/scientific computer complexes. Data sources for this kind of hardware were used to calculate ground benign π_E factors. Temperature and humidity must be closely controlled for equipment to be categorized in this mode.

6.2 Space Flight

The Reliability Notebook, RADC-TR-67-108, first added satellite orbit (S_O) to the list of environmental service conditions. The definition of this category assumed "laboratory zero conditions without access for maintenance". MIL-HDBK-217B, as originally proposed, changed the

TABLE 6.0-1 COMPARISON OF AVERAGE ENVIRONMENTAL FACTORS

ENVIRONMENT	SYMBOL	PART TYPES AVERAGED	AVERAGE ENVIRONMENTAL FACTOR		
			217C AND NOTICE 1	SURVEY	REVISED VALUE
Ground Benign	G_B	60	1.03	1.0	1.01
Space Flight	S_F	59	1.01	2.1	0.97
Ground Fixed	G_F	60	2.76	2.7	2.74
Naval Submarine	N_{SB}	57	N/A	6.0	6.6
Naval Sheltered	N_S	60	5.4	7.3	6.5
Ground Mobile	G_M	60	11.1	11.5	11.7
Manpack	M_P	57	N/A	12.5	13.7
Missile Free Flight	M_{FF}	54	N/A	12.6	13.7
Naval Unsheltered	N_U	58	15.7	16.8	16.4
Airbreathing Missile, Flight	M_{FA}	54	N/A	17.6	19.0
Naval Hydrofoil	N_H	57	N/A	19.2	21.1
Naval, Undersea, Unsheltered	N_{UU}	57	N/A	20.6	22.6
Airborne, Rotary Winged	A_{RW}	57	N/A	27.6	30.4
Undersea Launch	U_{SL}	54	N/A	37.1	40.3
Missile Launch	M_L	55	47.5	42.7	47.1
Cannon Launch	C_L	53	N/A	721	719

category from satellite orbit to space flight (S_F) but retained the earlier definition. When the "B" revision was released, the description was reworded to encompass earth orbital conditions approaching ground benign without access for maintenance. The related vehicle was neither under powered flight nor in atmospheric reentry. This definition was retained in MIL-HDBK-217C and the present study proposed to allow the existing identification to remain intact. The data survey showed that solar radiation and low ambient pressure were the major influence factors affecting reliability in this mode. Data collected to quantify space flight π_E values came from the W71 orbital sensor, SMS, ALSEP, C System and synchronous earth orbit satellites together with the Apollo transponder, ATS-F, communication subsystem, TIROS-N subsystem, and the ETS-2 satellite.

6.3 Ground Fixed

The original definition of ground fixed (G_F) environmental service assumed conditions less than ideal including installation in permanent racks with adequate cooling air, no vibration or shock, maintenance by military personnel and possible installation in unheated buildings. The phrase, "no-vibration or shock," was dropped out of the MIL-HDBK-217B and 217C description because a ground fixed installation might be subject to low level vibration or shock from adjacent equipment. This study proposes to eliminate the phrase, "by military personnel" from the definition. The reason for this is that equipment in the ground fixed mode could be maintained by military or civilian personnel with equivalent skill levels. Examples of hardware in the ground fixed environmental mode would be permanent installations of air traffic control, radar and communications facilities as well as most missile silo ground support equipment. The survey indicated that humidity was the influence factor which affected reliability the most in this mode. Typical data collected to quantify ground fixed π_E values came from Safeguard perimeter acquisition and missile site radars, Minuteman III ground support equipment, ground based VHF/UHF communication systems and small ground fixed weapon system computers together with several different air traffic control equipments.

6.4 Ground Mobile

The vehicle mounted ground category was originally considered in MIL-HDBK-217A, however airborne application "K" factors were used because of the lack of pertinent data. The Reliability Notebook RADC-TR-67-108 had a specific ground mobile (G_M) environmental service mode which assumed conditions more severe than ground fixed, mostly for vibration and shock. The cooling air supply was also considered more limited and maintenance less uniform. MIL-HDBK-217B changed the category to Ground, Mobile (and Portable) but the (and Portable) was dropped out again in MIL-HDBK-217C. The description of the mode has remained the same as it was in the Reliability Notebook. This study proposed to separate the mode into Ground Mobile-Tracked and Ground Mobile-Wheeled, however the survey indicated that there was no significant difference between the two. In addition, no data could be found at Aberdeen Proving Ground which showed a significant difference in failure rate between equipments transported on wheeled vehicles versus tracked vehicles. A probable cause for this is that the equipment was designed to withstand its intended application. Therefore, it was decided to retain the original ground mobile category without breakout. The survey found shock and vibration together with sand and dust to be primary reliability influence factors in the ground mobile environmental mode. Data to quantify π_E factors in this mode came from sources such as Pershing Ia ground support equipment and other tactical fire direction systems.

6.5 Naval Sheltered

The naval sheltered (N_S) environmental mode was first quantified in MIL-HDBK-217B (Proposed) where it was defined as conditions similar to ground fixed but subject to occasional high shock and vibration. This description was reworded when the "B" revision was released so that it applied to surface ship conditions. The same definition was retained in MIL-HDBK-217C but it now proposed to describe sheltered or below deck conditions, protected from elements of weather. The survey revealed that humidity was the influence factor most affecting reliability in this mode. Data sources used to calculate naval sheltered π_E's included surface ship transmitters, transceivers, computers, sonars, and radar equipment.

6.6 Naval Submarine

Naval submarine (N_{SB}) is a newly identified environmental mode which has been added to account for this increasingly important category. This mode is described simply as appropriate for "equipment installed in submarines." The survey results showed that humidity, salt fog, and sine vibration were the primary influence factors affecting reliability in the submarine mode. Major data sources used to calculate naval submarine π_E factors were the ship's inertial navigation system, the C-3 flight control systems, the electrostatic gyro monitor, the central navigation computer, the digital data combat computer, the satellite communications set and the VLF fleet broadcast system.

6.7 Naval Unsheltered

The naval unsheltered (N_U) environmental mode was first described in MIL-HDBK-217B (Proposed) as "nominal shipborne conditions but with repetitive high levels of shock and vibration." Nearby gunfire was considered the primary source of these dynamic stresses. When the "B" revision was released, the definition was modified to apply specifically to surface ships. This nominal description was retained by MIL-Handbook-217C but it is now proposed to revise it as follows: "Nonprotected shipboard equipment exposed to climatic conditions." The reason for this change is that gunfire no longer appears to be a significant reliability influence factor on most ships in the modern Navy. The survey showed salt fog, humidity and immersion to be the factors of primary importance. Typical equipment which would fall into the naval unsheltered mode are mast mounted radar electronics and missile/projectile fire control equipment such as SEAFIRE.

6.8 Missile Launch/Re-entry

A "K" factor for the missile environment was originally contained in MIL-HDBK-217A. The Reliability Notebook, RADC-TR-67-108 defined this environment as severe conditions of noise, vibration and other environments associated with small surface to air missiles and other tactical rocket weapons being fired. The Notebook went on to point out that these missile conditions may also apply to installations near main rocket engines during satellite launch. The description of the Missile Launch (M_L) category was changed slightly in MIL-Handbook-217B and -217C to read, "severe conditions of noise, vibration, and other environments related to missile launch, and space vehicle boost into orbit, vehicle re-entry and landing by parachute. Conditions may also apply to installation near main rocket engines during launch operations". When the present study was initiated, it was proposed to break Missile Launch into four categories shown in Table 6.8-1. In addition a fifth related new category, Missile Free Flight (M_{FF}), was proposed for non-powered flight. Insufficient data were collected to make a distinction between tactical and strategic missile launch so these two categories are as originally, combined into a single Missile Launch environmental mode. Data sources used to calculate missile launch π_E's included electronic flight controllers for liquid rocket engines, the C-3 Missile computer as well as Patriot and Pershing Guidance and Control Systems.

TABLE 6.8-1 MISSILE CATEGORIES

Environment	Symbol	Description
Missile, Launch/ Re-entry	M_{LR}	Severe conditions related to strategic missile launch, and space vehicle boost into orbit, vehicle re-entry and landing by parachute. Conditions may also apply to rocket propulsion powered flight.
Tactical Missile, Launch	T_{ML}	Severe conditions related to tactical missile launch. May also apply to rocket propulsion powered flight.
Undersea, Launch	U_{SL}	Conditions related to undersea torpedo/ missile launch.
Missile, Free Flight	M_{FF}	Non-powered free flight.
Airbreathing Missile, Flight	M_{FA}	Conditions related to powered flight of airbreathing missile.

6.9 Cannon Launch

This study proposes to add a Cannon Launch (C_L) environment to account for the new family of cannon launch guided projectiles and other weapon systems being added to the defense inventory. The mode is described as "extremely severe conditions related to cannon launch". Launch shocks in the neighborhood of 9000 g's may be experienced and this influence factor is the major contributor to unreliability. Data to quantify and validate π_E factors for this mode were obtained from the Copperhead guided projectile.

6.10 Miscellaneous Modes

Four new miscellaneous environmental modes have been added to the π_E tables. These modes are defined in Table 6.10-1. Portable field communications equipment is a typical example of hardware used in the Manpack (M_P) environment where the survey showed that immersion and temperature shock/cycling were the primary factors influencing reliability. Sonar sensors and other ASW equipments fall into the naval undersea unsheltered (N_{UU}) mode where humidity, leakage and salt atmosphere are of major significance. The survey also determined that salt, fog, immersion, humidity and random vibration were important influence factors in the naval hydrofoil (N_H) mode. Data from captive carried and cockpit mounted material were used to evaluate the airborne, rotary winged (A_{RW}) mode. The survey indicated that random/sine vibration and temperature shock/cycling were the main contributors to unreliability in this environment.

TABLE 6.10-1 MISCELLANEOUS CATEGORIES

Environment	Symbol	Description
Manpack	M_P	Portable electronic equipment being manually transported while in the operational mode.
Naval, Undersea, Unsheltered	N_{UU}	Equipment immersed in salt water.
Naval, Hydrofoil	N_H	Equipment installed in a hydrofoil vessel.
Airborne, Rotary Winged	A_{RW}	Equipment installed on helicopters.

6.11 Nonoperating

It is proposed to add the nonoperating category (N_O) to MIL-Handbook-217 in order to account for the dormancy and storage conditions which have a major impact on the reliability of many electronic equipments and weapons systems. This mode is particularly significant for those systems which can not be subjected to periodic functional tests to attain a high level of operational readiness. Some of the terms used in the Handbook part failure rate models are not appropriate to calculate nonoperating failure rates so revised models have been provided for this purpose. The survey showed that humidity as well as sand and dust can have an important influence on reliability under nonoperating conditions. The nonoperating mode is usually found in more than one phase of a system's segmented mission. Major sources for nonoperating data were two different surface to air missile systems and several satellite programs.

7.0 COMPLEX MISSION ENVIRONMENTS

Complex missions usually involve several environmental modes. In these cases, the mission profile must be examined to determine proper segmentation. For example, a space flight might consist of a period of nonoperation following the last functional test, a boost phase, an orbital phase, and a re-entry phase. In such a case, the reliability analysis should be segmented using appropriate π_E factors to calculate failure rates for ground fixed nonoperation (N_O) prior to launch, missile launch (M_L) conditions during boost and return from orbit, and space flight (S_F) while in orbit. The π_E factors are quantified within each part failure rate model and the resulting part failure rates are summed to obtain system failure rates. A simple model for this mission reliability (R_M) would appear as follows:

$$R_M = e^{-(\lambda_{NO}\, t_{NO} + \lambda_{ML}\, t_{ML} + \lambda_{SF} t_{SF})}$$

where

λ_{NO} = system ground fixed nonoperating failure rate

λ_{ML} = system missile launch/re-entry failure rate

λ_{SF} = system space flight failure rate

t_{NO} = nonoperating time period prior to launch

t_{ML} = missile launch/re-entry time period

t_{SF} = space flight time period.

Another example involves a tactical artillery missile fired from a wheeled vehicle capable of traversing rough terrain. The missile would be removed from depot storage and subjected to a functional test. It would then be carried by truck to the ammunition supply point for loading into the mobile launcher. The launcher travels cross country to the forward edge of the battle area and when a fire mission is received, power is turned on in the missile and shortly thereafter it is launched and proceeds to the target. As before, the appropriate π_E factors should be quantified within each part failure rate model and the resulting part failure rates are summed to obtain system failure rates for each segment of the mission. A model for this mission is shown below:

$$R_M = e^{-\left[(1-a)\left(\lambda_{NO_{GF}}\right) t_{NO_{GF}} + \lambda_{NO_{G_M}}\, t_{NO_{G_M}} + \lambda_{G_M}\, t_{G_M} + \lambda_{ML}\, t_{ML}\right]}$$

where

a = functional test efficiency (percent of failures detected)

$\lambda_{NO_{GF}}$ = system ground fixed nonoperating failure rate

$\lambda_{NO_{G_M}}$ = system ground mobile nonoperating failure rate

λ_{G_M} = system ground mobile operating failure rate

λ_{ML} = system missile launch failure rate

$t_{NO_{GF}}$ = depot storage time period

$t_{NO_{G_M}}$ = ground mobile nonoperating time period

t_{G_M} = ground mobile operating time period

t_{ML} = missile launch and flight time period

8.0 ENVIRONMENTAL STRESS METHOD

The scope of work for the revision of MIL-HDBK-217 environmental factors suggested the study of alternate methods for calculating the effects of environments on the reliability of electronic equipment. Accordingly, the feasibility of the environmental stress method described in this section was reviewed and evaluated.

As early as 1965, MIL-HDBK-217A recognized that, "more accuracy would be attained by developing failure rates around each environmental factor (humidity, vibration, etc.) and to a degree around the specific level for each environmental factor." Lack of resources has prevented a comprehensive investigation of the feasibility of this supplemental approach. The effects of temperature are already well quantified by the λ_b tables in MIL-HDBK-217. It would also be possible to predict the reliability of systems and electronic parts in specific levels of shock, vibration, humidity, and other pertinent environments. In other words, how well is the part or system designed to withstand a specified level/duration of shock or vibration? Draft MIL-STD-XXX, Procedure for Performing a Reliability Stress Analysis of Mechanical Equipment could be used to answer this question since it contains appropriate methodology for calculation of stress/strength safety margins that can be easily converted into probability values. The trouble is that the manpower required to perform this task on a typical system would be orders of magnitude greater than are presently allocated to reliability prediction. In addition, specific guidelines would be required to standardize the technique. A side benefit would be early identification of unreliable parts and or systems before the test programs are initiated. For example, testing has shown that metallurgically bonded diodes are much more reliable in a high shock environment than are the spring loaded contact type. The supplemental approach to reliability prediction suggested in this section would uncover this type of problem very early in the engineering development phase of a program.

Figure 8.0-1 contains preliminary data showing ranges of operational influence factor levels for environment mode. This type of information would facilitate analyses by dynamicists and materials engineers to determine mechanical stress/strength probability relationships, corrosion rates, fatigue, and ultimately a measure of system reliability in the various environments of a mission. A possible drawback to this approach is the fact that input levels of shock and vibration are either attenuated or amplified by the equipment design, so that the electronic parts may see much higher or much lower levels than the input to the assembly. Extensive system level calculations would be a prerequisite to part level analysis in order to quantify the levels actually seen by parts.

In summary, it appears that the environmental stress method described above is technically feasible. However, a study should be made to determine if commitment of the resources necessary to implement such a program could be justified when traded off against the benefits to be obtained.

☒ = NOT APPLICABLE

☐ = NO DATA

	ALTITUDE	DUST/SAND	LOW TEMPERATURE	TEMPERATURE SHOCK/CYCLING	TEMPERATURE – ALT	SOLAR RADIATION	PYROTECHNIC SHOCK	LOADS SHOCK	FUNGUS/MICROBES	SALT FOG	
GROUND, BENIGN	X	X	10°C 0°C non op	71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (8-A1)	X	X	X			X	
GROUND, FIXED	X	X	-40°C op -65°C non op -61°C (99%) -40°C op -62°C non op	71 C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (8-A1)	X	380 BTU's/sq ft/hr	X			15 lb/acre/yr	5 3 (9 3 6
GROUND, MOBILE, TRACKED	X	2nd worst for large sized sand (heavier particles)	-40°C op -65°C non op -40°C op -54°C non op cond freeze/frost -61°C (99%)	71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (8-A1)	X	380 BTU's/sq ft/hr	X	15-90g, 11M sec		15 lb/acre/yr	6-1 Co & 30 dev 5.2
GROUND, MOBILE, WHEELED	X	3rd for large particles	-40°C op -65°C non op -40°C op -65°C non op cond freeze/frost -61°C (99%)	71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (8-A1)	X	380 BTU's/sq ft/hr	X	15-90g, 11M sec		15 lb/acre/yr	6-1 Co & 30 dev 5.2
MANPACK	X	X		71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (8-A1)	X	380 BTU's/sq ft/hr	X			16 lb/acre/yr	
NAVAL, SHELTERED	X	X	-46°C OP -65°C NON OP Δ TO -55° NAVY -62°C NON OP 0°C OP 0° TO 50°C OP -62° TO 72°C NON OP	71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (8-A1)	X	X	30 rounds of 9.5 lb/in^{2}g Peak	1-10g 100M sec grade a, class a type I (901)	810C test 508	Shall withstand 62.5 to 375 ml/m^3/hr for 16 hours, 4-6% NaCl sol	10 30 dp low -3
NAVAL, UNSHELTERED	X	X	-45 C op -65 C non op to -30 navy -62 C storage -28 op cond freeze/frost -34 C (99%) -28 op -62 non op	71°C – -54° 5 min transfer 4 hr exposure to temperature (3 cycles) (8-A1)	X	104 ± 4 watts/ft^2 48 hours 50-72 watts for IR 4-7 for UV Remainder visible prec II 8 IOC 380 BTU's/sq ft/hr	30 rounds of 9.5 lb/in^2 peak	1-10g 100M sec grade a, class a type I (901)	810C test 508	Shall withstand 82.5 to 375 ml/m^3/hr for 16 hours 4-6% NaCl sol	10 fre 30 dp low dp dis
NAVAL, UNDERSEA UNSHELTERED	X	X	-28 C -65 op -62 C +71 C non op	71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (8-A1)	X	X	30 rounds of 9.5 lb/in^2 peak	Grade a, class a 810C type I, (901)	810C test 508	Shall withstand 62.5 to 375 ml/m^3/hr for 16 hours, 4-6% NaCl sol	
NAVAL, BENIGN, SUBMARINE	X	X	0°C op	X	X	X	30 rounds of 9.5 lb/in^2 peak	50-100g negligible grade a, class a type 1 (901)	Low 810C test 508	shall withstand 62.5 – 375 ml/m^3/hr for 16 hrs, 4-6% NaCl sol negligible	5 9 des 40
NAVAL, HYDROFOIL	X	X	0 C op	71 C – -54 C 5 min transfer 4 hr exposure to temperature (3 cycles) (8 A1)	X	104 ± watts ft^2 48 hours, 50-72 watts ir 4-7 watts uv remainder visible pror II 810C	30 rounds of 9.5 lb/in^2 peak	Grade a, class a 810C type I, (901)	810C test 508	62 5 to 375 ml/m^3/hr for 16 hours, 4 6% NaCl sol	30 of low dp des
AIRBORNE, INHABITED, TRANSPORT	Procedure I, method 500 of MIL STD 810 (8-A1)	2 19 gm/m^3 if on unpaved runway	-46°C op -66°C non op -54°C non op	7 C – -54 C 5 min transfer 4 hr exposure to temperature (3 cycles) (8 A1)		X	X	15-75g, 11 ms occasionally 1500g for ½ ms 4½ g's; side loads of 2 g's; vert lds of 2½ g's	810 fungus test ... procedure I method 508 1	X	
AIRBORNE, INHABITED, FIGHTER		X	-46°C op -66°C non op -54 C non op cond freeze/frost	71 C – -54 C 5 min transfer 4 hr exposure to temperature (3 cycles) (8 A1)		X	X	5-75g 11 ms occasionally 1500 for ½ ms	0 fungus test ... procedure I method 508 1	X	5

Figure 8.0-1. Environmental Matrix

FUNGUS/MICROBES	SALT FOG	HUMIDITY	EXPLOSIVE ATMOSPHERE	LEAKAGE (IMMERSION)	ACCELERATION	RANDOM VIBRATION	SINE VIBRATION	ACOUSTICAL NOISE	PRESSURE SHOCK	SPACE SIMULATION	TEMPERATURE – HUMIDITY – ALTITUDE	ELECTROMAGNETIC
	X	5-55	X	X	X	0 G	0 G	X	27 31" Hg	X	X	
	15 lb/acre/yr	5-95 30K ppm (98%) dew pt 31°C 5.24 ppm low	X	X	X	2-60 Hz 0-5G	2-60 Hz 0-5G 20-60 Hz single λ	X	15 30" Hg	X	X	
	15 lb/acre/yr	5-100 Condensation & frost/freeze T. 30K ppm (98%) dew pt 31°C 5.24 ppm low	X		X	10-300 Hz 1-10g	log sweep 5-500 Hz		15 30" Hg	X	X	
	15 lb/acre/yr	5-100 Condensation & frost/freeze T. 30K ppm (98%) dew pt 31°C 5.24 ppm low	X		X	10-300 Hz 1-10g	log sweep 5-500 Hz		15-30" Hg	X	X	
	15 lb/acre/yr		X		X			X	X	X	X	
810C test 508	Shall withstand 62.5 to 375 ml/m³/hr for 16 hours, 4-6% NaCl sol	10-100 (RH) 30K ppm (98%) dp 31°C high low 87 ppm -38°C		X		3-80 Hz, 1-10G	sine sweep-cont see mil-std 167		X	X	X	Field of 20 oersteds
810C test 508	Shall withstand 62.5 to 375 ml/m³/hr for 16 hours 4-6% NaCl sol	10-100 Cond freeze/frost 30K ppm (98%) dp 31°C low 133 ppm dp -32°C (98%) design to 96%				3-60 Hz, 1-20G	sine sweep-cont see mil-std 167		27-31" Hg	X	X	Field of 20 oersteds
810C test 508	Shall withstand 62.5 to 375 ml/m³/hr for 16 hours, 4-6% NaCl sol		X		X			X	27 31" Hg	X	X	Field = 20 oersteds
Low 810C test 508	shall withstand 62.5 - 375 ml/m³/hr for 16 hrs, 4 6% NaCl sol negligible	5-98% RH design to 96% 40-80%		X	X	6-33 Hz 0-1.5g negligible	5-33 Hz 0-1.5g negligible		10 30" Hg	X	X	Field - 20 oersteds
810C test 508	62.5 to 375 ml/m³/hr for 16 hours, 4 6% NaCl sol	30K ppm high of dp 31°C low 133 ppm dp = -32°C design to 95%	X							X		Field = 20 oersteds
810 fungus test [illegible] procedure [illegible] method 508.1	X	5-100	X	X	Mil std 810B test method 513.2 procedure 1 and 2	10 2000 Hz 2 30g 20 2000 Hz ran cont 25 100 Hz 8 h from guns	10 2000 Hz 2 30G	140 db 30 minutes exposure time	30 15 Hg	X		
[illegible]0 fungus test [illegible] procedure [illegible] [illegible] method 508.1	X	5-100 Cond freeze frost	X	X	Mil std 810B test method 513.2 procedure 1 and 2	10 2000 Hz 2 30g 20 2000 cont random 25 100 Hz 8 h from guns	10 2000 Hz 2 30G	140 db 30 minutes exposure time	30 15 Hg	X		

⊠ = NOT APPLICABLE

☐ = NO DATA

	ALTITUDE	DUST/SAND	LOW TEMPERATURE	TEMPERATURE SHOCK/CYCLING	TEMPERATURE – ALT	SOLAR RADIATION	PYROTECHNIC SHOCK	LOADS SHOCK	FUNGUS/MICROBES	SALT FOG
AIRBORNE, UNINHABITED, TRANSPORT	80,000 ft 1.08 In. Hg (99%) Procedure I, method 500 of MIL-STD-810 (B-A1)	2.18 gm/m³ if on unpaved runway	-54°C op -65°C non op -54°C non op -54°C @ 60K' (99%) -60°C non op -40°C op	71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (B-A1)	-86°C (99%)		⊠	5-75g @ 11 ms occasionally: 1500 for ½ ms (equip crash) safety 30g @ 11 ms	8[illegible] fungus test f[illegible] procedure I m[illegible]hod 508.1	
AIRBORNE, UNINHABITED, FIGHTER	70,000 ft 856 IN Hg (99%)	⊠	-54°C op -65°C non op -54°C non op freeze/frost cond -54°C (99%)	71°C – -54 C 5 min transfer 4 hr exposure to temperature (3 cycles) (B-A1)	-85°C (99%)		⊠	5 75g @ 11 ms occas. 1500 for ½ ms	810 [illegible]ungus test fo[illegible] [illegible]ocedure I met[illegible]od 508.1	
AIRBORNE, ROTARY WING	13,000 ft 16.2 IN Hg (99%)	Worst for heavier particles	-54°C non op -48°C (99%)	71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (B-A1)	-46°C (99%)	⊠	⊠		810 fungus test for procedure I method 508.1	
MISSILE, LAUNCH/REENTRY		⊠	-65°C op & non op	71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (B-A1)		⊠		45-100g for 11 ms occasionally: 1500 for ½ ms 15g-11 + 1 ms	⊠	⊠
TACTICAL MISSILE LAUNCH		⊠		71°C – -54°C 5 min transfer 4 hr exposure to temperature (3 cycles) (B-A1)		⊠		15g-11 + 1 ms	⊠	⊠
CANNON, LAUNCH	⊠	0.01 MM–1.00 MM with winds [illegible] 30 knots Size 0.0001 MM – 0.01 MM dia with density of 6 x 10^{-9} gm/M³ with winds [illegible] 35 knots		Method 503.1 of MIL-STD-810C low temp shall be -60°F		360 BTU/ft²/hr @ 125°F with wind < 5 knots for 4 hrs		mil-std-810C method 516.2 procedure II	Specified [illegible] mil-std-81[illegible]C, method 5[illegible]1, duration o[illegible] 90 days	Sea salt fallout in excess of 25 lbs/acre/yr
UNDERSEA, LAUNCH	⊠	⊠		Method 503.1 of MIL-STD-810C low temp shall be -60°F		⊠		15g-11 + 1 ms		
MISSILE, FREE FLIGHT		⊠	-65°C op & non op	Method 503.1 of MIL-STD-810C low temp shall be -60°F		⊠	⊠		⊠	⊠
AIRBREATHING MISSILE, FLIGHT		⊠		Method 503.1 of MIL-STD-810C low temp shall be -60°F			⊠	transfer [illegible] 10'/sec = 18" drop handling 15g, 75 ms ½ sine Captive 25g, 20 ms ½ sine	⊠	⊠
SPACE, FLIGHT		⊠	-54°C op -65 C non op	Method 503.1 of MIL STD 810C low temp shall be -60°F		Neutron (E > 10 KEV) NM/CM²SEC 10^{10} Fission (100 300M) Elect (E > 60 KEV) (Part/cm²/sec) 10^{8} Inner van Allen 1 4 2 R Prot 8 x 10^{4} Elect 10^{7} Outer Van Allen Prot 10^{8} Elect 2 x 10^{8}	⊠	⊠	⊠	⊠
NONOPERATING			-62 - -67 C for 24 hours	Method 503.1 of MIL STD 810C low temp shall be -60°F		360 BTU's/sq ft/hr				

FUNGUS/MICROBES	SALT FOG	HUMIDITY	EXPLOSIVE ATMOSPHERE	LEAKAGE (IMMERSION)	ACCELERATION	RANDOM VIBRATION	SINE VIBRATION	ACOUSTICAL NOISE	PRESSURE SHOCK	SPACE SIMULATION	TEMPERATURE – HUMIDITY – ALTITUDE	ELECTROMAGNETIC
fungus test procedure I [illegible]od 508.1		5-100% RH .08K ppm, dp -60°C		X	Mil-std-810B test method 513.2, procedure 1 and 2	20-2000 cont ran 25-100 Hz 8 ft random cont 25-100 Hz 8 ft from guns	20-2000 Hz 5-40g	160 dB I/ 30 minutes exposure time	043"-30 Hz	X		
fungus test procedure I [illegible]d 508.1		5-100% RH cond freeze/frost 19K ppm, lp = -58°C		X	mil-std-810B test method 513.2 procedure 1 and 2	20-2000 cont ran 25-100 Hz - 8H from guns		160 dB I, 30 minutes exposure time	043" 30" Hg	X		
fungus test procedure I [illegible] 508.1		18K ppm, dp 15 C low 19 ppm, dp -56 C	X	X	1½g mil-std-810B test method 513.2 procedure 1 and 2	A pilots seat = +0.4g or 4 times levels existing in unaccelerated flight (g) 25-100 Hz 8 ft from guns	sine sweep 5-2000 Hz 5-33 Hz - 2g 33-2K Hz - 5g			X		
X	X	1-100% RH		X		10-2000 Hz 5-60g	10-2000 Hz 5-60g	0.0002 dyne/cm²	10^{-10} to 31" Hg	X		
X	X			X				0.0002 dyne/cm²				
[illegible]ified [illegible] std 81 C, [illegible]thod 5[illegible] 1, [illegible] days	See salt fallout in excess of 25 lbs/acre/yr	-60°F – 160°F (100%) -25°F – 145°F (100%) 70°F – 160°F (5%) 70°F – 145°F (5%)	X	Method 512.1 of mil-std 810C, procedure I		Mil-Std-810C Method 514.2, procedure X						
			X									
X	X		X	X								
X	X		X	X								
X	X	X	X	X	X		X				X	

Figure 8.0-1 (Continued)

9.0 CONCLUSIONS AND RECOMMENDATIONS

The revised and updated π_E factors resulting from this study program are indicative of actual field experience and should facilitate more realistic reliability predictions. To further support this objective, 10 new environmental modes have been quantified and added to the π_E tables. The factors for five environments, (N_{UU}, N_H, U_{SL}, M_{FA}, and M_{FF}) were completely synthesized using the survey results because an inadequate quantity of field data was available to calculate factors. It may be premature to initiate widespread use of these synthesized factors, but they are recommended as guidelines until additional data become available.

It appears that a study effort should be considered to develop guidelines for the supplemental environmental stress method discussed in Section 8 of this report.

Collection of field failure rate data from the 21 environmental modes should be continuously maintained in order to provide a statistically significant data base for periodic revision of the MIL-HDBK-217 π_E tables.

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APPENDIX A

FIRST SURVEY

MIL-HDBK-217B ENVIRONMENTAL

FACTORS DATA SURVEY

Participants will be mailed a copy of the survey results. Complete the following:

NAME ______________________________

ADDRESS ______________________________

____

PHONE NO. ( ) ______________________________

1 In the following space please list any improvements in order of priority that you may wish to see incorporated into the present environmental factors in MIL-HDBK-217B. Disregard this question if you are not acquainted with MIL-HDBK-217B or if you have no inputs.

A. ______________________________

____

____

____

B. ______________________________

____

____

____

C. ______________________________

____

____

____

2 Do you wish t[illegible] a[illegible] environmental model for MIL-HDBK-217B with the basis being pa[illegible] evel, systems level, or another level or combination?

_______ Part Level _______ Systems Level _______ Subassemblies

Other ______________________________

____

Reason for selection ________________________________

____

____

3 Do you know of other persons or sources of information who should be contacted?

____

____

____

____

4 In the following matrix, indicate with an "X" the influence factors you believe are of major importance to a particular environment. Please answer only for the environmental categories with which you are familiar. It is not necessary to rate the importance of each factor. You may limit the influence factors for each selected environment to five or six. If you believe that a certain environmental category should be deleted from the list or any environments combined, indicate so. If there are environments or influences factors you wish to add, do so in the allocated spaces. Some other possible influence factors have been listed below. Do not base your selections on laboratory test results since this is a survey of field environments for operating equipment. Below are descriptions for each of the environmental categories. Influence factors have been purposely deleted from these descriptions. Your responses will be considered in defining these categories. If you add an environment, please give a description at the bottom of this list. Your comments on these descriptions will also be appreciated. Use extra sheets if required.

OTHER INFLUENCE FACTORS

Rain	Corrosive Atmosphere
Snow	Gunfire Vibration
Ice	Vibration-Temperature
Wind	
Dust-Sand	

ENVIRONMENT	DESCRIPTION
Ground, Benign	Nonmobile, laboratory environment readily accessible to maintenance.
Ground, Fixed	Conditions less than ideal to include installation in permanent racks with adequate cooling air, maintenance by military personnel and possible installation in unheated buildings.

Ground, Mobile, Wheeled	Mobile equipment installed upon wheeled vehicles. Maintenance less uniform than ground fixed conditions.
Ground Mobile, Tracked	Mobile equipment installed upon tracked vehicles. Maintenance less uniform than ground fixed conditions.
Manpack	Portable electronic equipment being manually transported while in the operational mode.
Naval, Sheltered	Sheltered or below deck conditions, protected from elements of weather.
Naval, Unsheltered	Nonprotected shipboard equipment exposed to climatic conditions.
Naval, Undersea, Unsheltered	Equipment immersed in salt water.
Naval, Benign, Submarine	Equipment installed in submarine.
Naval, Hydrofoil	Equipment installed in a hydrofoil vessel.
Airborne, Inhabited, Transport	Typical conditions in transport or bomber compartments occupied by aircrew and installed on long mission aircraft such as transports and bombers.
Airborne, Inhabited Fighter	Same as airborne inhabited transport but installed on high performance aircraft such as fighters and intercepters.
Airborne, Uninhabited, Transport	Bomb bay, equipment bay, tail, or wing installations on long mission aircraft such as transports and bombers.
Airborne, Uninhabited, Fighter	Same as airborne uninhabited transport but installed on high performance aircraft such as fighters and intercepters.
Airborne, Rotary Winged	Equipment installed in or on helicopter.
Missile, Launch	Severe conditions related to missile launch, and space vehicle boost into orbit, vehicle re-entry and landing by parachute. Conditions may also apply to installation near main rocket engines during launch operations.

Cannon Launch	Extremely severe conditions related to cannon launch.
Missile Free Flight	Non-powered atmospheric free flight.
Space, Flight	Earth orbital. Approaches Ground, Benign conditions without access for maintenance. Vehicle neither under powered flight nor in atmospheric re-entry.
Additional Environments:	

Influence Matrix

Environment / Influence Factors	Altitude	High temperature	Low temperature	Temperature shock	Temperature-altitude	Solar radiation	Pyrotechnic shock (high frequency)	Loads shock	Fungus	Salt fog	Humidity	Explosive atmosphere	Leakage (immersion)	Acceleration	Random vibration	Sine vibration	Acoustical noise	Pressure shock	Space simulation	Temperature-humidity-altitude	Electromagnetic interference	Electromagnetic radiation	Electromagnetic pulse (lightning)					
Ground, benign																												
Ground, fixed																												
Ground, mobile, wheeled																												
Ground, mobile, tracked																												
Manpack																												
Naval, sheltered*																												
Naval, unsheltered*																												
Naval, undersea, unsheltered																												
Naval, benign, submarine																												
Naval, hydrofoil																												
Airborne, inhabited, transport																												
Airborne, inhabited, fighter																												
Airborne, uninhabited, transport																												
Airborne, uninhabited, fighter																												
Airborne, rotary wing																												
Missile launch																												
Cannon launch																												
Missile, free flight																												
Space flight																												

*Environments significantly different from definition in MIL-HDBK-217.

APPENDIX B

SURVEY PARTICIPANTS

SURVEY PARTICIPANTS

Boeing Aerospace Co.
Houston, TX
Seattle, WA

Boeing Co.
Seattle, WA

Boeing Vertol Co.
Philadelphia, PA

British Aerospace Corp.
Hertfordshire, UK

FMC/NOD
Minneapolis, MN

General Dynamics
Ft. Worth, TX
Pomona, CA

General Dynamics
Convair Division
San Diego, CA

General Electric
Evendale, OH

General Electric
Lynn, MA

Grumman Aerospace Corp.
Bethpage, NY

Hughes Aircraft Co.
Canoga Park, CA
Culver City, CA
Fullerton, CA
Los Angeles, CA

Lockheed Electronics Co.
Plainfield, NJ

Lockheed - Georgia Co.
Marietta, GA

Lockheed Missiles and Space Co.
Sunnyvale, CA

Martin Marietta Aerospace
Orlando, FL

Martin Marietta Aerospace
Denver, CO

Pan American
Jamaica, NY

Pratt & Whitney Aircraft
West Palm Beach, FL

Raytheon Co.
Lexington, MA

RCA
Camden, NJ

Rockwell International
Columbus, OH

Sandia Laboratories
Albuquerque, NM

Sperry Flight Systems
Phoenix, AZ

Sperry-Univac
St. Paul, MN

Telcom Systems, Inc.
Arlington, VA

United Airlines
San Francisco, CA

Vought Corp.
Dallas, TX

The Hans W. Wynholds Co.
Washington, DC

Air Force Flight Dynamics Lab
Wright Patterson AFB, OH

Federal Aviation Administration
Washington, DC

Fleet Analysis Center
Corona, CA

MMCM
Hill AFB, UT

NASA Headquarters
Washington, DC

NASA Langley Research Ctr.
Hampton, VA

Naval Ordnance Station
Louisville, KY

Naval Sea Systems Command
Washington, DC

Naval Ship Engineering Ctr.
Norfolk, VA

Naval Surface Weapons Ctr.
Dahlgren Laboratory
Dahlgren, VA

Naval Weapons Engineering
Support Activity
Navy Yard
Washington, DC

Naval Weapons Support Center
Crane, IN

Naval Underwater Systems Ctr.
New London, CT

USAADTA
Ft. Rucker, AL

U.S. Army Communications Research &
Development CMD.
Ft. Monmouth, NJ

HQ, U.S. Army Test & Evaluation CMD.
Aberdeen Proving Ground, MD

USA Meradcom
Ft. Belvoir. VA

U.S. Army
Canal Zone

Aerojet Electronics
Azusa, CA

Aerospace Corporation
El Segundo, CA

Autonetics
Anaheim, CA

AVCO
Wilmington, MA

Charles Stark Draper Labs
Cambridge, MA

Ford Aerospace
Palo Alto, CA

GTE
Needham, MA

Harris Electronics
Syosset, NY

ITT Gilfillan
Van Nuys, CA

Litton Industries
Van Nuys, CA
Woodland Hills, CA

Naval Ocean Systems Center
San Diego, CA

Naval Strategic Systems Project Office
Washington, DC

NAVELEX
Crystal City, VA

Raytheon Co.
Andover, MA
Sudbury, MA

Rocketdyne
Canoga Park, CA

Sperry Systems Management
Great Neck, NY

APPENDIX C

SECOND SURVEY

MIL-HDBK-217B ENVIRONMENTAL

FACTORS DATA SURVEY #2

Participants will be mailed a copy of the survey results. Complete the following:

NAME ____

ADDRESS ____

____

PHONE (   ) ____

In the following matrix, the influence factors which were indicated as being significant in the first survey are represented by an open square. Twenty percent or more of the first survey respondents for each environment determined that the influence factor was significant for that environment. Write-in environments or factors were not subject to this rule. A "crossed-out" square indicates that most of the survey respondents did not consider the influence factor to be of major importance to that environment. High temperature has been omitted from the influence factors as it is already considered in the base failure rate model. If you wish to comment on the matrix, do so on Page C-4. Please rate the importance of each factor for the environment using a scale of 1 to 10. A rating of 10 represents the highest severity level (i.e., most critical or highly significant influence factor). A rating of 1 indicates minor significance of the influence factor to that particular environment. The same rating can be assigned to more than one influence factor for an environment. The same rating can be assigned to more than one influence factor for an environment. The results of this survey will be used to construct preliminary ratios of the severity of influence factors for a given environmental category. On the far left of the matrix is a column for you to rate the relative severity of each environment as compared to ground, benign. In the example on the bottom of Page C-5, a weighing factor of 1800 has been assigned to environment XYZ, meaning XYZ is 1800 times as severe as ground, benign. The example has been chosen to illustrate that there is no restriction to the magnitude of the ratings you assign.

In analyzing your weightings, it will be helpful for us to know the basis for your selection of each environment for which you answer. We would appreciate your assigning a 1, 2, or 3 to each of your selected environmental categories in the provided box on the left side of the table. One indicates a moderate level of familiarity with the environment: 2 indicates a high level of expertise in this area; and 3 indicates that your selection was based upon recorded failure rate data. If you have recorded data, indicate a "3" regardless of your familiarity level. See the example on the bottom of Page 4. Do not base your selections on laboratory test results since this is a survey of field environments. Following are the descriptions for each of the environmental categories.

ENVIRONMENT	DESCRIPTION
Ground, Benign	Nonmobile, laboratory environment readily accessible to maintenance.
Ground, Fixed	Conditions less than ideal to include installation in permanent racks with adequate cooling air and possible installation in unheated buildings.
Ground, Mobile, Wheeled	Mobile equipment installed upon wheeled vehicles.
Ground Mobile, Tracked	Mobile equipment installed upon tracked vehicles.
Manpack	Portable electronic equipment being manually transported while in the operational mode.
Naval, Sheltered	Sheltered or below deck conditions, protected from elements of weather.
Naval, Unsheltered	Nonprotected shipboard equipment exposed to climatic conditions.
Naval, Undersea, Unsheltered	Equipment immersed in salt water.
Naval, Benign, Submarine	Equipment installed in submarine.
Naval, Hydrofoil	Equipment installed in a hydrofoil vessel.
Airborne, Inhabited, Transport	Typical conditions in transport or bomber compartments occupied by aircrew and installed on long mission aircraft such as transports and bombers.
Airborne, Inhabited, Flighter	Same as airborne inhabited transport but installed on high performance aircraft such as fighters and intercepters.
Airborne, Uninhabited, Transport	Bomb bay, equipment bay, tail, or wing installations on long mission aircraft such as transports and bombers.

Airborne, Uninhabited Fighter	Same as airborne uninhabited transport but installed on high performance aircraft such as fighters and intercepters.
Airborne, Rotary Winged	Equipment installed in or on helicopters.
Missile, Launch/ Re-entry	Severe conditions related to strategic missile launch, and space vehicle boost into orbit, vehicle re-entry and landing by parachute. Conditions may also apply to rocket propulsion powered flight.
Tactical Missile, Launch	Severe conditions related to tactical missile launch. May also apply to rocket propulsion power flight.
Cannon, Launch	Extremely severe conditions related to cannon launch.
Undersea, Launch	Conditions related to undersea torpedo/missile launch.
Missile, Free Flight	Non-powered atmospheric free flight.
Airbreathing Missile, Flight	Conditions related to powered flight of air-breathing missile.
Space, Flight	Earth orbital. Approaches Ground, Benign conditions without access for maintenance. Vehicle neither under powered flight nor in atmospheric re-entry.
Nonoperating	Dormancy/storage conditions of equipment.

COMMENTS:

INFLUENCE MATRIX

Environmental Severity Ratio	Selection Basis	ENVIRONMENT / INFLUENCE FACTORS	Altitude	Dust/Sand	Low temperature	Temperature shock/cycling	Temperature-altitude	Solar radiation	Pyrotechnic shock (high frequency)	Loads shock	Fungus/Microbes	Salt fog	Humidity	Explosive atmosphere	Leakage (immersion)	Acceleration	Random vibration	Sine vibration	Acoustical noise	Pressure shock	Space simulation	Temperature-humidity-altitude	Electromagnetic Environment - EME
1		Ground, benign	X	X	X		X	X	X			X		X	X	X	X	X	X	X	X	X	
		Ground, fixed	X	X			X		X	X				X	X	X		X	X	X	X	X	
		Ground, mobile, wheeled	X				X	X	X					X		X				X	X	X	
		Ground, mobile, tracked	X				X	X	X					X		X				X	X	X	
		Manpack	X	X			X	X	X					X		X			X	X	X	X	
		Naval, sheltered	X	X	X		X	X	X						X					X	X	X	
		Naval, unsheltered	X	X			X		X												X	X	
		Naval, undersea, unsheltered	X	X			X	X	X					X		X			X		X	X	
		Naval, benign, submarine	X	X		X	X	X	X						X						X	X	
		Naval, hydrofoil	X	X			X		X					X							X		
		Airborne, inhabited, transport		X				X	X			X		X	X					X	X		
		Airborne, inhabited, fighter		X				X	X			X		X	X					X	X		
		Airborne, uninhabited, transport		X					X						X					X	X		
		Airborne, uninhabited, fighter		X					X						X					X	X		
		Airborne, rotary wing						X	X					X	X					X	X		
		Missile, launch/reentry		X				X			X	X			X						X		
		Tactical missile, launch		X				X			X	X			X								
		Cannon, launch	X	X				X				X		X	X						X		
		Undersea, launch	X	X				X						X	X						X		
		Missile, free flight		X				X	X		X	X		X	X								
		Airbreathing missile, flight		X					X		X	X		X	X								
		Space, flight		X					X	X	X	X	X	X	X	X		X	X	X		X	
		Nonoperating																					

EXAMPLE

1000	3	Environment XYZ	3	X	X	X	1	X	10	8	3	7	X	X	X	X	X	8	7	X	X	9	X

APPENDIX D

PRESENTATION TO POTENTIAL DATA CONTRIBUTORS

PRESENTATION TO POTENTIAL DATA CONTRIBUTORS

1 Rome Air Development Center (RADC) has contracted with Martin Marietta Corporation to evaluate and revise the current π_E factors in MIL-HDBK-217 for Reliability Prediction of Electronic Equipment. Our government program manager is Mr. Lester Gubbins. This task is being led at Martin Marietta at Orlando by Mr. Ed Kimball, under the direction of our Manager of Reliability and Maintainability, Mr. Bert F. Kremp.

2 Our contract objectives are to update the factors for environment now listed in MIL-HDBK-217, and to create factors for any newly defined environments. Our scope of work involves analysis of collected field data, augmented by a survey of industrial experts and an evaluation of the severity ratios of the influence factors for a given environment. The purpose of the survey is to determine the consensus of the industry as to the appropriate categorizations and significance of environments in the Handbook. Previous studies conducted by Martin Marietta provide information that can be used as building blocks in the overall data base. There exists the need for additional data in the area of Cruise missiles, and satellites. Review of various suggestions to RADC indicates that the previously mentioned environments should be researched to obtain more representative environmental factors.

3 Currently, 11 environments are presented in MIL-HDBK-217C. There are indications in the industry that the environmental categories should be expanded. This list of 23 environments was circulated during our first survey. Of special concern to us are the additions made in the naval, manpack, and the missile areas.

4 We have completed our second survey. Responses have been analyzed and a severity ranking of the proposed environments, as well as signif-icance ranking of environmental influence factors have been determined. These influence factors would be conditions such as vibration, temperature shock, humidity, dust/sand, which an electronic equipment might experience within a given environmental utilization mode.

We intend to analyze the survey results, which represent the opinion of the industry, the factors now found in the MIL-HDBK, and the field data we collect. Martin Marietta recognizes the difficulties involved with collecting statistically significant quantities of usable data in all desired field environments. It is anticipated that, even with follow-up data collection efforts, there will be a few areas of interest with insufficient field data to apply direct analytical techniques. However, the collected field data will be the primary means for decision making during the final evaluation of the MIL-HDBK-217 π_E factors.

5 We are looking for data in all of the environments we have categorized in the expanded listing, but this data must specifically be field data. Laboratory or test data, because of the contrived nature of the effects equipment sees in such environments, is not of use to us at this time.

Operating hours or estimates of hours are necessary, due to the importance of investigation of parts degradation over time. We would prefer data at the parts level, primarily because MIL-HDBK-217 is currently organized at that level and is intended for reliability prediction by parts stress analysis. Systems level data could be useful, however, if parts mix or parts lists can be obtained. Especially useful would be an environmental profile of the conditions your equipment experienced.

VIEWGRAPH PRESENTATION

RELIABILITY SECTION
PRODUCT ENGINEERING LABORATORY
MARTIN MARIETTA AEROSPACE
ORLANDO, FLORIDA

REVISION OF ENVIRONMENTAL

FACTORS FOR MIL-HDBK-217B

CONTRACT F30602-78-C-0227
ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK

GOVERNMENT PROGRAM MANAGER - MR. LESTER GUBBINS

ENVIRONMENTAL CATEGORIES

GROUND, BENIGN
GROUND, FIXED
GROUND, MOBILE*
NAVAL, SHELTERED
NAVAL, UNSHELTERED
AIRBORNE, INHABITED, TRANSPORT
AIRBORNE, INHABITED, FIGHTER
AIRBORNE, UNINHABITED, TRANSPORT
AIRBORNE, UNINHABITED, FIGHTER
MISSILE, LAUNCH/REENTRY
SPACE, FLIGHT
MANPACK
NAVAL, UNDERSEA, UNSHELTERED
NAVAL, BENIGN, SUBMARINE
NAVAL, HYDROFOIL
AIRBORNE, ROTARY WING
TACTICAL MISSILE, LAUNCH
CANNON, LAUNCH
UNDERSEA, LAUNCH
MISSILE, FREE FLIGHT
AIRBREATHING MISSILE, FLIGHT
NONOPERATING

*GROUND, MOBILE HAS BEEN EXPANDED TO GROUND, MOBILE, WHEELED AND GROUND, MOBILE, TRACKED DURING THIS STUDY.

ENVIRONMENTAL SURVEY

2-ROUND SURVEY OF INDUSTRY EXPERTS

STATISTICAL ANALYSIS OF RESPONSE

- SEVERITY RANKING OF ENVIRONMENTS
- SIGNIFICANCE RANKING OF INFLUENCE FACTORS

CONTRACT OBJECTIVES

- UPDATE FACTORS FOR ENVIRONMENTS IN MIL-HDBK-217B
- CREATE FACTORS FOR NEW ENVIRONMENTS

APPENDIX E

REVISED SEMICONDUCTOR BASE FAILURE RATE TABLES

TABLE 2.2.1-7
MIL-S-19500 TRANSISTORS, GROUP I, SILICON, NPN
BASE FAILURE RATE, λ_b, IN FAILURES PER 10^6 HOURS

T (°C)	S .1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	.00050	.00060	.00070	.00084	.00098	.0012	.0014	.0016	.0021	.0026
10	.00056	.00067	.00079	.00094	.0011	.0013	.0015	.0019	.0025	.0034
20	.00063	.00075	.00088	.0010	.0012	.0015	.0018	.0022	.0029	.0043
25	.00067	.00079	.00094	.0011	.0013	.0015	.0019	.0025	.0034	.0048
30	.00070	.00084	.00098	.0012	.0014	.0016	.0021	.0026	.0037	
40	.00079	.00094	.0011	.0013	.0015	.0019	.0025	.0034	.0048	
50	.00088	.0010	.0012	.0015	.0018	.0022	.0029	.0043		
55	.00094	.0011	.0013	.0015	.0019	.0025	.0034	.0048		
60	.00098	.0012	.0014	.0016	.0021	.0026	.0037			
65	.0010	.0012	.0015	.0018	.0022	.0029	.0043			
70	.0011	.0013	.0015	.0019	.0025	.0034	.0048			
75	.0012	.0014	.0016	.0021	.0026	.0037				
80	.0012	.0015	.0018	.0022	.0029	.0043				
85	.0013	.0015	.0019	.0025	.0034	.0048				
90	.0014	.0016	.0021	.0026	.0037					
95	.0015	.0018	.0022	.0029	.0043					
100	.0015	.0019	.0025	.0034	.0048					
105	.0016	.0021	.0026	.0037						
110	.0018	.0022	.0029	.0043						
115	.0019	.0025	.0034	.0048						
120	.0021	.0026	.0037							
125	.0022	.0029	.0043							
130	.0025	.0034	.0048							
135	.0026	.0037								
140	.0029	.0043								
145	.0034	.0048								
150	.0037									
155	.0043									
160	.0048									

TABLE 2.2.1-8
MIL-S-19500 TRANSISTORS, GROUP I, SILICON, PNP
BASE FAILURE RATE, λ_b, IN FAILURES FOR 10^6 HOURS

T (°C)	S .1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	.00065	.00083	.0010	.0012	.0015	.0017	.0020	.0026	.0032	.0044
10	.00077	.00095	.0012	.0014	.0016	.0019	.0023	.0031	.0039	.0057
20	.00089	.0011	.0013	.0015	.0019	.0022	.0028	.0035	.0049	.0077
25	.00095	.0012	.0014	.0016	.0019	.0023	.0031	.0039	.0057	.0092
30	.0010	.0012	.0015	.0017	.0020	.0026	.0032	.0044	.0065	
40	.0012	.0014	.0016	.0019	.0023	.0031	.0039	.0057	.0092	
50	.0013	.0015	.0019	.0022	.0028	.0035	.0049	.0077		
55	.0014	.0016	.0019	.0023	.0031	.0039	.0057	.0092		
60	.0015	.0017	.0020	.0026	.0032	.0044	.0065			
65	.0015	.0019	.0022	.0028	.0035	.0049	.0077			
70	.0016	.0019	.0023	.0031	.0039	.0057	.0092			
75	.0017	.0020	.0026	.0032	.0044	.0065				
80	.0019	.0022	.0028	.0035	.0049	.0077				
85	.0019	.0023	.0031	.0039	.0057	.0092				
90	.0020	.0026	.0032	.0044	.0065					
95	.0022	.0028	.0035	.0049	.0077					
100	.0023	.0031	.0039	.0057	.0092					
105	.0026	.0032	.0044	.0065						
110	.0028	.0035	.0049	.0077						
115	.0031	.0039	.0057	.0092						
120	.0032	.0044	.0065							
125	.0035	.0049	.0077							
130	.0039	.0057	.0092							
135	.0044	.0065								
140	.0049	.0077								
145	.0057	.0092								
150	.0065									
155	.0077									
160	.0092									

TABLE 2.2.4-7
MIL-S-19500 DIODES, GROUP IV, SILICON
BASE FAILURE RATE, λ_b, IN FAILURES PER 10^6 HOURS

T (°C)	S .1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	.00010	.00014	.00020	.00027	.00037	.00049	.00065	.00085	.0011	.0016
10	.00012	.00018	.00025	.00033	.00045	.00059	.00076	.0010	.0014	.0022
20	.00016	.00023	.00031	.00041	.00053	.00070	.00092	.0013	.0019	.0031
25	.00018	.00025	.00033	.00045	.00059	.00076	.0010	.0014	.0022	.0039
30	.00020	.00027	.00037	.00049	.00065	.00085	.0017	.0016	.0025	
40	.00025	.00033	.00045	.00059	.00076	.0010	.0014	.0022	.0039	
50	.00031	.00041	.00053	.00070	.00092	.0013	.0019	.0031		
55	.00033	.00045	.00059	.00076	.0010	.0014	.0022	.0039		
60	.00037	.00049	.00065	.00085	.0011	.0016	.0025			
65	.00041	.00053	.00070	.00092	.0013	.0019	.0031			
70	.00045	.00059	.00076	.0010	.0014	.0022	.0039			
75	.00049	.00065	.00085	.0011	.0016	.0025				
80	.00053	.00070	.00092	.0013	.0019	.0031				
85	.00059	.00076	.0010	.0014	.0022	.0039				
90	.00065	.00085	.0011	.0016	.0025					
95	.00070	.00092	.0013	.0019	.0031					
100	.00075	.0010	.0014	.0022	.0039					
105	.00085	.0011	.0016	.0025						
110	.00092	.0013	.0019	.0031						
115	.0010	.0014	.0022	.0039						
120	.0011	.0016	.0025							
125	.0013	.0019	.0031							
130	.0014	.0022	.0039							
135	.0016	0025								
140	.0019	.0031								
145	.0022	.0039								
150	.0025									
155	.0031									
160	.0039									

TABLE 2.2.5-4
MIL-S-19500 ZENER DIODES, GROUP V
BASE FAILURE RATE, λ_b, IN FAILURES PER 10^6 HOURS

T	S									
(°C)	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	.00041	.00048	.00055	.00061	.00070	.00078	.00089	.0010	.0012	.0016
10	.00046	.00053	.00060	.00066	.00075	.00085	.00099	.0012	.0015	.0019
20	.00049	.00056	.00065	.00072	.00082	.00094	.0011	.0013	.0017	.0026
25	.00053	.00060	.00066	.00075	.00085	.00099	.0012	.0015	.0019	.0031
30	.00055	.00061	.00070	.00078	.00089	.0010	.0012	.0016	.0022	
40	.00060	.00066	.00075	.00085	.00099	.0012	.0015	.0019	.0031	
50	.00065	.00072	.00082	.00094	.0011	.0013	.0017	.0026		
55	.00066	.00075	.00085	.00099	.0012	.0015	.0019	.0031		
60	.00070	.00078	.00089	.0010	.0012	.0016	.0022			
65	.00072	.00082	.00094	.0011	.0013	.0017	.0026			
70	.00075	.00085	.00099	.0012	.0015	.0019	.0031			
75	.00078	.00089	.0010	.0012	.0016	.0022				
80	.00082	.00094	.0011	.0013	.0017	.0026				
85	.00085	.00099	.0012	.0015	.0019	.0031				
90	.00089	.0010	.0012	.0016	.0022					
95	.00094	.0011	.0013	.0017	.0026					
100	.00099	.0012	.0015	.0019	.0031					
105	.0010	.0012	.0016	.0022						
110	.0011	.0013	.0017	.0026						
115	.0012	.0015	.0019	.0031						
120	.0012	.0016	.0022							
125	.0013	.0017	.0026							
130	.0015	.0019	.0031							
135	.0016	.0022								
140	.0017	.0026								
145	.0019	.0031								
150	.0022									
155	.0026									
160	.0031									

TABLE 2.2-2
DISCRETE SEMICONDUCTOR BASE RAILURE RATE PARAMETERS

Group	Part Type	λ_b Constants				ΔT
		A	N_T	T_M	P	
Transistors						
I	Si, NPN	0.0189	-1052	448	10.5	150
	Si, PNP	0.0648	-1324	448	14.2	150
	Ge, PNP	6.5	-2142	373	20.8	75
	Ge, NON	21	-2221	373	19	75
II	FET	0.52	-1162	448	13.8	150
III	Unijunction	3.12	-1779	448	13.8	150
Diodes						
IV	Si, Gen. Purp.	0.172	-2138	448	17.7	150
	Ge, Gen. Purp.	126	-3568	373	22.5	75
V	Zener/Avalanche	0.0068	-800	448	14	150
VI	Thryistors	0.82	-2050	448	9.6	150
VII	Microwave					
	Ge, Detectors	0.33	-477	343	15.6	45
	Si, Detectors	0.14	-392	423	16.6	125
	Si, Schottky Det.	0.005	-392	423	16.6	125
	Ge, Mixers	0.56	-477	343	15.6	45
	Si, Mixers	0.19	-394	423	15.6	125
VIII	IMPATT, Gunn, Varactor, PIN, Step Recovery & Tunnel	0.93	-1162	448	13.8	150
Transistors IX	Microwave	See Section 2.2.9				
X Opto-electronic	LED's, Isolators and Displays	126	-3734	398	22.5	100

Supersedes page 2.2-3, 9 April 1979.

APPENDIX F

REVISION SHEETS FOR MIL-HDBK-217

Use Environment

All part reliability models include the effects of environmental stresses through the factor, π_E. The definitions of these environments are shown in Table 2-3. The π_E factor is quantified within each part failure rate model. These environments encompass the major areas of equipment use. Most equipment will experience more than one environment during its normal use, particularly since the nonoperating mode has been added to the models. To utilize both the operating and nonoperating models with one or more environments, the reliability analysis should be segmented. This is illustrated by the following example.

Consider a tactical artillery missile fired from a wheeled vehicle capable of traversing rough terrain. The missile would be removed from depot storage in an uncontrolled environment and subjected to a functional test. It would then be carried by truck to the ammunition supply point for loading into the mobile launcher. The launcher travels cross country to the forward edge of the battle area and when a fire mission is received, power is turned on in the missile and shortly thereafter it is launched and proceeds to the target. As before, the appropriate π_E factors should be quantified within each part failure rate model and the resulting part failure rates are summed to obtain system failure rates for each segment of the mission. A model for this mission is shown below:

$$R_M = e^{-\left[(1-a)\left(\lambda_{NO_{GF}} t_{NO_{GF}}\right) + \lambda_{NO_{G_M}} t_{NO_{G_M}} + \lambda_{G_M} t_{G_M} + \lambda_{ML} t_{ML}\right]}$$

where

a = functional test efficiency (percent of failures detected)

$\lambda_{NO_{GF}}$ = system ground fixed nonoperating failure rate

$\lambda_{NO_{G_M}}$ = system ground mobile nonoperating failure rate

λ_{G_M} = system ground mobile operating failure rate

λ_{ML} = system missile launch failure rate

$t_{NO_{GF}}$ = depot storage time period

$t_{NO_{G_M}}$ = ground mobile nonoperating time period

t_{G_M} = ground mobile operating time period

t_{ML} = missile launch and flight time period

TABLE 2-3 ENVIRONMENTAL SYMBOL IDENTIFICATION AND DESCRIPTION

ENVIRONMENTAL MODE	π_E SYMBOL	DESCRIPTION
Ground, Benign	G_B	Nonmobile, laboratory environment readily accessible to maintenance.
Ground, Fixed	G_F	Conditions less than ideal to include installation in permanent racks with adequate cooling air and possible installation in unheated buildings.
Ground, Mobile	G_M	Mobile equipment installed upon wheeled or tracked vehicles.
Space, Flight	S_F	Earth orbital. Approaches Ground, Benign conditions without access for maintenance. Vehicle neither under powered flight nor in atmospheric re-entry.
Nonoperating	N_O	Dormancy/storage conditions of equipment.
Manpack	M_P	Portable electronic equipment being manually transported while in the operational mode.
Naval, Sheltered	N_S	Sheltered or below deck conditions, protected from elements of weather.
Naval, Unsheltered	N_U	Nonprotected shipboard equipment exposed to climatic conditions.
Naval, Undersea, Unsheltered	N_{UU}	Equipment immersed in salt water.
Naval, Submarine	N_{SB}	Equipment installed in submarine.
Naval, Hydrofoil	N_H	Equipment installed in a hydrofoil vessel.
Airborne, Inhabited, Transport	A_{IT}	Typical conditions in transport or bomber compartments occupied by aircrew without environmental extremes of pressure, temperature, shock and vibration, and installed on long mission aircraft such as transports and bombers.
Airborne, Inhabited, Fighter	A_{IF}	Same as A_{IT} but installed on high performance aircraft such as fighters and intercepters.

TABLE 2-3 (Continued)

ENVIRONMENTAL MODE	π_E SYMBOL	DESCRIPTION
Airborne, Uninhabited, Transport	A_{UT}	Bomb bay, equipment bay, tail, or where extreme pressure, vibration, and temperature cycling may be aggravated by contamination from oil, hydraulic fluid and engine exhaust. Installed on long mission aircraft such as transports and bombers.
Airborne, Uninhabited, Fighter	A_{UF}	Same as A_{UT} but installed on high performance aircraft such as fighters and intercepters.
Airborne, Rotary Winged	A_{RW}	Equipment installed in or on helicopters.
Missile, Launch	M_L	Severe conditions related to missile launch (air and ground), and space behicle boost into orbit, vehicle reentry and landing by parachute. Conditions may also apply to rocket propulsion powered flight.
Cannon, Launch	C_L	Extremely severe conditions related to cannon launch.
Undersea, Launch	U_{SL}	Conditions related to undersea torpedo mission/missile launch.
Missile, Free Flight	M_{FF}	Non-powered free flight.
Airbreathing Missile, Flight	M_{FA}	Conditions related to powered flight of airbreathing missile.

TABLE 2-3A TYPICAL EQUIPMENT USAGE

ENVIRONMENTAL MODE	TYPICAL EQUIPMENTS IN MODE
Ground, Benign	Laboratory instruments, laboratory test equipment, medical electronic equipment, large business/scientific computer complexes.
Ground, Fixed	Permanent installation of air traffic control, radar and communications facilities, missile silo ground support equipment.
Ground, Mobile	Tactical missiles and associated ground support equipment, mobile communications equipment, tactical fire direction systems.
Space Flight	Satellites, space probes, shuttles.
Nonoperating	Systems in dormancy/storage conditions.
Manpack	Portable field communications equipment and laser designators/rangefinders.
Naval, Sheltered	Surface ships communications equipment, computers, sonars.
Naval, Unsheltered	Mast mounted radar electronics, missile/projectile fire control equipment.
Naval, Undersea, Unsheltered	Sonar sensors, special purpose ASW equipment
Naval, Submarine	SINS, launch control systems, strategic missiles.
Naval, Hydrofoil	Communications equipment.
Airborne, Rotary Winged	Tactical missiles, laser designators, fire control systems.
Missile, Launch	Missiles in conditions described by Table 2-3.
Cannon, Launch	155 mm and 5 inch guided projectiles.
Undersea, Launch	Torpedoes, strategic missiles.
Missile, Free Flight	Missiles in conditions described by Table 2-3.
Airbreathing Missile, Flight	Cruise missiles.

2.1.1 Monolithic Bipolar and MOS Digital SSI/MSI Devices (less than 100 gates).

Part operating failure rate model (λ_p):

$$\lambda_p = \pi_Q \left[C_1 \pi_T \pi_V + (C_2 + C_3)\, \pi_E \right] \pi_L \quad \text{Failures}/10^6 \text{ hours}$$

where:

λ_p is the device failure rate in F/10^6 hours

π_Q is the quality factor, Table 2.1.5-1

π_T is the temperature acceleration factor, based on technology (Table 2.1.5-4) and is found in Tables 2.1.5-5 thru 2.1.5-13

π_V is the voltage derating stress factor, Table 2.1.5-14

π_E is the application environment factor, Table 2.1.5-3

C_1 & C_2 are the circuit complexity failure rates based upon gate count and are found in Tables 2.1.5-17 and 2.1.5-18. (See Tables 2.1.5-27 and 2.1.5-28 for gate count determination)

C_3 is the package complexity failure rate, Table 2.1.5-26

π_L is the device learning factor, Table 2.1.5-2

Part non-operating failure rate model (λ_{pNO}):

$$\lambda_{pNO} = \pi_Q \left[0.1\, C_1 + (C_2 + C_3)\, \pi_{E_{NO}} \right] \quad \text{Failures}/10^6 \text{ hours}$$

where:

π_Q, C_1, C_2, C_3 are as described for λ_p

$\pi_{E_{NO}}$ is the application environment factor, Table 2.1.5-3

Supersedes page 2.1.1-1, 9 April 1979

2.1.2 Monolithic Bipolar and MOS Linear Devices

Part operating failure rate model (λ_p):

$$\lambda_p = \pi_Q \left[C_1 \pi_T \pi_V + (C_2 + C_3)\, \pi_E \right] \pi_L \quad \text{Failures}/10^6 \text{ hours}$$

where:

λ_p is the device failure rate in $F/10^6$ hours

π_Q is the quality factor, Table 2.1.5-1

π_T is the temperature acceleration factor, based on technology (Table 2.1.5-4) and is found in Tables 2.1.5-5 thru 2.1.5-13

π_V is the voltage derating stress factor, Table 2.1.5-14

π_E is the application environment factor, Table 2.1.5-3

C_1 & C_2 are the circuit complexity failure rates based upon gate count and are found in Tables 2.1.5-17 and 2.1.5-18. (See Tables 2.1.5-27 and 2.1.5-28 for gate count determination)

C_3 is the package complexity failure rate, Table 2.1.5-26

π_L is the device learning factor, Table 2.1.5-2

Part non-operating failure rate model (λ_{PNO}):

$$\lambda_{PNO} = \pi_Q \left[0.1\, C_1 + (C_2 + C_3)\, \pi_{E_{NO}} \right] \quad \text{Failures}/10^6 \text{ hours}$$

where:

π_Q, C_1, C_2, C_3 are as described for λ_p

$\pi_{E_{NO}}$ is the application environment factor, Table 2.1.5-3

Supersedes page 2.1.1-1, 9 April 1979

2.1.3 Monolithic Bipolar and MOS Random Logic LSI and Microprocessor Devices (equal to or greater than 100 gates)

Part operating failure rate model (λ_p):

$$\lambda_p = \pi_Q \left[C_1\pi_T\pi_V + (C_2 + C_3)\pi_E\right]\pi_L \quad \text{Failures}/10^6 \text{ hours}$$

where:

λ_p is the device failure rate in F/10^6 hours

π_Q is the quality factor, Table 2.1.5-1

π_T is the temperature acceleration factor, based on technology (Table 2.1.5-4) and is found in Tables 2.1.5-5 thru 2.1.5-13

π_V is the voltage derating stress factor, Table 2.1.5-14

π_E is the application environment factor, Table 2.1.5-3

C_1 & C_2 are the circuit complexity failure rates based upon gate count and are found in Tables 2.1.5-17 and 2.1.5-18. (See Tables 2.1.5-27 and 2.1.5-28 for gate count determination)

C_3 is the package complexity failure rate, Table 2.1.5-26

π_L is the device learning factor, Table 2.1.5-2

Part non-operating failure rate model (λ_{PNO}):

$$\lambda_{PNO} = \pi_Q \left[0.1\, C_1 + (C_2 + C_3)\pi_{E_{NO}}\right] \quad \text{Failures}/10^6 \text{ hours}$$

where:

π_Q, C_1, C_2, C_3 are as described for λ_p

$\pi_{E_{NO}}$ is the application environment factor, Table 2.1.5-3

Supersedes page 2.1.1-1, 9 April 1979

2.1.4 Monolithic MOS and Bipolar Memories

2.1.4.1 Random Access Memories (RAMs)

Part operating failure rate model (λ_p):

$$\lambda_p = \pi_Q \left[C_1 \pi_T \pi_V + (C_2 + C_3)\, \pi_E\right] \pi_L \quad \text{Failures}/10^6 \text{ hours}$$

where:

λ_p is the device failure rate in F/10^6 hours

π_Q is the quality factor, Table 2.1.5-1

π_T is the temperature acceleration factor, based on technology (Table 2.1.5-4) and is found in Tables 2.1.5-5 thru 2.1.5-13

π_V is the voltage derating stress factor, Table 2.1.5-14

π_E is the application environment factor, Table 2.1.5-3

C_1 & C_2 are the circuit complexity failure rates based upon gate count and are found in Tables 2.1.5-17 and 2.1.5-18. (See Tables 2.1.5-27 and 2.1.5-28 for gate count determination)

C_3 is the package complexity failure rate, Table 2.1.5-26

π_L is the device learning factor, Table 2.1.5-2

Part non-operating failure rate model (λ_{PNO}):

$$\lambda_{PNO} = \pi_Q \left[0.1\, C_1 + (C_2 + C_3)\, \pi_{E_{NO}}\right] \quad \text{Failures}/10^6 \text{ hours}$$

where:

π_Q, C_1, C_2, C_3 are as described for λ_p

$\pi_{E_{NO}}$ is the application environment factor, Table 2.1.5-3

Supersedes page 2.1.1-1, 9 April 1979

2.1.4.2 Read-Only Memories (ROMs) and Programmable Read-Only Memories (PROMs)

Part operating failure rate model (λ_p):

$$\lambda_p = \pi_Q \left[C_1 \pi_T \pi_V + (C_2 + C_3)\,\pi_E\right] \pi_L \quad \text{Failures}/10^6 \text{ hours}$$

where:

λ_p is the device failure rate in F/10^6 hours

π_Q is the quality factor, Table 2.1.5-1

π_T is the temperature acceleration factor, based on technology (Table 2.1.5-4) and is found in Tables 2.1.5-5 thru 2.1.5-13

π_V is the voltage derating stress factor, Table 2.1.5-14

π_E is the application environment factor, Table 2.1.5-3

C_1 & C_2 are the circuit complexity failure rates based upon gate count and are found in Tables 2.1.5-17 and 2.1.5-18. (See Tables 2.1.5-27 and 2.1.5-28 for gate count determination)

C_3 is the package complexity failure rate, Table 2.1.5-26

π_L is the device learning factor, Table 2.1.5-2

Part non-operating failure rate model (λ_{PNO}):

$$\lambda_{PNO} = \pi_Q \left[0.1\, C_1 + (C_2 + C_3)\,\pi_{E_{NO}}\right] \quad \text{Failures}/10^6 \text{ hours}$$

where:

π_Q, C_1, C_2, C_3 are as described for λ_p

$\pi_{E_{NO}}$ is the application environment factor, Table 2.1.5-3

Supersedes page 2.1.1-1, 9 April 1979

TABLE 2.1.5-2. π_L, LEARNING FACTORS

The learning factor π_L is 10 under any of the following conditions:

(1) New device in initial production.
(2) Where major changes in design or process have occurred.
(3) Where there has been an extended interruption in production or a change in line personnel (radical expansion).

The factor of 10 can be expected to apply until conditions and controls have stabilized. This period can extend for as much as six months of continuous production.

π_L is equal to 1.0 under all production conditions not stated in (1), (2) and (3) above.

TABLE 2.1.5-3. Application Environment Factor π_E

Environment	π_E	
	Operating	Nonoperating
S_F	0.90	0.09
G_B	0.38	0.04
G_F	2.5	0.25
N_{SB}	4.5	0.45
N_S	3.4	0.34
M_P	3.8	0.38
G_M	4.2	0.41
M_{FF}	3.9	0.38
A_{IT}	3.5	-
M_{FA}	5.4	0.54
N_U	5.7	0.57
A_{UT}	4.0	-
N_H	5.9	0.58
N_{UU}	6.3	0.63
A_{RW}	8.5	0.84
A_{IF}	7.0	-
U_{SL}	11.	1.1
A_{UF}	8.0	-
M_L	13.	1.3
C_L	220.	22.

Supersedes page 2.1.5-2, 9 April 1979

2.1.6 EXAMPLE FAILURE RATE CALCULATIONS FOR MONOLITHIC DEVICES

Example One

Description: An 8192 bit N-channel MOS UV-EPROM in a Ground, Fixed application, junction temperature of 55°C, procured to vendor equivalent B-2 quality level. The production line has been in continuous production. The device is a ceramic/metal DIP, solar seal hermetic package with 24 pins.

From Section 2.1.4.2, the operating failure rate model is:

$$\lambda_p = \pi_Q \left[C_1 \pi_T \pi_V \pi_{PT} + (C_2 + C_3)\, \pi_E\right] \pi_L$$

Table 2.1.5-1 Quality Level B-2; $\pi_Q = 6.5$

Table 2.1.5-3 Ground, Fixed Environment: $\pi_E = 2.5$

Table 2.1.5-4 NMOS, Hermetic Package: corresponding to π_T
Table 2.1.5-8; $\pi_T = 0.71$

Table 2.1.5-14 $\pi_V = 1.0$

Table 2.1.5-24 8192 bits; $C_1 = 0.055$, $C_2 = 0.0024$

Table 2.1.5-25 $\pi_{PT} = 1.56$

Table 2.1.5-26 24 pin Hermetic DIP solder seal; $C_3 = 0.009$

Table 2.1.5-2 $\pi_L = 1$

$$\lambda_p = 6.5 \; [(0.055)0.71(1.0)(1.56) + (0.0024 + 0.009)2.5] \; 1.0$$

$$\lambda_p = 0.59/10^6 \text{ hours.}$$

From Section 2.1.4.2, the non-operating failure rate model is:

$$\lambda_{PNO} = \pi_Q \left[0.1\, C_1 + (C_2 + C_3)\, \pi_{ENO}\right]$$

Table 2.1.5-3 Ground, Fixed Environment: $\pi_{ENO} = 0.25$

$$\lambda_{PNO} = 6.5\; [(0.1)(0.055) + (0.0024 \times 0.009)\; 0.25]$$

$$\lambda_{PNP} = 0.036/10^6 \text{ hours.}$$

Example Two

Description: Device type M33510/01801 is being used in an airborne inhabited, transport environment. The device is procured as quality level B-2 and has been in continuous production. The device is in a 16 pin, glass seal hermetic C-DIP package. The device has a worst case power dissipation of 0.77 watts.

The type number shows that the device is included in MIL-M-38510, described in slash sheet 18, type 01. The device is fabricated using TTL digital bipolar technology.

Table 2.1.5-26 shows a 100 gate complexity for this device. Since the device complexity is equal to 100 gates, the random logic LSI digital model in Section 2.1.3 applies. The operating failure rate equation is:

$$\lambda_p = \pi_Q \left[C_1 \pi_T \pi_V + (C_2 + C_3)\,\pi_E\right] \pi_L$$

Table 2.1.5-1 Quality Level B-2; $\pi_Q = 6.5$

Table 2.1.5-3 Airborne, Inhabited, Transport Environment, $\pi_E = 3.5$

Table 2.1.5-4 TTL, Hermetic Package, corresponding to π_T Table 2.1.5-5

$T_C = 60°C$

$T_J = T_C + \theta_{JC} P_{max} = 60 + 30(0.77) = 83°C$

From Table 2.1.5-5, $\pi_T = 1.3$

Table 2.1.5-14 $\pi_V = 1.0$

Table 2.1.5-20 100 gate complexity; $C_1 = 0.015$, $C_2 = 0.0012$

Table 2.1.5-26 16 pin hermetic DIP, glass seal, $C_3 = 0.0059$

Table 2.1.5-2 $\pi_L = 1.0$

$\lambda_p = 6.5\,[(0.015)1.3(1.0) + (0.0012 + 0.0059)3.5]\,1.0$

$\lambda_p = 6.5\,[0.020 + 0.025]$

$\lambda_p = 0.29/10^6$ hrs.

2.1.7 HYBRID MICROCIRCUIT

The hybrid operating failure rate model is:

$$\lambda_p = \left\{\Sigma N_C \lambda_C \pi_G + [N_R \lambda_R + \Sigma N_I \lambda_I + \lambda_S] \pi_F \pi_E\right\} \pi_Q \pi_D$$

(failures/10^6 hour)

where:

$\Sigma N_C \lambda_C \pi_G$ is the sum of the adjusted failure rates for the active components and capacitors in the hybrid from section 2.1.7.1 N_C is the number of each particular component
λ_C is the component failure rate
π_G is the die correction factor Table 2.1.7-1

$N_R \lambda_R$ is the number of (N_R) and failure rate contribution (λ_R) of the chip or substrate resistors (section 2.1.7.2)

$\Sigma N_I \lambda_I$ is the sum of the failure rate contributions of the interconnections (λ_I) from section 2.1.7.3

λ_S is the failure rate contribution of the hybrid package. (Table 2.1.7-4)

π_E is the Environmental Factor for the film resistors, interconnections and package from Table 2.1.7-5

π_Q is the quality factor from Table 2.1.7-6

π_D is the density factor from Table 2.1.7-7

π_F is the circuit function factor
= 1.0 for digital hybrids
= 1.25 for linear or linear-digital combinations

The hybrid non-operating failure rate model is:

$$\lambda_{PNO} = \left\{\Sigma N_C \lambda_C \pi_G + [0.0001 N_R + 0.000174 \Sigma N_I + \lambda_{S_{25°C}}] \pi_{E_{NO}}\right\} \pi_Q \pi_D$$

Failures/10^6 hours

where:

$\Sigma N_C \lambda_C \pi_G$, N_R, ΣN_I, π_Q, π_D are applied in the same manner as in the operating failure rate model

$\lambda_{S_{25°C}}$ is the failure rate contribution of the hybrid package at 25°C (70°F), (Table 2.1.7-4)

$\pi_{E_{NO}}$ is the environmental factor for the film resistors, interconnections and package from Table 2.1.7-5

TABLE 2.1.7-5

Environmental Factor for Resistors,
Interconnections and Packages

Environment	π_E	
	Operating	Nonoperating
S_F	0.32	0.18
G_B	0.20	0.12
G_F	0.78	0.45
N_{SB}	0.99	0.57
N_S	1.7	0.98
M_P	2.0	1.2
G_M	2.2	1.3
M_{FF}	2.1	1.2
A_{IT}	1.4	-
M_{FA}	2.9	1.7
N_U	3.2	1.8
A_{UT}	2.1	-
N_H	3.1	1.8
N_{UU}	3.4	2.0
A_{RW}	4.5	2.6
A_{IF}	2.8	-
U_{SL}	6.1	3.5
A_{UF}	4.2	-
M_L	7.0	4.0
C_L	120.	69.

Si NPN transistor die, 60% stress ratio, page 2.2.1-1

$\lambda_b (\pi_E\ \pi_A\ \pi_Q\ \pi_R\ \pi_{S2}\ \pi_C)\ \pi_G$
(.02) 25 (1.5) 0.12 (1.0) 0.88 (1.0) 0.4 = 0.0316

Si PNP transistor die, 60% stress ratio, page 2.2.1-1
(same model as NPN transistor above)
(0.34) 25 (1.5) 0.12 (1.0) 0.88 (1.0) 0.4 = 0.0539

Si general purpose diode die, 60% stress ratio, page 2.2.4-1

$\lambda_b (\pi_E\ \pi_Q\ \pi_R\ \pi_A\ \pi_{S2}\ \pi_C)\ \pi_G$
(.0095) 25 (.15) 1.0 (1.0) 0.7 (1.0) .2 = 0.005

Ceramic chip capacitor, 60% stress ratio, 1000 pf., page 2.6.4-1

$\lambda_b (\pi_E\ \pi_Q\ \pi_{CV})\ \pi_G$
(.0063) 8.0 (1.0) 1.0 (.8) - 0.0403

Thick Film Resistor - Table 2.1.7-2

.0015

Package - Table 2.1.7-4, seal perimeter = 4.2 in.

$\lambda_S = .108$

Interconnection - Table 2.1.7-3

Au-Al: .00130
Solder: .000871

$\pi_E = 3.2$ Table 2.1.7-5

$\pi_Q = 1.0$ Table 2.1.7-6

Density = 38/(.563 + .10) = 57.3

$\pi_D = 1.34$ Table 2.1.7-1

$\pi_F = 1.25$ (for linear application, page 2.1.7-1)

$$\lambda_p = \{.0864 + .1206 + 2\,(.0316) + 2\,(.0539) + 2\,(.005) + 2\,(.0403) + [17(.00015) + 34\,(.00130) + 4\,(.00087) + .108]\,(1.25)\,3.2\}\,1.0\,(1.34)$$

$\lambda_p = 1.48$

The model for the non-operating failure rate is:

$$\lambda_{P_{NO}} = \left\{ \Sigma N_C \lambda_C \Pi_G + [0.0001\ N_R + 0.000174\ \Sigma N_I + \lambda_{S_{25°c}}]\ \Pi_{E_{NO}} \right\} \pi_Q\ \pi_D$$

Package - Table 2.1.7-4, seal perimeter = 4.2 in., temperature = 25°c

$$\lambda_{S_{25°c}} = 0.014$$

$\Pi_{E_{NO}}$ = 1.8 Table 2.1.7-5

$$\lambda_{P_{NO}} = \{0.0864 + 0.1206 + 2(0.0316) + 2(0.0539) + 2(.005) + 2(0.0403) + [?7(0.0001) + 34(0.000174) + 4(0.000174) + 0.014]\ 1.8\}\ (1.0)(1.34)$$

$$\lambda_{P_{NO}} = 0.68$$

DISCRETE SEMICONDUCTORS
CONVENTIONAL TRANSISTORS

2.2.1 Transistors, Group I

SPECIFICATION	STYLE	DESCRIPTION
MIL-S-19500		Si, NPN Si, PNP Ge, PNP Ge, NPN

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b (\pi_E \times \pi_A \times \pi_Q \times \pi_R \times \pi_{S_2} \times \pi_C) \text{ Failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.2.1-1 through 10.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{no}} \times \pi_Q \times \pi_C \text{ Failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.2.1-1

Group I Transistors
Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.09
S_F	0.4	0.04
G_F	5.8	0.54
N_{SB}	11	1
N_S	8.6	0.81
A_{IT}	12	-
M_P	12	1.1
M_{FF}	12	1.1
M_{FA}	17	1.6
G_M	18	1.7
N_H	19	1.7
N_{UU}	20	1.9
A_{UT}	20	-
N_U	21	2.0
A_{IF}	25	-
A_{RW}	27	2.5
L_{SL}	36	3.3
A_{UF}	40	-
M_L	41	3.9
C_L	690	66

TABLE 2.2.1-2
π_A FOR GROUP I TRANSISTORS

Application	π_A
Linear	1.5
Switch	0.7
Si, low noise, r. f., <1W.	15.0

TABLE 2.2.1-3
π_Q, QUALITY FACTOR

Quality Level	π_Q
JANTXV	0.12
JANTX	0.24
JAN	1.2
Lower*	6.0
Plastic**	12.0

*Hermetic packaged devices.
**Devices sealed or encapsulated with organic materials.

TABLE 2.2.1-4
π_R FOR GROUP I TRANSISTORS

Power Rating (watts)	π_R
$\leq$ 1	1
> 1 to 5	1.5
> 5 to 20	2.0
> 20 to 50	2.5
> 50 to 200	5.0

DISCRETE SEMICONDUCTORS
FET

2.2.2 Transistors, Group II

SPECIFICATION	STYLE	DESCRIPTION
MIL-S-19500		Silicon Field Effect Transistors, Gallium Arsenide FET

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b(\pi_E \times \pi_A \times \pi_Q \times \pi_C) \text{ Failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.2.2-1 through 5.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \times \pi_C \text{ Failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.2.-1

Group II Transistors
Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.4
S_F	0.6	0.24
G_F	4.0	1.6
N_{SB}	6	2.4
N_S	8.6	3.4
A_{IT}	12	-
M_P	12	4.8
M_{FF}	12	4.8
M_{FA}	17	6.7
G_M	18	7.2
N_H	19	7.4
N_{UU}	20	7.9
A_{UT}	20	-
N_U	21	8.3
A_{IF}	25	-
A_{RW}	27	11
U_{SL}	36	14
A_{UF}	40	-
M_L	41	16
C_L	690	280

TABLE 2.2.2-2
π_A FOR GROUP II TRANSISTORS

Application	π_A
Silicon	
Linear	1.5
Switch	0.7
High Frequency (>400 HMz. & aver. power < 300 mW.)	5.0
GaAs	
Low Noise	7.0
Driver (≤ 100 mW.)	50.0

TABLE 2.2.2-3
π_C FOR GROUP II TRANSISTORS

Complexity	π_C
Single Device	1.0
Dual Unmatched	0.7
Dual Matched	1.2
Dual Complementary	0.7
Tetrode	1.1

TABLE 2.2.2-4
π_Q FOR GROUP II TRANSISTORS

Quality Level	π_Q
Silicon	
JANTXV	0.12
JANTX	0.24
JAN	1.2
LOWER*	6.0
PLASTIC**	12.0
GaAs	1.0

* - hermetic packaged devices
** - devices sealed or encapsulated with organic materials

DISCRETE SEMICONDUCTORS
UNIJUNCTION

2.2.3 Transistors, Group III

SPECIFICATION	STYLE	DESCRIPTION
MIL-STD-19500		Unijunction

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times \pi_E \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.2.3-1 through 3.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.01 \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

TABLE 2.2.3-1

Group III Transistors
Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	1
S_F	1	1
G_F	1	1
N_{SB}	10	10
N_S	8.6	8.6
A_{IT}	12	
M_P	12	12
M_{FF}	12	12
M_{FA}	17	17
C_M	18	18
N_H	19	19
N_{UU}	20	20
A_{UT}	20	
N_U	21	21
A_{IF}	25	
A_{RW}	27	27
U_{SL}	36	36
A_{UF}	40	
M_L	41	41
C_L	690	690

TABLE 2.2.3-2
π_Q, QUALITY FACTOR

Quality Level	π_Q
JANTXV	0.5
JANTX	1.0
JAN	5.0
Lower*	25.0
Plastic**	50.0

*Hermetic packaged devices.
**Devices sealed or encapsulated with organic material.

DISCRETE SEMICONDUCTORS
DIODES, GENERAL PURPOSE

2.2.4 Diodes, Group IV

SPECIFICATION	STYLE	DESCRIPTION
MIL-S-19500		Silicon, General Purpose Germanium, General Purpose

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b(\pi_E \times \pi_Q \times \pi_K \times \pi_A \times \pi_{S_2} \times \pi_C) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.2.4-1 through 8.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \times \pi_C \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.2.4-1

Group IV Diodes
Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.71
S_F	1	0.71
G_F	3.9	2.8
N_{SB}	4.9	3.5
N_S	4.7	3.3
A_{IT}	12	-
M_P	12	8.6
M_{FF}	12	8.7
M_{FA}	17	12
G_M	18	13
N_H	19	13
N_{UU}	20	14
A_{UT}	20	-
N_U	21	15
A_{IF}	25	-
A_{RW}	27	19
U_{SL}	36	25
A_{UF}	40	-
M_L	41	29
C_L	690	490

TABLE 2.2.4-2
π_Q, QUALITY FACTOR

Quality Level	π_Q
JANTXV	0.15
JANTX	0.3
JAN	1.5
Lower*	7.5
Plastic**	15.0

*Hermetic packaged devices.
**Devices sealed or encapsulated with organic material.

TABLE 2.2.4-3
π_R FOR GROUP IV DIODES

Current Rating (amps.)	π_R
$\leq$ 1	1
> 1 to 3	1.5
> 3 to 10	2.0
>10 to 20	4.0
>20 to 50	10.0

DISCRETE SEMICONDUCTORS
ZENER AND AVALANCHE DIODES

2.2.5 Diodes, Group V

SPECIFICATION	STYLE	DESCRIPTION
MIL-STD-19500		Voltage Regulator and Voltage Reference (Avalanche and ZENER)

Part operating failure rate model (λ_p):

$$\lambda_P = \lambda_b(\pi_E \times \pi_A \times \pi_Q) \text{ Failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.2.5-1 through 4.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.00031\ \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

TABLE 2.2.5-1

Group V Diodes
Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.37
S_F	1	0.37
G_F	3.9	1.5
N_{SB}	5.8	2.2
N_S	8.7	3.3
A_{IT}	12	-
M_P	12	4.5
M_{FF}	12	4.5
M_{FA}	17	6.3
G_M	18	6.8
N_H	19	6.8
N_{UU}	20	7.4
A_{UT}	20	-
N_U	21	7.8
A_{IF}	25	-
A_{RW}	27	9.9
U_{SL}	36	13
A_{UF}	40	-
M_L	41	15
C_L	690	260

TABLE 2.2.5-2
π_A FOR GROUP V DIODES

Application	π_A
Voltage Regulator	1.0
Voltage Reference (Temp. Compensated)	1.5

TABLE 2.2.5-3
π_Q, Quality Factor

Quality Level	π_Q
JANTXV	0.3
JANTX	0.6
JAN	3.0
Lower*	15.0
Plastic**	30.0

*Hermetic packaged devices.
**Devices sealed or encapsulated with organic materials.

2.2.6 Diodes, Group VI

SPECIFICATION	STYLE	DESCRIPTION
MIL-STD-19500		Thyristors

Part operating failure rate model (λ_p):

$\lambda_p = \lambda_b \times \pi_Q \times \pi_E \times \pi_R$ failures/10^6 hours

where the factors are shown in Tables 2.2.6-1 through 4.

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = 0.0012\ \pi_Q \times \pi_{E_{NO}} \text{ failures}/10^6 \text{ hours}$$

TABLE 2.2.6-1

Group VI Diodes
Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	1.1
S_F	1	1.1
G_F	3.9	4.2
N_{SB}	5.8	6.2
N_S	8.7	9.3
A_{IT}	12	-
M_P	12	13
M_{FF}	12	13
M_{FA}	17	18
G_M	18	19
N_H	19	20
N_{UU}	20	21
A_{UT}	20	-
N_U	21	22
A_{IF}	25	-
A_{RW}	27	29
U_{SL}	36	28
A_{UF}	40	-
M_L	41	44
C_L	690	740

TABLE 2.2.6-2
π_Q, Quality Factor

Quality Level	π_Q
JANTXV	.5
JANTX	1.0
JAN	5.0
Lower*	25.
Plastic**	50.

*Hermetic packaged devices.
**Devices sealed or encapsulated with organic material.

TABLE 2.2.6-3
π_R FOR GROUP VI THYRISTORS

Rated Average Forward Anode Current (amps.)	π_R
≤ 1	1
> 1 to 5	3
> 5 to 25	10
> 25 to 50	15

DISCRETE SEMICONDUCTORS
MICROWAVE DIODES

2.2.7 Diodes, Group VII

SPECIFICATION	STYLE	DESCRIPTION
MIL-S-19500		Microwave Detectors and Mixers, Silicon and Germanium Silicon Schottky Detectors

Part operating failure rate model (λ_p):

$$\lambda p = \lambda_b \times \pi_E \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.2.7-1 through -7.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.2.7-1

Group VII Diodes
Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.04
S_F	1	0.04
G_F	6.4	0.26
N_{SB}	8	0.32
N_S	11	0.44
A_{IT}	25	-
M_P	35	1.4
M_{FF}	36	1.4
M_{FA}	50	2
G_M	31	1.2
N_H	54	2.2
N_{UU}	58	2.3
A_{UT}	40	-
N_U	33	1.3
A_{IF}	50	-
A_{RW}	78	3.1
U_{SL}	110	4.2
A_{UF}	80	-
M_L	120	4.9
C_L	2000	82

TABLE 2.2.7-2
π_Q, QUALITY FACTOR

Quality Level	π_Q
JANTXV	1
JANTX	2
JAN	3.5
Lower *	5.

*Hermetic packaged devices.

DISCRETE SEMICONDUCTORS
VARACTOR, STEP RECOVERY, TUNNEL

2.2.8 Diodes, Group VIII

SPECIFICATION	STYLE	DESCRIPTION
MIL-S-19500		Varactor, PIN, IMPATT Step Recovery, Tunnel & Gunn

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times \pi_E \times \pi_Q \times \pi_R \times \pi_A \text{ failures}/10^6 \text{ hours}$$

where: λ_b = 0.5 for IMPATT, 0.7 for Gunn, Table 2.2.8-5 for others and remaining factors are in Tables 2.2.8-1 through -4.
Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.022\, \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

TABLE 2.2.8-1

Group VIII Diodes
Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.02
S_F	1	0.02
G_F	3.9	0.06
N_{SB}	5.8	0.1
N_S	8.7	0.15
A_{IT}	12	-
M_P	12	0.2
M_{FF}	12	0.2
M_{FA}	17	0.28
G_M	18	0.3
N_H	19	0.3
N_{UU}	20	0.32
A_{UT}	20	-
N_U	21	0.34
A_{IF}	25	-
A_{RW}	27	0.44
U_{SL}	36	0.59
A_{UF}	40	-
M_L	41	0.67
C_L	690	11

TABLE 2.2.8-2
π_Q, QUALITY FACTOR

Quality Level	π_Q
GUNN & IMPATT	1.0
All other diodes	
JANTXV	0.5
JANTX	1.0
JAN	5.0
LOWER*	25.0

*Hermetic packaged devices

TABLE 2.2.8-3
π_R, POWER RATING FACTOR

Power Rating	π_R
PIN Diodes	
<10W.	0.5
100W.	* 1.3
1000W.	* 2.0
3000W.	* 2.4
All other Diodes	1.0

* - π_R = .326(ln P) - .25 for $10 \le P \le 3000W$.

TABLE 2.2.8-4
π_A, APPLICATION FACTOR

APPLICATION	π_A
Varactors	
Voltage Control	0.5
Multiplier	2.5
All other diodes	1.0

2.2.9 Microwave Transistors, Group IX

SPECIFICATION	DESCRIPTION
MIL-S-19500	Bipolar microwave power transistor for frequencies above 200 MHz and average power $\geq$ 1 watt.

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_B \pi_Q \pi_A \pi_F \pi_T \pi_M \pi_E$$

where:

λ_B = 0.10 failures/10^6 hours

π_Q = quality factor, Table 2.2.9-1

π_A = application factor, Table 2.2.9-2

π_F = factor for frequency and peak operating power, Table 2.2.9-3

π_T = temperature factor, Table 2.2.9-4

π_M = matching network factor, Table 2.2.9-5

π_E = environmental factor, Table 2.2.9-6

See bibliography items 42-46 for the model background.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.1 \times \pi_Q \times \pi_{ENO} \text{ failures}/10^6 \text{ hours}$$

TABLE 2.2.9-1
π_Q, QUALITY FACTOR

QUALITY LEVEL*	π_Q*
JANTXV with IR scan for die attach and screen for barrier layer pinholes on gold metallized devices	1
JANTX or Equivalent	2
JAN or Equivalent	4
LOWER QUALITY	10

* These quality values apply to hermetically sealed devices only, and do not apply to devices sealed or encapsulated with organic materials.

TABLE 2.2.9-5
π_M, MATCHING NETWORK FACTOR

INTERNAL MATCHING	π_M
Input & Output	1
Input Only	2
No Matching	4

TABLE 2.2.9-6

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.15
S_F	1	0.15
G_F	2	0.3
N_{SB}	3.6	0.53
N_S	4.7	0.69
A_{IT}	3	-
M_P	7.4	1.1
M_{FF}	7.5	1.1
M_{FA}	11	1.5
G_M	7.8	1.2
N_H	11	1.7
N_{UU}	12	1.8
A_{UT}	4	-
N_U	11	1.7
A_{IF}	6	-
A_{RW}	16	2.4
U_{SL}	22	3.3
A_{UF}	8	-
M_L	25	3.7
C_L	250	38

DISCRETE SEMICONDUCTORS
OPTO-ELECTRONIC DEVICES

2.2.10 Opto-electronic Semiconductor Devices, Group X.

SPECIFICATION	DESCRIPTION
MIL-S-19500	Light Emitting Diode (LED)
MIL-S-19500	Opto-electronic Coupler (Isolator)
None	LED Alpha-numeric Display

Part operating failure rate model (λ_p):

$$\lambda_P = \lambda_b \pi_C \pi_E \pi_Q \text{ failures}/10^6 \text{ hours}$$

where:

λ_b = base failure rate in failures/10^6 hrs., Table 2.2.10-4.
π_C = complexity factor, Table 2.2.10-3.
π_E = environmental factor, Table 2.2.10-1.
π_Q = quality factor, Table 2.2.10-2.

The above model includes all failures except degradation of output light from the light emitting elements. For model background and guidance concerning light degradation, see Bibliography Item No. 49.

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = 0.0006 \ \pi_C \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

TABLE 2.2.10-1

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.17
S_F	1	0.17
G_F	2.4	0.42
N_{SB}	3.7	0.64
N_S	5.7	0.99
A_{IT}	2.8	-
M_P	7.7	1.3
M_{FF}	7.8	1.4
M_{FA}	11	1.9
G_M	7.8	1.4
N_H	12	2.1
N_{UU}	13	2.2
A_{UT}	4.2	-
N_U	11	1.9
A_{IF}	5.6	-
A_{RW}	17	3
U_{SL}	23	4
A_{UF}	8.4	-
M_L	26	4.6
C_L	450	77

TABLE 2.2.10-2
π_Q, QUALITY FACTOR

Quality Level	π_Q
JANTXV	1
JANTX	2
JAN	10
LOWER*	50
PLASTIC**	100

*-Applies to all hermetic packaged alpha-numeric displays and to NON-JAN hermetic packaged LED's and isolators.
**-Applies to all devices encapsulated with organic materials.

2.3 TUBES, ELECTRONIC VACUUM

The tube failure rate model is

$$\lambda_p = \lambda_b \; \pi_E \; \pi_L$$

where:

- λ_p = tube failure rate in failures/10^6 hr.
- λ_b = base failure rate in failures/10^6 hr. and is a function of tube type and operating parameters (see Table 2.3-1).
- π_E = environmental factor (see Table 2.3-4).
- π_L = learning factor (see Table 2.3-5).

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi E_{NO} \text{ failures}/10^6 \text{ hours}$$

where:

λp_{NO} for magnetrons = 0.12 failures/10^6 hours

Otherwise, λ_b is determined as follows:

Per Table 2.3-1 with the following clarifications
Transmitting tubes: λ_b = 75 failures/10^6 hours
TWT: λ_b per peak power < 10 watts unless listed otherwise

Table 2.3-2: λb = 29 failures/10^6 hours
Table 2.3-3: λb = 66 failures/10^6 hours

TABLE 2.3-1
λ_b, BASE FAILURE RATE FOR TUEES
(includes both random and wearout failures)

TUBE TYPE	λ_b (f./10^6 hr.)
RECEIVER	
Triode, Tetrode, Pentode	5
Power Rectifier	10
CRT	15
THYRATRON	50
CROSSED FIELD AMPLIFIER	
QK681	260
SFD261	150
PULSED GRIDDED	
2041	140
6952	390
7835	140
TRANSMITTING	
Triode } {Peak Pwr ≤200 kW, Freq. ≤200 MHz.	75
Tetrode & Pentode } Aver Pwr ≤2 kW	100
If any of above limits are exceeded	250
TWT	
M5768	310
MA2001A	170
VA138D	50
VA643	90
VTR5210A1	150
WJ3751	90
ZM3167	90
If TWT of interest is not listed above, use:	
Peak Power <10 watts	20
Peak Power ≥10 watts, <100 watts	50
Peak Power ≥100 watts, <10,000 watts	150
Peak Power ≥10,000 watts	400

TABLE 2.3-4

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	0.5	0.0008
S_F	0.5	0.0008
G_F	1.0	0.0016
N_{SB}	8.6	0.0069
N_S	6.9	0.0055
A_{IT}	4.6	-
M_P	18	0.014
M_{FF}	18	0.015
M_{FA}	25	0.02
G_M	[illegible]	0.0074
N_H	28	0.022
N_{UU}	30	0.024
A_{UT}	5.7	-
N_U	13	0.011
A_{IF}	9	-
A_{RW}	40	0.032
U_{SL}	53	0.043
A_{UF}	11	-
M_L	61	0.049
C_L	1000	0.83

TABLE 2.3-5
π_L, LEARNING FACTOR FOR ALL TUBES*

t (Yrs.)	1	2	3
π_L	10	2.3	1

* - $\pi_L = 10(t)^{-2.1}$ for $1 \leq t \geq 3$

$= 10$ for $t < 1$

$= 1$ for $t > 3$

Where t = number of years since introduction to military field use.

2.4.7 Tables and Figures for Laser Model Parameters.

This section presents the tables and figures for quantifying the parameters of the laser failure rate models in Sections 2.4.1 through 2.4.6.

TABLE 2.4.7-1

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	0.2	
S_F	0.2	
G_F	1	
N_{SB}	1.1	See
N_S	5	Note
A_{IT}	3.5	1
M_P	2.3	
M_{FF}	2.4	
M_{FA}	3.3	
G_M	5	
N_H	3.6	
N_{UU}	3.9	
A_{UT}	5.7	
N_U	5	
A_{IF}	7	
A_{RW}	5.2	
U_{SL}	7.0	
A_{UF}	11	
M_L	8	
C_L	N/A	

Note 1: For nonoperating wear-out information, see Bibliography item 40, pages 64-65.

TABLE 2.4.7-2

GAS OVERFILL FACTOR, π_O **

CO_2 OVERFILL * PERCENT	π_O
0	1.00
25	0.75
50	0.50

*Overfill percent is based on the percent increase over the optimum CO_2 partial pressure which is normally in the range of 1.5 to 3 Torr for most sealed CO_2 lasers.

**The equation for π_O is:

$\pi_O = -0.01$ (% overfill) + 1.

TABLE 2.4.7-3

BALLAST FACTOR, π_B **

PERCENT OF BALLAST VOLUMETRIC INCREASE	π_B
0	1.0
50	0.58
100	0.33
150	0.19
200	0.11

*The equation for π_B is: $\pi_B = \left(\frac{1}{3}\right)^{\frac{\%\ \text{Vol. Inc.}}{100}}$

RESISTORS
MIL-R-39008, RCR; MIL-R-11, RC

2.5.1 Composition Resistors

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-39008	RCR	Insulated Fixed Composition Est. Rel.
MIL-R-11	RC	Insulated Fixed Composition

Part operating failure rate model (λ_p):

$\lambda_p = \lambda_b \times (\pi_E \times \pi_R \times \pi_Q)$ (failures/10^6 hours)

where the factors are shown in Tables 2.5.1-1 through -4.

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$\lambda_{P_{NO}} = 0.00018\ \pi_{E_{NO}} \times \pi_Q$ failures/10^6 hours

TABLE 2.5.1-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.19
S_F	1	0.19
G_F	2.9	0.56
N_{SB}	4.0	0.77
N_S	5.2	1
A_{IT}	2.8	-
M_P	8.5	1.6
M_{FF}	8.6	1.6
M_{FA}	13	2.5
G_M	8.3	1.6
N_H	13	2.5
N_{UU}	14	2.7
A_{UT}	5.7	-
N_U	12	2.3
A_{IF}	5.7	-
A_{RW}	19	3.6
U_{SL}	25	4.8
A_{UF}	11	-
M_L	29	5.5
C_L	490	94

TABLE 2.5.1-2
π_R, Resistance Factor

Resistance Range (ohms)	π_R
Up to 100 K	1.0
>0.1MΩ to 1 MΩ	1.1
>1.0MΩ to 10 MΩ	1.6
>10MΩ	2.5

TABLE 2.5.1-3
π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
MIL-R-11	5.0
LOWER	15.

RESISTORS
MIL-R-39017, RLR; MIL-R-55182, RNR
MIL-R-22684, RL; MIL-R-10509, RN

2.5.2 Film Resistors

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-39017	RLR	Fixed Film, Insulated, Est. Rel.
MIL-R-22684	RL	Fixed Film, Insulated
MIL-R-55182	RN(R, C, or N)	Fixed Film, Est. Rel.
MIL-R-10509	RN	Fixed Film, Insulated

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b(\pi_E \times \pi_R \times \pi_Q) \quad \text{(failures/}10^6\text{ hours)}$$

where the factors are shown in Tables 2.5.2-1 through -5.

Part non-operating failure rate model ($\lambda_{p_{NO}}$):

$$\lambda_{p_{NO}} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures/}10^6\text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.5.2-1
Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
C_B	1	0.46
S_F	0.4	0.18
G_F	2.4	1.1
N_{SB}	4.2	1.9
N_S	4.7	2.2
A_{IT}	2.8	-
M_P	8.8	4.1
M_{FF}	8.9	4.1
M_{FA}	12	5.7
G_M	7.8	3.6
N_H	14	6.3
N_{UU}	15	6.7
A_{UT}	8.5	-
N_U	14	6.4
A_{IF}	5.7	-
A_{RW}	19	9
U_{SL}	26	12
A_{UF}	17	-
M_L	30	14
CL	510	230

TABLE 2.5.2-2
π_R, RESISTANCE FACTOR

Resistance Range (ohms)	π_R
Up to 100 K	1.0
>0.1 M to 1 M	1.1
>1.0 M to 10 M	1.6
>10 M	2.5

TABLE 2.5.2-3
π_Q, QUALITY FACTOR

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
MIL-R-10509	5.0
MIL-R-22684	5.0

RESISTORS
MIL-R-11804, RD

Power Film

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-11804	RD	Power Film

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b(\pi_E \times \pi_R \times \pi_Q) \text{ (failures/}10^6 \text{ hours)}$$

where the factors are shown in Tables 2.5.2-6 through -9.

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = 0.0093\ \pi_{E_{NO}} \times \pi_Q \text{ failures/}10^6 \text{ hours}$$

TABLE 2.5.2-6

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.12
S_F	1	0.12
G_F	2.4	0.29
N_{SB}	5.5	0.66
N_S	4.7	0.56
A_{IT}	6.2	-
M_P	11	1.3
M_{FF}	12	1.4
M_{FA}	16	1.9
G_M	8.8	1.1
N_H	18	2.2
N_{UU}	19	2.3
A_{UT}	11	-
N_U	15	1.8
A_{IF}	8.5	-
A_{RW}	25	3
U_{SL}	34	4.1
A_{UF}	21	-
M_L	39	4.7
C_L	660	79

TABLE 2.5.2-7
π_Q, QUALITY FACTOR

Failure Rate Level	π_Q
MIL-SPEC	1.0
Lower	3.0

TABLE 2.5.2-8
RESISTANCE FACTOR, π_R, FOR MIL-R-11804

Resistance Range (ohms)	π_R
10 to <100	1.2
100 to <100 K	1.0
100 K to <1 meg	1.3
≥1 meg	3.5

RESISTORS
MIL-R-83401, RZ

2.5.3 Resistor Network

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-83401	RZ	Resistor Networks, Fixed, Film

Part operating failure rate model (λ_p):

$$\lambda_P = .00066\ (N_R \times \Pi_T \times \Pi_E \times \Pi_Q)\ \text{failures}/10^6\ \text{hours}$$

where:

N_R is the number of film resistors in use (do not include resistors that are not used)

Π_T is the temperature factor, Table 2.5.3-1

Π_E is the environmental factor, Table 2.5.3-2

Π_Q is the quality factor, Table 2.5.3-3

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = .00066\ (N_R \times \pi_{E_{NO}} \times \pi_Q)\ \text{failures}/10^6\ \text{hours}$$

TABLE 2.5.3-1. Temperature Factor, π_T*

T_p (°C.)	π_T	T_p (°C.)	π_T	T_p (°C.)	π_T
25	1.0	60	4.2	95	13.3
30	1.25	65	5.0	100	15.4
35	1.56	70	5.9	105	17.8
40	1.92	75	7.1	110	20.
45	2.4	80	8.3	115	24.
50	2.9	85	9.8	120	27.
55	3.5	90	11.4	125	31.

$$* - \pi_T = \mathrm{Exp}\left[-4056\left(\frac{1}{T_p + 273} - \frac{1}{298}\right)\right]$$

where T_p is package temperature in °C. If T_p is unknown, it can be estimated using $T_p = T_A + 55S$. T_A is ambient temperature (°C.) and S is the ratio of total operating power/package rated power. Any device operating at T_p >125°C. is over-stressed.

TABLE 2.5.3-2

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.004
S_F	1	0.004
G_F	2.4	0.010
N_{SB}	4.2	0.017
N_S	4.7	0.019
A_{IT}	2.8	-
M_P	8.8	0.035
M_{FF}	8.9	0.036
M_{FA}	12	0.050
G_M	7.6	0.031
N_H	14	0.054
N_{UU}	15	0.058
A_{UT}	8.5	-
N_U	14	0.056
A_{IF}	5.7	-
A_{RW}	19	0.078
U_{SL}	26	0.10
A_{UF}	17	-
M_L	30	0.012
C_L	510	2.0

TABLE 2.5.3-3. Quality Factor, π_Q

QUALITY LEVEL	π_Q
MIL-SPEC	1
Lower	3

RESISTORS
MIL-R-39005, RBR; MIL-R-93, RB

2.5.4 Wirewound Resistors

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-39005	RBR	Accurate Fixed Wirewound, ER
MIL-R-93	RB	Accurate Fixed Wirewound

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b(\pi_E \times \pi_R \times \pi_Q) \text{ (failures/}10^6\text{ hours)}$$

where the factors are shown in Tables 2.5.4-1 through 4.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.0034\ \pi_{E_{NO}} \times \pi_Q \text{ failures/}10^6\text{ hours}$$

TABLE 2.5.4-1

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.24
S_F	1.5	0.27
G_F	2.4	0.59
N_{SB}	5.8	1.4
N_S	4.7	1.2
A_{IT}	6	-
M_P	12	2.9
M_{FF}	12	2.9
M_{FA}	17	4.1
G_M	9.8	2.4
N_H	18	4.5
N_{UU}	20	4.9
A_{UT}	20	-
N_U	16	3.9
A_{IF}	12	-
A_{RW}	27	6.5
U_{SL}	36	8.7
A_{UF}	40	-
M_L	41	10
C_L	610	150

TABLE 2.5.4-2
π_R, Resistance Factor

Resistance Range (ohms)	π_R
Up to 10 K	1.0
>10 K to 100 K	1.7
>100 K to 1 M	3.0
>1 M	5.0

TABLE 2.5.4-3
π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
MIL-R-93	5.0
LOWER	15.

RESISTORS
MIL-R-39007, RWR; MIL-R-26, RW

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-39007	RWR	Power Type, Fixed Wirewound
MIL-R-26	RW	Power Type, Fixed Wirewound

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b(\pi_E \times \pi_R \times \pi_Q) \quad \text{failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.5.4-5 through -8.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.005\ \pi_{E_{NO}} \times \pi_Q \quad \text{failures}/10^6 \text{ hours}$$

TABLE 2.5.4-5

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.13
S_F	0.6	0.08
G_F	1.5	0.20
N_{SB}	5	0.67
N_S	4.7	0.63
A_{IT}	4	-
M_P	11	1.4
M_{FF}	11	1.4
M_{FA}	15	2.0
G_M	8.3	1.1
N_H	16	2.2
N_{UU}	17	2.3
A_{UT}	8.5	-
N_U	14	1.8
A_{IF}	8	-
A_{RW}	23	3.1
U_{SL}	31	4.2
A_{UF}	17	-
M_L	36	4.9
C_L	610	81

TABLE 2.5.4-6
π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
MIL-R-26	5.0
LOWER	15.

TABLE 2.5.4-7
RESISTANCE FACTOR, π_R

MIL-R-39007 Style	Resistance Range (ohms)							
	Up to 500	>500 to 1K	>1K to 5K	>5K to 7.5	>7.5K to 10K	>10K to 15K	>15K to 20K	>20K
RWR 71	1.0	1.0	1.2	1.2	1.6	1.6	1.6	NA
RWR 74	1.0	1.0	1.0	1.2	1.6	1.6	NA	NA
RWR 78	1.0	1.0	1.0	1.0	1.2	1.2	1.2	1.6
RWR 80	1.0	1.2	1.6	1.6	NA	NA	NA	NA
RWR 81	1.0	1.6	NA	NA	NA	NA	NA	NA
RWR 84	1.0	1.0	1.1	1.2	1.2	1.6	NA	NA
RWR 89	1.0	1.0	1.4	NA	NA	NA	NA	NA

RESISTORS
MIL-R-39009, RER: MIL-R-18546, RE

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-39009	RER	Power Types, Chassis Mounted, Fixed Wirewound
MIL-R-18546	RE	Power Type, Chassis Mounted, Fixed Wirewound

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times (\pi_E \times \pi_R \times \pi_Q) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.5.4-9 through -12.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.00265\ \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

TABLE 2.5.4-9

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.19
S_F	1	0.19
G_F	2.4	0.45
N_{SB}	5	0.94
N_S	4.7	0.89
A_{IT}	4	-
M_P	11	2.0
M_{FF}	11	2.0
M_{FA}	15	2.8
G_M	8.3	1.6
N_H	16	3.1
N_{UU}	17	3.3
A_{UT}	8.5	-
N_U	14	2.6
A_{IF}	8	-
A_{RW}	23	5.0
U_{SL}	31	5.9
A_{UF}	17	-
M_L	36	6.9
C_L	610	120

TABLE 2.5.4-10
π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
MIL-R-18546	5.0
LOWER	15.

2.5.5 Thermistors

SPECIFICATION	STYLE	DESCRIPTION
MIL-T-23648	RTH	Bead, Disk and Rod Type

The predicted failure rate is given as follows:

Environmental Mode Factors

Environment	Predicted Failure Rate (Failures/10^6 Hrs)					
	Bead Type Style RTH 24, 26, 28, 30, 32, 34, 36, 38 to 40		Disk Type Style RTH 6, 8, 10		Rod Type Style RTH 12, 14, 16, 18, 20, 22, 42	
	λ_{op}	λ_{NO}	λ_{op}	λ_{NO}	λ_{op}	λ_{NO}
G_B	0.021	0.0063	0.065	0.0195	0.105	0.0315
S_F	0.021	0.0063	0.065	0.0195	0.105	0.0315
G_F	0.100	0.0300	0.310	0.0930	0.500	0.1500
N_{SB}	0.169	0.0507	0.506	0.1518	0.843	0.2529
N_S	0.300	0.0900	0.900	0.2700	1.500	0.4500
A_{IT}	0.250	-	0.750	-	1.250	-
M_P	0.351	0.1053	1.054	0.3162	1.756	0.5268
M_{FF}	0.354	0.1062	1.062	0.3186	1.770	0.5310
M_{FA}	0.495	0.1485	1.484	0.4452	2.473	0.7419
G_M	0.520	0.1560	1.600	0.4800	2.600	0.7800
N_H	0.540	0.1620	1.619	0.4857	2.698	0.8094
N_{UU}	0.579	0.1737	1.737	0.5211	2.895	0.8685
A_{UT}	0.340	-	1.000	-	1.700	-
N_U	0.400	0.1200	1.200	0.3600	2.000	0.6000
A_{IF}	0.500	-	1.500	-	2.250	-
ARW	0.776	0.2328	2.327	0.6981	3.878	1.1634
U_{SL}	1.043	0.3129	3.128	0.9384	5.213	1.5639
A_{UF}	0.680	-	2.000	-	3.400	-
M_L	1.200	0.3600	3.600	1.0800	6.000	1.8000
C_L	20.20	6.06	60.70	18.21	101.30	30.40

RESISTORS
MIL-R-39015, RTR; MIL-R-27208, RT

2.5.6 Variable Resistor, Wirewound

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-39015	RTR	. .able Lead Screw Activated Wirewound, Established Reliability
MIL-R-27208	RT	Variable Lead Screw Activated Wirewound

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times \pi_{TAPS}(\pi_E \times \pi_R \times \pi_Q \times \pi_V) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.5.6-1 through -5 and 2.5.8-5.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.01\ \pi_{TAPS} \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

TABLE 2.5.6-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.6?
S_F	1	0.69
G_F	2.4	1.7
N_{SB}	7.2	5.0
N_S	5.7	4.0
A_{IT}	4.2	-
M_P	15	10
M_{FF}	15	10
M_{FA}	21	15
G_M	9.8	6.8
N_H	23	16
N_{UU}	25	17
A_{UT}	8.5	-
N_U	13	9.3
A_{IF}	8.5	-
A_{RW}	33	23
U_{SL}	45	31
A_{UF}	17	-
M_L	51	36
C_L	870	600

TABLE 2.5.6-2

π_R, Resistance Factor

Resistance Range (ohms)	π_R
10 to 2K	1.0
>2K to 5K	1.4
>5K to 20K	2.0

TABLE 2.5.6-3
π_Q, Quality Factor

Failure Rate Level	π_Q
S	.02
R	.06
P	.2
M	.6
MIL-R-27208	3.
LOWER	10.

TABLE 2.5.6-4
π_V, Voltage Factor

Ratio of Applied * Voltage to Rated Voltage	π_V
1.0	2.00
0.9	1.40
0.8	1.22
0.7	1.10
0.6 to 0.3	1.00
0.2	1.05
0.1	1.10

$^*V_{Applied} = \sqrt{RP_{APPLIED}}$
R=total pot. resistance.
V_{RATED} = 40v. for RT26 & 27.
= 90v. for RTR12, 22 & 24; RT12 & 22.

RESISTORS
MIL-R-12934, RR

WIREWOUND, PRECISION

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-12934	RR	Precision Wirewound

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times \pi_{TAPS} \times \pi_Q(\pi_R \times \pi_V \times \pi_C \times \pi_E) \text{ (failures/}10^6\text{ hours)}$$

where the factors are shown in Tables 2.5.6-6 through -11 and 2.5.8-5.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.12\ \pi_{TAPS} \times \pi_Q \times \pi_E \text{ failures/}10^6\text{ hours}$$

TABLE 2.5.6-6

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.0006
S_F	1	0.0006
G_F	2.4	0.0014
N_{SB}	11	0.0065
N_S	5.7	0.0036
A_{IT}	5	-
M_P	24	0.014
M_{FF}	24	0.043
M_{FA}	34	0.020
G_M	11	0.0066
N_H	37	0.022
N_{UU}	39	0.023
A_{UT}	11	-
N_U	14	0.0084
A_{IF}	10	-
A_{RW}	53	0.032
U_{SL}	71	0.043
A_{UF}	21	-
M_L	81	0.049
C_L	1400	0.80

Table 2.5.6-7
π_Q, Quality Factor

Failure Rate Level	π_Q
MIL-SPEC	2.5
Lower	5.0

RESISTORS
MIL-R-19, RA & MIL-R-39002, RK

WIREWOUND, SEMIPRECISION

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-19	RA	Semiprecision
MIL-R-39002	RK	Semiprecision

(Note: MIL-R-39002 is not an established reliability potentiometer.)

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times \pi_{TAPS}(\pi_R \times \pi_V \times \pi_Q \times \pi_E) \text{ (failures/}10^6\text{ hours)}$$

where the factors are shown in Tables 2.5.6-12through -16 and 2.5.8-5.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.066\pi_{TAPS} \times \pi_Q \times \pi_{ENO} \text{ (failures/}10^6\text{ hours)}$$

TABLE 2.5.6-12

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.16
G_F	1	0.16
G_F	2.4	0.38
N_{SB}	8.4	1.3
N_S	5.7	0.9
A_{IT}	5	-
M_P	17	2.7
M_{FF}	N/A	N/A
M_{FA}	N/A	N/A
G_M	16	2.5
N_H	27	4.2
N_{UU}	29	4.5
A_{UT}	N/A	N/A
N_U	N/A	N/A
A_{IF}	10	-
A_{RW}	38	6.1
U_{SL}	N/A	N/A
A_{UF}	N/A	N/A
M_L	N/A	N/A
C_L	N/A	N/A

TABLE 2.5.6-13
π_Q, Quality Factor

Failure Rate Level	π_Q
MIL-SPEC	2.0
LOWER	4.0

RESISTORS
MIL-R-22, RP

WIREWOUND, POWER

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-22	RP	High Power

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times \pi_{TAPS} \times \pi_Q(\pi_R \times \pi_V \times \pi_C \times \pi_E) \text{ (failures/10}^6\text{ hours)}$$

where the factors are shown in Tables 2.5.6-17 through -22 and 2.5.8-5.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.073\, \pi_{TAPS} \times \pi_Q \times \pi E_{NO} \times \pi_C \text{ failures/10}^6\text{ hours}$$

TABLE 2.5.6-17

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.019
S_F	1	0.019
G_F	3.0	0.058
N_{SB}	8.4	0.16
N_S	5.7	0.11
A_{IT}	5	-
M_P	17	0.34
M_{FF}	N/A	N/A
M_{FA}	N/A	N/A
G_M	16	0.31
N_H	27	0.52
N_{UU}	29	0.56
A_{UT}	N/A	N/A
N_U	N/A	N/A
A_{IF}	10	-
A_{RW}	38	0.74
U_{SL}	N/A	N/A
A_{UF}	N/A	N/A
M_L	N/A	N/A
C_L	N/A	N/A

TABLE 2.5.6-18
π_Q, Quality Factor

Failure Rate Level	π_Q
MIL-SPEC	2.0
Lower	4.0

RESISTORS
MIL-R-22097, RJ
MIL-R-39035, RJR

2.5.7 Variable Nonwirewound Resistors
Nonwirewound Trimmer Resistors

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-22097	RJ	Trimmer
MIL-R-39035	RJR	Trimmer

Part operating failure rate model (λ_p):

$$\lambda_b \times \pi_{TAPS}(\pi_R \times \pi_V \times \pi_Q \times \pi_E) \text{ (failures/}10^6\text{ hours)}$$

where the factors are shown in Tables 2.5.7-1 through 5 and 2.5.8-5

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.022\ \pi_{TAPS} \times \pi_{E_{NO}} \times \pi_Q \text{ failures/}10^6\text{ hours}$$

TABLE 2.5.7-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.76
S_F	1	0.76
G_F	2.9	2.2
N_{SB}	10	7.6
N_S	5.7	4.3
A_{IT}	5	-
M_P	18	14
M_{FF}	18	14
M_{FA}	25	19
G_M	11	8.2
N_H	27	21
N_{UU}	29	22
A_{UT}	11	-
N_U	15	11
A_{IF}	10	-
A_{RW}	39	30
U_{SL}	53	40
A_{UF}	21	-
M_L	61	47
C_L	1000	780

TABLE 2.5.7-2

π_Q, Quality Factor

Failure Rate Level	π_Q
S	.02
R	.06
P	.2
M	.6
MIL-R-22097	3.
LOWER	10.

RESISTORS
MIL-R-94, RV

Variable Composition Resistors

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-94	RV	Low Precision

Part operating failure rate model (λ_p):

$$\lambda p = \lambda_b \times \pi_{TAPS}(\pi_R \times \pi_V \times \pi_Q \times \pi_E) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.5.7-6 through -10 and 2.5.8-5.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.03\, \pi_{TAPS} \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

TABLE 2.5.7-6

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.37
S_F	1	0.37
G_F	1.8	0.67
N_{SB}	10	3.7
N_S	5.9	2.2
A_{IT}	6	-
M_P	21	7.7
M_{FF}	21	7.8
M_{FA}	29	11
G_M	17	6.4
N_H	32	12
N_{UU}	34	13
A_{UT}	27	-
N_U	21	7.8
A_{IF}	12	-
A_{RW}	46	17
U_{SL}	62	23
A_{UF}	54	-
M_L	71	26
C_L	1200	440

TABLE 2.5.7-7

π_Q, Quality Factor

Failure Rate Level	π_Q
MIL-SPEC	2.5
LOWER	5.0

RESISTORS
MIL-R-23285, RVC
MIL-R-39023, RQ

Variable Film and Precision Resistors

SPECIFICATION	STYLE	DESCRIPTION
MIL-R-39023	RQ	Nonwirewound, Precision
MIL-R-23285	RVC	Film

Part operating failure rate model (λ_p):

$$\lambda p = \lambda_b \times \pi_{TAPS}(\pi_R \times \pi_V \times \pi_Q \times \pi_E) \text{ (failures}/10^6 \text{ hours)}$$

where the factors are shown in Tables 2.5.7-11 through -16 and 2.5.8-5

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{TAPS} \times \pi_Q \times \pi_{E_{NO}} \quad \text{failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.5.7-11

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.29
S_F	1	0.29
G_F		0.83
N_{SB}		[illegible].5
N_S		1.6
A_{IT}	[illegible]	–
M_P	18	[illegible].1
M_{FF}	18	[illegible].1
M_{FA}	25	7.3
C_M	11	3.1
N_H	27	7.9
N_{UU}	29	8.4
A_{UT}	15	–
N_U	15	4.2
A_{IF}	10	–
A_{RW}	39	11
U_{SL}	53	15
A_{UF}	30	–
M_L	61	18
C_L	1000	300

TABLE 2.5.7-12

π_Q, Quality Factor

Failure Rate Level	π_Q
MIL-SPEC	2
Lower	4

CAPACITORS
MIL-C-25, CP;
MIL-C-12889, CA

2.6.1 Paper and Plastic Film Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-25	..	Paper
MIL-C-12889	.	Paper, RFI Bypass

Part operating failure rate model (λ_p):

$$\lambda p = \lambda_b(\pi_E \times \pi_Q \times \pi_{CV}) \text{ failures}/10^6 \text{ hrs}$$

where the factors are shown in Tables 2.6.1-1 through -6

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.1-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.59
S_F	1	0.59
G_F	1.9	1.1
N_{SB}	4.8	2.8
N_S	5.7	3.3
A_{IT}	5	-
M_P	10	5.9
M_{FF}	10	5.9
M_{FA}	14	8.2
G_M	8.3	4.9
N_H	15	9.0
N_{UU}	16	9.6
A_{UT}	13	-
N_U	14	8.1
A_{IF}	10	-
A_{RW}	22	13
U_{SL}	30	17
A_{UF}	25	-
M_L	34	20
C_L	570	340

TABLE 2.6.1-2
Base Failure Rate Tables for Capacitor Spec and Style

Spec MIL-C	Style	λ_b Table No.
12889	All	2.6.1-5
25	CP04, 5, 8, 9, 10, 11, 12, 13; Char K	2.6.1-6
	CP25, 26, 27, 28, 29, 40, 41, 67, 69, 70, 72, 75, 76, 77, 78, 80, 81, 82; Char E, F	2.6.1-5

TABLE 2.6.1-3

π_Q, Quality Factor

Failure Rate Level	π_Q
MIL-SPEC	3
Lower	7

TABLE 2.6.1-4

π_{CV}, Capacitance Factor

Capacitance *	π_{CV}
MIL-C-25 *:	
.0034uF.	0.7
.15 "	1.0
2.3 "	1.3
16. "	1.6
MIL-C-12889	
All	1.0

* - $\pi_{CV} = 1.2C^{.095}$

where C is μF.

CAPACITORS
MIL-C-11693 CZ

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-11693	CZ	Paper, Metallized Paper Metallized Plastic, RFI Feed-Thru, ER and Non-ER

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b(\pi_E \times \pi_Q \times \pi_{CV}) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.6.1-7 through 13.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_p \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.1-7

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.35
S_F	1	0.35
G_F	2.4	0.84
N_{SB}	4.8	1.7
N_S	8.8	3.1
A_{IT}	5	-
M_P	10	3.5
M_{FF}	10	3.5
M_{FA}	14	4.9
G_M	8.3	2.9
N_H	15	5.3
N_{UU}	16	5.6
A_{UT}	13	-
N_U	14	4.9
A_{IF}	10	-
A_{RW}	22	7.7
U_{SL}	30	11
A_{UF}	25	-
M_L	34	12
C_L	570	200

Table 2.6.1-8
Base Failure Rate Tables
for Capacitor Spec. and Style

Spec. MIL-C	Style	λ_b Table No.
11693	Characteristic E, W	2.6.1-11
	Characteristic K	2.6.1-12
	Characteristic P	2.6.1-13

Table 2.6.1-9
π_Q, Quality Factor

Failure Rate Level	π_Q
M	1.0
Non-ER	3.0
LOWER	10.

Table 2.6.1-10
π_{CV}, Capacitance Factor

Capacitance *	π_{CV}
0.0031 μF.	0.7
0.061 μF.	1.0
1.8 μF.	1.5

*- $\pi_{CV} = 1.4C^{0.12}$
where C is μF.

CAPACITORS
MIL-C-14157, CPV;
MIL-C-19978, CQ AND CQR

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-14157	CPV	Paper and Plastic Film, Est. Rel.
MIL-C-19978	CQ and CQR	Paper and Plastic Film, ER and Non-ER

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b(\pi_E \times \pi_Q \times \pi_{CV}) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.6.1-14 through 21.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.1-14

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.005
S_F	1	0.005
G_F	2.4	0.013
N_{SB}	4.4	0.023
N_S	5.7	0.030
A_{IT}	4	-
M_P	9.2	0.046
M_{FF}	9.3	0.047
M_{FA}	13	0.065
G_M	7.8	0.041
N_H	14	0.071
N_{UU}	15	0.076
A_{UT}	11	-
N_U	13	0.067
A_{IF}	8	-
A_{RW}	20	0.11
U_{SL}	27	0.14
A_{UF}	21	-
M_L	31	0.16
C_L	530	2.6

Table 2.6.1-15
Base Failure Rate Tables for Capacitor Spec and Style

Spec MIL-C	Style	λ_b Table No.
14157	CPV07	2.6.1-18
	CPV09	2.6.1-20
	CPV17	2.6.1-19
19978	Char. P, L	2.6.1-18
	Char. E, F, G, M	2.6.1-19
	Char. K, Q, S	2.6.1-20
	Char. T	2.6.1-21

Table 2.6.1-16
π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
L	3.0
MIL-C-19978 Non-ER	10.0
LOWER	30.

Table 2.6.1-17
π_{CV}, Capacitance Factor

Capacitance	π_{CV}
MIL-C-14157: *	
.0017 µF.	0.7
.027 "	1.0
.20 "	1.3
1.0 "	1.6
MIL-C-19978 :**	
.00032	0.7
.033	1.0
1.0	1.3
15.0	1.6

*-$\pi_{CV}=1.6C^{0.13}$
**-$\pi_{CV}=1.3C^{0.077}$
where C is µF.

CAPACITORS
MIL-C-18312, CH;
MIL-C-39022, CHR

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-18312	CH	Metallized Paper, Paper-Plastic, Plastic
MIL-C-39022	CHR	Metallized Paper, Est. Rel

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \; (\pi_E \times \pi_Q \times \pi_{CV}) \text{ failures}/10^6 \text{ hrs.}$$

where the factors are shown in Tables 2.6.1-22 through -27.

Part non-operating failure rate model ($\lambda_{p_{NO}}$):

$$\lambda_{p_{NO}} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours.}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.1-22

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.23
S_F	1	0.23
G_F	2.4	0.55
N_{SB}	4.4	1.0
N_S	5.7	1.3
A_{IT}	4	-
M_P	9.2	2.1
M_{FF}	9.3	2.1
M_{FA}	13	3.0
G_M	7.8	1.8
N_H	14	3.2
N_{UU}	15	3.5
A_{UT}	11	-
N_U	13	3.0
A_{IF}	8	-
A_{RW}	20	4.6
U_{SL}	27	6.2
A_{UF}	21	-
M_L	31	7.1
C_L	530	120

Table 2.6.1-23
Base Failure Rate Tables
for Capacitor Spec and Style

Spec MIL-C	Style	λ_b Table No.
39022	CHR09 and CHR12 (50V rated), CHR49	2.6.1-26
	CHR09,12 (above 50 volt rated), CHR01, 10, 19, 29, 59	2.6.1-27
18312	Char R	2.6.1-26
	Char N	2.6.1-27

Table 2.6.1-24
π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
L	3.0
MIL-C-18312	
Non-ER	7.0
LOWER	20.

Table 2.6.1-25
π_{CV}, Capacitance Factor

Capacitance *	π_{CV}
0.0029 μF.	0.7
0.14 "	1.0
2.4 "	1.3

* - $\pi_{CV} = 1.2C^{0.092}$
where C is μF.

CAPACITORS
MIL-C-55514, CFR

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-55514	CFR	Plastic, Metallized Plastic, ER

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \ (\pi_E \times \pi_Q \times \pi_{CV}) \ \text{failures}/10^6 \text{ hrs.}$$

where the factors are shown in Tables 2.6.1-28 through -33.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \ \text{failures}/10^6 \text{ hours.}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.1-28

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.75
S_F	1	0.75
G_F	1.9	1.4
N_{SB}	5	3.8
N_S	5.7	4.3
A_{IT}	5	-
M_P	11	7.9
M_{FF}	11	8
M_{FA}	15	11
G_M	9.3	7
N_H	16	12
N_{UU}	17	13
A_{UT}	14	-
N_U	16	12
A_{IF}	10	-
A_{RW}	23	18
U_{SL}	31	24
A_{UF}	28	-
M_L	36	27
C_L	610	460

Table 2.6.1-29
Base Failure Rate Tables
for Capacitor Spec and Style

Spec MIL-C	Style	λ_b Table Number
55514	Char. M, N	2.6.1-32
	Char. Q, R, S	2.6.1-33

Table 2.6.1-30

π_Q, Quality Factor Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
LOWER	10.0

Table 2.6.1-31

π_{CV}, Capacitance Factor

Capacitance*	π_{CV}
.0049 μF.	.7
0.33 μF.	1.0
7.1 μF.	1.3
50. μF.	1.5

* - $\pi_{CV} = 1.1C^{0.085}$

where C is μF.

CAPACITORS
MIL-C-83421, CRH

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-83421	CRH	Super-Metallized Plastic, ER

Part operating failure rate model (λ_p):

$\lambda_p = \lambda_b \ (\pi_E \times \pi_Q \times \pi_{CV})$ failure/10^6 hrs.

where the factors are shown in Tables 2.6.1-34 through -37.

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$\lambda_{P_{NO}} = 0.00056 \ \pi_{E_{NO}} \times \pi_Q$ failures/10^6 hours

TABLE 2.6.1-34

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.24
S_F	1	0.24
G_F	3.7	0.89
N_{SB}	4.4	1.1
N_S	5.7	1.4
A_{IT}	6	-
M_P	9.2	2.2
M_{FF}	9.3	2.2
M_{FA}	13	3.1
G_M	7.8	1.9
N_H	14	3.4
N_{UU}	15	3.6
A_{UT}	11	-
N_U	13	3.1
A_{IF}	8	-
A_{RW}	20	4.9
U_{SL}	27	6.6
A_{UF}	21	-
M_L	31	7.6
C_L	530	130

Table 2.6.1-35

π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
LOWER	10.0

Table 2.6.1-36

π_{CV}, Capacitance Factor

Capacitance *	π_{CV}
.0029 µF.	.7
.14 µF.	1.0
2.4 µF.	1.3
23.0 µF.	1.6

* $\pi_{CV} = 1.2C^{0.092}$

where C is µF.

CAPACITORS
MIL-C-5, CM,
MIL-C-39001, CMR

2.6.2 MICA Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-5	CM	MICA
MIL-C-39001	CMR	MICA (Dipped), Est. Rel.

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b (\pi_E \times \pi_Q \times \pi_{CV}) \text{ failures}/10^6 \text{ hrs.}$$

where the factors are shown in Tables 2.6.2-1 through 8.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.2-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.53
S_F	1	0.53
G_F	1	0.53
N_{SB}	5	2.7
N_S	6.2	3.3
A_{IT}	4.2	-
M_P	11	5.8
M_{FF}	11	5.8
M_{FA}	15	8.0
G_M	8.8	4.7
N_H	16	8.5
N_{UU}	17	9.0
A_{UT}	17	-
N_U	15	8.0
A_{IF}	8.5	-
A_{RW}	23	12
U_{SL}	31	16
A_{UF}	34	-
M_L	36	19
C_L	610	320

Table 2.6.2-2
Base Failure Rate Tables for Capacitor
Spec and Style

Spec MIL-C	Style	λ_b Table Number
5	Temp.range M	2.6.2-5
	Temp.Range N	2.6.2-6
	Temp.Range O	2.6.2-7
	Temp.Range P	2.6.2-8
39001	Temp.Range O	2.6.2-7
	Temp.Range P	2.6.2-8

Table 2.6.2-3
π_Q, Quality Factor

Failure Rate Level	π_Q
T	0.01
S	0.03
R	0.1
P	0.3
M	1.0
L	1.5
Non-ER Dipped	3
Non-ER Molded	6
LOWER	15.

Table 2.6.2-4
π_{CV}, Capacitance Factor

Capacitance *	π_{CV}
2.1 pF.	.5
22 pF.	.75
300 pF.	1.0
.002 µF.	1.3
.0086 µF.	1.6
.029 µF.	1.9
.084 µF.	2.2

*- $\pi_{CV} = 0.45C^{.14}$ where C is pF.

CAPACITORS
MIL-C-10950, CB

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-10950	CB	Button Mica

Part operating failure rate model (λ_p):

$\lambda_p = \lambda_b \; (\pi_E \times \pi_Q \times \pi_{CV})$ failures/10^6 hrs

where the factors are shown in Tables 2.6.2-9 through 14.

Part non-operating failure rate model (λp_{NO}):

$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q$ failures/10^6 hours.

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.2-9

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.036
S_F	1	0.036
G_F	2.4	0.087
N_{SB}	5	0.18
N_S	5.2	0.19
A_{IT}	4.2	-
M_P	11	0.38
M_{FI}	11	0.38
M_{FA}	15	0.53
C_M	8.8	0.32
N_H	16	0.58
N_{UU}	17	0.63
A_{UT}	17	-
N_U	15	0.54
A_{IF}	8.5	-
A_{RW}	23	0.84
U_{SL}	31	1.1
A_{UF}	34	-
M_L	36	1.3
C_L	610	22

Table 2.6.2-10
Base Failure Rate Tables for Capacitor Spec & Style

Spec MIL-C	Style	λ_b Table Number
10950	CB50	2.6.2-13
	Other	2.6.2-14

Table 2.6.2-12
Π_{CV}, Capacitance Factor

Capacitance *	Π_{CV}
8.0 pF.	.5
47. "	.75
162. "	1.0
509. "	1.3
1260. "	1.6
2650. "	1.9
5010. "	2.2

* - $\pi_{CV} = .31C^{0.23}$
where C is pF.

Table 2.6.2-11
π_Q, Quality Factor

Failure Rate Level	π_Q
MIL-SPEC	5.0
Lower	15.0

CAPACITORS
MIL-C-11272, CY;
MIL-C-23269, CYR

2.6.3 Glass Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-11272	CY	Glass Capacitors
MIL-C-23269	CYR	Glass Capacitors, Est. Rel

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \; (\pi_E \times \pi_Q \times \pi_{CV}) \text{ failures}/10^6 \text{ hrs.}$$

where the factors are shown in Tables 2.6.3-1 through 6.

Part non operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.3-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.36
S_F	1	0.36
G_F	1.4	0.51
N_{SB}	5	1.8
N_S	6.2	2.2
A_{IT}	4.2	-
M_P	11	4.0
M_{FF}	11	4.0
M_{FA}	15	5.4
G_M	8.8	3.2
N_H	16	5.8
N_{UU}	17	6.1
A_{UT}	17	-
N_U	15	5.4
A_{IF}	8.5	-
A_{RW}	23	8.3
U_{SL}	31	11
A_{UF}	34	-
M_L	36	13
C_L	610	220

Table 2.6.3-2
Base Failure Rate Tables for Capacitor Spec and Style

Spec MIL-C	Style	λ_b Table Number
23269	All	2.6.3-5
11272	Temp. Range C	2.6.3-5
11272	Temp. Range D	2.6.3-6

Table 2.6.3-3
π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
L	3
Non-ER	3
LOWER	10.

Table 2.6.3-4
π_{CV}, Capacitance Factor

Capacitance *	π_{CV}
.22 pF.	.5
3.9 "	.75
30. "	1.0
200. "	1.3
870. "	1.6
3000. "	1.9
3500. "	2.2

* - $\pi_{CV} = 0.62C^{0.14}$
where C is pF.

2.6.4 Ceramic Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-11015	CK	Ceramic, General Purpose
MIL-C-39014	CKR	Ceramic, General Purpose, Est. Rel.

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \ (\pi_E \times \pi_Q \times \pi_{CV}) \ \text{failures}/10^6 \ \text{hrs.}$$

where the factors are shown in Tables 2.6.4-1 through 6.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \ \text{failures}/10^6 \ \text{hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.4-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.43
S_F	0.8	0.34
G_F	1.6	0.69
N_{SB}	5	2.2
N_S	5.5	2.4
A_{IT}	8.5	-
M_P	11	4.7
M_{FF}	11	4.7
M_{FA}	15	6.5
G_M	7.8	3.4
N_H	16	6.9
N_{UU}	18	7.7
A_{UT}	17	-
N_U	12.4	5.3
A_{IF}	17	-
A_{RW}	24	10
U_{SL}	32	14
A_{UF}	34	-
M_L	36	15
C_L	610	260

Table 2.6.4-2
Π_Q Quality Factor

Failure Rate Level	Π_Q
S	0.03
R	0.1
P	0.3
M	1.0
L	3
Non-ER	3
LOWER	10.

Table 2.6.4-3
Π_{CV}, Capacitance Factor

Capacitance *	Π_{CV}
6.1 pF.	.5
240. "	.75
3300. "	1.0
.036 μF.	1.3
.24 "	1.6
1.1 "	1.9
4.3 "	2.2

* - $\pi_{CV} = .41C^{0.11}$
where C is pF.

CAPACITORS
MIL-C-20, CC/CCR

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-20	CC/CCR	Ceramic, Temperature Compensating

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times (\pi_E \times \pi_Q \times \pi_{CV}) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.6.4-7 through 12.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours.}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.4-7

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.21
S_F	1	0.21
G_F	2.4	0.5
N_{SB}	1	0.21
N_S	5	1
A_{IT}	4.2	–
M_P	11	2.2
M_{FF}	11	2.2
M_{FA}	15	3.1
G_M	8.8	1.8
N_H	16	3.4
N_{UU}	18	3.6
A_{UT}	17	–
N_U	17	3.5
A_{IF}	8.5	–
A_{RW}	24	4.8
U_{SL}	32	6.5
A_{UF}	34	–
M_L	36	7.6
C_L	610	130

Table 2.6.4-8
Base Failure Rate Tables
for Capacitor Spec and Style

Spec MIL-C	Style	λ_b Table Number
20	CC 20,25,30,32,35,45, 85,95-97	2.6.4-11
	CC 5-9,13-19,21,22,26, 27,31,33,36,37,47, 50-57,75-79,81-83	2.6.4-12
	CCR 05-09,13-19,54-57, 75-79,81-83,90	

Table 2.6.4-9

Π_Q, Quality Factor

Failure Rate Level	Π_Q
S	0.03
R	0.1
P	0.3
M	1.0
Non-ER	3
LOWER	10.

Table 2.6.4-10

Π_{CV}, Capacitor Factor

Capacitance *	Π_{CV}
.25 pF.	.5
7.4 "	.75
81. "	1.0
720. "	1.3
4100. "	1.6
.017 µF.	1.9
.058 "	2.2

* - $\Pi_{CV} = .59C^{0.12}$
where C is pF.

CAPACITORS
MIL-C-39003, CSR

2.6.5 Tantalum Electrolytic Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-39003	CSR	Tantalum Electrolytic (solid), Est. Rel.

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b (\pi_E \times \pi_{SR} \times \pi_Q \times \pi_{CV}) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.6.5-1 through 5.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.0046\ \pi_{E_{NO}} \times \pi_Q \text{ failures }/10^6 \text{ hours}$$

TABLE 2.6.5-1

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.09
S_F	0.8	0.07
G_F	2.4	0.22
N_{SB}	4.4	0.4
N_S	4.9	0.45
A_{IT}	6	-
M_P	9.2	0.84
M_{FF}	9.3	0.85
M_{FA}	13	1.2
G_M	7.8	0.71
N_H	14	1.3
N_{UU}	15	1.4
A_{UT}	11	-
N_U	13	1.2
A_{IF}	12	-
A_{RW}	20	1.8
U_{SL}	27	2.5
A_{UF}	21	-
M_L	31	2.9
C_L	530	48

Table 2.6.5-2
Series Resistance,
π_{SR} for MIL-C-39003

Circuit Resistance (ohms/volt)	π_{SR}
≥ 3.0	0.07
2.0	0.10
1.0	0.20
0.8	0.30
0.6	0.40
0.4	0.60
0.2	0.80
0.1	1.0

Table 2.6.5-3
π_{CV}, Capacitance Factor

Capacitance*	π_{CV}
.003 uF.	0.5
.091 "	0.75
1.0 "	1.0
8.9 "	1.3
50. "	1.6
210. "	1.9
710. "	2.2

$* \pi_{CV} = 1.0C^{0.12}$
where C is uF.

Table 2.6.5-4
π_Q, Quality Factor

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
L	1.5
LOWER	10.

CAPACITORS
MIL-C-3965, CL;
MIL-C-39006, CLR

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-3965	CL	Tantalum, Electrolytic (Non-solid)
MIL-C-39006	CLR	Tantalum, Electrolytic (Non-solid) Est. Rel.

Part operating failure rate model (λ_p):

$\lambda_p = \lambda_b \; (\pi_E \times \pi_C \times \pi_Q \times \pi_{CV})$ failures/10^6 hours.

where the factors are shown in Tables 2.6.5-6 through -13.

Part non-operating failure rate model (λp_{NO}):

$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q$ failures/10^6 hours

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.5-6

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.33
S_F	1	0.33
G_F	1.4	0.46
N_{SB}	5	1.6
N_S	6.7	2.2
A_{IT}	11	-
M_P	11	3.4
M_{FF}	11	3.4
M_{FA}	15	4.8
G_M	10	3.3
N_H	16	5.3
N_{UU}	17	5.7
A_{UT}	14	-
N_U	15	5.0
A_{IF}	21	-
A_{RW}	23	7.6
U_{SL}	31	10.2
A_{UF}	28	-
M_L	36	11.8
C_L	610	200

TABLE 2.6.5-7
BASE FAILURE RATE TABLES FOR CAPACITOR SPECIFICATION AND STYLE

Spec MIL-C	Style	λ_b Table No.
3965	CL24, 25, 26, 27, 34, 35, 36, 37	2.6.5-11
	CL20, 21, 22, 23, 30, 31, 32, 33, 40, 41, 42, 43, 46, 47, 48, 49, 51, 52, 53, 54, 55, 56, 64, 65, 66, 67, 70, 71, 72, 73	2.6.5-12
	CL14, 16, 10, 13, 17, 18,	2.6.5-13
39006	all	2.6.5-12

TABLE 2.6.5-8
π_Q, QUALITY FACTOR

Failure Rate Level	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
L	1.5
Non-ER	3
LOWER	10.

TABLE 2.6.5-9
π_{CV}, CAPACITANCE FACTOR

Capacitance *	π_{CV}
.091 µF.	0.7
20. "	1.0
1100. "	1.3

* - $\pi_{CV} = .82C^{0.066}$ where C is µF.

CAPACITORS
MIL-C-39018, CU

2.6.6 Aluminum Electrolytic Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-39018	CU	Aluminum Oxide Electrolytic

Part operating failure rate model (λ_p):

$\lambda_p = \lambda_b \times \pi_E \times \pi_Q \times \pi_{CV}$ failures/10^6 hours.

where the factors are shown in Tables 2.6.6-1 through 4.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.0085\ \pi_{E_{NO}} \times \pi_Q \times \pi_{CV} \text{ failures}/10^6 \text{ hours}$$

TABLE 2.6.6-1

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.16
S_F	1	0.16
G_F	2.4	0.38
N_{SB}	5.8	0.93
N_S	6.7	1.1
A_{IT}	8.5	-
M_P	12	1.9
M_{FF}	12	1.9
M_{FA}	17	2.7
G_M	12	1.9
N_H	19	3.0
N_{UU}	20	3.2
A_{UT}	21	-
N_U	13	2.1
A_{IF}	17	-
A_{RW}	27	4.2
U_{SL}	36	5.7
A_{UF}	42	-
M_L	41	6.6
C_L	690	110

TABLE 2.6.6-2
π_Q, QUALITY FACTOR

Quality Level	π_Q
MIL-Spec	3
Lower	10

TABLE 2.6.6-3
π_{CV}, CAPACITANCE FACTOR

Capacitance*	π_{CV}
2.5 µF.	0.4
55. "	0.7
400. "	1.0
1700. "	1.3
5500. "	1.6
14,000. "	1.9
32,000. "	2.2
65,000. "	2.5
120,000. "	2.8

* - $\pi_{CV} = .34C^{0.12}$ where C is µF.

2.6.6 Aluminum Electrolytic Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-62	CE	Aluminum, Dry Electrolyte

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times \pi_E \times \pi_Q \times \pi_{CV} \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.6.6-5 through 8.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.011 \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours.}$$

TABLE 2.6.6-5

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	1.3
S_F	1	1.3
G_F	2.4	3
N_{SB}	5.8	7.3
N_S	6.7	8.5
A_{IT}	8.5	-
M_P	12	15
M_{FF}	12	15
M_{FA}	17	21
G_M	12	15
N_H	19	23
N_{UU}	20	25
A_{UT}	21	-
N_U	13	17
A_{IF}	17	-
A_{RW}	27	33
U_{SL}	36	45
A_{UF}	42	-
M_L	41	52
C_L	690	870

TABLE 2.6.6-6
π_Q, QUALITY FACTOR

Quality Level	π_Q
MIL-Spec	3
Lower	10

TABLE 2.6.6-7
π_{CV}, CAPACITANCE FACTOR

Capacitance	π_{CV}
3.2 µF.	0.4
62. "	0.7
400. "	1.0
1600. "	1.3
4800. "	1.6
12,000. "	1.9
26,000. "	2.2
50,000. "	2.5
91,000. "	2.8

* - $\pi_{CV} = .32C^{0.19}$ where C is µF.

2.6.7 Variable Ceramic Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-81	CV	Variable Ceramic

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times (\pi_E \times \pi_Q) \text{ failures}/10^6 \text{ hours}$$

where the factors are covered by Tables 2.6.7-1 through -5.

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the Table value at 25° and 0.1 stress ratio

TABLE 2.6.7-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.18
S_F	0.8	0.14
G_F	3.4	0.6
N_{SB}	7.9	1.4
N_S	7.7	1.4
A_{IT}	5.7	-
M_P	17	2.9
M_{FF}	17	2.9
M_{FA}	23	4.1
G_M	9.8	1.7
N_H	25	4.5
N_{UU}	27	-
A_{UT}	35	6.2
N_U	20	3.6
A_{IF}	11	-
A_{RW}	36	6.4
U_{SL}	49	8.6
A_{UF}	70	-
M_L	56	10
C_L	950	170

TABLE 2.6.7-2
BASE FAILURE RATE TABLES FOR
CAPACITOR SPECIFICATION AND STYLE

Spec MIL-C	Style	λ_b Table No.
81	CV11,14,21,31, 32,34,40,41	2.6.7-4
	CV35, 36	2.6.7-5

TABLE 2.6.7-3
π_Q, QUALITY FACTOR

Quality Level	π_Q
MIL-Spec	4
Lower	20

CAPACITORS
MIL-C-14409, PC

2.6.8 Variable Piston Type Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-14409	PC	Variable, Piston Type Tubular Trimmer

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times (\pi_E \times \pi_Q) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.6.8-1 through 5.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the table value at 25° and 0.1 stress ratio

TABLE 2.6.8-1

Environmental Mode Factors

Environment	π_E	π_{NO}
G_B	1	0.44
S_F	1	0.44
G_F	2.9	1.3
N_{SB}	6.9	3
N_S	7.2	3.2
A_{IT}	5.7	-
M_P	14	6.4
M_{FF}	15	6.5
M_{FA}	20	9
G_M	9.3	4
N_H	22	9.8
N_{UU}	24	11
A_{UT}	28	-
N_U	8.4	3.7
A_{IF}	11	-
A_{RW}	32	14
U_{SL}	43	19
A_{UF}	56	-
M_L	49	22
C_L	830	370

TABLE 2.6.8-2
BASE FAILURE RATE TABLES FOR CAPACITOR SPECIFICATION AND STYLE

Spec MIL-C	Style	λ_b Table No.
14409	G, H, J, L, T	2.6.8-4
	Char. Q	2.6.8-5

TABLE 2.6.8-3
π_Q, QUALITY FACTOR

Quality Level	π_Q
MIL-Spec	3
Lower	10

2.6.9 Variable Air Trimmer Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-92	CT	Variable, Air, Trimmer

Part operating failure rate model (λ_p):

$$\lambda_p = \lambda_b \times (\pi_E \times \pi_Q) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.6.9-1 through 3.

Part non-operating failure rate model ($\lambda_{p_{NO}}$):

$$\lambda_{p_{NO}} = 0.016\, \pi_{E_{NO}} \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

TABLE 2.6.9-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.037
S_F	1	0.037
G_F	3.4	0.13
N_{SB}	7.9	0.29
N_S	7.7	0.28
A_{IT}	5.7	-
M_P	17	0.61
M_{FF}	17	0.61
M_{FA}	23	0.86
G_M	9.8	0.36
N_H	25	0.94
N_{UU}	27	1.0
A_{UT}	35	-
N_U	20	0.76
A_{IF}	11	-
A_{RW}	36	1.3
U_{SL}	49	1.8
A_{UF}	70	-
M_L	56	2.1
C_L	950	35

Table 2.6.9-2

π_Q, Quality Factor

Failure Rate Level	π_Q
MIL-Spec	5
Lower	20

CAPACITORS
MIL-C-23183, CG

2.6.10 Vacuum or Gas Capacitors

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-23183	CG	Vacuum or Gas, Fixed and Variable

Part operating failure rate model (λ_p):

$\lambda_p = \lambda_b \times (\pi_E \times \pi_Q \times \pi_{CF})$ failures/10^6 hours

where the factors are shown in Tables 2.6.10-1 through 7.

Part non-operating failure rate model ($\lambda_{p_{NO}}$):

$$\lambda_{p_{NO}} = \lambda_b \times \pi_{E_{NO}} \times \pi_Q \times \pi_{CF} \text{ failures}/10^6 \text{ hours}$$

Where λ_b is the table value at 25° and 0.1 stress ratio

TABLE 2.6.10-1

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.22
S_F	1	0.22
G_F	3.4	0.75
N_{SB}	8.7	1.9
N_S	7.7	1.7
A_{IT}	8.5	-
M_P	18	4
M_{FF}	N/A	N/A
M_{FA}	N/A	N/A
G_M	10	2.2
N_H	28	6.2
N_{UU}	30	6.6
A_{UT}	53	-
N_U	24	5.4
A_{IF}	17	-
A_{RW}	40	8.9
U_{SL}	N/A	N/A
A_{UF}	110	-
M_L	N/A	N/A
C_L	1000	230

Table 2.6.10-2
Base Failure Rate Tables for MIL-C-23183
Capacitor Styles

Style	λ_b Table No.
CG 20,21,30,31,32,40,41,42, 43,44,51,60,61,62,63,64,67	2.6.10-5
CG 65,66	2.6.10-6
CG 50	2.6.10-7

Table 2.6.10-3
Π_Q Quality Factor

Failure Rate Level	π_Q
MIL-Spec	3
Lower	20

Table 2.6.10-4
π_{CF}, Configuration Factor

Configuration	π_{CF}
Fixed	0.1
Variable	1.0

2.7.1 Transformers

SPECIFICATION	STYLE	DESCRIPTION
MIL-T-27	TF	Audio, Power, and High Power Pulse
MIL-T-21038	TP	Low Power Pulse
MIL-T-55631	-	IF, RF, and Discriminator

The general model for these devices is as follows:

$$\lambda_p = \lambda_b (\pi_E \times \Pi_Q)$$

λ_p = failures/10^6 hours

λ_b = base failure rate

π_E = environmental factor

Π_Q = quality factor

The general model for the base failure rate:

$$\lambda_b = Ae^x \text{ where } x = \left(\frac{T_{HS} + 273}{N_T}\right)^G$$

T_{HS} = Hot spot temperature in degrees C and e is natural logarithm base, 2.718.

N_T = Temperature constant

G = Acceleration constant

A = Adjustment factor for different insulation classes

See Tables 2.7.1-1 thru 2.7.1-4 for equation constants. The models are valid only if T_{HS} is not above the temperature rating for a given insulation class.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.002\ \pi_{E_{NO}} \times \pi_Q$$

TABLE 2.7.1-1
Transformer Base Failure Rate Model Constants versus Insulation Class

SPECIFICATION	Insulation Class					
MIL-T-27	Q	R	S	V	T	U
MIL-T-21038	Q	R	S	T	U	V
MIL-T-55631	O	A	B	C	-	-
Model Constants	Maximum Operating Temperature					
	85°C	105°C	130°C	155°C	170°C	>170°C
A	0.00159	0.0018	0.00152	0.00458	0.00508	0.0065
N_T	329	352	364	409	398	477
G	15.6	14.0	8.7	10.0	3.8	8.4

TABLE 2.7.1-2
Quality Factor, π_Q

Family Type	Mil-Spec.	Lower
Pulse Transformers	1.5	5.0
Audio Transformers	3.0	7.5
Power Transformers and Filters	8.0	30.0
RF Transformers	12.0	30.0

TABLE 2.7.1-3

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.15
S_F	1	0.15
G_F	5.7	0.83
N_{SB}	5.1	0.75
N_S	5.7	0.83
A_{IT}	11	-
M_P	11	1.6
M_{FF}	11	1.6
M_{FA}	15	2.2
G_M	12	1.7
N_H	16	2.4
N_{UU}	18	2.6
A_{UT}	14	-
N_U	14	2.1
A_{IF}	21	-
A_{RW}	24	3.4
U_{SL}	32	4.6
A_{UF}	28	-
M_L	36	5.3
C_L	610	90

2.7.2 Coils

SPECIFICATION	STYLE	DESCRIPTION
MIL-C-15305	-	Fixed and Variable, RF
MIL-C-39010	-	Molded, RF, ER

The general operating model for these devices is as follows:

$$\lambda_p = \lambda_b (\pi_E \times \pi_Q \times \pi_C)$$

where: λ_p = Total failure rate in failures/10^6 hours

λ_b = Base failure rate

π_E = Environmental factor

π_Q = Quality factor

π_C = Construction factor (fixed or variable).

The general model for the base failure rate:

$$\lambda_b = Ae^x \text{ where } x = \left(\frac{T_{HS} + 273}{N_T}\right)^G$$

where: T_{HS} = Hot spot temperature in degrees C and e is natural logarithm base, 2.718.

N_T = Temperature Constant

G = Acceleration Constant

A = Adjustment factor for different insulation classes.

See Tables 2.7.2-1 thru 2.7.2-5 for equation constants. The models are valid only if T_{HS} is not above the temperature rating for a given insulation class.

Part non-operating failure rate model (λp_{NO}):

$$\lambda p_{NO} = 0.0004\, \pi_{E_{NO}} \times \pi_Q \times \pi_C$$

INDUCTIVE DEVICES
MIL-C-15305
MIL-C-39010

TABLE 2.7.2-1

Coil Base Failure Rate Model Constants versus Insulation Class

Specification	Insulation Class			
MIL-C-15305	O	A	B	C
MIL-C-39010	-	A	B	F
Model Constants	Maximum Operating Temperature			
	85°C	105°C	125°C	150°C
A	3.35×10^{-4}	3.79×10^{-4}	3.19×10^{-4}	9.63×10^{-4}
N_T	329	352	364	409
G	15.6	14.0	8.7	10.0

TABLE 2.7.2-2
Quality Factor, π_Q

Failure Rate Level	π_Q Factor
S	0.03
R	0.1
P	0.3
M	1.0
MIL-C-15305	4.0
Lower	20.0

TABLE 2.7.1-3

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.86
S_F	1	0.86
G_F	3.6	3.1
N_{SB}	5.1	4.4
N_S	5.7	4.9
A_{IT}	11	-
M_P	11	9.5
M_{FF}	11	9.5
M_{FA}	15	13
G_M	12	10
N_H	16	14
N_{UU}	18	15
A_{UT}	14	-
N_U	14	12
A_{IF}	21	-
A_{RW}	24	21
U_{SL}	32	28
A_{UF}	28	-
M_L	36	31
C_L	610	520

TABLE 2.7.2-4
Construction Factor, π_C

Construction	π_C
Fixed	1
Variable	2

The failure rate model is:

$$\lambda_p = \left(\frac{t^2}{\alpha_B^{\,3}} + \frac{1}{\alpha_W}\right) \times 10^6 \text{ (failures/}10^6\text{ hours)}$$

where

λ_p = the average failure rate (failures/10^6 hours)

t = motor operating time period, selected by the user, for which average failure rate is calculated (hours). Each motor must be replaced when it reaches the end of this operating period to make the calculated λ_p valid.

λ_B = Bearing Weibull Characteristic Life as determined from Table 2.8.1-1 for constant ambient temperature operation or Section 2.8.1.1 for cycled temperature.

λ_W = Winding Weibull Characteristic Life as determined from Table 2.8.1-1 for constant ambient temperature operation or Section 2.8.1.2 for cycled temperature.

Part nonoperating failure rates:

AC Motor $\lambda_{p_{NO}}$ = 0.02 (failures/10^6 hours)

DC Motor $\lambda_{p_{NO}}$ = 0.05 (failures/10^6 hours)

2.8.2 SYNCHROS & RESOLVERS

The part failure rate model (λ_p) is:

$$\lambda_p = \lambda_b (\Pi_S \times \Pi_N \times \Pi_E) \text{ failures}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.8.2-1 thru 2.8.2-4 Synchros and resolvers are predominatly used in service requiring only slow and infrequent motion. Mechanical wearout problems are not serious so that the electrical failure mode dominates, and no mechanical mode failure rate is required in the model above.

TABLE 2.8.2-1 λ_b FOR RESOLVERS & SYNCHROS VS. FRAME TEMPERATURE*

T(°C)	$\lambda_b(f/10^6$ hrs)	T(°C)	$\lambda_b(f/10^6$ hrs)
30	.0083	85	.0325
35	.0088	90	.0407
40	.0095	95	.0523
45	.0103	100	.0690
50	.0114	105	.0937
55	.0126	110	.131
60	.0142	115	.191
65	.0162	120	.288
70	.0187	125	.453
75	.0221	130	.744
80	.0265	135	1.28

* - $\lambda_b = .00535\, e^{\left(\frac{T+273}{334}\right)^{8.5}}$

where T = frame temperature (°C) and e = natural logarithm base, 2.718. If frame temperature is unknown, assume T = 40 + ambient temperature.

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = 0.0078\ \Pi_S \times \Pi_N \times \Pi_{E_{NO}} \text{ failures}/10^6 \text{ hours}$$

TABLE 2.8.2-2 π_S FOR SYNCHROS AND RESOLVERS, BASED ON TYPE AND SIZE

DEVICE TYPE	π_S		
	Size 8 or Smaller	Size 10-16	Size 18 or Larger
Synchro	2	1.5	1
Resolver	3	2.25	1.5

TABLE 2.8.2-3 π_N FOR SYNCHROS AND RESOLVERS, BASED ON NUMBER OF BRUSHES

Number of Brushes	π_N
2	1.4
3	2.5
4	3.2

TABLE 2.8.2-4

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1.2	1.1
S_F	N/A	N/A
G_F	2.3	2.1
N_{SB}	5.6	5.1
N_S	8.1	7.4
A_{IT}	3	-
M_P	12	11
M_{FF}	12	11
M_{FA}	17	16
G_M	12	11
N_H	18	17
N_{UU}	19	17
A_{UT}	13	-
N_U	16	15
A_{IF}	6	-
A_{RW}	26	24
U_{SL}	35	32
A_{UF}	25	-
M_L	N/A	N/A
C_L	680	620

2.8.3 ELAPSED TIME METERS

The part operating failure rate model (λ_p) is:

$$\lambda_p = \lambda_b (\Pi_T \times \Pi_E) \text{ failure}/10^6 \text{ hours}$$

where the factors are shown in Tables 2.0.3-1 thru 2.8.3-3

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = \lambda_b \times \pi_{E_{NO}}$$

λ_b is shown in Table 2.8.3.-1.

TABLE 2.8.3-1 λ_b FOR E. T. METERS

TYPE	λ_b (f./10^6 hr.)
A.C.	20
Inverter Driven	30
Commutator D.C.	80

TABLE 2.8.3-2 Π_T FOR E. T. METERS

Operating T (°C.) / RATED T (°C.)	Π_T
0 to .5	.5
.6	.6
.8	.8
1.0	1.0

TABLE 2.8.3-3

Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.0004
S_F	1	0.0004
G_F	2.5	0.0010
N_{SB}	5.6	0.0023
N_S	8.8	0.0035
A_{IT}	3.9	-
M_P	1[illegible]	0.0047
M_{FF}	N/A	N/A
M_{FA}	N/A	N/A
G_M	12	0.0047
N_H	18	0.0072
N_{UU}	19	0.0078
A_{UT}	13	-
N_U	16	0.0063
A_{IF}	7.7	-
A_{RW}	26	.01
U_{SL}	N/A	N/A
A_{UF}	25	-
M_L	N/A	N/A
C_L	N/A	N/A

2.9 RELAYS

Table 2.9-1. Prediction Procedure for Relays

<table>
<tr><td>
<u>Part Specifications Covered</u>

<u>Military Specifications</u>

1. MIL-R-5757   3 MIL-R-19523   5. MIL-R-19648
2. MIL-R-6016   4. MIL-R-39016   6. MIL-R-83725
7. MIL-R-83726*
</td></tr>
<tr><td>
<u>Part failure rate model (λ_p)</u>

$(\lambda_p) = \lambda_b (\pi_E \times \pi_C \times \pi_{cyc} \times \pi_F \times \pi_Q)$ (failures/10^6 hours)

where the factors are shown in these tables:

π_E - Table 2.9-4
π_C - Table 2.9-5
π_F - Table 2.9-7
π_{cyc} - Table 2.9-6

π_Q - Table 2.9-8

Note - Values of π_{cyc} for cycling rates beyond the basic design limitations of the relay are not valid. Design Specifications should be consulted prior to evaluation of π_{cyc}.
</td></tr>
</table>

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$\lambda_{P_{NO}} = 0.006\ \pi_{E_{NO}} \times \pi_Q \times \pi_C$ failures/10^6 hours

* - Prediction procedure does not apply to Class C (solid state) relays of this specification.

TABLE 2.9-4

MIL-SPEC
Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.29
S_F	1	0.29
G_F	2.3	0.67
N_{SB}	10	2.9
N_S	6.1	1.8
A_{IT}	4.0	-
M_P	21	6.1
M_{FF}	21	6.1
M_{FA}	29	8.4
G_M	8.2	2.4
N_H	32	9.3
N_{UU}	34	9.9
A_{UT}	12	-
N_U	14	4.1
A_{IF}	8.0	-
A_{RW}	46	13
U_{SL}	62	18
A_{UF}	24	-
M_L	71	21
C_L	N/A	N/A

TABLE 2-9.4

Lower Quality
Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	2	0.58
S_F	-	0.58
G_F	4.6	1.3
N_{SB}	30	8.7
N_S	18	5.2
A_{IT}	8.0	-
M_P	63	18
M_{FF}	63	18
M_{FA}	82	24
G_M	25	7.3
N_H	96	28
N_{UU}	100	29
A_{UT}	30	-
N_U	38	11
A_{IF}	16	-
A_{RW}	140	41
U_{SL}	190	55
A_{UF}	60	-
M_L	210	61
C_L	N/A	N/A

Table 2.9-5. π_c Factor For Contact Form

Contact Form	π_c
SPST	1.00
DPST	1.50
SPDT	1.75
3PST	2.00
4PST	2.50
DPDT	3.00
3PDT	4.25
4PDT	5.50
6PDT	8.00

This table applies to active conducting contacts.

2.10 SWITCHES

Toggle or pushbutton (single body)

TABLE 2.10-1

Prediction Procedures for Toggle or Pushbutton Switches

Part specifications covered	Description
1. MIL-S-3950	
2. MIL-S-8805	Snap-action toggle or pushbutton

Part operating failure rate model (λ_p)

$$\lambda_p = \lambda_b (\pi_E \times \pi_C \times \pi_{cyc} \times \pi_L) \text{ failures}/10^6 \text{ hours}$$

where factors are shown in:

π_E - Table 2.10-4
π_C - Table 2.10-5
π_{cyc} - Table 2.10-6
π_L - Table 2.10-7

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = \lambda_b \times \pi_{E_{NO}} \times \pi_C \text{ failures}/10^6 \text{ hours}$$

Base failure rate model (λ_b)

Description	λ_b	
	MIL-SPEC	Lower Quality
Snap-action	0.00045	0.034
Non-snap action	0.0027	0.04

Table 2.10-2. **Prediction Procedure for Basic Sensitive Switch**

Part specifications covered	Description
MIL-S-8805	Basic sensitive

Part operating failure rate model (λ_p)

$$\lambda_p = \lambda_b (\pi_E \times \pi_{cyc} \times \pi_L) \text{ failures}/10^6 \text{ hours}$$

where factors are shown in:

π_E - Table 2.10-4

π_{cyc} - Table 2.10-6

π_L - Table 2.10-7

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = \lambda_b \pi_{E_{NO}}$$

Base failure rate model (λ_b)

$\lambda_b = \lambda_{bE} + n \lambda_{bC}$ (if actuation differential is >0.002 inches)

$\lambda_b = \lambda_{bE} + n \lambda_{bD}$ (if actuation differential is <0.002 inches)

where n = 1/2 the number of active contacts, e.g., 1PST has two contacts, 1PDT has four contacts.

Description	MIL-SPEC	Lower Quality
λ_{bE}	0.1	0.1
λ_{bC}	0.0009	0.45
λ_{bD}	0.0018	1.25

Rotary (wafer)

Table 2.10-3. Prediction Procedure for Rotary Switches

Part specification covered	Description
MIL-S-3786	Rotary, ceramic or glass wafer, silver alloy contacts

Part operating failure rate model (λ_p)

$$\lambda_p = \lambda_b \, (\pi_E \times \pi_{cyc} \times \pi_L) \text{ failures}/10^6 \text{ hours}$$

where factors are shown in:

π_E - Table 2.10-4

π_{cyc} - Table 2.10-6

π_L - Table 2.10-7

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = \lambda_b \, \pi_{E_{NO}}$$

Base failure rate model (λ_b)

$\lambda_b = \lambda_{bE} + n \, \lambda_{bF}$ (for ceramic RF wafers)

$\lambda_b = \lambda_{bE} + n \, \lambda_{bG}$ (for rotary switch medium power wafers)

where n is the number of active contacts

Description	MIL-SPEC	Lower Quality
λ_{bE}	0.0067	0.1
λ_{bF}	0.00003	0.02
λ_{bG}	0.00003	0.06

TABLE 2.10-4

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	2.412
S_F	1	2.412
G_F	2.9	6.995
N_{SB}	10	24.120
N_S	5.7	13.748
A_{IT}	5	-
M_P	21	50.411
M_{FF}	21	50.893
M_{FA}	29	70.913
G_M	14	34.492
N_H	32	77.908
N_{UU}	34	82.973
A_{UT}	50	-
N_U	20	47.999
A_{IF}	10	-
A_{RW}	46	111.193
U_{SL}	63	151.474
A_{UF}	100	-
M_L	71	172.217
C_L	1200	2904

2.11 CONNECTOR

2.11.1 Connector, general (except printed circuit board types)

TABLE 2.11.1-1. Prediction Procedure for Connectors

PART SPECIFICATIONS COVERED (Table 2.11-2 shows connector configurations)

Type	MIL-C-SPEC	Type	MIL-C-SPEC
Rack and panel	24308 28748 83733	Coaxial, RF	3607 3643 3650 3655 25516 39012
Circular	5015 26482 38999 81511 83723	Power	3767

Part Failure Rate Model (λ_p)

The failure rate model (λ_p) is for a mated pair of connectors. For a single connector, divide λ_p by two.

$$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K) \text{ failures}/10^6 \text{ hours}$$

where:

π_E - Table 2.11.1-6

π_P - Table 2.11.1-7

π_K - Table 2.11.1-8

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = \lambda_b \times \pi_{E_{NO}} \times \pi_P \text{ failures}/10^6 \text{ hours}$$

where λ_b = 20°C and appropriate insert material

TABLE 2.11.1-6

MIL-SPEC
Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1	0.12
S_F	1	0.12
G_F	1.2	0.14
N_{SB}	4.1	0.49
N_S	5.3	0.64
A_{IT}	5.0	-
M_P	8.5	1.0
M_{FF}	8.5	1.0
M_{FA}	12	1.4
G_M	8.3	1.0
N_H	13	1.6
N_{UU}	14	1.7
A_{UT}	5	-
N_U	13	1.6
A_{IF}	10	-
A_{RW}	19	2.3
U_{SL}	25	3
A_{UF}	10	-
M_L	29	3.5
C_L	490	59

TABLE 2.11.1-6

Lower Quality
Environmental Mode Factors

Environment	π_E	$\pi_{E_{NO}}$
G_B	1.5	0.18
S_F	1.5	0.18
G_F	4.7	0.56
N_{SB}	8.1	0.97
N_S	11	1.3
A_{IT}	15	-
M_P	17	2.0
M_{FF}	17	2.0
M_{FA}	24	2.9
G_M	25	3.0
N_H	26	3.1
N_{UU}	28	3.4
A_{UT}	15	-
N_U	27	3.2
A_{IF}	30	-
A_{RW}	37	4.4
U_{SL}	50	6.0
A_{UF}	30	-
M_L	58	7.0
C_L	970	120

2.11.2 PRINTED CIRCUIT BOARD CONNECTOR

Table 2.11.2-1 Prediction Procedure for PCB Connectors

Specification	Description
MIL-C-21097	One-Piece Connector
MIL-C-55302	Two-Piece Connector

Part Failure Rate Model (λ_p)

The failure rate, λ_p, is for a mating pair of connectors and is:

$$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K) \text{ failures}/10^6 \text{ hours}$$

where the factors are:

π_E Table 2.11.2-4

π_P Table 2.11.2-5

π_K Table 2.11.2-6

Base Failure Rate (λ_b)

$$\lambda_b = Ae^x$$

where $x = \left(\frac{N_T}{T+273}\right) + \left(\frac{T+273}{T_o}\right)^P$

e = 2.718, natural logarithm base
T = operating temperature (°C)
T = ambient + temperature rise (Table 2.11.2-2)

A = 0.216
T_o = 423
P = 4.66
N_T = -2073.6

λ_b values are shown in Table 2.11.2-3.

Part non-operating failure rate model ($\lambda_{P_{NO}}$):

$$\lambda_{P_{NO}} = 0.00021\, \pi_{E_{NO}} \times \pi_P \text{ failures}/10^6 \text{ hours}$$

Table 2.11.2-4 based on Environmental Service

TABLE 2.11.2-4

MIL-SPEC
Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.65
S_F	1	0.65
G_F	3.4	2.2
N_{SB}	4.1	2.7
N_S	5.7	3.7
A_{IT}	5	-
M_P	8.5	5.5
M_{FF}	8.5	5.5
M_{FA}	12	7.8
G_M	8.3	5.4
N_H	13	8.5
N_{UU}	13	8.5
A_{UT}	5	-
N_U	13	8.5
A_{IF}	10	-
A_{RW}	19	12
U_{SL}	25	16
A_{UF}	10	-
M_L	29	19
C_L	490	320

TABLE 2.11.2-4

Lower Quality
Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1.5	0.98
S_F	1.5	0.98
G_F	6.8	4.4
N_{SB}	8.2	5.3
N_S	12	7.8
A_{IT}	10	-
M_P	17	11
M_{FF}	17	11
M_{FA}	24	16
G_M	17	11
N_H	26	17
N_{UU}	26	17
A_{UT}	10	-
N_U	27	18
A_{IF}	20	-
A_{RW}	37	24
U_{SL}	50	32
A_{UF}	20	-
M_L	58	38
C_L	970	630

2.12 PRINTED WIRING BOARDS

The specifications applicable to printed wiring boards are:

MIL-P-55110 Printed Wiring Boards

Part non-operating failure rate model (λ_{PNO}):

$$\lambda_{PNO} = \lambda_b \times N \times \pi_{ENO}$$

The operating rate model for printed wiring boards is:

$$\lambda_p = \lambda_b N \pi_E$$

where: λ_p = board failure rate in f./10^6 hr.

λ_b = $6(10)^{-6}$ failures/10^6 hr. for two-sided boards

= $5(10)^{-4}$ failures/10^6 hr. for multi-layer boards

N = number of plated-through holes

π_E = (see Table 2.12)

π_{ENO} = (see Table 2.12)

The above model is applicable only to high quality boards that have received screening and burn-in and that use G-10 or equivalent epoxy materials.

TABLE 2.12

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.48
S_F	1	0.48
G_F	2.4	1.1
N_{SB}	4.4	2.1
N_S	5.7	2.7
A_{IT}	4.2	-
M_P	6.7	3.2
M_{FF}	9.3	4.4
M_{FA}	13	6.1
G_M	7.8	3.7
N_H	14	6.7
N_{UU}	15	7.2
A_{UT}	10	-
N_U	13	6.4
A_{IF}	8.4	-
A_{RW}	20	9.6
U_{SL}	27	13
A_{UF}	20	-
M_L	31	15
C_L	530	250

2.12-1

2.13 CONNECTIONS

The part operating failure rate model (λ_p) is:

$\lambda_p = \lambda_b (\Pi_E \times \Pi_T \times \Pi_Q)$ failures/10^6 hours

where:

λ_b = base failure rate (Table 2.13-1)

Π_E = environmental factor (Table 2.13-2)

Π_T = tool type factor (Table 2.13-3 for crimp type)

= 1 for all types except crimp

Π_Q = quality factor (Table 2.13-4 for crimp type)

= 1 for all types except crimp

TABLE 2.13-1 BASE FAILURE RATE, λ_b

CONNECTION TYPE	λ_b (F/10^6 HR.)
Wirewrap	.0000025
Solder, reflow lap to P.W. boards	.00008
Solder, wave to P.W. boards	.00029
Hand solder	.0026
Crimp	.00026
Weld	.0013

Part non-operating failure rate model (λp_{NO}):

$\lambda p_{NO} = \lambda_b \times \pi_{E_{NO}} \times \pi_T \times \pi_Q$

λ_b is covered in Table 2.13-1.

TABLE 2.13-2

Environmental Mode Factors

Environment	π_E	π_{ENO}
G_B	1	0.33
S_F	1	0.33
G_F	2.1	0.69
N_{SB}	3.5	1.2
N_S	4.4	1.4
A_{IT}	3.0	-
M_P	7.3	2.4
M_{FF}	7.3	2.4
M_{FA}	10	3.4
G_M	7.3	2.4
N_H	11	3.7
N_{UU}	12	3.9
A_{UT}	4	-
N_U	9.9	3.3
A_{IF}	6	-
A_{RW}	16	5.3
U_{SL}	22	7.1
A_{UF}	8	-
M_L	25	8.2
C_L	420	140

TABLE 2.13-3. TOOL TYPE FACTORS (Π_T) FOR CRIMP CONNECTIONS

TOOL TYPE	Π_T
Automated	1
Manual	2

Notes: 1 Automated encompasses all powered tools not hand-held.

2 Manual includes all hand-held tools.

TABLE 2.13-4. QUALITY FACTORS (Π_Q) FOR CRIMP CONNECTIONS

QUALITY GRADE	Π_Q	COMMENTS
Automated Tools	1.0	Daily pull tests recommended.
Manual Tools:		
Upper	0.5	Only MIL-SPEC or approved equivalent tools and terminals, pull test at beginning and end of each shift, color coded tools and terminations.
Standard	1.0	Only MIL-SPEC tools, pull test at beginning of each shift.
Lower	10.0	Anything less than standard criteria.

TABLE 2.14-1

FAILURE RATES FOR MISCELLANEOUS PARTS (FAILURES/10^6 HOURS)

PART TYPE	FAILURE RATE
Microwave Ferrite Devices	
Isolators & Circulators (≤ 100W.)	$0.1 \times \pi_{E1}$
Isolators & Circulators (> 100W.)	$0.2 \times \pi_{E1}$
Phase Shifter (latching)	$0.1 \times \pi_{E1}$
Dummy Loads	
< 100W.	$0.01 \times \pi_{E2}$
100W. to ≤ 1000W.	$0.03 \times \pi_{E2}$
> 1000W.	$0.1 \times \pi_{E2}$
Terminations (thin or thick film loads used in stripline and thin film circuits	$0.03 \times \pi_{E2}$

Note: $\pi_{E_{NO}}$ approaches zero for these parts, therefore not applicable

Environmental Mode Factors

Environment	π_{E_1}
G_B	1
S_F	1
G_F	2.4
N_{SB}	3.7
N_S	6.2
A_{IT}	5
M_P	7.7
M_{FF}	7.8
M_{FA}	11
G_M	8.8
N_H	12
N_{UU}	13
A_{UT}	6
N_U	12
A_{IF}	7
A_{RW}	17
U_{SL}	23
A_{UF}	10
M_L	26
C_L	450

Environmental Mode Factors

Environment	π_{E_2}
G_B	1
S_F	1
G_F	2.4
N_{SB}	5.5
N_S	4.7
A_{IT}	4.2
M_P	11
M_{FF}	12
M_{FA}	16
G_M	8.8
N_H	18
N_{UU}	19
A_{UT}	11
N_U	15
A_{IF}	8.5
A_{RW}	25
U_{SL}	34
A_{UF}	21
M_L	39
C_L	660

APPENDIX G

DATA SUMMARY TABLES

TABLE G-1

Primary Types of Equipment Represented by Data

Environmental Category	Equipment Type
Ground	Laboratory Test Equipment, Computer Complexes, SAFEGUARD Perimeter Acquisition and Missile Site Radars, Minuteman III GSE, VHF/UHF Communications Systems, Air Traffic Control Equipment, Pershing Ia GSE, Tactical Fire Direction Systems, Pershing Azimuth Laying Equipment
Submarine/Ship	Surface Ship Transmitters, Transceivers, Computers, Sonars, and Radar Equipment; C-3 Flight Control Systems, SINS, Electrostatic Gyro Monitor, AN/UYK-20 Digital Data Combat Computer, AN/WSC-3 Satellite Communications Set, AN/URC-62 VLF Fleet Broadcast System
Space Flight	W71 Orgital Sensor, SMS, ALSEP, C System, Apollo Transponder; ATS-F, TIPOS-N, ETS-2 Satellites
Airborne, Rotary Wing, Missile	TADS/PNVS System C-3 Missile Computer, Patriot G&C System, Pershing G&C System, Liquid Rocket Engine Electronic Flight Controllers, Copperhead Guided Projectile

TABLE G-2 MICROELECTRONICS OPERATING/NONOPERATING DATA SUMMARY

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($\times 10^6$)	FAILURE RATE* ($FAIL/10^6$ HRS)
Digital	G_F	D	13	55.235	0.2643
		D-1	298	403.403	0.7529
		B	171	8520.348	0.0206
		B-1	2	186.796	0.0166
	G_F	B-2	1	0.910	2.2201
	N_O/G_F**	S	5	5328.202	0.0012
	N_O/G_F**	B	4	1480.574	0.0035
	M_P	B	0	0.480	1.9064
	N_{SB}	B-1	0	106.284	0.0086
	A_{RW}	B	0	0.012	78.2051
	N_{SB}	C-1	0	166.010	0.0055
	N_U	B	0	0.0027	338.8888
	N_{SB}	B	72	2637.022	0.0283
	S_F	B	2	698.050	0.0044
	G_B	S	1133	112623.990	0.0102
		D	4	43.182	0.1216
Digital	G_B	D-1	15	20.511	0.8142
Linear	N_{SB}	B	1	8.808	0.2293
	N_U	B	0	0.0031	295.1612
	A_{RW}	B	0	0.018	50.8333
	M_P	B	0	0.438	2.0880
	N_O/G_F**	S	5	2269.720	0.0028
	N_O/G_F**	B	5	435.574	0.0145
	G_B	S	35	19403.618	0.00017
	S_F	B	0	107.140	0.0085
	G_F	B	37	721.824	0.0544
Linear	G_F	S	10	81.859	0.1405
Memory	G_B	D-1	610	938.857	0.6586
	G_B	D	538	1043.648	0.5230
	G_F	B-1	0	10.440	0.0876
		D	33	51.154	0.6871
		D-1	95	120.450	0.8137
	G_F	B	0	19.601	0.0467
	N_U	B	0	0.0018	508.3333
	A_{RW}	B	0	0.0058	157.7586
Memory	N_{SB}	B-1	0	17.549	0.0521
LSI	G_B	D	10	17.078	0.6734
	G_B	D-1	78	52.240	1.5445
	G_F	D	14	17.600	0.8892
LSI	G_F	D-1	6	7.770	0.9459
Totals			3197	157596.507	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

TABLE G-3

Transistor Operating/Nonoperating Data Summary

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (x 10^6)	FAILURE RATE* (FAIL/10^6 HRS)
MIL-S-19500 Group I	G_F	JANTXV	0	7.412	0.1234
↓	G_F	JANTX	715	37471.170	0.0193
	G_F	JAN	494	5155.152	0.0973
	G_F	Lower	388	363.460	1.0856
	G_B	JANTX	15	21.800	0.7660
	G_B	Lower	2740	8059.000	0.3423
	S_F	JANTX	0	452.460	0.0020
	N_S	JANTX	36	61.600	0.6201
	N_S	JAN	6	92.191	0.0369
	M_P	JAN	1	0.501	4.0333
	N_O/G_F**	Lower	13	30800.000	0.0004
	N_O/G_F**	JANTX	33	28697.080	0.0012
	N_O/S_F***	JANTX	0	29.910	0.0305
	N_{SB}	JAN	203	20.990	9.8919
	N_{SB}	Lower	1198	8281.588	0.1461
	M_L	JAN	0	0.033	27.9347
	G_M	JAN	0	5.229	0.1750
	G_M	JANTX	0	0.195	4.6923
	G_M	Lower	0	0.348	2.6293
	A_{RW}	JANTX	0	0.0304	30.1316
MIL-S-19500 Group I	N_U	JANTX	0	0.0056	163.5714
MIL-S-19500 Group II	G_F	Lower	8	28.980	0.3261
↓	G_F	JANTX	1	222.180	0.0091
	G_F	JAN	2	3.190	0.9734
	N_S	JAN	0	0.406	2.2537
	S_F	JANTX	3	1008.151	0.0041
	N_O/G_F**	Lower	4	11340.000	0.000040
	N_O/G_F**	JAN	41	6264.000	0.0069
	N_O/G_F**	JANTX	6	17905.600	0.00040
	N_{SB}	JAN	4	2.200	2.3864
	G_B	Lower	408	594.000	0.6983
	G_B	JAN	1	20.800	0.0971
	M_L	JAN	0	0.00025	3750.0000
	G_M	Lower	1	0.021	0.0840
	A_{RW}	JANTX	0	0.00045	2033.3333
MIL-S-19500 Group II	N_U	JANTX	0	0.00040	2287.5000

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

***Nonoperating space flight

TABLE G-3 (Continued)

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($\times 10^6$)	FAILURE RATE* (FAIL/10^6 HRS)
MIL-S-19500 Group III	G_F	JANTX	4	67.800	0.0774
↓	S_F	JANTX	0	2.320	0.0130
	N_S	JANTX	1	0.170	11.8824
	N_{SB}	JAN	0	1.763	0.5190
	M_L	JAN	0	0.00073	2496.5893
	G_M	Lower	0	0.031	29.3269
	N_O/S_F**	JANTX	0	0.554	1.6520
	A_{RW}	JANTX	0	0.0040	228.7500
MIL-S-19500 Group III	N_U	JANTX	0	0.0004	2287.5000
Totals			6326	156982.327	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating space flight

TABLE G-4

Diode Operating/Nonoperating Data Summary

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (x 106)	FAILURE RATE* (FAIL/10^6 HRS)
MIL-S-19500	G_F	Lower	17	306.940	0.0611
Group IV	G_F	JANTXV	0	48.500	0.0026
	G_F	JANTX	0	10716.500	0.000085
	G_F	JAN	96	9998.874	0.0099
	S_F	JANTXV	0	447.800	0.0020
	S_F	JANTX	0	114.315	0.0080
	G_B	JAN	621	7690.700	0.0818
	M_P	JAN	0	0.501	1.8270
	NS	JAN	5	238.964	0.0264
	N_{SB}	JANTXV	190	91.220	2.1318
	N_{SB}	JAN	113	17066.809	0.0068
	M_L	JAN	0	0.036	25.7268
	N_OG_F**	JANTX	0	19700.000	0.000040
	N_OS_F***	JANTX	0	20.220	0.0452
	N_U	JANTX	0	0.012	76.2500
	M_P	JAN	4	2.609	2.0127
Group IV	A_{RW}	JANTX	0	0.049	18.6734
Group V	G_F	Lower	91	78.590	1.1953
	G_F	JANTXV	1	535.850	0.0038
	G_F	JAN	18	374.020	0.0556
	G_F	JANTX	9	540507.000	0.000019
	S_F	JANTXV	0	29.700	0.0308
	S_F	JANTX	0	35.926	0.0255
	N_{SB}	JANTXV	26	5.480	5.1095
	N_{SB}	JAN	19	229.904	0.0905
	G_B	Lower	229	1389.000	0.1684
	G_B	JAN	6	8.100	0.9074
	N_S	JAN	4	21.225	0.2473
	N_O/G_F**	JANTX	2	2521.000	0.0012
		JAN	0	607.000	0.0015
	M_L	JAN	0	0.017	53.4744
	N_O/S_F***	JANTX	0	3.930	0.2328
	N_U	JANTX	0	0.0044	207.9545
	A_{RW}	JANTX	0	0.015	59.8039
Group V	A_{RW}	JAN	0	0.004	228.7500
MIL-S-19500					

*All failure rates are calculated at upper single-sided 60 percent confidence level.

**Nonoperating ground fixed

***Nonoperating space flight

TABLE G-4 (Continued)

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (x 10^6)	FAILURE RATE* (FAIL/10^6 HRS)
MIL-S-19500	G_F	JANTXV	8	190.600	0.0496
Group VI	G_F	JAN	0	31.800	0.0280
↓	M_P	JAN	0	0.021	43.8470
	G_B	Lower	68	820.000	0.0859
	N_{SB}	JANTXV	0	0.077	11.8830
	N_{SB}	JAN	2	44.911	0.0691
	N_S	JAN	0	0.350	2.6143
Group VI	M_L	JAN	0	0.00024	3750.0000
Group VII	G_F	Lower	1	31.160	0.0648
↓	S_F	JANTX	0	29.255	0.0313
	N_S	JAN	0	0.015	62.2449
	N_{SB}	JANTX	0	5.590	0.1639
Group VII	N_O/G_F**	JANTX	0	937.300	0.0009
Group VIII	G_F	JANTX	1298	7676.000	0.1707
↓	S_F	JANTX	0	19.997	0.0458
	N_S	JAN	0	21.582	0.0424
	A_{RW}	JANTX	0	0.049	18.6734
Group VIII MIL-S-19500	N_U	JANTX	0	0.00020	4575.0000
Totals			2828	621596.180	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

TABLE G-5

Tube Operating Data Summary

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (X 10^6)	FAILURE RATE* (FAIL/10^6 HRS)
RECEIVER	N_{SB}	-	20	0.133	164.2857
TRANSMITTER	N_{SB}	-	18	0.279	70.9677
TOTALS			38	0.412	

*All failure rates are calculated at upper single-sided 60 percent confidence level.

TABLE G-6

Resistor Operating/Nonoperating Data Summary

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($X 10^6$)	FAILURE RATE* ($FAIL/10^6$ HRS)
MIL-R-11 RC	G_F	MIL	0	26.250	0.0349
MIL-R-19 RA	G_F	MIL	1	4.220	0.4810
MIL-R-22 RP	G_F	MIL	1	6.100	0.3311
MIL-R-26 RW	G_F	MIL	4	41.520	0.1264
MIL-R-26 RW	M_P	MIL	0	0.167	5.4809
MIL-R-26 RW	G_M	MIL	0	3.202	0.2860
MIL-R-94 RV	G_F	MIL	10	186.760	0.0616
MIL-R-94 RV	N_S	MIL	0	1.060	0.8632
MIL-R-94 RV	G_M	MIL	3	2.035	2.0516
MIL-R-10509 RN	G_M	MIL	0	10.743	0.0852
MIL-R-10509 RN	N_O/G_F**	MIL	0	3296.100	0.00028
MIL-R-10509 RN	G_F	MIL	3	42.420	0.0984
MIL-R-12934 RR	N_O/G_F**	MIL	2	868.000	0.0035
MIL-R-22097 RJ	G_F	MIL	10	32.140	0.3578
MIL-R-27208 RT	G_B	MIL	0	3.900	0.2346
MIL-R-27208 RT	N_S	MIL	6	77.120	0.0953
MIL-R-39002 RK	G_F	Lower	5	84.970	0.0741
MIL-R-39005 RBR	G_F	S	0	16885.000	0.000054
MIL-R-39005 RBR	S_F	S	0	155.269	0.0059
MIL-R-39005 RBR	N_O/G_F**	S	12	5475.000	0.0024
MIL-R-39005 RBR	N_O/S_F**	M	0	10.860	0.0842
MIL-R-39007 RWR	G_B	S	0	0.660	1.3864
MIL-R-39007	S_F	M	0	51.100	0.0179
RWR	G_F	S	484	38445.168	0.0128
↓	S_F	S	0	155.269	0.0059
↓	N_{Sb}	S	1	23.340	0.0865
↓	M_P	R	0	0.083	10.9618
↓	N_S	S	0	29.031	0.0315
↓	M_L	S	0	37155.000	0.000025
↓	G_M	M	0	0.028	32.6786
↓	G_M	P	0	0.250	3.6600
↓	G_M	R	0	0.374	2.4465
MIL-R-39007 RWR	N_U	M	0	0.0029	315.5170

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

***Nonoperating space flight

TABLE G-6 (Continued)

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (X 10^6)	FAILURE RATE* (FAIL/10^6 HRS)
MIL-R-39007 RWR	A_{RW}	M	0	0.017	55.1204
MIL-R-39008 RCR	G_F	S	163	29060.740	0.0058
↓	M_P	S	0	0.083	10.9618
	S_F	S	0	2984.029	0.00031
	N_{SB}	S	159	9569.470	0.0170
	G_B	S	0	12.000	0.0763
	A_{RW}	M	0	0.00045	2033.3333
	N_S	S	17	393.980	0.0476
MIL-R-39008 RCR	M_L	S	0	0.020	44.8288
MIL-R-39009 RER	G_F	S	0	790.200	0.0012
↓	N_S	S	1	2.410	0.8382
	G_M	M	0	0.378	2.4206
	A_{RW}	P	0	0.0013	703.8461
MIL-R-39009 RER	M_P	P	1	0.083	24.1997
MIL-R-39015 RTR	G_M	M	0	0.642	1.4250
MIL-R-39017 RLR	A_{RW}	R	0	0.326	2.8050
	N_U	R	0	0.814	1.1240
MIL-R-39035 RJR	G_B	S	0	9.800	0.0934
↓	N_S	S	2	1.240	2.5040
	N_O/S_F***	S	0	93.530	0.0097
	N_U	M	0	0.0020	457.5000
	A_{RW}	M	0	0.0063	145.2380
MIL-R-39035 RJR	G_F	S	33	104834.840	0.00034
MIL-R-55182 RNR	S_F	R	0	2183.000	0.00042
↓	A_{RW}	S	0	0.031	29.9019
	S_F	S	0	1336.920	0.00068
	G_B	S	2	199.000	0.0156
	N_{SB}	S	12	170.420	0.0798
	N_S	S	9	297592.630	0.000035
	M_L	S	0	0.215	4.2513
	N_O/G_F**	S	2	149344.000	0.000020
MIL-R-55182 RNR	N_O/S_F***	R	0	34.080	0.0268
MIL-R-55182 RNC	A_{RW}	M	0	0.0013	703.8461

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

***Nonoperating space flight

TABLE G-6 (Continued)

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($X 10^6$)	FAILURES RATE* ($FAIL/10^6$ HRS)
MIL-R-55182 RNC	M_P	S	0	2.316	0.3950
NETWORKS	G_F	MIL	4	217.354	0.0242
NETWORKS	G_B	MIL	0	0.138	6.6304
THERMISTOR	G_F	-	4	3.940	0.2322
THERMISTOR	G_B	-	0	0.060	15.2500
THERMISTOR	M_L	-	0	0.0029	98.0707
THERMISTOR	N_O/G_F **	-	0	154.000	0.0063
TOTALS			947	70210.255	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

TABLE C-7

Capacitor Operating/Nonoperating Data Summary

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($x 10^6$)	FAILURE RATE* ($FAIL/10^6$ HRS)
MIL-C-5 CM	G_F	MIL	0	1.709	0.5354
MIL-C-5 CM	N_O/G_F**	MIL	2	6169.000	0.0005
MIL-C-20 CC	N_O/G_F**	MIL	1	31870.000	0.000060
MIL-C-25 CP	G_F	MIL	0	1226.356	0.00075
	N_{SB}	MIL	0	13.550	0.0675
	N_S	MIL	114	374.657	0.3132
	N_O/G_F**	MIL	5	3392.800	0.0018
MIL-C-25 CP	M_L	MIL	0	0.0093	98.5036
MIL-C-81 CV	G_F	MIL	11	154.200	0.0314
	N_{SB}	MIL	0	2.080	0.4399
	S_F	MIL	0	155.269	0.0059
	N_S	MIL	1	1.970	1.0254
MIL-C-81 CV	N_O/G_F**	MIL	0	762.000	0.0012
MIL-C-10950 CB	N_U	MIL	1	5.262	0.3839
MIL-C-11272 CY	N_O/S_F***	MIL	0	34.080	0.0263
MIL-C-11693 CZ	N_S	M	0	20.158	0.0454
MIL-C-11693 CZ	G_F	S	15	188.799	0.0885
MIL-C-14157 CPV	G_B	L	0	0.300	3.0500
MIL-C-14157 CPV	S_F	L	0	0.014	65.3571
MIL-C-14157 CPV	A_{RW}	M	0	0.0027	338.8880
MIL-C-14409 PC	G_B	MIL	0	0.076	12.0395
MIL-C-14409 PC	G_F	MIL	0	7.118	0.1285
MIL-C-19978 CQ	M_P	M	1	0.042	48.310
MIL-C-19978 CQ	G_F	MIL	12	746.095	0.018
MIL-C-19978 CQ	N_S	MIL	15	619.138	0.027
MIL-C-39001 CMR	G_F	S	0	776.363	0.0018
	N_{SB}	S	0	0.128	7.1484

*All failure rates are calculated at upper single-sided 60 percent confidence level
**Nonoperating ground fixed
***Nonoperating space flight

TABLE G-7 (Continued)

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($x\ 10^6$)	FAILURE RATE* ($FAIL/10^6$ HRS)
MIL-C-39001 CMR	S_F	S	0	0.195	4.6923
	G_B	S	0	6.300	0.1452
	N_S	S	1	70.386	0.0287
	N_O/G_F**	M	0	8.800	0.1040
	M_L	S	0	0.0029	311.9673
	A_{RW}	M	0	0.0027	336.8888
MIL-C-39001 CMR	N_U	M	0	0.0052	175.9615
MIL-C-39003 CSR	G_F	L	2	83.830	0.0370
	G_F	S	3	20868.155	0.00020
	S_F	S	1	515.800	0.0039
	G_B	S	7	22.600	0.3717
	N_S	S	2	27.190	0.1142
	N_O/S_F***	S	0	33.190	0.0275
	A_{RW}	M	0	0.026	35.7421
	M_P	M	1	0.167	12.0999
MIL-C-39003 CSR	N_U	M	0	0.0075	122.0000
MIL-C-39006 CLR	N_O/G_F**	S	0	3435.000	0.0002
MIL-C-39006 CLR	G_F	S	20	4855.000	0.0045
MIL-C-39006 CLR	N_O/G_F**	HI-REL	7	5216.500	0.0016
MIL-C-39014 CKR	M_P	M	4	1.2[illegible]4	4.0578
MIL-C-39014 CKR	S_F	M	0	7.480	0.[illegible]223
MIL-C-39014 CKR	A_{RW}	M	0	0.097	[illegible]4135
MIL-C-39014 CKR	N_U	M	0	0.022	381.2500
MIL-C-39018 CU	N_{SB}	MIL	563	1969.550	0.2899
	G_F	MIL	691	946.451	0.7395
	N_S	MIL	1	75.143	0.0269
	M_L	MIL	3	0.016	254.9310
	A_{RW}	MIL	0	0.0067	136.5671
MIL-C-39018 CU	N_U	MIL	0	0.0021	435.7142

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

***Nonoperating space flight

TABLE G-7 (Continued)

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (x 106)	FAILURE RATE* (FAIL/10^6 HRS)
MIL-C-39022 CHR	N_S	S	1	243.330	0.0038
MIL-C-3965 CL	N_O/G_F**	MIL	2	8.400	0.3696
MIL-C-55514 CFR	G_F	S	0	424.000	0.0022
MIL-C-83421 CRH	S_F	S	0	1.165	0.7854
MIL-C-83421 CRH	N_U	M	0	0.0052	175.9615
MIL-C-83421 CRH	A_{RW}	M	0	0.0027	338.8888
MIL-C-83421 CRH	A_{RW}	P	0	0.0013	703.8461
Total			1459	85341.899	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

TABLE G-8

Inductive Device Operating/Non-Operating Data Summary

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (X 10^6)	FAILURES RATE* (FAIL/10^6 HRS)
MIL-C-15305	N_O/G_F **	S	5	4008.000	0.0015
MIL-C-15305	N_U	M	0	0.00080	1143.7500
MIL-C-15305	A_{RW}	M	0	0.0067	136.5671
MIL-C-39010	G_F	S	4	3661.533	0.0014
	N_S	S	3	11.036	0.3783
	N_{SB}	S	0	0.154	5.5916
MIL-C-39010	G_B	S	0	0.224	4.0794
MIL-T-27	G_F	MIL	9	874.401	0.0120
	S_F	MIL	0	166.580	0.0055
	G_B	MIL	2	4.200	0.7393
	N_{SB}	MIL	0	0.154	5.9416
	N_O/G_F **	MIL	0	1003.000	0.0009
	N_O/S_F ***	MIL	0	12.580	0.0727
	M_L	MIL	0	0.0016	576.196
	[illegible]	MIL	0	26.877	0.0340
	N_P	MIL	1	0.042	48.3995
	A_{RW}	MIL	0	0.0018	508.3333
MIL-T-27	N_U	MIL	0	0.00050	1830.0000
TOTALS			24	9769.168	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

***Nonoperating space flight

TABLE G-9

Rotating Devices Operating/Non-Operating Data Summary

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (X 10^6)	FAILURES RATE* (FAIL/10^6 HRS)
MOTORS	G_F	-	19	11.700	1.3376
SYNCHROS AND RESOLVERS	G_F	-	2	6.800	0.4566
TOTALS			21	18.500	

*All failure rates are calculated at upper single-sided 60 percent confidence level

TABLE G-10

RELAY OPERATING/NON-OPERATING DATA SUMMARY

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (X 10^6)	FAILURE RATE* (FAIL/10^6 HRS)
MIL-R-39016	N_O/G_F **	MIL	0	0.193	4.7409
↓	G_F	MIL	4	18.100	0.2762
↓	N_S	MIL	3	5.014	0.8327
↓	S_F	MIL	0	0.258	3.5465
MIL-R-39016	G_B	MIL	0	4.800	0.1906
MIL-R-5757	M_P	MIL	2	0.125	24.8400
MIL-R-6016	S_F	MIL	0	4.875	0.1877
MIL-R-83736	G_F	MIL	0	0.190	4.8158
TOTALS			9	33.555	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

TABLE G-11

SWITCH OPERATING/NON-OPERATING DATA SUMMARY

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($X 10^6$)	FAILURE RATE* ($FAIL/10^6$ HRS)
MIL-S-3950	G_F	MIL	5	38.690	0.1628
↓	N_O/G_F**	MIL	8	333.564	0.0283
↓	S_F	MIL	0	0.141	6.4802
↓	G_B	MIL	2	17.000	0.1826
MIL-S-3950	N_S	MIL	10	13.393	0.8587
MIL-S-3786	G_F	Lower	3	19.549	0.2136
MIL-S-3786	S_F	Lower	0	1.290	0.7093
MIL-S-3786	N_S	Lower	1	0.530	3.8113
TOTAL			29	424.157	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

TABLE G-12

CONNECTOR OPERATING/NON-OPERATING DATA SUMMARY

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($\times 10^6$)	FAILURE RATE* (FAIL/10^6 HRS)
MIL-C-21097	G_F	LOWER	0	5.295	0.1728
MIL-C-24308	G_F	MIL	5	45.930	0.1372
MIL-C-24308	A_{RW}	MIL	0	0.0040	228.7500
MIL-C-24308	M_P	MIL	1	0.125	16.1497
MIL-C-25516	N_S	LOWER	0	1.910	0.4791
MIL-C-28748	G_F	LOWER	1	61.290	0.0330
	N_O/G_F**	LOWER	0	48.770	0.0188
	N_O/S_F***	LOWER	0	1.330	0.6879
	S_F	LOWER	0	82.495	0.0111
	G_B	LOWER	0	0.298	3.0705
	N_S	LOWER	0	2.660	0.3440
MIL-C-28748	N_{SB}	LOWER	0	0.126	7.2619
MIL-C-3607	G_F	MIL	4	138.500	0.0379
MIL-C-3607	G_F	LOWER	17	5.468	3.4290
MIL-C-3607	S_F	LOWER	0	6.338	0.1444
MIL-C-3787	G_F	MIL	0	6.740	0.1358
MIL-C-5015	A_{RW}	MIL	0	0.0049	186.7346
MIL-C-5015	G_F	MIL	1	37.590	0.0537
MIL-C-55302	N_U	MIL	0	0.0010	915.0000
MIL-C-55302	A_{RW}	MIL	0	0.0135	67.7777
MIL-C-55302	M_P	MIL	1	0.042	48.3995
TOTALS			30	444.930	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

***Nonoperating space flight

TABLE G-13

CONNECTION OPERATING/NON-OPERATING DATA SUMMARY

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (X 10^6)	FAILURE RATE* (FAIL/10^6 HRS)
CONNECTIONS	N_O/G_F**	LOWER	10	55472.770	0.00021
TOTALS			10	55472.770	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

TABLE G-14

PRINTED WIRING BOARD OPERATING/NON-OPERATING DATA SUMMARY

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS ($X\ 10^6$)	FAILURE RATE* ($FAIL/10^6$ HRS)
MIL-P-55110	G_F	LOWER	1	88.880	0.0227
MIL-P-55110	N_S	LOWER	0	0.710	1.2887
TOTALS			1	89.590	

*All failure rates are calculated at upper single-sided 60 percent confidence level

TABLE G-15

MISCELLANEOUS PARTS OPERATING/NON-OPERATING DATA SUMMARY

PART TYPE	ENVIRONMENT	QUALITY	FAILURES	PART HOURS (X 10^6)	FAILURE RATE* (FAIL/10^6 HRS)
METERS	G_F	-	3	11.032	0.3784
QUARTZ CRYSTALS	G_F	-	0	0.611	1.4975
↓	G_B	-	0	0.200	4.5750
	N_O/G_F**	-	4	232.000	0.0226
	N_O/G_F**	-	0	1.500	0.6100
	N_O/G_F**	-	0	3.400	0.2691
	N_O/S_F***	-	0	0.554	1.6516
QUARTZ CRYSTALS	M_L	-	0	0.00086	1090.1754
FUSES	G_F	-	0	0.040	22.8750
	N_C/S_F***	-	0	2.770	0.3303
LAMPS INCANDESCENT	G_F	-	3	39.820	0.1048
LAMPS INCANDESCENT	N_S	-	0	3.180	0.2877
TOTALS			10	295.108	

*All failure rates are calculated at upper single-sided 60 percent confidence level

**Nonoperating ground fixed

***Nonoperating space flight

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