RL-TR-92-197
Final Technical Report
July 1992

ROME LABORATORY

RELIABILITY ASSESSMENT OF CRITICAL ELECTRONIC COMPONENTS

IIT Research Institute

William K. Denson

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

Rome Laboratory
Air Force Systems Command
Griffiss Air Force Base, NY 13441-5700

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

RL-TR-92-197 has been reviewed and is approved for publication.

APPROVED: Richard A Hyle Jr

RICHARD A. HYLE, Jr.
Project Engineer

FOR THE COMMANDER: John J. Bart

JOHN J. BART
Chief Scientist
Electromagnetics & Reliability Directorate

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1992	Final Mar 89 - Jun 92

4. TITLE AND SUBTITLE

RELIABILITY ASSESSMENT OF CRITICAL ELECTRONIC COMPONENTS

5. FUNDING NUMBERS

C - F30602-89-C-0062
PR - 2338
TA - 02
WU - 4E

6. AUTHOR(S)

William K. Denson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

IIT Research Institute
201 Mill Street
Rome NY 13440

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Rome Laboratory (ERSD)
525 Brooks Road
Griffiss AFB NY 13441-505

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

RL-TR-92-197

11. SUPPLEMENTARY NOTES

Rome Laboratory Project Engineer: Richard A. Hyle, Jr./ERSD (315) 330-2660

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This document presents failure rate prediction procedures for resistors, capacitors, switches, inductive devices, relays, connectors, interconnection assemblies and rotating devices. Data were collected from military maintenance records, warranty records, published information and field operations to support the model development. The existing failure rate models were examined to identify areas that were deficient and needed to be updated/revised. The objectives were: 1) Be reflective of current state-of-the-art in part manufacturing technology; 2) Include all part types being used in military systems; 3) Be based only on information that is available during design phases; 4) Be as accurate and precise as possible. The goal of the new model development was to simplify the models in a manner that made their complexity consistent with their precision and accuracy, while at the same time including provisions to account for the primary variable affecting reliability. A new prediction methodology was developed to model the failure rate of devices that exhibit wearout failure mechanisms (i.e., switches, relays, etc.). Additional new part types have been added (i.e., ceramic chip capacitors, tantalum chip capacitors, etc.) which may be included in MIL-HDBK-217E.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Translation Models, Reliability/Maintainability	358
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	U/L

EXECUTIVE SUMMARY

The objective of this study was to update the MIL-HDBK-217 failure rate prediction models for Capacitors, Resistors, Inductive Devices, Switches, Relays, Connectors, Interconnection Assemblies and Rotating Devices. These models were developed or modified primarily from the statistical analysis of field failure rate data collected during this study. This data was collected mainly from military maintenance records with additional information and data collected from warranty records, published information and laboratory test results. Particular attention was given to the requirement that all data used in support of the models be of high quality. To address this, IITRI used only that data for which there existed confidence that it indeed was accurate.

An objective of this model development exercise was also to simplify the models in a manner that made their complexity consistent with their precision and accuracy, while at the same time including provisions to account for the primary variables affecting reliability.

Each part type was studied to determine their primary modes and mechanisms of failure. This information was used to structure a hypothetical model whose factors were then quantified from analysis of failure rate data. All reliability models relied on field data except for interconnection assemblies which used laboratory test data. Laboratory test data was used because the model for interconnection assemblies predicts the number of thermal cycles to failure and its development thus relied on cycle to failure data which is only available through laboratory tests.

A new prediction methodology was also developed to model the failure rate of devices that exhibit wearout failure mechanisms. Devices exhibiting these mechanisms, and those modeled accordingly, are; switches, relays and interconnection assemblies (which include Plated Through Holes (PTH) and Surface Mount Technology (SMT)). This methodology essentially converts a time to failure statistic such as Mean-Time-to-Failure (MTTF) or characteristic Life (α) to an average failure rate over the design Life Cycle or preventative maintenance interval. Since a closed form solution for the calculation of this average failure rate is not possible, it was accomplished by means of Monte-Carlo simulations.

The change in predicted failure rate between the models proposed herein and the existing MIL-HDBK-217 models varied significantly from part type to part type. However, from the comparison of the proposed models to the existing models, the following conclusions can be made:

(1) Capacitor failure rates are generally lower than MIL-HDBK-217E models, although they exhibited a higher dependence on environment.

(2) Film resistors and resistor networks were approximately consistent with MIL-HDBK-217E, and composition were slightly higher.

(3) Predicted failure rates for inductive devices are generally consistent with MIL-HDBK-217E models.

(4) The predicted failure rates for switches and relays are generally much higher, have a much higher dependence on environment, and lower dependence on quality than MIL-HDBK-217E models.

(5) The predicted failure rate for connectors is generally lower than MIL-HDBK-217E models.

(6) The predicted failure rate of interconnection assemblies/printed wiring boards depend much more on specific design attributes, and therefore can be either higher or lower than MIL-HDBK-217E model.

(7) The electric motor predicted failure rates are generally consistent with MIL-HDBK-217E.

The above comparisons are qualitative since the actual ratio of new model to the MIL-HDBK-217E model can vary significantly depending on the specific variables used in the prediction.

Acronyms/Symbols

α	-	Weibull Characteristic Life
Al	-	Aluminum
β	-	Weibull Shape Parameter
C	-	Capacitance Value
CR	-	Cycling Rate
D	-	Defect Density
DO56	-	Air Force Maintenance Database
DIP	-	Dual In-Line Package
DPDT	-	Double Pole Double Throw
ΔT	-	Change in Temperature
Ea	-	Activation Energy as Used in the Arrhenius Relationship
EMP	-	Electromagnetic Pulse
ESD	-	Electrostatic Discharge
F	-	Failures
FLHP	-	Full Horse Power
FSN	-	Federal Stock Number
I	-	Current
IC	-	Integrated Circuit
IPB	-	Illustrated Parts Breakdown
K	-	Boltzmans Constant
L	-	Inductance
λ	-	Failure Rate
LC	-	Life Cycle
MCTF	-	Mean Cycles To Failure
MLB	-	Multilayer Board
MTTF	-	Mean Time To Failure
NOC	-	Not Otherwise Classified
P	-	Power
PC	-	Printed Circuit
PCB	-	Printed Circuit Board
PGA	-	Pin Grid Array
PPM	-	Parts Per Million
PWB	-	Printed Wiring Board
θ	-	Thermal Resistance
QPL	-	Qualified Product Listing
R	-	Resistance in ohms
RF	-	Radio Frequency
RIW	-	Reliability Improvement Warranty
S	-	Stress Ratio
SIP	-	Single In-Line Package
SMC	-	Surface Mount Component
SMT	-	Surface Mount Technology
SPC	-	Statistical Process Control
SPST	-	Single Pole Single Throw
SR	-	Series Resistance
SSR	-	Solid State Relay
T	-	Temperature
T_A	-	Ambient Temperature
TCE	-	Thermal Coefficient of Expansion
Ta	-	Tantalum
TCR	-	Temperature Coefficient of Resistance
T_{HS}	-	Hot Spot Temperature
V	-	Voltage
V_A	-	Applied Maximum Voltage
V_R	-	Rated Voltage
X	-	Dielectric Thickness

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

LIST OF TABLES (CONT'D)

LIST OF TABLES (CONT'D)

LIST OF FIGURES

1.0 INTRODUCTION

The purpose of this study effort was to update the failure rate prediction models contained in MIL-HDBK-217E, "Reliability Prediction of Electronic Equipment" for:

Resistors
Capacitors
Inductive Devices
Switches
Relays
Connectors
Interconnection Assemblies
Rotating Devices

This was accomplished for each part type by reviewing the existing models, identifying areas needing updating or revising, studying the failure physics, collecting failure rate data, hypothesizing a model, statistically analyzing the data, and using all information and data available to construct new or revised models. Objectives of these models are that they:

(1) Be reflective of current State-of-the-Art in part manufacturing technology,

(2) Include all part types used in military systems,

(3) Be based only on information that is available during equipment design phases,

(4) Be as accurate and precise as possible given the constraint of #3 above.

(5) Accurately represent various quality levels and environments

In failure rate modeling of components, defect related failure mechanisms (special cause) and inherent failure mechanisms (common cause) must be treated separately. With a few exceptions, the predominant failure mechanisms of the parts being modeled herein are special cause. For parts that exhibit these mechanisms as being predominant, the best model that can be derived is a statistical regression model from field experience data. To accomplish the above modeling objectives, field failure rate data collected from a wide variety of sources was statistically analyzed. Since the data was collected from a variety of sources and from various manufacturers, the models will be representative of industry average failure rates and will predict the failure rate for the "average" manufacturer. They will also be indicative of how well the part manufacturers, as a whole, are able to control their processes, and how defect free they are able to manufacture them.

Since the majority of failures in the early and mid life of electronic parts are related to some form of defect and are highly process related, the observed failure rates can vary significantly as a function of manufacturer. It would intuitively seem logical that the variability of military parts manufactured and screened in accordance with the applicable specifications would exhibit a smaller degree of variation than commercial quality parts. However, this decreased variability typically cannot be observed from field data, possibly due to the fact that there is inherently greater variation in military environmental stresses, thus masking any decreased variability that may be present. One way to account for variability and increase the precision of the model is to require detailed process specific information as an input to the prediction model. It is typically not feasible to require such information as an input to the model, since such information is only available to the part manufacturer. Examples of this information are defect density, contamination levels, material compositions, and statistical process control information. These inherent limitations in the type of data that can be used as input to the failure rate models such as those in MIL-HDBK-217 highlight the fact that such models are generic, industry average models and not manufacturer specific.

Other objectives of this study were to simplify the models, make them more consistent with other models in MIL-HDBK-217, and to make their complexity consistent with their accuracy and precision. For example, there is currently a separate set of environment factors for individual types of resistors. Most other models in the handbook, including microcircuits, have only one set of environment factors. Given the precision and accuracy of the prediction model expected, and the fact that it is generally impossible to distinguish the difference in environmental effects for each individual resistor type from field data, it is proposed that a single quality and environment factor be used for a generic part type (such as resistors, capacitors, switches, etc.). The exception to this is that if, within a generic component category, there exist part types exhibiting different predominant failure mechanisms.

2.0 FAILURE RATE MODELING

2.1 FAILURE RATE MODELING APPROACH

A general failure rate modeling approach was defined to provide the basic structure for the failure rate prediction model development process. Figure 2-1-1 presents the model development approach and the following paragraphs briefly describe the primary tasks in this approach.

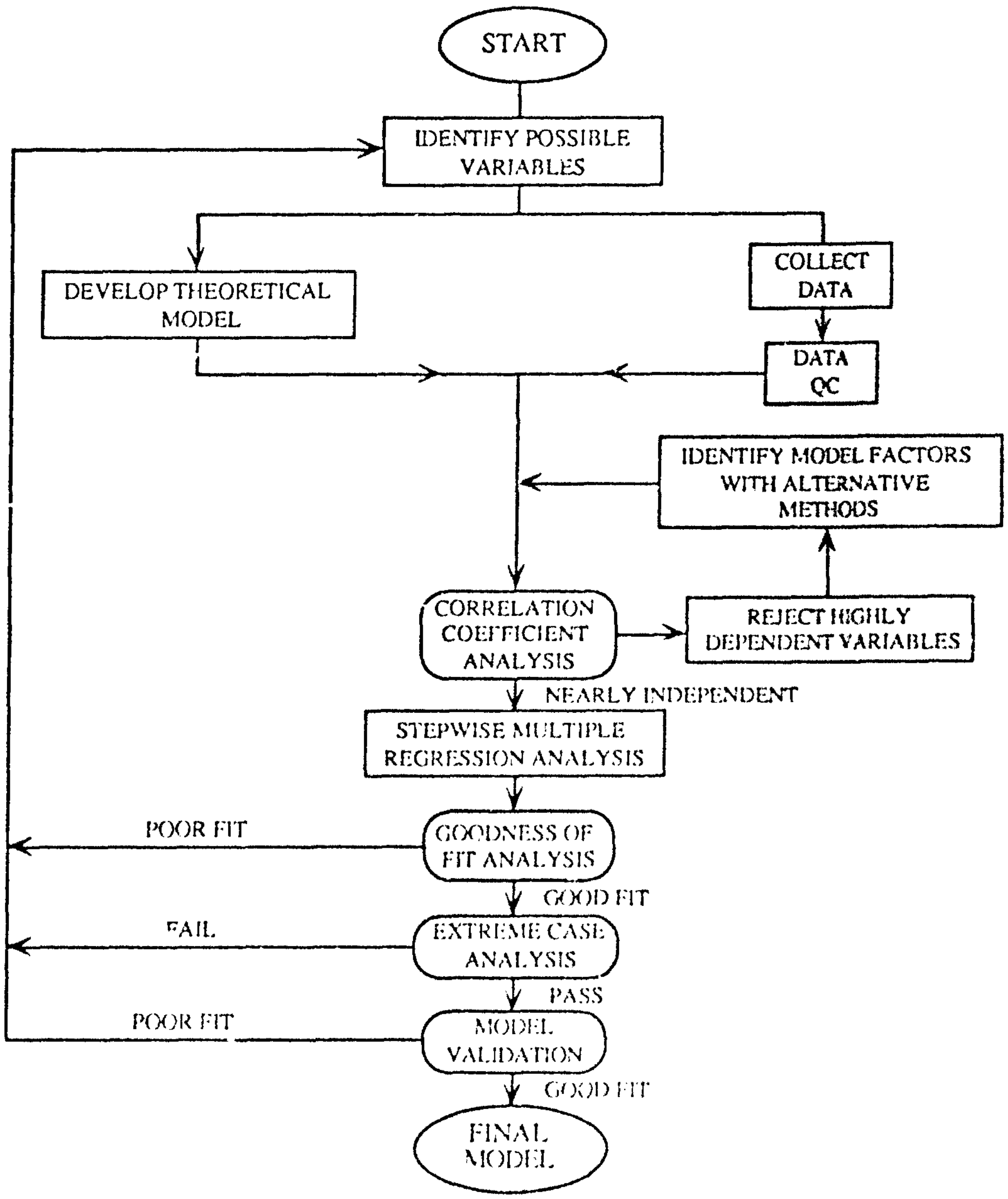


FIGURE 2-1-1: MODEL DEVELOPMENT APPROACH

2.1.1 Identify Potential Variables

The first step of the model development process was to identify variables which could potentially have an effect on failure rate. These variables were limited to information available to engineers during equipment design phases. Determination of these variables was based on physics of failure information. Appendix B lists the variables tracked (if available) for each part type being modeled. All variables listed are potential model parameters and are either a function of device construction/design, circuit application, application environment, or a combination thereof. The identification of these parameters early in the data collection phase served to focus the data collection efforts and refine the theoretical models.

2.1.2 Data Collection

Effective data collection was critical to the successful completion of this effort. Details of this portion of the effort are presented in Section 3.0 of this report.

2.1.3 Theoretical Model Development

A series of theoretical failure rate prediction models was hypothesized to provide the resultant models with a sound theoretical/engineering backing. Basically, theoretical model development involved evaluation of the effects of the parameters identified in the "Identify Potential Variables" phase. In addition, the optimal model form (i.e., additive, multiplicative, combination) was determined and the time dependency of each part types failure rate was studied.

The failure rate models proposed consist of two additive failure rate terms, of which one or both are applicable to each part type. The first is a constant failure rate term associated with random failures due to defects or event related failure mechanisms. This contribution term cannot be modeled with a physics -of- failure approach and therefore is generally a multiplicative model in which the factors represent the predominant failure accelerating variables. Since it is primarily a defect related failure rate, it is an industry average failure rate and represents the capabilities of current manufacturing technologies. The second term models wearout failure mechanisms. These are usually referred to as common cause and are inherent mechanisms. Physics of failure approaches are applicable to these failure mechanisms since they are generally more understood than defect related mechanisms.

These two terms are additive since they are typically separate failure mechanisms for which different modelling approaches are taken. For example, wearout failure mechanisms are modeled with time-to-failure distributions (Lognormal or Weibull with beta > 1) whereas defect related failure mechanisms are typically modeled with a constant failure rate.

If the failure mechanisms being modeled are independent, the failure rates associated with each can be added. An example of this is relays in which one potential failure mode is binding of the moving mechanism. This most likely is due to a combination of part defect and environmental/use conditions. Since it is primarily a defect related failure mechanism, it can be modeled with a constant failure rate. An example of a potential common cause failure mode is the arcing and resulting high resistance material formed between the contacts during the switching operation. This mechanism is a result of the use and load conditions to which the relay has been subjected. It is a wearout failure mechanism for which an increasing failure rate (such as Weibull with $\beta > 1$) is appropriate. Since these two mechanisms are statistically independent, the failure rates associated with each can be added to derive the total failure rate.

Several current MIL-HDBK-217E models include provisions for the failure rate to increase dramatically when the maximum electrical or temperature stress is approached. Examples of this are capacitors which have these provisions for voltage and temperature, and resistors which have it for temperature. Although stresses of these levels will undoubtedly adversely affect the failure rate, it is very difficult to quantify the failure rate under these stress conditions, particularly because different failure mechanisms are predominant than in the case where the part is used within its rated stresses. This difficulty, coupled with the fact that most other models in MIL-HDBK-217 do not include these provisions, has led IITRI to propose that the new models do not include these provisions. Therefore, it must be understood and clearly noted that the models are valid only for situations in which the parts are applied in a manner which stresses them below their rated values. Additionally, the models are only valid within the range of stresses of the data on which the model is based.

A general rule that IITRI followed in development of the constant failure rate defect portion of the models was to include only those factors that were observed to significantly affect reliability. Model factors unsubstantiated by empirical data were only included in cases where parameters are known to effect reliability. Example of these types of factors include temperature, environment, and quality.

Development of the theoretical models relied heavily on published literature. The literature included many instances of mathematical models relating failure rate (or mean time-to-failure) to temperature, power, derating and other factors. Many other technical articles or documents provided a qualitative assessment of reliability influences. These were useful to define the relative effect of numerous variables. In very general terms, the theoretical models (constant failure rate portion) were of the following form.

$$\lambda_t = \lambda_b \pi_T \pi_E \pi_Q \prod_{i=1}^{n} \pi_i$$

where

λ_t = theoretical failure rate prediction

λ_b = base failure rate, dependent on device type

π_T = temperature factor (Discussed further in Section 2.2)

$$= \exp\left(-A\left(\frac{1}{T} - \frac{1}{T_r}\right)\right)$$

where

A = constant, activation energy (Ea) divided by K (Boltzmans constant)

T = device temperature

T_r = reference temperature

π_E = environment factor based upon device application environment

π_Q = quality factor based upon device screen level and qualification status

$\prod_{i=1}^{n} \pi_i$ = the product of Pi factors based upon variables from the list of potential model input variables found to have a significant effect on failure rate

The development of theoretical device failure rate prediction models was an integral part of the overall model development process. Information collected through the literature review and vendor surveys was reviewed and evaluated to aid in the development of theoretical models for each component type. The theoretical models serve the following functions:

- Assure prediction models conform to physical and chemical principles
- Select variables when not possible by purely statistical techniques

2.1.4 Data Analysis

The next phase of the modeling approach was data analysis of the failure rate data collected through an intensive data collection effort (described in Section 3.0). Techniques used were correlation coefficient analysis, regression analysis, goodness-of-fit testing and others. These are described in the following paragraphs.

The first data analysis task was correlation coefficient analysis. The objective of this analysis was to identify highly correlated variables. As part of this task, correlation coefficients were computed for each pair of independent variables. The correlation coefficient is a measure of the relation between two variables and varies between -1 and 1 (from perfect negative to perfect positive correlation). Regression analysis requires that all independent variables are uncorrelated; therefore, the effects of correlated variables could not be simultaneously quantified. If the variables were correlated inherently (e.g., temperature and power), a decision was made to include only the most significant variable in the regression analysis. If the variables were correlated due to chance (e.g., quality vs. temperature), then several options were considered. If a valid theoretical or empirical relationship was found for one of the correlated variables, then the effect of that variable was removed from the data by assuming the relationship to be correct. If this assumption was correct, then the effect of the remaining correlated variable could be accurately assessed by data analysis.

The next step in the model development process was to apply stepwise multiple regression analysis. Regression analysis is described in detail in Draper and Smith (Reference 2). This technique was used to compute the coefficients of an assumed model form in a least squares fit to the data. Regression solutions were found for decreasing confidence limits beginning with 90%. In addition, standard error statistics were computed for each significant variable to obtain an indication of the accuracy of coefficient estimates. Additionally, upper and lower 90% confidence interval values were determined for each coefficient. In general, variables were not included in the proposed model if they did not significantly affect failure rate with at least 70% confidence. However, if a variable such as device quality was known to influence failure rate from an engineering perspective, then coefficients were computed with less than 70% confidence and a corresponding factor was proposed. In these instances, the resultant factor should be considered approximate.

Generally, transformations were performed on the data to yield multiplicative model forms. To accomplish this, a logarithmic transformation of the failure rate was made so that a linear regression could be accomplished. For example, multiple linear regression analysis assumes a model of the following form;

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \dots b_n X_n + E$$

where Y is the dependent variable (in this case failure rate), X_i's are the independent variables, b_i's are the coefficients to be estimated by the analysis, and E is the residual error. Since a multiplicative model was generally used for the models herein, a logarithmic transformation of the failure rate was required before the regression analysis was performed. Once the coefficients were derived from the analysis, the antilogarithm was taken to yield the final model. As another example, the effect of junction temperature is often modeled by use of the equivalent Arrhenius relationship, which indicates that the failure rate is a function of temperature, and takes the form,

$$\lambda = A \exp(-B/T)$$

where T is the temperature, λ is the failure rate and A and B are constants. By taking the natural logarithm of each side, the equation becomes

$$\ln\lambda = \ln A - \frac{B}{T}$$

which can be solved by regression analysis with 1/T the independent variable and $\ln\lambda$ the dependent variable.

In addition to quantitative regression that was used to relate failure rate to continuous variables such as temperature and rated power, qualitative regression techniques were also employed. Qualitative regression (often termed covariance analysis) is used to model the effect of variables which cannot be measured on a numerical scale (e.g., screen class). A matrix of indicator variables (0 or 1) is defined and used as the independent variables to represent the qualitative variable.

The F-ratio and Critical F are parameters which are used in conjunction with regression analysis to determine significance of independent variables. The Critical F value corresponds to the degrees of freedom of the model (equal to the number of data points minus the number of coefficients minus one) and a specified confidence limit. This number may be used to test the significance of each variable as it is considered for addition to or deletion from the model. The F-ratio value for a regression is the quotient of the mean square due to regression and the mean square due to residual variation. If the F-ratio value for any independent variable is greater than the Critical F value, then it was considered a significant factor influencing failure rate and was included in the regression solution.

2.1.4.1 Analyzing Data with No Observed Failures

The original data records were combined by adding the number of failures and dividing by the total number of part hours for those records having the same variables being analyzed. In this analysis, a record is generated for a specific part in a specific system. For each of these records, there can be zero, one or more observed failures. A regression analysis was then performed on the combined records that had one or more observed failures. This was done on failure records only since it is impossible to run regressions on failure rates of zero. Observances of no failures does not imply a failure rate of zero, but rather enough part hours have not been accrued to experience failures. To address the problem of analyzing zero failure data points the following options were considered:

(1) Use only data records with failures.

(2) Use the lower 60% confidence level for zero failure data records, providing a minimum number of operating hours have been observed. This translates to the assumption that .9 failures have occurred in the given number of part hours.

(3) Use of a very low failure rate (i.e., several orders of magnitude lower than the lowest observed failure rate) for zero failure records.

(4) Use of only those records with failures for model development and multiplication of the derived base failure rates by the ratio: [observed hours without failures/total observed hours]. For example, if 70 percent of the total part hours correspond to records with failures, the failure rates derived from the regression analysis of the data records with failures would be multiplied by .7.

Option 1 is not desirable since it ignores observed part hours with no failures and will result in pessimistic prediction models. Option 2 is also not desirable since it, in essence, assumes failures have occurred that in fact, have not. Option 3 alleviates the concerns of pessimistic prediction models, but confounds the derivation of specific model factors. Option 4 is the best available option since it 1) allows accurate quantification of relative model factors and 2) results in an overall accurate model. This occurs since it is scaled in a manner that allows accurate prediction of the entire population of parts regardless if there have been enough hours to observe failures in the particular data set used to derive the model.

It is necessary to modify the predicted failure rate by the percentage of zero failure hours to account for all observed hours after the regression results are obtained. The regression analysis can only utilize non-zero failure rates and therefore only the failure records can be used to quantify model variables. The zero failure records are only used to scale the predicted failure rates in accordance with the behavior of the entire population. Therefore, the hours and failures of the entire dataset cannot be used since only a subset (those with failures) are used to derive the model variables.

2.1.5 Model Evaluation

A danger in developing models with multiple regression techniques is that the resulting models can yield unrealistically high or low results if the extremes of model input variables are used. The next phase of the model development process was therefore to perform an extreme case analysis. Predictions were performed using the proposed model for parameters beyond the ranges found in the data. The intent of the extreme case analysis was two-fold: (1) to identify any set of conditions which cause the proposed model to numerically "blow up," (2) to identify any set of conditions which predict a failure rate which is intuitively incorrect. For instance, a model that predicted an unscreened device with a lower failure rate than a similar screened device or that predicted a negative failure rate would be examples of an intuitively incorrect model. IITRI was very sensitive to this effect and included models that have such extreme values only in cases where it is justified from theoretical or empirical considerations. Reasons for failing the extreme case analysis primarily involve an incorrect choice of model form. If the extreme case analysis indicated that the proposed model was unacceptable, then the entire model development process was begun again.

It is very important that the resulting models predict failure rates that are credible to practicing reliability engineers. For this reason, the developed models were reviewed to ensure that they yield results that are both reasonable and intuitively correct. To accomplish this, predicted failure rates were calculated using typical parameter values. Level 2 derating requirements of Reference 76 will be used to define typical values and are used to normalize the models since the derating values in that document represent typical and realistic values being used. The actual derating values to be used for this purpose are not important, only that they are representative of current design practices. The predicted failure rates were then analyzed to verify that they yield reasonable results that are representative of typical observed values. If the model factors resulting from the analysis are not reasonable from an engineering perspective, the factors causing the inconsistency were deleted and the regression analysis was performed again. A portion of this effort was also to identify and remove outlier data points that may not have been considered as such by the statistical analysis. While such outliers were often obvious and discarded in the original dataset, there were instances where selected data point(s) that were not considered outliers by the statistical analysis were severely impacting the results.

Particular attention was given to the models that appear to be yielding excessively high or low failure rates. If this was the case, each model exhibiting these characteristics was reevaluated and corrected until reasonable and intuitive results are obtained.

Additionally, the models were analyzed relative to the existing MIL-HDBK-217E models. For mature technologies, or cases where there is no obvious reason for failure rates to be getting worse, the models were scrutinized to determine if the pessimistic failure rate is justified or whether it is merely a statistical anomaly of the modeling process. It should also be noted that in cases where the new models differ substantially from the old, it could be due to a lack of data in the original dataset used to derive the MIL-HDBK-217E models.

The goodness-of-fit of the regression solution was then measured using the R-squared statistic. The R^2 coefficient or multiple coefficient of determination is equal to the ratio of the sum of squares of the deviations explained by the regression to the sum of the squares of the deviations of the observed data. The R^2 value was used as a means to determine the ability of the regression model to predict the observed results. The coefficient ranges from 0 to 1.0. A coefficient value of 1.0 indicates a perfect fit between the model and the observed data. While there is no minimum acceptable coefficient, higher values indicate better correlation between predicted and observed failure rates. The range of R^2 values in this analysis was from .30 to .78.

2.2 TEMPERATURE EFFECTS

An investigation into the effects of temperature was a crucial part of this failure rate modeling effort. Based on the published literature, the impact of device temperature was determined to be an important variable affecting the failure rate of most part types being modeled.

It was concluded in this study that, of the devices studied, the reliability of capacitors, variable resistors, inductors, transformers, and motors exhibit a strong dependency on temperature. It will be shown in Section 4.1.3.2 that for capacitors, the acceleration rates predicted from analysis of accelerated life tests are much higher than those used historically in MIL-HDBK-217. This could be due to higher acceleration rates at the highly accelerated test conditions relative to field usage. With the exception of resistors, the other components types listed above have similar reliability concerns to capacitors due to the similar nature of the insulating material. Nevertheless, it is obvious that, for these part types, temperature must be accounted for in the model. In general there was no evidence that, at field use conditions, the current MIL-HDBK-217 acceleration rates are erroneous. Therefore, for most of the applicable part types, current MIL-HDBK-217 temperature acceleration factors will be used as a baseline to derive the new models.

While, in general, quality and/or environment were derived from analysis of the empirical dataset, in no case during this effort could a temperature factor be derived from the empirical field data due to the fact that an accurate operating temperature of the components was rarely known. Although this uncertainty in temperature precludes derivation of a temperature factor from field data, temperature is known from laboratory data to heavily influence the reliability of most part types being modeled and must be accounted for. Alternative methods of deriving a temperature factor were therefore used, such as; life test data, knowledge of temperature effects of failure mechanism similar to those being modeled, results reported in the literature, and existing reliability models.

Based on historical data, the Arrhenius relationship adequately models the reaction rate of many failure mechanisms within a specific temperature range. The Arrhenius model is based on empirical data and predicts that the rate of a given chemical or physical reaction, in this case a failure mechanism, will be exponential with the inverse of temperature. Conceptually, the Arrhenius model is given by:

$$\text{Reaction Rate} \propto \exp(-E_a/KT)$$

where

E_a = activation energy (eV)

K = Boltzman's constant

= 8.617×10^{-5} (eV/°K)

T = temperature (°K)

Every chemical reaction has a unique activation energy associated with it. Most components have several such reactions proceeding simultaneously, each capable either individually and/or jointly of causing a part failure. However, consideration of each reaction separately would be too complex to analyze with the available data. It has been found, however, that for general classes of components with similar failure mechanism distributions the cumulative effects of the various reactions can be approximated by an Arrhenius model for a specified temperature range. This relationship has been designated as the "equivalent Arrhenius relationship." Because of the documented accuracy of this approach and the limitations of the available data, it was decided to investigate the effects of temperature using the equivalent Arrhenius relationship. It must be emphasized that beyond the range of normal usage temperatures, this relationship will no longer be applicable. It must also be noted that while the Arrhenius relationship was originally derived to model chemical reaction rates, it is used herein as an empirical model describing the temperature dependence of failure rate.

2.3 MODELING WEAROUT FAILURE MECHANISMS

Several part types being modeled can exhibit wearout failure mechanisms. These part types include: motors, switches, relays, surface mounted devices, connectors and Aluminum electrolytic capacitors. If wearout failure mechanisms are the predominant reliability drivers for a particular part type, a constant failure rate model clearly is not applicable.

IITRI has analyzed several alternative methods of modeling these device types, including:

(1) A time dependent failure rate
(2) A step function failure rate
(3) A constant failure rate and a wearout time beyond which the model is not valid
(4) A constant average failure rate for the entire life cycle of the part

Since it is desirable that the models to be developed be independent of time and based on a constant failure rate, the use of Number 4 above is proposed. In this approach, an average failure rate is calculated over the life cycle of the equipment in which the part is operating. The average hazard rate over the life cycle cannot be used because it is a measure of the instantaneous failure rate of a part under the condition that it has not yet failed. The condition of interest in this modeling effort is the failure rate after a portion of the population has failed. This model is based on the premise that parts are replaced upon failure and that an effective constant failure rate is achieved after a given time due to the fact that the effective "time zero" of replaced parts become random after a significant portion of the population is replaced.

Since this failure rate cannot be derived in a closed form, Monte Carlo simulations were performed to estimate the failure rate of the Weibull distribution as a function of time, assuming that parts are replaced upon failure, and assuming the Weibull distribution is valid. Since the term failure rate implies a constant hazard rate from the exponential distribution, its use as a time varying function is not entirely accurate. Therefore, some have referred to this time dependent failure rate as the "Rate-of-Occurrence-of-Failure".

The Weibull Probability Density Function (pdf) of time to failure is:

$$f(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} e^{-\left(\frac{t}{\alpha}\right)^{\beta}}$$

The time to failure of a given component that follows this pdf is:

$$TTF_{ij} = \alpha_i [- \ln (1 - RND)]^{\frac{1}{\beta}}$$

where;

TTF_{ij} = Time to failure of the i^{th} component which has been replaced j times. TTF_{ij} is relative to the "time zero" of the i^{th} component

α_i = Weibull characteristic life, time at which 63.2% of the population will have failed (without replacements) β = Weibull Shape Parameter

RND = Random number equally distributed between 0 and 1

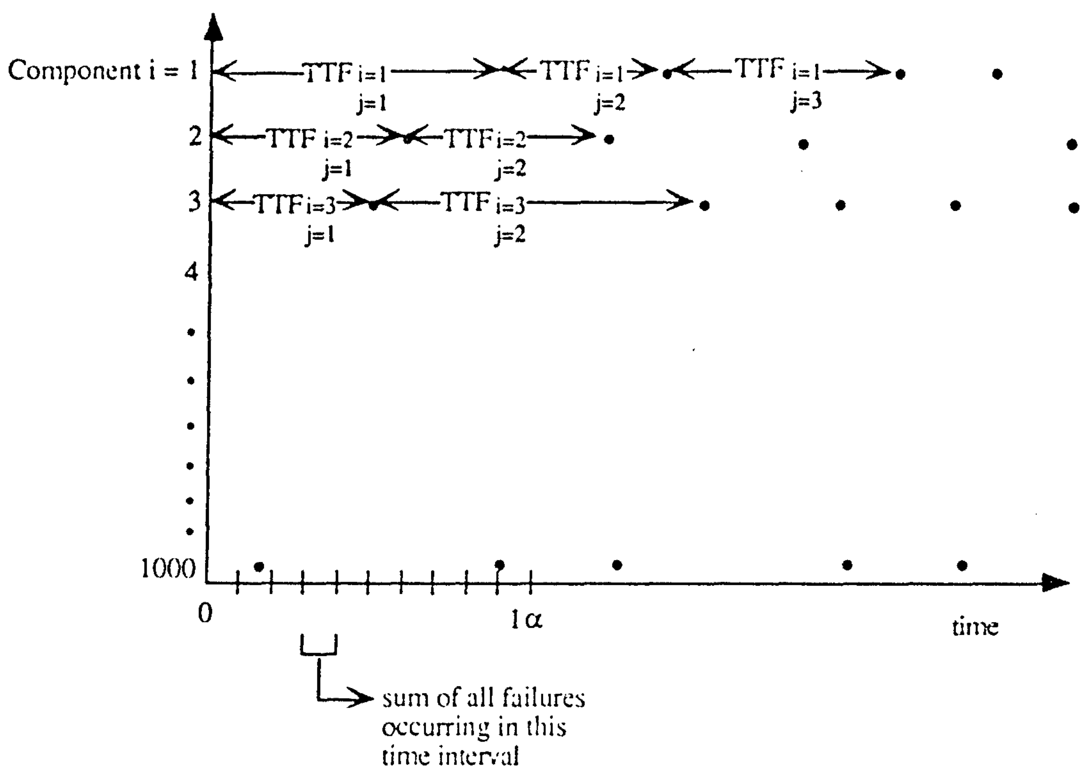
The "Rate of Occurrence of Failure" was calculated for each β value in the following manner:

1. The TTF for component i = 1 was calculated. This process was repeated for 100 failures of the i = 1 component (j = 1 - 100)

2. This process was repeated 1000 times (i = 1 - 1000)

3. Total failures in each time increment of .1 α were tallied.

The following figure illustrates this concept (dots represent failure in time);



Ten simulations were performed, using $\alpha = 1$ and varying the beta value from 1 to 10. Appendix C presents the actual results of these simulations. Since the simulations were performed with $\alpha = 1$, the results can be converted to an actual situation by using an α in absolute time units.

It can be seen from these results that the failure rate of α's greater than one starts out very low, increases when the hazard rate of the initial population starts to increase, oscillates as parts are being replaced, and reaches an asymptotic value after some period of time. The actual failure rate unit of these simulations is failures per 1000 components per .1 α. Therefore, dividing by 100 yields the unit failures per alpha.

The asymptotic failure rate, regardless of beta, is very close to one. The times at which the asymptote is reached, however, is dependent on beta. These values are illustrated in Table 2.3-1.

TABLE 2.3-1:
APPROXIMATE TIMES AT WHICH ASYMPTOTIC FAILURE RATES ARE REACHED

beta	asymptote
2	1α
4	2.4α
6	4.2α
8	7.0α
10	11α

An average cumulative failure rate was then calculated as a function of beta and the Life Cycle (LC)/alpha ratio. These average failure rates are summarized in Table 2.3-2 and in Figure 2.3-1. The values summarized in this table are average failure rates from time 0 to time LC/α and were computed by dividing the total simulated number of failures by the time (in units of α).

The units of the average cumulative failure rate are in failures per alpha. Dividing the cumulative failure rate by α (in 10^6 hours) yields a failure rate of $F/10^6$ hrs.

TABLE 2.3-2: CUMULATIVE FAILURE RATE SUMMARY

$$\lambda\left(\frac{F}{\alpha}\right)$$

$\frac{LC}{\alpha}$	β									
	1	2	3	4	5	6	7	8	9	10
.1	1	.41	.13	.02	0.0	0.0	0.0	0.0	0.0	0.0
.2	1	.43	.15	.05	.01	0.0	0.0	0.0	0.0	0.0
.3	1	.50	.23	.10	.03	.02	.01	0.0	0.0	0.0
.4	1	.57	.31	.20	.09	.04	.02	.02	.01	0.0
.5	1	.62	.41	.25	.17	.10	.06	.04	.02	.01
.6	1	.68	.51	.34	.26	.20	.12	.09	.08	.04
.7	1	.74	.61	.46	.39	.36	.27	.25	.20	.15
.8	1	.78	.68	.59	.58	.53	.46	.50	.42	.40
.9	1	.84	.76	.71	.71	.71	.71	.74	.72	.73
1.0	1	.90	.82	.80	.82	.85	.86	.91	.93	.94
1.5	1	.97	.92	.84	.82	.89	.75	.74	.72	.70
2.0	1	1.01	.98	.94	.94	.95	.94	.96	.96	.96
2.5	1	1.04	1.01	.97	.94	.94	.93	.89	.88	.86
3.0	1	1.06	1.03	1.00	.98	.98	.99	.99	.98	.98
3.5	1	1.08	1.05	1.01	.99	.98	.99	.97	.94	.93
4.0	1	1.08	1.07	1.03	1.02	1.01	1.01	1.01	1.00	1.00
4.5	1	1.09	1.07	1.04	1.03	1.01	1.02	.99	.98	.97
5.0	1	1.09	1.08	1.05	1.03	1.02	1.03	1.02	1.01	1.01

The time is normalized to the ratio: Life Cycle (LC)/alpha. Components not using hours as the independent variable (i.e., switches which use actuations) can either equate # cycles to time or can use total number of cycles expected as LC. Life cycle in the context of this model is the design life of the equipment in which the part is operating.

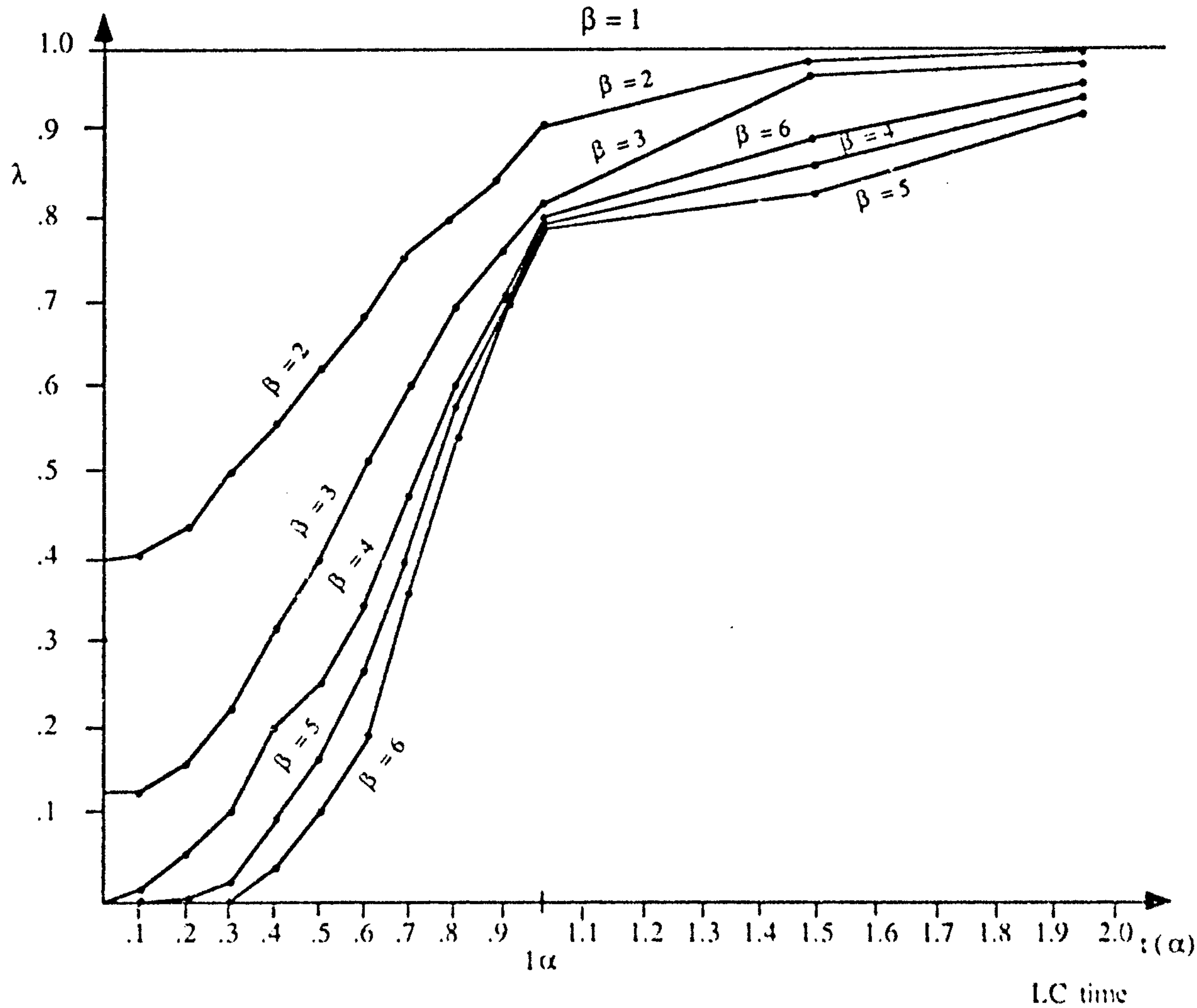


FIGURE 2.3-1:
CUMULATIVE AVERAGE FAILURE RATE AS A FUNCTION
OF LIFE CYCLE, α, AND β

For example, if the Life Cycle of a motor is .5 α and β=3 for the motor,

$$\lambda = .41 \frac{F}{\alpha}$$ (Failure rate relative to life cycle)

If α = 100,000 hrs:

$$\lambda = \frac{.41}{.1 \bullet 10^6} = 4.1 \text{ F}/10^6 \text{ hrs.} \qquad \text{(Dividing by } \alpha \text{ achieves absolute } \lambda\text{)}$$

Additionally, if preventative maintenance (PM) is performed, the PM interval can be used for LC, thus yielding the average failure rate in the PM interval.

The methodology developed herein allows a constant average failure rate to be predicted over the life cycle (or preventative maintenance interval) if the α and β of a part are known. This allows modeling of wearout items providing these values can be determined.

Many reliability models yield the MTTF. Since the proposed model uses the characteristic life (α) as the variable to predict the failure rate, α must be derived from the MTTF. The ratio $\frac{MTTF}{\alpha}$ is not constant but depends on β. The following relates the β value to the percent failed at the mean life (MTTF) (from Reference 51).

TABLE 2.3-3:
PERCENT FAILED AT MTTF AS A FUNCTION OF β

β	Percentile
.5	75%
1.0	64
2.0	54.5
3.0	51
4.0	50
5.0	50
6	50
7	50
8	50
9	50
10	50

Using Weibull probability paper, the ratio of α/MTTF can be calculated. This data is summarized in Table 2.3-4. For typical β's of 2-4, this ratio is modest, on the order of 1.06 to 1.15. This indicates that there will be a negligible error if the MTTF is used instead of α. In fact, several models to be presented later use the mean number of cycles to failure.

TABLE 2.3-4:
α/MTTF RATIO AS A FUNCTION OF β

β	α/MTTF
1	1
2	1.15
2.5	1.12
3.0	1.10
4.0	1.06

These simulation results illustrate that the failure rates associated with wearout failure mechanisms are very close to zero, provided that the characteristic life of a given component is much greater than the design life of the equipment in which it operates. This should occur if the components wearout characteristics are understood and the proper design precautions have been taken to ensure a robust design. The ultimate objective of design and reliability engineers is to achieve a design robust enough to operate reliably in a given application for a given life cycle. This methodology provides a tool to ensure this robustness has been achieved.

3.0 DATA COLLECTION

An aggressive data collection effort was undertaken to collect failure rate data on the part types being modeled. The objectives of this data collection effort were as follows:

(1) To obtain data on relatively new components. Although collection of data on recently manufactured components was given priority, the general methodology used was to accept data of parts manufactured since 1980. (The last time most of the models were updated was 1977).

(2) To collect as much data on all part types in as many environments and as many quality levels as possible.

(3) To insure the data is high quality from reputable data sources.

(4) To collect data from maintenance activities which repair and report data to the piece part level.

This data collection effort consisted of four basic sources:

(1) Data collected from the maintenance of military electronic equipment
(2) Life test results
(3) Published data available in the literature
(4) Data collected as a result of a solicitation effort during this program

Collection of data from military equipments was the most important to the successful completion of this effort. It is also, by far, the most tedious and time consuming. For these reasons, it will be described in more detail.

Table 3.0-1 presents the military systems from which data was obtained in this effort, their application environment, and the source of maintenance/reliability data used. The following paragraphs provides a more detailed discussion on these data sources.

TABLE 3.0-1:
DATA SOURCES

EQUIPMENT	APPLICATION	DATA SOURCE
GRC-171	Ground Mobile	D056
ARN-118	Airborne (Variety of Aircraft)	RIW, D0-56
ARC-164	Airborne (Variety of Aircraft)	RIW, D0-56
ALQ-172	B-52	Warranty Data through MODAS
Flight Control Computer	F-16	D0-56

GRC-171: This is a ground mobile, trailer mounted, communication system used in the Air Force. This system provided IITRI with failure rate data on connectors, resistors, capacitors, switches, relays and inductors. One reason this system was selected was to correlate failures in ground communications equipment and airborne communications equipment.

ARN-118: This is a tactical navigation unit used in a variety of aircraft. IITRI has collected recent information on this equipment from F-4C/D/E/G, F-15A/B/C/D, and A-10 aircraft. This system provided IITRI with information on connectors, resistors, capacitors, switches, relays and inductors. Failures from the F-4s, F-15s, and A-10s are based on 1635 aircraft and 582,745 flying hours. These figures are based on a 12 month period from June 1989 to May 1990. IITRI collected all of the DO56 part replacement records pertaining to this equipment on those selected aircraft. This system was chosen due to it's versatility in use with a variety of aircraft. In addition to DO56 data, the original RIW data was also used for this system.

ARC-164: This is an airborne communication unit used in a variety of aircraft. IITRI has collected recent information on this equipment from F-4C/D/E/G, F-15A/B/C/D, and A-10 aircraft. This system provided IITRI with information on connectors, resistors, capacitors, switches, relays and inductors. Failures from the F-4s, F-15s, and A-10s are based on 1635 aircraft and 582,745 flying hours. A K factor was then applied to these operating hours to account for on-hours while the aircraft is not in flight. These figures are based on a 12 month period from June 1989 to May

1990. IITRI collected all of the DO56 part replacement records pertaining to this equipment on those selected aircraft. This system was chosen because of its use in a variety of aircraft and to draw any correlations that can be made against ground communication equipments. In addition to DO56 data, the original RIW data from the equipment manufacturer was also used for this system.

ALQ-172: This is an airborne electronic countermeasures (ECM) pod used in the B-52 aircraft. This system provided IITRI with information on connectors, resistors, capacitors, switches, relays, inductors, and transformers. There were approximately 600 part failures from 80 installed equipments with 60,288 operational hours. The failures are based on 2 years of warranty information from ITT. This system was chosen because all of the data was reported to the USAF through a verifiable warranty program from ITT.

Flight Control Computer: This is the main computer in the F-16. IITRI has collected recent information on this equipment. This system provided IITRI with information on connectors, resistors, capacitors, switches, relays, and inductors. Data collected is based on 400,048 flying hours from 1089 aircraft. IITRI collected all of the DO56 part replacement records pertaining to this equipment on those selected aircraft. RIW data was also used for this system.

Reliability Improvement Warranty (RIW) programs typically yield very high quality piece part data since it is generally taken by a single maintenance activity and accurately reported. Data reported at the piece part level from maintenance systems such as DO56 and MODAS is generally suspect, but for the systems for which these sources were used, IITRI confirmed that the data was indeed accurate, complete, and could be used to obtain the appropriate data. This assurance was obtained by contacting the maintenance activities to verify that all maintenance actions are recorded and reported to MODAS faithfully.

Table 3.0-2 summarizes the procedures required to obtain piece part failure rate data from military systems and Table 3.0-3 summarizes additional data sources used. The additional sources are primarily from manufacturers life data, published data, or data solicited during this study as a result of a survey.

TABLE 3.0-2:
DATA SUMMARIZATION PROCEDURE

(1) Identify System based on:

- Environments/Quality
- Age
- Component Types
- Availability of Quality Data

(2) Build Parts List:

- Obtain IPB (Illustrated Parts Breakdown)
- Insure correct version of system consistent with maintenance data
- Identify characteristics of components (part numbers, FSN (Federal Stock Number) from microfiche, vendor catalogs, etc.)
- Enter part characteristics into database

(3) Obtain Failure Data:

- RIW, DO56, warranty records
- Match failures to IPB
- Insure part replacements were component failures
- Add failure data to database

(4) Obtain Operating Data

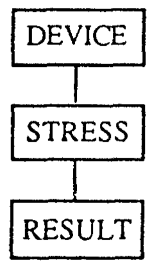
- Verify equipment inventory
- Equipment hours, part hours
- Application environment

TABLE 3.0-3:
ADDITIONAL DATA SOURCES USED

- Commercial Equipment Warranty Records
- RAC Databases
- Navy 3M Motor Data
- Life Data from Manufacturers
- Loughborough University Database
- Martin Marietta
- CECOM
- Published Documents/Symposiums

3.1 DATABASE

The database used to store and manipulate the reliability data obtained in this study has been implemented in Informix 4GL running on a MIPS 2460 platform and consists of three records types as follows:



The device record holds component characteristic data on the specific part, the stress record is information regarding the test (stresses, environment, duration, etc.) and the result record is information regarding the results of the test (number tested, number failed, failure mechanism, time/cycles to failure, etc.). The stress and result records are common to all part types but the device record is unique to a particular class of part. The specific parameters of the device record for the part types being addressed are given in Appendix B.

3.2 DATABASE PROFILE

Table 3.2-1 presents a high level summary of the total part operating hours (including hours from zero failure records) from field data and number of failures for each generic component type. Interconnect assembly (PWB) data is not included in this table since that model is based on temperature cycling laboratory data and not on field data.

The general approach taken in this effort was not to collect data on specific part styles and spec. numbers, but rather to collect as much data as possible from as many different sources as possible in the hopes that data on the predominant device types and specs. are collected.

TABLE 3.2-1:
SUMMARY OF DATA COLLECTED

Component	Part Hours (10^9)	Failures
Capacitors (Total)	154.04	1013
Paper	6.41	18
Plastic	17.0	79
Mica	16.9	199
Air Variable	.903	1
Al Electrolytic	24.7	256
Ta Electrolytic	48.5	232
Ceramic	38.3	228
Glass	1.33	0
Resistors (Total)	561	1208
Fixed	535.6	909
Network	1.306	15
Thermistor	1.856	15
Varistor	.69	11
Variable	21.5	258
Transformers (Total)	2.557	150
Audio	.080	7
Flyback	.595	4
Isolation	.045	0
Power	.975	133
Pulse	.349	2
Switching	.437	4
Torroidal	.076	0
Inductors (Total)	38.8	64
Choke	16.7	12
Fixed	20.8	52
Variable	1.3	0
Motors (Total)	1032.45	4714
Electric (General)	502.6	1597
Sensor	21.2	2189
Servo	66.25	808
Stepper	442.4	120

TABLE 3.2-1:
SUMMARY OF DATA COLLECTED (CONTD)

Component	Part Hours (10^9)	Failures
Switches (Total)	13.96	27002
Centrifugal	.0045	304
Coaxial	.018	16
DIP	1.98	1
Float	.0032	22
Flow	.021	80
Humidity	.00024	4
Inertial	.137	9
Keyboard	.068	0
Microwave (Waveguide)	.0513	69
Pressure	.176	3134
Push Button	6.98	22079
Reed	1.22	13
Rocker	.447	31
Sensitive	.347	440
Slide	1.37	36
Thermostatic	.282	210
Rotary	.856	554
Relays (Total)	92.2	11792
Electromechanical	44.4	10261
Solid State	47.7	1408
Power	.018	9
Thermal	.0081	10
Time Delay	.055	104
Connectors (Total)	106.1	254
Signal	76.1	8
Rectangular	2.35	139
Elastomeric	.168	16
Edge Card	.600	31
Cylindrical	9.37	12
RF	17.1	28
Hexagonal	.0085	4
Rack and Panel	.146	8
Telephone	.245	8

Table 3.2-2 summarizes the applicable specifications of parts for which data was collected. Although there is some data on every specification listed, in some cases there is a limited amount

of data on parts of some specs. This is not a major obstacle to model development since the data was pooled together with data from other parts of the same generic category. In the majority of cases, this pooling yielded a sufficient amount of data on which to derive a model.

TABLE 3.2-2:
PART SPECIFICATIONS

RESISTOR
MIL-R-26
MIL-R-39007
MIL-R-39008
MIL-R-39009
MIL-R-39015
MIL-R-39017
MIL-R-55182
MIL-R-81349
MIL-R-82401
MIL-R-83401
MIL-R-94
MIL-T-23648

CAPACITOR
MIL-C-11015
MIL-C-11693
MIL-C-39003
MIL-C-39006
MIL-C-39014
MIL-C-39018
MIL-C-5
MIL-C-62
MIL-C-81
MIL-C-83421
MIL-C-83500

TRANSFORMER/ INDUCTOR
MIL-C-39010
MIL-T-27
MIL-T-55631

RELAY
MIL-R-27745
MIL-R-28750
MIL-R-39016
MIL-R-5757
MIL-R-6106
MIL-R-83726
MS-24143
MS-24166
MS-24168
MS-24192
MS-24376
MS-24568
MS-25269
MS-25271
MS-25323
MS-25327
MS-27222
MS-27400
MS-27401
MS-27418
MS-27997

ROTARY SWITCH
MIL-S-3786

CIRCUIT BREAKER
MIL-C-39019
MIL-C-55629
MS-24510
MS-25244

SWITCH
MIL-S-1743
MIL-S-22885
MIL-S-24236
MIL-S-24263
MIL-S-24523
MIL-S-24524
MIL-S-24525
MIL-S-3950
MIL-S-55433
MIL-S-83731
MIL-S-8805
MIL-S-8834
MS-16106
MS-21350
MS-21352
MS-21354
MS-24524
MS-24525
MS-24547
MS-24655
MS-24656
MS-25068
MS-25098
MS-25100
MS-25201
MS-25253
MS-25306
MS-25307
MS-25308
MS-27406
MS-27716
MS-27719
MS-27753
MS-27903
MS-2885
MS-35058
MS-35059
MS-3508
MS-35258
MS-75038
MS-90311

TABLE 3.2-2:
PART SPECIFICATION (CONT'D)

CONNECTOR
MIL-C-21097
MIL-C-21907
MIL-C-22857
MIL-C-23353
MIL-C-24308
MIL-C-26482
MIL-C-28748
MIL-C-3643
MIL-C-3767
MIL-C-38999
MIL-C-39012
MIL-C-39024
MIL-C-5015
MIL-C-55302
MIL-C-55339
MIL-C-81511
MIL-C-83723
MIL-C-83733
MS-14005
MS-14006
MS-14008
MS-17346
MS-18159
MS-18160
MS-18163
MS-18164
MS-18165
MS-18166
MS-18175
MS-18176
MS-18177
MS-18179
MS-18243
MS-18244
MS-18245
MS-20026
MS-24055
MS-24055
MS-24056
MS-24264
MS-27144
MS-27187
MS-27336
MS-27467

CONNECTOR (CONT'D)
MS-27468
MS-27473
MS-27474
MS-27477
MS-27488
MS-27497
MS-27499
MS-27656
MS-28748
MS-3100
MS-3101
MS-3102
MS-3103
MS-3106
MS-3108
MS-3110
MS-3112
MS-3114
MS-3116
MS-3118
MS-3120
MS-3122
MS-3124
MS-3126
MS-3137
MS-3404
MS-3476
MS-35173
MS-35184
MS-35307
MS-35368
MS-3776
MS-9012
MS-90335

SOCKET
MS-25328
MS-27400

CONNECTION
MIL-T-55155
MIL-T-81714
MS-17143
MS-25036
MS-27656
MS-35431
MS-55155
MS-77038
MS-77066
MS-77068
MS-77069
MS-77072

4.0 MODEL DEVELOPMENT

This section of the report presents the derivation of the failure rate model of each component type. The component types for which models were developed are:

- Capacitors
- Resistors
- Inductive Devices
  - Transformers
  - Inductors

- Switches
  - Standard Switches
  - Rotary Switches
  - Circuit Breakers
  - Thermal Switches

- Relays
- Connectors
  - Connectors
  - Connections
  - Sockets

- Interconnection Assemblies/ Printed Wiring Boards

- Rotating Devices

For each of the above component types, this section of the report contains; a discussion of reliability issues, failure modes and mechanisms, a review and critique of the current MIL-HDBK-217E model, and the model derivation. The proposed MIL-HDBK-217 models are presented in Section 5.0.

4.1 CAPACITORS

Capacitors are passive electronic components used in a variety of circuit applications including DC blocking, AC coupling between circuits, energy storage, filtering, timing, and bypassing. Although available in many different styles and materials, capacitors are made with two conductors (electrodes) between which is an insulating dielectric. This dielectric can be mica, paper, plastic, polystyrene, polycarbonate, ceramic, glass, vacuum, air, aluminum oxide and tantalum oxide. Each of these dielectrics has its own unique reliability properties when exposed to temperature, humidity, mechanical stresses and voltage.

Circuit designers will typically select a capacitor based on factors such as frequency range, volumetric efficiency, series resistance, stability, noise, voltage capability, capacitance range and cost. Since an ideal capacitor is purely reactive with zero equivalent series resistance, there is no power dissipation and associated temperature rise. Since all capacitors may not exhibit this ideal characteristic, there may be some temperature rise associated with operation. Reference 52 defines the temperature rise (ΔT) associated with AC power dissipation to be the following for aluminum electrolytic capacitors;

$$\Delta T = \frac{I^2 R}{KA}$$

where

I = Ripple Current (in amps)
R = Equivalent Series Resistance (ESR) in ohms
K = Thermal Constant .0006 w/in^2 (for Al Electrolytics)
A = Surface area of the capacitor

The power dissipation for DC leakage is negligible. Additionally, in the majority of cases the temperature rise from the ESD is also negligible. Therefore the capacitor operating temperature can be considered to be the ambient temperature. In addition to temperature, the applicable stress influencing reliability is applied voltage relative to the voltage capability of the capacitor.

The manufacturing process strongly influences the reliability of capacitors. For example, capacitors with dielectrics deposited on the electrode, or the electrode deposited on the dielectric typically have greater stability characteristics. The internal connections are always reliability concerns with capacitors, particularly when exposed to high vibration environments or environments with extreme temperature cycling. Capacitor hermeticity is also a concern if it is to be used in an uncontrolled environment, due to the possible absorption of moisture into the dielectric. This can cause a change in capacitance, reduction of the voltage capability or a direct short.

4.1.1 Capacitor Failure Modes and Mechanisms

The following pages summarize the various capacitor types, their reliability characteristics, potential failure modes/mechanisms, approximate probability of occurrence if available, accelerating stresses, whether it is a wearout or defect mechanism, potential screening stresses, and expected screening effectiveness.

While the percentages listed are based on the best available data, it is understood that these values can and will vary greatly as a function of the manufacturing process and the actual use environment. Therefore, this information is only used in this study to identify predominant failure mechanisms that must be accounted for in the model and their relative rate of occurrence.

Capacitor, Variable

Applicable Specs.:	MIL-C-81	(Ceramic)
	MIL-C-92	(Air)
	MIL-C-14409	(Glass)

Variations:

Dielectric:	Ceramic
	Air
Configuration:	Rotating Piston
	Non-Rotating Piston
	Trimmer

Unique Characteristics:

- Many failures are of a mechanical nature due to the more complex mechanical configuration relative to fixed capacitors.

TABLE 4.1-1:
VARIABLE CAPACITOR FAILURE MODES

Failure Mech/Mode	Accelerating Stress(es)	Wearout or Defect	Screen	Screening Effectiveness
Open	Temp. Cycling Vibration	Defect	Temp. Cyc. Vibration	Med-High
Short	Temp. Voltage	Defect	Burn-In	High

Capacitors, Aluminum Electrolytic

Applicable Specs.: MIL-C-39018

Variations: Polarized
Non-Polarized

Unique Characteristics:

- Loss of Electrolyte through vaporization is a potential wearout failure mechanism. Weight loss of the electrolyte has been shown to follow the following relationship (Reference 52);

$$W = Ae^{\frac{-B}{T}}$$

W = Weight Loss
A = Magnitude Constant
B = Constant
T = Temperature

- Shorts can result due to dissolving of the electrolyte in a storage environment or in a lightly stressed use environment (per MIL-STD-1131). Current processing techniques have significantly reduced the probability of occurrence of this failure mechanism.

TABLE 4.1-2:
AL ELECTROLYTIC FAILURE MODES

Failure Mech/Mode	%	Accelerating Stress(es)	Wearout or Defect	Screen	Screening Effectiveness
Short	38	Temp. Voltage	Defect	Burn In	High
Open	31	Vibration Temp. Cycling	Defect	Vibration Temp. Cycling	High
Electrolyte Loss/Seal	31	Temp. Cyc. Temp.	Wearout	None	N/A

Capacitors, Tantalum Electrolytic, Wet Slug

Applicable Specs.: MIL-C-39006

Variations:

Case Material: Tantalum

Seal: Hermetic
Non Hermetic

Unique Characteristics:

- Cannot tolerate reverse voltage, even for a brief time.
- The silver cased version can result in silver migration if a low reverse voltage is applied.
- Temperature cycling can cause seal damage and electrolyte leakage.

- Loss of Electrolyte is the predominant wearout mechanism.

TABLE 4.1-3:
TANTALUM WET SLUG F[illegible]URE MODES

Failure Mech/Mode	Accelerating Stress(es)	W[illegible] or [illegible]	[illegible] [illegible]en	Screening Effectiveness
Electrolyte Leakage Capacitance)	Temp. Cyc. (Seal) Temperature (Loss of	Wear[illegible]	[illegible]	N/A
Short	Voltage Temperature	Defect	[illegible]	High
Open	Vibration Temp. Cycling	Defect	Temp. Cyc. Vibration	High

<u>Capacitors, Tantalum Electrolytic, Solid, Fixed</u>

Applicable Specs.: MIL-C-39003

Variations: None (Same basic configuration and manufacturing techniques)

Unique Characteristics:

- Dielectric is not formed by rolling foil or monolithically depositing oxide/conductors, but rather are formed by sintering tantalum pellets into pellets of high porosity and surface area. The pellets are then anodized to form the dielectric layer. Intuitively it appears as this fabrication technique will yield electrolytes more prone to defects. This effect will be inherent in the derived base failure rate.

- Solid tantalum capacitors have a unique current related failure mechanism that is highly dependent on series resistance used in the circuit. This is due to intrinsic faults in the oxide that continuously heal themselves upon application of current. However, some faults are too large to heal themselves and can result in a thermal runaway condition if sufficient current limiting series resistance is not present. Current processing techniques have significantly reduced the probability of occurrence from this mechanism.

TABLE 4.1-4:
SOLID TANTALUM FAILURE MODES

Failure Mech./Mode	%	Accelerating Stress(es)	Wearout or Defect	Screen	Screening Effectiveness
Open	36	• Vibration • Temp. Cycling	Both	Temp. Cycling Vibration	High
Short	31	• Temp. • Voltage • Low Impedance Source	Defect	Burn In	High
High Leakage Current	33	• Voltage • Current (Source Impedance)	Defect	Burn In Vibration	Low

Capacitors, Tantalum Electrolytic, Foil, Fixed

Applicable Specs.: MIL-C-3965
MIL-C-39006

Variations:

Hermeticity: Hermetic
Non Hermetic

Polarization: Polarized
Non Polarized

Unique Characteristics:

- Wearout mechanism possible (loss of Electrolyte)

TABLE 4.1-5:
TANTALUM FAILURE MODES

Failure Mech/Mode	%	Accelerating Stress(es)	Wearout or Defect	Screen	Screening Effectiveness
Loss of Electrolyte	17.5	• Temp. Voltage • Time	Wearout	None	N/A
Short	31	• Voltage Temp.	Both	Burn In	High
Intermittent/ Open	36.5	• Temp. Cyc.	Defect	Temp. Cyc.	High
Leakage Current	15	• Temp. Voltage	Defect	Burn In	High

Capacitors, Mica and Glass, Fixed

Applicable Specs.: MIL-C-5
MIL-C-10950
MIL-C-23269
MIL-C-39001

Variations:

Dielectric: Glass
Mica

Form: Radial Lead
Button Style (Feed through and standoff styles)

Hermeticity: Hermetic (CB60 series)
Non Hermetic (CB11 series)

TABLE 4.1-6:
MICA AND GLASS FAILURE MODES

Failure Mode/Mech	% Occurrence (*)	Accelerating Stress(es)	Wearout or Defect	Screen	Screening Effectiveness
Short (Dielectric Breakdown, Silver Migration)	(Predominant) 75-100	• Temp. • Voltage • Moisture	Defect	Burn In	High
Open	0-25	• Temp. Cyc. • Thermal Shock	Wearout	None	N/A
Change in Capacitance (Moisture Absorption)	0-50	• Moisture • Temp.	Wearout	None	N/A

*Estimates based on Qualitative information.

<u>Capacitors, Ceramic, Fixed</u>

Applicable Specs.: MIL-C-11015
MIL-C-39014
MIL-C-20
MIL-C-55681 (Chip)

Variations:

Dielectric: Barium titenate
Calcium titenate
Stroutium titenate
Lead niobate

Form: Tubular
Feed through
Disks
Monolithic Multi-layer

TABLE 4.1-7:
CERAMIC FAILURE MODES

Failure Mode/Mech	% Occurrence	Accelerating Stress(es)	Wearout or Defect	Screen	Screening Effectiveness
Short (Dielectric Breakdown)	49	• Voltage • Temp.	Defect	Burn In	Good
Open (Connection Failure)	18	• Temp. Cyc.	Defect	X Ray Temp. Cyc.	High
Drift Surface Contamination	4	• Temp. • Voltage	Both	Burn In	High
Low Insulation Resistance Surf. Contam.	29	• Temp. • Voltage	Both	Burn In	High

Capacitors, Paper and Plastic, Fixed

Applicable Specs.: MIL-C-39022
MIL-C-19978
MIL-C-27287
MIL-C-83421
MIL-C-55514
MIL-C-25
MIL-C-12889
MIL-C-11693

Variations:

Dielectric: Paper-Foil
Metallized Paper
Mylar Foil
Metallized Mylar
Polystyrene
Teflon
Polycarbonate

Form: Usually Wound Foil

TABLE 4.1-8:
PLASTIC AND PAPER FAILURE MODES

Failure Mech/Mode	%	Accelerating Stress(es)	Wearout or Defect	Screen	Screening Effectiveness
Open	47	Temp. Cycling	Defect	Temp. Cycling	Medium
Short	11	Temp., Voltage	Both	Burn-In	High
Capacitance Shift	42	Temp., Voltage	Both	Burn-In	High

4.1.2 Current MIL-HDBK-217E Capacitor Model Review

The following items summarize the findings after reviewing the current MIL-HDBK-217E capacitor models. These items were then addressed more specifically in the model development phase of this effort. It should also be noted that only those items determined to be feasible are explicitly included in the models developed.

(1) The base failure rate expression is complex and statistically unjustified. It includes provisions to make the predicted failure rate extremely high for stresses close to or over the rated stress. It also makes the predicted failure rate very low at stresses below the rated value. While it may be applicable for voltage stress, it does not follow the well accepted Arrhenius relationship for temperature acceleration.

(2) The package type is only used in the case of tantalum capacitors. It may be desirable to include package type directly in the failure rate model for other types of capacitors.

(3) The time dependent properties of capacitor failures are not addressed. If wearout mechanisms are predominant for a particular capacitor type, then the data collected in the early life of that part is not representative of the reliability in the later portion of the parts life. An example of this is dielectric breakdown, which typically will exhibit a decreasing failure rate in early life. On the other hand some electrolytic types will predominantly fail in a wearout manner, especially if not under a sufficient voltage stress.

(4) Chip and surface mount capacitors, such as CDR (MIL-C-55681), CWR (MIL-C-55365), CRL (MIL-C-83500) types are not adequately addressed.

(5) Some capacitor specifications have been canceled or classified as inactive for new designs, such as MIL-C-14157, 18312, 11272, 3965, and 92.

(6) There are several base failure rate tables presented for each capacitor type as a function of rated temperature. Typically the differences in the predicted failure rate between capacitors of different rated temperatures is insignificant relative to prediction model accuracy.

4.1.3 Capacitor Model Development

4.1.3.1 Hypothesized Capacitor Model

The hypothesized model for capacitors is:

λ_p = $\lambda_b \pi_E \pi_Q \pi_T \pi_V \pi_{VR} \pi_C \pi_{SR} + \lambda_E (t)$

λ_b = Base failure rate, function of capacitor type

π_E = Environment Factor

π_Q = Quality Factor, function of screens and of the control the manufacturer has on the manufacturing process (QPL status)

π_T = Temperature Factor, based on the Arrhenius Model

$$= e^{\left[\frac{-Ea}{K}\left(\frac{1}{T_1} - \frac{1}{298}\right)\right]}$$

E_a = Activation energy

T_1 = Device operating temperature

π_V = Voltage stress factor

$$= \left(\frac{V_A}{V_R}\right)^n$$

where V_A = Applied maximum voltage

V_R = Rated voltage

n = Function of dielectric material.

π_{VR} = Rated voltage factor

The premise of including a rated voltage factor in the theoretical model is that the thicker dielectrics of higher voltage capacitors are easier to make defect free than the thinner dielectrics of low-voltage capacitors. Since failures are usually precipitated at a defect site, the probability of failure is proportional to the inverse of dielectric thickness.

Using a derivation methodology similar to that used to model the reliability of oxides in integrated circuits, it can be shown that the defect density (D) is inversely proportional to the square of the dielectric thickness (X) (Ref. 35):

$$D \propto \frac{1}{X^2}$$

From extreme value statistics (Ref. 35), it can be shown that the defect density is directly proportional to the failure rate (λ):

$$D \propto \lambda$$

Since the rated voltage of a capacitor is directly proportional to its dielectric thickness ($X \propto V_R$):

$$\lambda \propto D \propto \frac{1}{X^2} \propto \frac{1}{V_R^2}$$

$$\lambda \propto \frac{1}{V_R^2}$$

Since only a percentage of all failures are precipitated by defects, the above relationship must be scaled accordingly. A and B are constants dependent on the percentage of failures that are defect related.

$$\lambda \propto \left[A + \frac{B}{V_R^2} \right]$$

Whether or not the factor is important depends on the defect density for capacitors as a function of dielectric thickness. It may be true that the dielectric thickness of capacitors are large enough so that the premise of this model ($D \propto \frac{1}{X_2}$) is not valid. As with the other factors, it will be validated or deleted upon statistical analysis of the data.

π_C = Capacitance factor

= $A_1 + B_1 C$

where A_1, B_1 = Constants
C = Capacitance

The rationale for this factor is that physics dictates that the probability of failure due to a defect is directly proportional to the dielectric area and hence capacitance. Proportionality constants A_1 and B_1 will compensate for the percentage of failure modes susceptible to dielectric defects.

π_{SR} = Series resistance factor, applicable to solid tantalum electrolytic capacitors only.

$\lambda_E(t)$ = Failure rate of certain types of electrolytics due to the wearout mechanism of electrolyte loss.

4.1.3.2 Summary of Capacitor Data Analysis

Initial analysis of the capacitor failure rate data consisted of analysis of variance and correlations coefficient of the following variables:

Capacitor Dielectric Material
Fixed vs. Variable
Operating Environment
Package (Hermetic/Non Hermetic)
Operating vs. Nonoperating
Quality
Rated Voltage
Capacitance

The correlation coefficients indicated that there were several highly correlated variables, making it difficult to devise certain factors. The most significant of these was, as expected, the correlation between quality and environment. To alleviate this, the Quality Factors in Table 4.1-9 from MIL-HDBK-217E were assumed to be correct. This relative ranking of quality factors is also consistent with the MIL-SPEC requirements.

TABLE 4.1-9:
CAPACITOR QUALITY FACTOR

Quality	π_Q
D	.001
C	.01
S, B	.03
R	.1
P	.3
M	1
L	3
Non ER	3
Lower	10

Although quality was correlated to environment, to the extent possible the initial regression results suggested the above relative factors were consistent with the collected data. These factors were then used in the regression so that valid environment factors could be derived. It was also determined that the above quality factors should be used for all capacitor types and not a function of capacitor type.

Additionally, certain factors considered necessary for inclusion into the model could not be quantified from the field data collected due to lack of details available in the data. These factors were voltage stress and temperature. As an alternative to field data analysis, these factors were derived from life test data, published information, or current MIL-HDBK-217 factors.

To address the temperature factor, the literature was reviewed to determine the applicable form for a temperature acceleration factor and to determine the applicable constants in that factor. The following lists information regarding the Arrhenius activation energies found in the literature. Included are the capacitor type, equivalent Arrhenius activation energy, the model cited (Arrhenius or other) and the reference from which the information was extracted.

Capacitor Type	Activation Energy	Model	Reference
Tantalum	1.0 - 1.45	Arrhenius	1
Al Electrolytic	.75 (Equivalent)	$\frac{\lambda(T_1 + 10)}{\lambda(T_1)} = 2$	52
Paper	.92 (Equivalent)	$\frac{\lambda(T_1 + 8)}{\lambda(T_1)} = 2$	73
Multilayer Ceramic	1.0 - 2.0	Arrhenius	71
Ceramic	1.3 - 1.4	Arrhenius	72
Multilayer Ceramic	1.0	Arrhenius	70
Multilayer Ceramic	1.33	Arrhenius	69
Multilayer Ceramic	.90 1.19 1.9 1.49	Arrhenius	82
Multilayer Ceramic	.7 - .75	Arrhenius	37
Multilayer Ceramic	1.3	Arrhenius	14

From this information, it can be seen that the Arrhenius model is the most predominant model used in the capacitor industry to model temperature acceleration rates. The activation energies cited are much higher than the current values in MIL-HDBK-217E. This could possibly be due to the fact that the values were derived primarily from accelerated life test results (temperature and/or voltage acceleration) which may inherently accelerate the temperature related failure mechanisms more than the other non-temperature related mechanisms that would be experienced in the field. The conclusion of this analysis is that reliability is a strong function of temperature and that temperature must be accounted for in the reliability model. Therefore, since the temperature acceleration rates would be enormous if the activation energies derived from the high temperature life tests were used, and since the current MIL-HDBK-217 acceleration rates are reasonable for field use conditions, factors consistent with the current models will be kept.

Although the current models are not based on the Arrhenius relationship, an equivalent activation energy was calculated and used in the temperature factor. The activation energy for each capacitor type was first calculated using the current 217 models. To accomplish this, the equivalent activation energy was derived by calculating the acceleration due to temperature between 0°C and the maximum rated operating temperature for each specific capacitor type. The general assumption on which the temperature factor is based is that the activation energy is solely a function of dielectric material. These activation energies are given in Table 4.1-10:

TABLE 4.1-10:
CAPACITOR ACTIVATION ENERGIES

Dielectric Material	E_a
Ceramic (CC/CCR)	.34
Al Electrolytic (CE)	.45
Plastic (CFR)	.22
Paper/Plastic (Met.) (CH)	.22
Tan Elect. (CL/CLR)	.19
Mica (CM/CMR)	.37
Paper (CP)	.22
Paper/Plastic (CPV/CQ/CQR)	.24
Glass	.37
Variable Vacuum/Gas	.13
Variable Air	.25
Variable Ceramic	.13

The temperature acceleration factors were then calculated for each data record by using the Arrhenius equation with the activation energies in Table 4.1-10 and the ambient temperatures in Table 4.1-11. The default temperature in Table 4.1-11 were taken from MIL-HDBK-217E. The failure rate was then compensated (divided) by the temperature acceleration factor and the regressions were run.

TABLE 4.1-11:
OPERATING TEMPERATURES

Environment	T_A (°C)
A_{IA}	55
A_{IB}	55
A_{IC}	55
A_{IF}	55
A_{IT}	55
A_{RW}	55
A_{UA}	71
A_{UB}	71
A_{UC}	71
A_{UF}	71
A_{UT}	71
C_L	40
G_B	30

Environment	T_A (°C)
G_{MS}	30
G_F	40
G_M	55
M_{FA}	45
M_{FF}	45
M_L	55
M_P	35
N_H	40
N_S	40
N_{SB}	40
N_U	75
N_{UU}	20
S_F	30
U_{SL}	35

The initial regressions used both capacitance and rated voltage as variables. The hypothesized model was that the failure rate should be proportional to capacitance and voltage in the following relationship;

$$\lambda \; \alpha \; A + B \frac{C}{V}$$

where A and B are constants, C is capacitance and V is rated voltage.

Since the rated voltage and capacitance were highly correlated in the dataset used, the effects of both could not simultaneously be quantified. Given this situation, the fact that physics dictates that capacitance should be a more dominant reliability driver of capacitors, and the fact that capacitance was a significant factor in the initial regression analysis, voltage was discarded as a model variable and capacitance was analyzed separately. It should be noted however that while the rated voltage was discarded as a variable, the voltage stress ratio (actual/rated) is considered essential to the model and will be discussed further later in this section.

The capacitance factor was calculated in a separate regression and was significantly different between electrolytic and nonelectrolytic capacitor types. These π_C factors were determined to be:

Electrolytic: $\lambda \; \alpha \; C^{.23}$
All others: $\lambda \; \alpha \; C^{.09}$

where C = Capacitance in Microfarads

A separate regression was performed for Electrolytics and Nonelectrolytics due to the unique physics of failure of each. Once the above relationships were established, the regression was performed again by normalizing the failure rate to these relationships (i.e., dividing the observed failure rate by these factors). It is necessary to perform these regressions again since continuous variables such as capacitance have a different model form relative to discrete variables and must be analyzed separately.

As expected, environment was a significant variable. The factors derived for the environments for which there existed data are summarized in Table 4.1-12. The environment G_{BC}, although not defined in MIL-HDBK-217, is used here to denote commercial quality components operating in a ground benign environment. A_u refers to the uninhabited portion of an aircraft, although the specific type of aircraft was not known. All other environments are defined in MIL-HDBK-217E.

TABLE 4.1-12:
OBSERVED ENVIRONMENT FACTORS

Environment	π_E
G_{BC}	1
A_{UA}	202
A_{UF}	530
A_{IC}	1540
A_U	15
G_F	69
A_{IF}	3400

This data suggests that the current environment factor is not stringent enough. However, after reviewing the models developed with an extreme value analysis, it was concluded that the resultant failure rates were unrealistically high, indicating that the results were an aberration of the statistical modeling process. It is however clear that the current environment factor should be increased to reflect the large observed dependence of environment on failure rate. This was accomplished by using the relative rankings of the MIL-HDBK-217E models, calculating a weighted average of the factor (for A_{UA}, A_{UF}, and A_U) and recalculating the factor based on this ratio. Section 4.2.3.2 presents a more detailed description of a similar process that was used for resistors. The modified factors are presented in the model summary section of this report.

Variable capacitors were analyzed relative to fixed capacitors and the relative failure rate was determined to be 8.03 times higher for variable. Therefore, the correction factor for capacitor type is given in Table 4.1-13. This factor is not explicitly included in the model but rather is inherent in the base failure rates. Although it may appear to be intuitive to have a separate set of environment factors for fixed and variable capacitors, there was not enough data on variable types to justify a separate factor. Therefore, the environment factor, while derived predominantly from fixed capacitors, is also used for variable types.

TABLE 4.1-13:
FIXED VS. VARIABLE FACTOR

Type	Multiplying Factor
Fixed	1
Variable	8

Although not explicitly presented in the model, analysis of operating vs. nonoperating data yielded an average nonoperating factor of .009 over all capacitor types, indicating that capacitors on the average have a 110 times lower failure rate in a nonoperating environment. However, the model is normalized to the operating environment.

The dielectric type factor was the last factor to be quantified and was determined to be the following:

TABLE 4.1-14:
DIELECTRIC FACTOR

Dielectric	Multiplying Factor	% of Hours from Records with Failures
Paper	1.00	11.6
Tantalum Electrolytic (solid and wet)	0.184	68.8
Aluminum Electrolytic	0.538	7.01
Plastic	3.25	4.92
Mica	2.45	9.74
Ceramic	0.555	56.0
Air	0.0874	.330

The right column of the above table presents percentage of hours associated with failure records. per the discussion in Section 2.0. The base failure rate from the regression analysis was determined to be .00637 F/10^6 and therefore multiplying this by the above dielectric multiplying factors and the percent of hours corresponding to failure records yields the following base failure rates:

TABLE 4.1-15.
BASE FAILURE RATE

Dielectric	λ_b F/10^6
Paper	.00074
Ta Elec.	.00081
Al Elec.	.00024
Plastic	.00102
Mica	.00152
Ceramic	.00198
Air	.0000018

An important part type studied was chip capacitors, both tantalum and ceramic. A failure rate for these could not be modeled with field data like the other capacitor styles since there were no observed failures for these types. This indicates that they are either highly reliable, that there were not enough hours observed, or both. There were, for ceramic chip capacitors, a total of 17.1 x 10^6 observed part hours in air inhabited cargo and attack environments. Using the application environment factors derived from the data to multiply the observed part hours, it indicates that the equivalent number of part hours was as high as 256 x 10^6 with no failures. This indicates a failure rate less than .0039 is appropriate. The available life test data for ceramic chip capacitors (Reference 15) indicated that an average failure rate, after accounting for voltage and temperature, is approximately .0034 F/10^6. This agrees well with the worst case value of .0039 derived from field data. Therefore, .0039 will be the base failure rate for ceramic chip capacitors.

The best available life data for Solid Tantalum chip capacitors is from Reference 18 and is summarized in Table 4.1-16.

TABLE 4.1-16:
SOLID TANTALUM LIFE DATA

Chip Type	Temp.	Op Voltage	Part Hours	Failures
Solid Ta (3.3 mF, 20 V)	85°C	50 Volts	9,000 hrs	18

Although test conditions were at a highly accelerated voltage and temperature, calculating a base failure rate after accounting for these variables yields a value of .00010. This value was derived by dividing the observed failure rate of 2000 ($18/.009 \times 10^6$) by the acceleration due to voltage and temperature. The commonly accepted form for the voltage acceleration factor is:

$$\lambda \, \alpha \left(\frac{V}{V_R}\right)^n$$

where

V = operating voltage
V_R = rated voltage
n = constant

For tantalum capacitors, n = 17 and therefore the acceleration is;

$$\pi_V = \left(\frac{50}{20}\right)^{17} = 5.82 \times 10^6$$

The temperature acceleration is;

$$\pi_T = \frac{.19}{8.617 \times 10^{-5}} \left(\frac{1}{85 + 273} - \frac{1}{298}\right) = 3.4$$

Therefore the base failure rate for tantalum chip capacitors is:

$$\lambda_b = \frac{2000}{(5.8 \times 10^6)(3.4)} = .0001 \text{ F}/10^6$$

To derive a voltage acceleration factor for capacitors, the relationship given above is used. Table 4.1-17 summarizes the values of n reported in the literature for various capacitor types.

TABLE 4.1-17:
VALUES OF n FOR VARIOUS CAPACITOR TYPES

Capacitor Type	n	Reference
Tantalum	17	1
Solid Tantalum	23	83
Tantalum Chip	18	8
Mica	10-12	6
Multilayer Ceramic Chip	2.7	14
Multilayer Ceramic Chip	3	37
Polystyrene	6	68
Multilayer Ceramic Chip	2-4	70
Multilayer Ceramic Chip	2.04	71
Ceramic	3.1-3.6	72
Paper/Paper Film	4.5	73
Aluminum Electrolytics	5	52
Solid Tantalums	17	75

To implement a voltage stress factor for capacitors, there must be a normalization factor on which to base the equation. This factor is normalized to the Level II derating guidelines in Reference 76. These derating values are:

$$\frac{V}{V_R} = .6 \text{ for all fixed capacitors}$$

$$\frac{V}{V_R} = .5 \text{ for all variable capacitors}$$

If the actual applied voltage was not known it was assumed they were derated in accordance with the above criteria. Since the data was derived from the field, the vast majority of data records did not have known voltages and therefore the derating criteria was assumed for most data.

At the Level II derating voltage, the voltage factor must equal 1. For fixed capacitors, this factor is:

$$\pi_V = \left(\frac{V}{.6\ V_R}\right)^n$$

and for variables, it is:

$$\pi_V = \left(\frac{V}{.5\ V_R}\right)^n$$

The proposed values of n are summarized in Table 4.1-18.

TABLE 4.1-18:
PROPOSED n VALUE

Capacitor Type/Dielectric	n
Paper	4.5
Tantalum	17
Aluminum Electrolytic	5
Plastic/Polystyrene	6
Mica	10
Ceramic	3

A boundary condition necessary in this model is to not have the failure rate approach zero as the voltage approaches zero. Therefore, voltage acceleration factor must take the form:

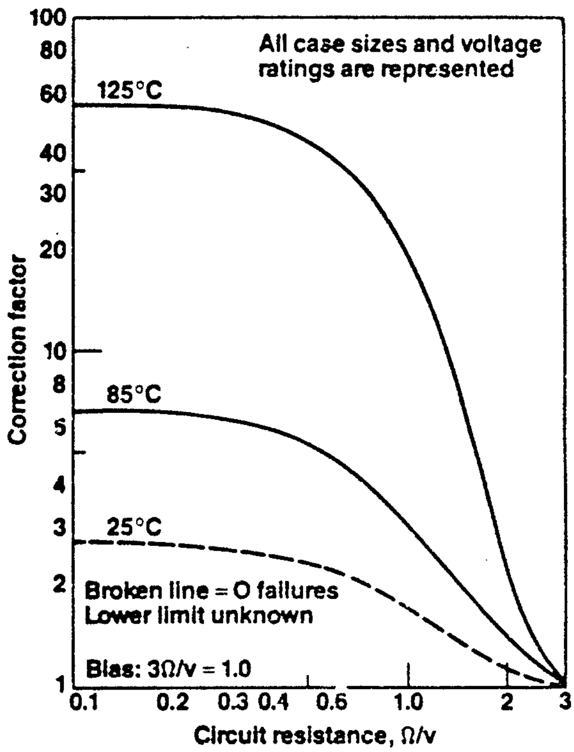
$$\pi_V = \left(\frac{V}{.6\ V_R}\right)^n + 1$$

$$\text{Since } S = \frac{V}{V_R}, \quad \pi_V = \left(\frac{S}{.6}\right)^n + 1$$

The base failure rate must be compensated accordingly by dividing by 2 since $\pi_V = 2$ at the nominal voltage stress condition. Therefore, the base failure rates in the final models in Section 5.0 are half that of those in Table 4.1-15.

Tantalum electrolytic capacitors are known to exhibit a unique failure mechanism which is a function of the available current. The model for tantalums must therefore include provisions for this failure mechanism. Several references (Reference 4, 5) have suggested that the lowest circuit impedance above which the failure rate does not worsen should be lower than the MIL-HDBK-217E value of 3Ω/V due to improved manufacturing processes relative to those of the time the current factor was derived. It has since been changed to 1Ω/V. Moynihan has suggested that the correction factor should be a function of circuit resistance (Ω/V) and temperature as illustrated in Figure 4.1-1 from Reference 5. While this relationship suggests the use of a more modest function of circuit resistance, and also suggests that its value is a function of temperature, there is no quantitative data presented in Ref. 5 to define the value above which the failure rate does not worsen. Therefore, since there is no data available to support changing the current value, the factor will be left intact without change.

Many references on capacitor reliability report that wearout characteristics are prevalent under highly accelerated stress conditions. Several also report that under these conditions, infant mortality failures are observed which exhibit Weibull β's < 1 (Reference 8). Infant mortality failures are generally indicative of defect related failure mechanisms which normally affect only a small percentage of a part population. If wearout type mechanisms were prevalent for capacitors used in fielded systems, the observed failure rate would be much higher than it is since wearout mechanisms generally affect a large portion of the population. Normal use conditions are typically much less severe (thus dramatically increasing wearout times) than the highly accelerated conditions for which wearout mechanisms are observed. This, coupled with the fact that the observed data for capacitors generally implies high levels of reliability and very small cumulative percent failure, indicates that failures observed in the field are primarily random defect related and not wearout. This also implies that a wearout term is not applicable for capacitors.



Failure Rate Vs. Impedance and Temperature Curves
Published by Moynihan

FIGURE 4.1-1: EFFECT OF IMPEDANCE ON FAILURE RATE

4.2 RESISTORS

Resistors can be grouped into three primary types; composition, film and wirewound. Composition types, usually made from a carbon composition material, are widely used due to their availability in a wide range of values and power ratings, along with their low cost. They consist of a solid resistive element encased in a molded body with leads imbedded into the ends of the resistive element.

Film resistors can be manufactured using thick or thin film technology. Thin film resistors are usually made by vacuum depositing a film on a ceramic substrate. Various film materials are used including tin, metal glaze (powdered glass, palladium and silver), cermet (precious metals and a binder material), and carbon.

Wirewound resistors are made by winding a special alloy resistive wire around an insulating core. Since the resistance can be tightly controlled by carefully controlling the length of wire used, very high precision values can be obtained. They are also available in high power values. Because they are made by winding wire around a core, they are inherently inductive and thus their properties deviate from a pure resistance at high frequencies.

Variable resistors are made from a resistive element which is contacted by a wiper arm thereby varying the resistance between one end of the element and the wiper. They are made from a variety of materials similar to those used in fixed resistors and are available in a wide range of power ratings, ranging from small PC mountable trimmer potentiometers to high power wirewound rheostats.

Resistors generally are highly reliable if properly designed and applied into a circuit. The power is the variable that is derated during the part derating exercises, and also is the one that heavily influences reliability. Some resistors are also very intolerant to over-voltage or over-current conditions, even for brief periods of time. In fact some film resistors are highly susceptible to high amplitude, short duration pulses such as ESD and EMP, especially the high resistance, low power type of resistor. Some other types such as carbon compositions, are not susceptible to these conditions. Some resistor types also exhibit change in resistance when simultaneously exposed to long periods of temperature and humidity, and of course this susceptibility is a strong function of the packaging of the resistor.

For most resistor types, the predominant failure mode is change in resistance, although shorts and opens also occur. Typically the resistance will change (and the resistor will eventually fail) as a function of temperature, electrical stress and humidity. For the resistance to change, there is generally a migration of the resistive material or a change in the physical composition of the resistive element under the applied stresses.

Since the reliability of resistors is very high, life testing that has historically been performed on electronic components is generally not applicable. Instead, tests used for resistors are a resistance value test and possibly a temperature humidity test.

Due to their wide spread use and inadequate failure rate models, special attention has been given in this effort to resistor networks. After studying the reliability issues of these networks, the following conclusions were drawn.

- Essentially the same materials have been used over the last 15 years, and resistor networks are generally a mature technology, although there are still considerable variations in the quality of materials. SPC programs implemented by manufacturers have proven to be very successful in assuring reliability and quality.

- TCR (Temperature Coefficient of Resistance) is very important and can vary widely depending on the mix in the resistance material (i.e., one mix is good at the upper end of the temperature range and another mix may be good at the lower range). This makes it difficult to find a mix good for entire range of temperatures, and illustrates the fact that there can be large variations in the reliability properties as a function of manufacturer and within a manufacturer.

- There is a large difference in reliability between suppliers of materials.

- The resistor ESD classifications in MIL-STD-1686 and DoD-HDBK-263 are erroneous because parts cannot generically be classified as Class 2 independent of resistance and power.

- The major change in resistance occurs in the first 100 hours, and then levels off.

- Infant mortality failures are typically workmanship related.

- Low value resistors (i.e., <100KΩ) are susceptible to current related failure mechanisms and high (>100KΩ) value resistors are susceptible to voltage (overstress conditions).

- Primary failure mode is drift and if enough power is applied, open (almost never short).

- Failures are accelerated by a combination of electrical stress and temperature.

- There is typically more variability in axial leaded devices due to the fact that the screening process for networks yields a high degree of repeatability.

- There is a strong correlation in the value of resistance (in relation to the population) and its reliability. Therefore, variability reduction (SPC) is key in the delivery of reliable products.

4.2.1 Resistor Failure Modes and Mechanisms

This section summarizes, for each generic resistor type, predominant failure mechanisms, accelerating stresses, and approximate percentage of occurrence.

Resistors, Composition

Applicable Specs.: MIL-R-39008 (RCR)

Variations: None

Unique Characteristics:

(1) Moisture intrusion can cause shifts in resistance values, especially if in an uncontrolled storage condition or with ≤ 10% power applied.

TABLE 4.2-1:
COMPOSITION RESISTOR FAILURE MECHANISMS

Failure Mode	Failure Mechanism	Accelerating Factors	Distribution (%)
Resistance (R) change	moisture intrusion	moisture, temperature	45
R change, open	non-uniform comp. material	voltage/current, temp.	15
R change	contaminants	voltage/current, temp.	15
Open	lead defects	moisture, temperature, voltage/current	25

Resistor, Fixed Film

Applicable Specs.: MIL-R-55182
MIL-R-39017

Variation: Package Style
Hermeticity

Unique Characteristics:

(1) Metal film resistors are unaffected by moisture.

TABLE 4.2-2:
FILM RESISTOR FAILURE MECHANISMS

Failure Mode	Failure Mechanism	Accelerating Factors	Distribution (%)
R change	moisture ingression	moisture, temperature, contamination	31
R change	substrate defects	temp., voltage/current	25
R change, open	film imperfections	temp., voltage/current	25
Open	lead termination	shock, vibration, temp., voltage/current	9.5
R change, open	film material damage	temp., voltage/current	9.5

Resistor, Wirewound

Applicable Specs.: MIL-R-39005

Variation: N/A (all basically similar)

Unique Characteristics:

(1) Construction of wirewound resistors is that of a resistive wire wound on a (usually) ceramic core. As such, an additional reliability concern is that of the insulation separating the turns of the wire.

TABLE 4.2-3:
WIREWOUND RESISTOR FAILURE MECHANISMS

Failure Mode	Failure Mechanism	Accelerating Factors	Distribution (%)
Open	wire imperfection	voltage/current, temp.	32
R change, short	wire insulation flaw	voltage/current, temp.	20
R change, short	corrosion	temp., humidity	32
Open	lead defects	shock, vibration, voltage/current	10
R change, short	intrawinding insulation breakdown	temp., voltage/current	6

Resistor, Variable Non-wirewound

Applicable Specs.: MIL-R-39035

Variations: Resistive Material

- Cermet
- Metal Film
- Size, Power
- Single Turn, Multi-turn

Unique Characteristics:

(1) Many failures are due to the mechanical elements of the resistor.

(2) Corrosion, oxidation, and wear of the contact are reliability concerns.

TABLE 4.2-4:
VARIABLE COMPOSITION RESISTOR FAILURE MECHANISMS

Failure Mode	Failure Mechanism	Accelerating Factors	Distribution (%)
Open, R change	corrosion	temp., humidity	48
R change	moisture intrusion	moisture, temp.	28
	wiper movement	shock, vibration	8.5
Non-variable	binding, jamming	mechanical actuation, corrosion	6
Open	terminal defect	voltage/current, temp.	5
Open	burnout of resistive element	voltage/current, temp.	4.5

Resistor, Variable Wirewound

Applicable Specs.: MIL-R-39015

Variations: Resistive Material

- Cermet
- Metal Film
- etc.

Unique Characteristics:

(1) Mechanical assembly, including wiper arm, are reliability concerns.

(2) Wear of the wire causes resistance increases.

TABLE 4.2-5:
VARIABLE WIREWOUND RESISTOR FAILURE MECHANISMS

Failure Mode	Failure Mechanism	Accelerating Factors	Distribution (%)
R change, open	contamination	temp., contamination	25
Noise	corrosion	moisture, temp.	9.5
R change, short	insulation breakdown	moisture, temp., voltage/current	15
Short	contamination bridging	contamination, moisture, temp.	6.5
R change, open	wiper arm wear	mechanical actuations	9.5
R change	seal defects	contamination, moisture, temp.	9.5
Non-variable	jamming, stripping	mechanical actuations	17

Resistor, Networks

Applicable Specs.: MIL-R-83401

Variations:

- Number and configuration of elements
- Element Material
- Package Enclosure

Unique Characteristics: (Listed previously)

Resistor, Thermistor

Applicable Specs.: MIL-T-23648

Variations: Configuration: Bead
Disk
Washer
Probes
Rods

Unique Characteristics:

(1) Prone to thermal runaway conditions (with negative temp. coefficient devices).

(2) Stability is a critical reliability concern.

TABLE 4.2-6:
THERMISTOR FAILURE MECHANISMS

Failure Mode	Failure Mechanism	Accelerating Factors	Distribution (%)
R change	moisture intrusion	moisture, temp.	32
Open	body anomalies	temp., voltage/current	30
Open	lead termination defect	vibration, temp. voltage/current	20
R change, open	non-uniform resistance material	temp., voltage	10.5
Other	other	--	7.5

4.2.2 Current MIL-HDBK-217E Resistor Model Review

The following items summarize the findings after review of the current MIL-HDBK-217E resistor models.

(1) The base failure rate equations are complex, not statistically justified, and include provisions for the failure rate to increase dramatically for stresses close to the rated stress. Base failure rates are very low for stresses well below the rated maximum.

(2) Some of the base failure rate tables indicate indistinguishable differences. For example, the differences between MIL-R-22684 and MIL-R-39017, and between MIL-R-55182 and MIL-R-10509 indicate an approximate 2% difference in failure rate.

(3) The format for the resistor network model is not consistent with the others.

(4) The resistance range factor for power wirewound resistors has a range of 1 to 1.6, which is insignificant relative to the expected model precision.

(5) There is no adequate means to calculate the failure rate of non-plated through hole technology parts, such as surface mount and chip devices.

(6) The complexity of the thermistor model is not consistent with the other models.

(7) A primary failure mechanism of variable resistors is corrosion of the wiper contact which results in an intermittent or open condition.

(8) The range of the voltage factor for variable resistors is 1 to 1.2, which is insignificant relative to the expected precision of the model.

(9) The resistor network model indicates that there is a linear relationship between failure rate and the number of resistive elements. This seems illogical because the resistor network failure rate contribution of the package is not expected to be proportional to the number of resistive elements.

4.2.3 Resistor Model Development

4.2.3.1 Hypothesized Resistor Model

The following is the hypothesized model form for resistors:

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_{PR} \pi_S \pi_{TO}$$

λ_b = Base failure rate, function of resistor type

π_Q = Quality Factor

π_E = Environment Factor

π_T = Temperature factor based on the Arrhenius relationship

π_{PR} = Rated Power Factor

π_S = Electrical Stress Factor, function of current or power

π_{TO} = Tolerance Factor

4.2.3.2 Summary of Resistor Data Analysis

Initial analysis of the resistor failure rate data indicated that there was a high correlation between environment and quality, which was expected. Due to this correlation the initial regression analysis with unmodified quality and environments yielded inconsistent and intuitively incorrect results. For this reason, either a quality or environment factor had to be derived off-line and the regression re-run with the new factor. It was determined that the factor for quality would be derived since there are standard procedures for quantifying the reliability differences between various quality levels of military part types. The vast majority of the data was either of commercial quality level or of the standard MIL quality level M, between which the current MIL-HDBK-217 models indicate there is an approximately 10:1 difference in failure rates. This is the quality factor therefore that will be used. The observed failure rates were modified in accordance with this quality factor and the regression was re-run.

The following environment factors in Table 4.2-7 were derived from the regression:

TABLE 4.2-7:
OBSERVED RESISTOR ENVIRONMENT FACTORS

A_U	25.0
A_I	43.4
G	1.0

Although these are more generic environments than those currently in the handbook, it is the most detailed level at which the regression analysis indicated statistically significant results. These results indicated that, in general, the airborne applications were more severe than current models.

An average of the current 217E environment factors for all resistors are given in Table 4.2-8.

TABLE 4.2-8:
CURRENT ENVIRONMENT FACTORS

G_B	1
G_F	2.0
G_M	8.28
A_{IC}	9.0
A_{UC}	15.3
A_{IF}	11.6
A_{UF}	21.9
A_{RW}	31.3
N_U	20.8
N_S	6.14
M_L	43.7
M_F	18.7
C_L	868

Average of the generic categories of current factors and factors derived in this effort are given in Table 4.2-9.

TABLE 4.2-9:
217E/DERIVED ENVIRONMENT COMPARISON

Environment	Current 217E	Derived
A_U	18.6	25
A_I	14.8	43
G_B	1	1

These values indicate that on average, the current models are 2.03 times optimistic ((25 + 43)/(18.6 + 14.8)). Thus, adjusting the current models in accordance with these factors and adjusting all other environment categories proportionally yields the factors in Table 4.2-10.

TABLE 4.2-10:
RESISTOR ENVIRONMENT FACTORS

G_B	1
G_F	4
G_M	16
A_{IC}	18
A_{UC}	31
A_{IF}	23
A_{UF}	43
A_{RW}	63
N_U	42
N_S	12
M_L	87
MF	37
C_L	1728
S_F	.5

Also analyzed as a variable was whether the resistor was of a fixed or variable type. Variable types are mechanically more complex and therefore typically exhibit higher failure rates than their fixed counterparts. Additionally, they have a unique failure mechanism that fixed resistors do not; corrosion and contamination of the contact. These mechanisms are temperature dependent and thus should follow the Arrhenius relationship with a specific activation energy. Initial regressions did not account for temperature and indicated that variable resistors exhibited a 2.5 times higher failure rate than fixed. Temperature was then accounted for by calculating an activation energy using the current models and default temperatures for each environment, and using the Arrhenius relationship to determine the temperature acceleration factor. This was accomplished only for variable resistors. Since adequate data was not available describing the temperature dependence of fixed resistors, it will not be a factor for fixed types. The activation energies used are listed in Table 4.2-11.

TABLE 4.2-11:
RESISTOR ACTIVATION ENERGIES

Composition	.31
Non-wire Wound	.09
Film	.22
Cermet or Carbon Film	.09
Wire wound	.23

After modifying the observed failure rate for temperature, the regression was re-run and it indicated that there was no statistical difference between fixed and variable. Therefore, since temperature is only used as a factor for variable types, it is the only factor distinguishing fixed and variable resistors.

Additional variables analyzed to determine their impact on reliability were: tolerance, resistance and rated power. Tolerance was analyzed under the hypothesis that tighter tolerance resistors would be more likely to fail due to drift mechanisms, but the regression showed it is not an indicator of reliability.

Resistance value was analyzed and indicated the following relationship:

$$\lambda \alpha R^{.028} \text{ (R in ohms)}$$

Due to its relative insignificance, it will not be included in the model. Power was however a significant variable and was determined to be:

$$\lambda \propto P^{.39} \text{ (P = Rated Power in Watts)}$$

The observed failure rate was then divided by this factor for each data record and the regression was re-run. The base failure rates in the right column of Table 4.2-12 were derived by multiplying the base failure rate from the regression analysis by the percentage of hours from failure records.

Another variable analyzed separately was the number of sections in resistor networks. Inconsistent results and a low correlation to failure rate indicate that, based on the data, the number of sections does not influence of resistor network reliability.

TABLE 4.2-12:
RESISTOR BASE FAILURE RATES

Resistor Type	Regression λ	% Hours From Failure Records	λ After Accounting for % Failure Hours
Carbon Comp.	.041	4.26	.0017
Thin Film	.0025	28.8	.00072
Carbon Film	.00044	29.4	.00013
Thick Film	.00052	11.0	.000057
Resistor Network*	.0019	99.9	.0019
Nichrome	.52	2.15	.0118
Varistor	.0024	94.2	.0023
Thermistor	.043	4.5	.0019
Wire Wound	.042	5.62	.0024
Metal Film	.042	8.8	.0037

*The values for resistor networks were derived separately from the regression analysis using the data in Table 4.2-13.

TABLE 4.2-13:
RESISTOR NETWORK DATA

Hours (10^6)	Failures	π_E	π_P	π_Q	** λ_b
33.6	2	*53	.62	1	.0018
1200	10	23	62	1	.00058
23,473	72	1	.62	10	.00050
9.6	3	23	.58	1	.023
				Geometric Mean	.0019

* average of A_{UF} and A_{UC} π_E

** λ_b calculated by the following;

$$\lambda_b = \frac{\text{Failures/hours}}{\pi_E \pi_P \pi_Q}$$

Resistor networks were analyzed separately since there were only a few datapoints available which resulted in anomalous results from the regression analysis. Table 4.2-13 summarizes this analysis. The observed failure rate was divided by the appropriate values of the environment, power rating, and quality factors. The geometric mean of these values were then taken which yielded the resistor network base failure rate of .0019.

4.3 INDUCTIVE DEVICES

General classes of inductive devices are coils and transformers. Coils are reactive devices made by winding an insulated wire around a ferrous or non-ferrous core. Use of a ferrous core dramatically increases the inductance. Transformers are basically two coils wound on a common iron core which closes the magnetic circuit and allows the conversion of voltage (up or down) when an alternating current is applied to one of the coils.

Inductive devices are relatively simple and have proven to be reliable if used properly. The failure modes/mechanisms that occur are insulation breakdown, open circuit, and a change in the magnetic core characteristics (if applicable). The occurrence of open circuits is application sensitive and can result from extreme current or mechanical damage. Changes in core characteristics can result from exposure to extreme temperatures. However, the predominant failure mode is insulation breakdown between windings for heavy wire windings and open circuit for fine wire windings.

Inductive device design dictates the rate of insulation breakdown. This mechanism depends on the type of insulation (type of material, thickness and purity) and is accelerated by temperature, current and humidity.

Since ideal inductors are also a purely reactive device, they dissipate very little power under operating conditions. However, since there is a resistance associated with the wire, there will be some dissipation that must be accounted for when calculating its operating temperature. Therefore, the hot spot temperature should be calculated and used in the failure rate equation. The methodology for calculating this temperature will not be changed from the current 217E methodology.

Tests used for inductors include (if applicable) current, winding-to-winding breakdown, winding-to-core breakdown, and winding-to-case breakdown, all with or without accelerating temperature and humidity.

4.3.1 Inductive Device Failure Modes and Mechanisms

Tables 4.3-1 through 4.3-3 summarize the predominant failure modes/mechanisms along with their accelerating stresses and approximate percentage of occurrence.

TABLE 4.3-1:
INDUCTOR FAILURE MODES AND MECHANISMS*

Failure Mode	Failure Mechanism	Accelerating Factors
short	insulation breakdown	voltage, current storage, temp., humidity
open	broken winding wires	shock
	broken lead	shock, vibration

*Actual percentage of occurrence not available.

TABLE 4.3-2:
TRANSFORMER FAILURE MECHANISMS

Failure Mode	Failure Mechanism	Accelerating Factors	Distribution (%)
Open	wire over-stress	voltage, current	25
Open	faulty leads	vibration, shock	5
Short	corroded windings	humidity, temp.	25
Short	insulation breakdown	voltage, humidity, temp.	25
Short	insulation deterioration	humidity, temp.	20

TABLE 4.3-3:
RF COIL FAILURE MECHANISM DISTRIBUTION

Failure Mode	Failure Mechanism	Accelerating Factors	Distribution (%)
Open	wire over-stress	voltage, current	37
Open	faulty leads	vibration, shock	17
Short	insulation breakdown	voltage, humidity, temp.	14
Short	insulation deterioration	humidity, temp.	32

4.3.2 Current MIL-HDBK-217E Inductive Devices Model Review

The MIL-HDBK-217E inductive device models have been analyzed to determine areas of deficiency and possible areas of improvement. The following summarizes these findings:

(1) The base failure rate equation does not appear to be based on the Arrhenius relationship.

(2) The construction type given in the models may have insufficient detail. Some inductive devices have a more complex mechanical construction and thus are more susceptible to failure when exposed to environments with high levels of shock and vibration.

(3) Chip and surface mount inductors are not addressed.

(4) There is a non-linear relationship between failure rate and temperature rating.

(5) The weight vs. temp. rise needs to account for transformers less than one pound.

4.3.3 Inductive Device Model Development

4.3.3.1 Hypothesized Inductive Device Model

The hypothesized model for inductive devices is:

$\lambda_p = \lambda_b \pi_T \pi_E \pi_D \pi_Q$

λ_b = Base failure rate function of device type, insulating material

π_T = Temperature acceleration factor, per the Arrhenius relationship

π_E = Environment Factor

π_D = Dielectric Material Factor

π_Q = Quality Factor

4.3.3.2 Summary of Inductive Device Data Analysis

4.3.3.2.1 Transformers

An analysis of the transformer dataset was performed to determine if correlations between variables existed or whether there were outlier datapoints. As expected, there was a high correlation between quality and environment. While an initial regression was performed that indicated that quality was not a significant factor, it is probably due to the correlation between variables. Therefore, the conclusion of this analysis should not be that quality is not an important variable, but rather the data and analysis methodologies available cannot quantify its effect.

Since both quality and environment are important reliability factors and should be included in the model, one must be derived off-line and used in subsequent regressions to quantify the other. It was therefore chosen to derive the quality factor using the current MIL-HDBK-217E π_Q values as a baseline. The current MIL-HDBK-217E π_Q factors range from 2.5 to 3.75 and since this range is insignificant relative to the precision of the prediction model, an average of 3:1 will be used for the ratio of commercial to military quality.

An equivalent activation energy in the Arrhenius equation could not be derived since precise temperatures for each observed failure rate was not known. The current MIL-HDBK-217E model for transformers does not use an Arrhenius relationship, but rather the following equation:

$$\lambda_b = A\, e^{\left[\frac{T_{HS} + 273}{N_T}\right]^G}$$

This relationship was apparently structured to allow the failure rate to increase dramatically as the maximum rated temperature (N_T) is exceeded. Calculating an equivalent activation energy between 0°C and the rated temperature of the transformer yields an average value of .11 eV. This was derived by calculating the base failure rate at 0°C and at the maximum rated temperature, and calculating the activation energy necessary to derive the same ratio of failure rate between these two temperature extremes when using the Arrhenius relationship. .11eV is a relatively low activation energy, but typical of dielectric breakdown mechanisms.

Therefore, the temperature acceleration factor was calculated using a .11 activation energy (and normalized to 25°C, as are the current MIL-HDBK-217 models) and default temperatures for each environment defined in Reference 64.

The observed failure rates were then adjusted for quality and temperature and the regression was re-run to quantify, if possible, the effects of:

- Environment
- Transformer Type
- Frequency of Operation
- Secondary Voltage and Current

After several iterations of combining variables in attempts to yield statistically significant results, the environment factors in Table 4.3-4 were derived.

TABLE 4.3-4:
OBSERVED ENVIRONMENT FACTORS

Env.	π_E
G_{BC}	1
A_U	5.27
A_{UA}	11.2

G_F and G_M environments were observed not to be significantly different from G_{BC}. These environment factors are not significantly different from the existing MIL-HDBK-217E factors and therefore the environment factor will remain unchanged.

The base failure rates in the right column of Table 4.3-5 were obtained by multiplying the base failure rate (λ_b regression) by the % hours from failure records.

TABLE 4.3-5:
TRANSFORMER BASE FAILURE RATES

Type	λ_b Regression	% Hours from Failure Records	λ_b
Switching	.014	4.1	.00057
Flyback	.160	3.4	.0054
Audio	.100	13.7	.0137
Power	.162	30.0	.0486
RF	.187	71.1	.133

Also analyzed were the effects of operating frequency and secondary voltage or current. Although no discernable affects due to these variables could be identified while analyzed as a continuous variable, operating frequency is partially accounted for in the base failure rate since there are separate failure rates for power, audio, and RF types.

4.3.3.2.2 Inductors

An analysis very similar to transformers was performed for inductors. An equivalent activation energy could not be derived from the field data due to uncertainty in the actual temperatures of operation. Therefore, an equivalent activation energy of .11 eV was chosen for consistency with the transformer model. The base failure rate was then modified in accordance with the temperature factor using this activation energy and the default temperatures for the individual environments.

The initial analysis of the data indicated several correlations; between quality and environment, inductor type and environment, and RF types and choke types.

Due to the correlation between quality and environment, the current quality factor ratio of 20:1 was chosen for commercial quality and military quality M. The observed failure rates were then normalized to this factor and the regression was re-run.

The observed environment factors are given in Table 4.3-6 as follows:

TABLE 4.3-6:
OBSERVED INDUCTOR ENVIRONMENT FACTORS

G_B	1
G_F	55
G_M	23
A_I	175
A_u	225

From this data, it appears as though the current environment are not severe enough. However, since the results were more significant for transformers, and coils have similar reliability characteristics, the environment factor for transformers will be used.

There also was not enough data to quantify the difference between fixed and variable types. Therefore, the current 1:2 ratio will be kept. The data set was modified (divided by) for this factor and the regression was re-run.

The base failure rates obtained from the regression analysis are given in Table 4.3-7:

TABLE 4.3-7:
INDUCTOR BASE FAILURE RATES

Type	λ_b Regression	% Hours from Failure Records	λ_b
Choke	.00025	11.4	.000030
All others (including fixed and variable, low freq. and RF)	.0021	1.07	.000025

4.4 SWITCHES

Switches electrically transfer power or function from one circuit to another, resulting in the completion of the circuit. The actuation is manually applied, differentiating them from relays. The achievement of the transfer function is accomplished in two basic methods:

(1) Mechanical (contact mating)

(2) Electronic (solid state, inductive, no mechanical contacts)

Mechanical switches employ a method of mating contacts through a variety of actuations. Some examples include:

- Snap Action
- Wiping
- Cross Bar

Each type of contact style and actuation is configured in relation to their application. Lamp or inductive loads require snap action configurations to reduce the contact degrading during arcing. Dry circuit applications require the cross bar configuration to eliminate corrosion build up creating a resistive connection.

Electronic circuit transfer devices do not employ contacts to perform its function but instead transfer power through transistor like saturation of a semiconductor layer. Mainly utilized in low power applications, their unique clean transfer and isolation properties make them popular in microwave electronic circuits. With the exception of Solid State Relays, these electronic switches are not addressed in this study.

The majority of switch failure modes and mechanisms relate to the contacts. Under ideal conditions the resistance at the contact interface is zero but in reality resistance is present. Design and application factors which influence contact failure are:

(1) Contacting Materials - different materials exhibit varying degrees of resistance to oxidation. An oxide film causes increased contact resistance and heat. Table 4.4-1 shows various physical properties for different contact materials.

TABLE 4.4-1:
CONTACT MATERIAL PROPERTIES IMPACT SWITCH RELIABILITY

Contact Material	Melting Point (°C)	Resistivity (μΩ-cm)	Temp. Coefficient of Resistivity (per °C)	Thermal Conductivity (cal-cm / sec-°C-cm^2)	Oxidation Resistance	Arcing Effects
Gold	1,063	2.42	0.0034	0.71	Excellent	Pits and transfer at high current and voltage
Molybdenum	2,625	5.7	0.0033	0.35	Good	Pits and transfer at high current and voltage
Palladium	1,552	11.	0.0038	0.11	Fair	Resists arc erosion
Platinum	1,773	10.60	0.0030	1.17	Very Good	Resists arc erosion
Silver	960	1.63	0.0038	1.01	Excellent	Pits and transfers at high current and voltage
Tungsten	3,410	5.52	0.0045	0.48	Good	Resists arc erosion

(2) Operating Environment - the presence of foreign particles in the environment and the formation of surface film increases the contact resistance and adversely affects the failure rate of the contacts.

(3) Contact Pressure - the higher the contact pressure the greater the contact area due to the yielding of contact asperities (microscopic peaks and valleys). It also can degrade the contact faster due to wear.

The predominant accelerating stresses in manually actuated switches is temperature and load during switching. Temperature is generated by the natural transfer of power, occurring during the mating of contacts. The resulting effects of this increased temperature include contact material fatigue, oxidation, and contact contamination. All of the above conditions result in increased contact resistance, resulting in even higher temperature increases.

Typical failure mechanisms associated with switches are contact pitting due to arcing on break, contact material transfer, contact weldment on make (resulting from excessive resistance and heat generation), and mechanical failures resulting from the construction or packaging of the particular switch. Application factors affecting the failure rate of switches are:

- Switching voltage - for source voltages less than 14V, arcing typically does not cause serious problems but for source voltage greater than 14V, arcing can occur causing contact pitting.

- Actuation frequency - contacts wear when exposed to more frequent actuations.

- Altitude - the dielectric strength of air is less at higher altitudes causing arcing to occur for longer durations.

Switches which are not currently covered in MIL-HDBK-217E but should be added are:

- Centrifugal switches
- Capacitive-touch switches
- Membrane switches
- Circuit breakers with hydraulic-magnetic trip mechanism
- Ground fault interrupters (part of circuit breakers)
- Slide switches

A centrifugal switch is actuated by rotational velocity. The simplest type consists of a speed-sensing unit that mounts directly on a rotating shaft, and a stationary contact switch assembly. The basic control element is a conical-spring steel disc that has centrifugal weights fastened to the outer edge of its circular base.

A capacitive touch-switch consists of two conductive layers on opposite sides of an insulating material such as glass or a printed-circuit board. The conductive layers create a capacitance that decreases when a layer is touched. Interface circuitry converts the capacitance change into a usable switching action.

Inductive switches, mainly used where high cyclic rates are required, are classified in the electronic category but rely on magnetics for their functionality. As the switch is actuated, an iron core is slid through a coil creating a frequency change resulting in a signal transfer.

Membrane switches are devices in which conductive leads on the underside of a flexible membrane are pushed through a hole in a spacer to make contact with conductive leads on a base. Optional overlays are provided for user interface.

The hydraulic-magnetic construction circuit breaker consists of a solenoid with a dash pot time-delay element (i.e., iron core). The dash pot time-delay tube contains a silicone fluid and a return core spring. Operation depends on changes in the magnetic flux. Changes in flux are caused by changes in coil current, which in turn cause changes in the position of the iron core within the coil. The speed at which the core moves is controlled by the damping effect of the silicone liquid in the tube.

A ground-fault interrupter is composed of many elements including a differential current transformer, op-amps, synchronous demodulator, resistors, capacitors and diodes. The ground-fault interrupter removes power when it senses a current imbalance (not just an overload) between the hot and neutral conductors supplying operating power. A ground fault results when a current-carrying part of a circuit accidentally contacts any grounded conducting material, whether the resistance path to ground is high (e.g., human body) or low.

4.4.1 Switch Failure Modes and Mechanisms

The following tables summarize the failure modes of switches along with their approximate relative rate of occurrence.

TABLE 4.4-2:
SWITCHES, GENERAL FAILURE MODES

Failure Mode	% Occurrence
Open	15%
Shorted	8%
Intermittent	19%
Out of Spec.	14%
Other	18%
Unstable	10%
Drift	9%
Leaking	7%

TABLE 4.4-3:

FLOAT SWITCH FAILURE MODES

Failure Mode/Mechanism	% Occurrence
Cracked/Fractured	8%
False Response	23%
Leaking	8%
No Operation	23%
Out of Adjustment	15%
Seized	8%
Stuck Closed	8%
Stuck Open	8%

TABLE 4.4-4

REED SWITCHES FAILURE MODES

Failure Mode/Mechanism	% Occurrence
Intermittent	10%
No Operation	30%
Open	10%
Out of Spec.	30%
False Response	20%

TABLE 4.4-5:

TOGGLE SWITCHES FAILURE MODES

Failure Mode/Mechanism	% Occurrence
Open	24%
Short	16%
Intermittent	25%
Mechanical	35%

As with the other part types, the data listed in the previous tables are based on the best available data and will clearly be a function of device type, manufacturer, application, etc. Therefore, the distributions given were only used to identify predominant failure modes and to test the reasonableness of the hypothesized model.

4.4.2 Review of MIL-HDBK-217E Switch Models

The MIL-HDBK-217E switch section was analyzed for completeness and adequacy. The findings of this investigation are listed below. The items that were included as factors in the final model were a function of data availability and of the findings of this study. Therefore, not all factors discussed were included in the final model.

(1) Part types that should be addressed for addition are centrifugal switches, capacitive-touch switches, membrane switches, hydraulic-magnetic circuit breakers, ground fault interrupters and slide switches.

(2) Contact material should be considered for inclusion in the model because of their varying resistance to failure.

(3) AC versus DC application should be included in the model because arcing is more prevalent in DC operation.

(4) The difference in failure rate between thermal and thermal-magnetic circuit breakers should be included.

(5) The switch failure rate is currently proportional to actuation frequency when cycling frequency is greater than 1 cycle/hour and independent of cycling frequency when cycling frequency is less than 1 cycle/hour. This approach to switch failure rate prediction is too simplistic. If the failure rate is directly proportional to the cycling frequency, then all failure mechanisms should relate to actuation cycles. In practice, there are mechanisms relating to the switch package which are independent of cycling frequency.

4.4.3 Switch Model Development

4.4.3.1 Hypothesized Switch Model

The model hypothesized for switches is the following:

λ_P = $\lambda_b \pi_Q \pi_E \pi_C + \lambda_U$

λ_b = Base failure rates as a function of switch type and configuration

π_Q = Quality Factor

π_E = Environment Factor, function of hermeticity

π_C = Contact configuration factor

λ_U = Usage Factor, function of load, cycling rate, contact material, and whether the load is applied during switching. This is a wearout failure mechanism modeled per Section 2.3.

4.4.3.2 Switch Data Analysis

4.4.3.2.1 Standard Switches

Initial regression analysis of the data indicated that the environment factors derived for those environments for which there existed data were consistent with the current MIL-HDBK-217 environment factors. The environment factor will therefore be kept unchanged. The regression was run again with the current MIL-HDBK-217 environment factors and quality was specifically analyzed. This regression analysis indicated that, based on the available data, that there was no significant difference between quality levels. This is not intuitively correct and does not imply that there is no difference in the failure rates, merely that the difference is smaller than that which can be quantified based on the database and statistical techniques used. Typically, failure rate differences of greater than 2:1 can be identified with the techniques used. Differences less than this are difficult to identify given the inherent amount of noise in field failure rates. Therefore, since a difference of less than 2:1 cannot be distinguished from the data, and quality intuitively makes a difference, a 2:1 ratio in military vs. lower qualities will be used.

The next variable analyzed was the switch current rating. Unfortunately, there was insufficient data available to quantify the effects of contact current rating based on the data available. The stress (both rated and actual) however will be addressed in the utilization factor to be discussed in Section 4.4.4. There was also insufficient data to quantify the effect of contact material.

The base failure rates of various types and styles of switches were derived after compensating for the above described quality and environment factors. These base failure rates are given in Table 4.4-6:

TABLE 4.4-6:
SWITCH BASE FAILURE RATES

Type	λ_b (Regression)	% Hours from Failure Records	λ_b
Rocker	.186	25.5	.047
Slide	.082	7.3	.0060
Push Button/Toggle	.577	35.3	.204
Reed	.101	1.88	.0019
DIP	.118	.20	.00024
Pressure	5.75	99.27	5.53
Limit	8.58	99.99	8.58
Centrifugal	6.82	100.0	6.82
Microwave (Waveguide)	3.52	98.8	3.48
Liquid Level	4.71	100	4.71

The column on the right is compensated for the zero failure hours observed.

The last variable analyzed was the number of active contacts. For example, the number of active contacts in a DPDT switch is 4, a SPST is 1, and a 3PST is 3. The relationship between failure rate and number of contacts is:

$$\pi_C = (\#\text{ contacts})^{.33}$$

4.4.3.2.2 Rotary Switches

There was insufficient data available to quantify the effects of either quality or environment for rotary switches. Due to similar failure mechanisms to standard switches, the quality and environment factors previously described for switches will be used.

A regression was run normalized to these factors and the base failure rates in Table 4.4-7 were derived.

TABLE 4.4-7:
ROTARY SWITCH BASE FAILURE RATES

Type	λ_b (Regression)	% Hours from Failure Records	λ_b
Rotary Switch	1.13	19.5	.22
Thumbwheel	3.59	9.9	.36

Since there was insufficient data to derive a factor for number of active contacts specifically for Rotary Switches, the factor derived for standard switches will be used.

4.4.3.2.3 Circuit Breakers

Although Circuit Breakers are considered in the general category of switches, they were analyzed separately due to their inherently different construction characteristics. The data set was first analyzed to determine if there were correlations within the data or outliers which would prevent a valid derivation of model parameters. Several outliers were excluded, one of which implied that a naval unsheltered environment was much more reliable than a ground fixed environment.

Quality and environment were highly correlated, making it impossible to quantify the effects of both. Therefore, the MIL-HDBK-217E environments were assumed to be correct, the observed failure rate was adjusted to compensate for environment and the regression was re-run. This analysis indicated an approximate 20:1 ratio in failure rate between commercial and military parts. However, the significance of this factor was relatively low and therefore the available data does not contradict the current 8.4:1 ratio in failure rates between commercial and military parts. Therefore, the Quality and environment factors are given in Tables 4.4-8 and 4.4-9.

TABLE 4.4-8:
CIRCUIT BREAKER
ENVIRONMENT FACTOR

Environment	π_E	Environment	π_E
G_B	1	N_u	27
G_F	2	N_S	8
G_M	15	M_L	66
A_{IC}	7	M_F	25
A_{UC}	11	C_L	N/A
A_{IF}	9	S_F	.5
A_{UF}	12		
A_{RW}	46		

TABLE 4.4-9:
CIRCUIT BREAKER
QUALITY FACTOR

Quality	π_Q
MIL-SPEC	1.0
Lower	8.4

The contact configuration was also regressed against and the results were very consistent with the current factor, which is equal to the number of contacts, as in Table 4.4-10. Therefore, the contact configuration will be kept intact.

TABLE 4.4-10:
CONTACT CONFIGURATION FACTOR

Configuration	π_C
SPST	1
DPST	2
3PST	3
4PST	4

It was also attempted to quantify the failure rate as a function of the rated current of the circuit breaker. However, since it was highly correlated to number of contacts, its effect could not explicitly be quantified and was therefore not included in the model.

The observed failure rate was then adjusted for quality, environment, and contact configuration, and the regression was re-run to quantify the base failure rates for each type of circuit breaker. These base failure rates are given in Table 4.4-11:

TABLE 4.4-11:
CIRCUIT BREAKER BASE FAILURE RATES

Type	λ_b (F/10^6)
Magnetic	.68
Power Switch	1.74
Thermal	.68

4.4.3.2.4 Thermal Switches

Bimetallic thermal switches were analyzed separately. Applicable specs. for these are MIL-S-12285 and MIL-S-24236. Since all data available for thermal switches was from a G_B environment and from commercial device types, the model was normalized to these variables.

Since there was no data available on MIL-Spec. thermal switches, a quality factor could not be derived from the data. Therefore, the ratio of 2:1 between commercial and military derived for basic switches will also be used for thermal switches. Similarly, the current MIL-HDBK-217 environment factors will also be used.

The proposed model for thermal switches is therefore:

$$\lambda_p = \lambda_b \pi_Q \pi_E$$

There was a total of 193, 879, 400 operating hours with 12 observed failures in the dataset; yielding a base failure rate of .0619. Since this failure rate is in reference to a commercial part, dividing by 2 yields a base failure rate normalized to a military quality part.

4.4.4 Switch Utilization Factor (λ_U)

Switch and relay contacts can exhibit wearout failure mechanisms when exposed to repeated switching operations under electrical load. This is primarily due to the arcing and subsequent carbon generation of the contact. The variables accelerating this degradation mechanism are contact configuration and material, voltage, current, temperature, operating interval and inductance and capacitance of the load being switched. Although all of these variables affect wearout times for switches and relays, the predominant variables, and those readily available to designers are current voltage, inductance and capacitance. Therefore, these are the variables researched further for use in the utilization factor.

References 4 and 74 present data and analysis of switching cycles to failure under various operational conditions. The equations in Table 4.4-12 from Reference 4 relate the characteristic life (in 10^6 cycles) to applied operating voltage and current for both AC resistive loads and DC loads.

TABLE 4.4-12:
CONTACT LIFE EXPECTANCY (10^6 ACTUATIONS)

Contact Current Rating (Amps)	AC Resistive Load	DC Load
3 *(0-4)	$\frac{29.08}{V^{.75} I^{1.14}}$	$\frac{26.323}{V^{1.33} I^{1.3} e^{130 L/R}}$
5 *(>4-8)	$\frac{103.45}{V^{.75} I^{1.14}}$	$\frac{123.187}{V^{1.33} I^{1.3} e^{130 LR}}$
10 *(>8)	$\frac{219.74}{V^{.75} I^{1.14}}$	$\frac{307.94}{V^{1.33} I^{1.3} e^{130 L/R}}$

*Range for which model is assumed valid.

An attempt was made to regress on the constant in these equations as a function of rated current in an effort to derive a single equation representing the number of cycles to failure as a function of rated current, applied voltage, and applied current. This attempt was unsuccessful due to the fact that the linear regression implied negative cycles to failure for low rated current relays. Therefore, the approach taken was to assume the equations in the previous table are valid for the ranges of current ratings. The equation for 3 amp rating was assumed valid for the range 0-4 amps, for the 5 amp rating, >4-8, and for the 10 amp rating, >8.

Table 4.4-13 summarizes data available from Reference 74 on dry reed contacts made of cobalt hardened diffused gold, containing carbon with a top layer of ruthenium. Contained in this table is the voltage, current, Weibull α parameter (characteristic life), Weibull β parameter, characteristic life predicted from Table 4.4-12 and the predicted/observed ratio. Several conclusions were made from this data. Fi , the predicted mean cycles to failure are generally pessimistic by an average failure of .41. Although not entirely accurate, it does err on the conservative side which is desirable in this situation. Second, the beta values (needed for the wearout failure rate term) observed range from 1.1 to 8.6, with a mean of 3.5. Again, a conservative beta (lower value) is desirable since it will yield the worst case failure rates in the early life of the component. Therefore, a beta value of 3 will be used in the model.

TABLE 4.4-13:
DRY REED CONTACT DATA

V (V)	I (A)	α (10^6)	β	α Predicted (10^6)	(Predicted / Observed)
200	.025	26	3.2	36	1.4
100	.050	165	1.1	28	.17
50	.100	82	6.3	21	.25
6.7	.75	55	3.2	9.7	.17
200	.05	45	8.6	16	.35
100	.100	20	2.2	13	.65
50	.200	250	1.5	9.7	.039
28.6	.35	140	5.3	7.8	.056
20	.500	7.5	1.4	6.7	.89
13.3	.75	47	2.5	5.8	.12

As with the majority of electronic components, the failure rate of switch and relay contacts is a strong function of quality, and of the manufacturing process. Reference 77 presents data illustrating this dependence and indicates there are several orders of magnitude difference in the times to failure between a good part and a marginal part. Since the models being developed herein are generic models, they cannot explicitly account for specific manufacturing process variables. The effects of marginal manufacturing processes are however partially accounted for in the quality factor, assuming that the process controls and screens are effective in reducing defects related to early and mid life failures. Given these limitations, the models developed herein are representative of industry wide average failure rates.

Reference 77 also contains time to failure data on dry reed contacts. While enough data did not exist to validate the predicted failure rate, the available data does indicate that the predicted mean-time-to-failure is in the right range.

Since the wearout failure is being separately accounted for, the constant failure rate portion of the predicted failure rate must be decreased so that only non-wearout failure rates are included. From the failure mode distributions, it is apparent that approximately 50% of observed failures can be attributed to failure mechanisms that the wearout term is intended to model. The base failure rates must be decreased by 50% to accommodate this. Therefore, the final proposed models in Section 5 of this report contain base failure rates which are 50% of those contained in Table 4.4-6 derived from the regression analysis. The value of 50% was derived from the data in Table 4.4-2 by assuming that "open", "intermittent", and "out of spec." failure modes are wearout related. The percentage of these sum to 48%, or approximately 50% of the total failure rate. These failure modes were identified as wearout related since the ultimate mode of failure for switch contacts subjected to wear is open, intermittently open or increased contact resistance (out of spec).

4.5 RELAYS

The two main categories of relays are electromechanical relays and solid state relays (SSRs). Electromechanical relays are magnetically-operated devices available in many different styles, each having unique mechanical construction and electrical characteristics. Solid state relays control load currents through solid state switches such as TRIACs, SCRs or power transistors. Unlike electromechanical relays, solid-state relays have no moving parts and are often used in applications where rapid on/off cycling would lead to wear out of conventional electromechanical relays.

The major failure modes/mechanisms for electromechanical relays consist of contacts sticking, contact material transferring, contacts welding, high contact resistance, mechanical failure, and coil opening or shorting. For some applications, contact sticking and high contact pressure may be intermittent and difficult to diagnose. Coil failures are usually attributed to excessive voltage, electrolysis or other chemical reactions or harsh environments. Excessive temperature, especially if prolonged, may deteriorate the insulation, causing the coil to fail. Most electromechanical relay failure modes are fairly easily detected by visual inspection.

Failure modes in SSRs are primarily associated with the TRIAC or SSR switching characteristics. Most common failures take the form of SSR false turn-on with no turn-on signal. For example, turn-on can occur if operating temperatures exceed the thyristor rating or transients from the switched load or AC line momentarily exceed the thyristor breakover voltage. Other failure modes/mechanisms include thermo-mechanical fatigue caused by cyclic temperature surges, chemical reactions such as channeling and physical changes such as crystallization of materials.

The physical design of an electromechanical relay can be described by the contact combination or form and the construction type. The current-carrying parts of a relay that are used for making and breaking the electrical circuits are available in various combinations of contact forms. Single-throw contact forms have a pair of contacts open in one armature position and closed in another. Double-throw contact combinations have three contacts, of which one is in contact with the second but not with the third in one relay position, and in the reverse connection in the other relay position. Double-make and double-break contact forms have two independent contacts that are both connected to a third contact in one position on the relay. The choice of contact material and the shape of contacts impact relay failure rate. Contact reliability concerns for relays are very similar to those of switches, and therefore the contact reliability discussion presented previously are applicable.

Relay failure rate is significantly influenced by application variables including; ambient temperature, shock and vibration, contact material, shape of contacts, the amount of contact force and the wiping or sliding of contacts. The selection of a relay for a particular application is based on user requirements including:

- Class of application (e.g., military, commercial, industrial, machine tool control, etc.)
- Environmental requirements (e.g., high temperature, corrosion, shock, sand, etc.)
- Enclosure (e.g., open, sealed)
- Coil specification (e.g., resistance or impedance, voltage or current, temperature rise)
- Contact specification (e.g., form, current, voltage, AC/DC, frequency, etc.)
- Mechanical life expectancy
- Electrical life expectancy
- Electrical characteristic specifications (e.g., contact resistance, insulation resistance dielectric strength)
- Operational specifications

A number of test methods have been standardized to assure reliable performance of relays. Several of the more important tests are listed in Table 4.5-1.

TABLE 4.5-1:

TESTS PERFORMED TO ASSURE RELAY RELIABILITY

Test Type	Description/Purpose
Contact Resistance	Determines the resistance offered by electrically contacting surfaces to a flow of current. For practical reasons, leads and terminal resistances within the unit or test may be included in the measurement. In many applications, contact resistance is required to be low and stable to avoid voltage drop across the contacts, which adversely affects the accuracy of circuit conditions, and to prevent overheating at high currents.
Insulation Resistance Test	Measures the resistance between mutually insulated members of a relay. Values of insulation resistance can be important in the design of high impedance circuits. Low insulation resistance may permit excessive leakage current that can affect isolation of independent circuits. Excessive leakage current can also be indicative of the presence of corrosive impurities that can cause deterioration by electrolysis or heating.
Dielectric Withstanding Voltage Test	Detects flaws in materials, design, or construction of the unit which might result in failure to withstand the specified test potential. It is a static test, conducted without contact switching and in the absence of contact arcing.
Winding Resistance Test	Measuring the direct current resistance of a relay coil winding.
Winding Inductance Test	Measuring the inductance of the coil winding. In relays, coil inductance is a function of the number of turns of wire and the geometry and reluctance of the magnetic circuit.
Winding Impedance Test	Measuring the impedance of relay windings designed for use on alternating current.
Contact Bounce Test	Measurement of the duration of the intermittent opening or closing of contacts caused by contact bounce.
Contact Chatter Test	Monitoring contact chatter when relays are subjected to vibration, shock, and acceleration tests.
Functioning Time Test	Measure the operate and release time of relays.
Leak Test for Hermetically Sealed Relays	Determine the effectiveness of the seal of a hermetically sealed relay, which either is evacuated or contains air or gas. A defect in any portion of the surface area of a seal part can permit the entrance of damaging contaminants that could reduce the effective life of the relay.

4.5.1 Relay Failure Modes/Mechanisms

The failure modes and mechanisms for armature relays are summarized in Table 4.5-2.

TABLE 4.5-2:
ARMATURE RELAY FAILURE MECHANISMS

Failure Mechanism	Accelerating Factors	Distribution (%)
contact contamination	moisture, temp.	18
poor contact alignment	actuations, vibration	8
contact corrosion	actuations, voltage, humidity	6.5
opened coil	current, vibration	8.5
unstable coil	humidity, voltage, temp.	15
contact welding	current	7
spring fatigue	actuations	9
contact corrosion	humidity, temp.	19
binding, jamming	actuations, contaminants	9

4.5.2 MIL-HDBK-217E Relay Models Review

Review of the current MIL-HDBK-217 relay models resulted in the following observations:

(1) Model development activities for relays specifically addressed the impact of cyclic operation and relay terminology. The existing relay cycling factor depends on relay quality and cycling rate. Examples of computed cycling factors per the current model are given in Table 4.5-3.

TABLE 4.5-3:
EFFECTS OF RELAY QUALITY ON CYCLING FACTOR

Cycling Rate (Cycles/Hour	Cycling Factor	
	MIL-SPEC	Lower Quality
1	.1	1
1	.1	1
10	1	1
100	10	10
1000	100	100
10000	1,000	10,000

Several aspects of this factor seem illogical. Initially, the difference between MIL-Spec. and lower relays becomes smaller as the cycling rate increases (and is the same value for cycling rates between 10 and 1,000 cycles/hr.). In practice, the opposite should be true. High quality relays and contacts may be able to withstand repeated cycling better than the lower quality parts.

(2) Specific characteristics of the relay (e.g., incorporate contact material, AC/DC operation, frequency, shape, contact force, amount of wiping/sliding) should be investigated for possible inclusion in the model.

4.5.3 Relay Model Development

4.5.3.1 Hypothesized Relay Model

The hypothesized relay model form is as follows:

$$\lambda_p = \lambda_b \pi_E \pi_Q + \lambda_u$$

where:

λ_b = base failure rate as a function of generic relay type

π_E = Environment Factor

π_Q = Quality Factor

λ_u = Usage failure rate factor, function of load type, cycling rate, current, and voltage

4.5.3.2 Relay Data Analysis

Initial regression results of the relay data were relatively consistent with expectations. This was undoubtedly due to the fact that there were a large percentage of records (98%) which had observed failures, thus resulting in a relatively large dataset to analyze. There were therefore relatively few iterations required to arrive at the final results.

The results of the environment analysis are summarized in Tables 4.5-4 and 4.5-5. Table 4.5-4 summarizes the current MIL-HDBK-217 environment factors and Table 4.5-5 summarizes those obtained from the regression analysis.

TABLE 4.5-4:
CURRENT 217E ENVIRONMENT FACTOR

Environment	π_E
G_B	1
G_F	2
G_M	15
A_{IC}	7
A_{UC}	11
A_{IF}	9
A_{UF}	12
A_{RW}	46
N_U	27
N_S	8
M_L	66
M_F	25
C_L	NA
S_F	.5

TABLE 4.5-5:
REGRESSION ANALYSIS

Environment	π_E
A	28
A_{RW}	100
G_M	7.4
G_F	1.0
S_F	.098
G_B	.12
N_s	.98

Comparison of existing factors (combined if necessary for consistency with the environment/combination of environments in Table 4.5-5) to observed environment factors is given in Table 4.5-6. The column labeled "current" denotes the π_E value of MIL-HDBK-217E for such environment for which a regression solution was obtained. The "observed" column presents the regression solution, and the Column "Observed Normalized to G_B" presents the observed factors normalized to a G_B environment. This was accomplished by dividing the observed factor for each environment by the observed factor of .12 for G_B. In this manner the π_E for G_B is one. It is these factors that are the proposed π_E values for the new model. In cases where there is not an observed environment factor for a particular environment, the ratio of proposed to current π_E values of similar environments were used to multiply the current values. For example, there was not sufficient data identify an observed factor for each airborne environment. Therefore, all airborne environments were combined for the analysis and a π_E factor of 233 was obtained. The current average factor is 9.7 and therefore the ratio is 233/9.7 = 24. Each current airborne π_E was therefore multiplied by 24 to obtain the proposed π_E values. Other environmental factors were derived similarly.

TABLE 4.5-6:
COMPARISON OF NEW/OLD ENVIRONMENT FACTORS

Environment	Current	Observed	Observed Normalized to G_B
A	*9.7	28	233
A_{RW}	46	100	833
G_M	15	7.4	64
G_B	1	.12	1
G_F	2	1.0	8.3
S_F	.5	.098	.82
N_S	8	.98	8.2

*Average of all air environments.

Therefore, modifying the current MIL-HDBK-217 for these environments normalized to a G_B environment yields the factors given in Table 4.5-7:

TABLE 4.5-7:
PROPOSED RELAY ENVIRONMENT FACTOR

G_B	1
G_F	8.3
G_M	64
A_{IC}	168
A_{UC}	264
A_{IF}	216
A_{UF}	288
A_{RW}	833
N_U	27
N_S	8.2
$*M_L$	1584
$**M_F$	600
C_L	N/A
S_F	.82

*Obtained using the ratio of G_M
** Obtained using the ratio for all airborne environments

The environment factor for solid state relays is not expected to be as stringent as for mechanical types and therefore the current MIL-HDBK-217E environment factor will be kept.

The quality factor obtained from the regression is given in Table 4.5-8. Although 1.9:1 is a relatively modest factor, it was significant from the regression analysis.

TABLE 4.5-8:
OBSERVED QUALITY FACTOR

Quality	π_Q
Military	1
Lower	1.9

The base failure rates obtained for different types of relays are (after accounting for zero failure hours) give in Table 4.5-9.

TABLE 4.5-9:
RELAY BASE FAILURE RATES

Type	λ_b (Regression)	% Hours with Failure Records	λ_b
General Purpose	.034	96.0	.033
Solid State	.029	99.9	.029
Time Delay	.17	87.2	.148
Reed	.17	95.9	.163

Additional factors analyzed were number of contacts and current rating of the contacts. There was a very low statistical significance in the rated current factor and the regression illustrated a negative relationship between failure rate and number of contacts. Due to these results, rated current and number of contacts will not be included in the proposed model. Although originally identified as potential model variables, the effects of contact shape and material could not be obtained from the data.

The wearout failure mechanisms for relay contacts is essentially the same as for switches. Therefore, the utilization factor for relays will be the same as that derived for switches. From the Relay Failure Mode/Mechanism information, it is apparent that approximately 40% of observed relay failures are due to wearout. Therefore, the base failure rates for relays in the final model in Section 5 will be decreased 40% since this percentage will be accounted for in the λ_U failure rate.

4.6 CONNECTORS

The following is a listing of connectors commonly utilized in military systems and considered in this section.

Connectors (including power and shielded):

- Rack and Panel
- Circular
- Power
- Shielded
- Phone

PCB Connectors (designed specifically for printed circuit boards):

- Ribbon
- Edge Board
- Pin

IC Sockets (not connectors but included in 5.1.12 of MIL-HDBK-217E):

- Dual In Line Package (DIP)
- Pin Grid Array (PGA)
- Leadless Chip Carrier

Connections:

- Terminal
- Connector Panel
- Wirewrap
- Crimp
- Clip
- Solder
- Weld

Connector failure modes include shorts, opens, high resistance, and intermittent failure. Based on data collection from military and commercial applications, short and intermittent failures are the predominant modes of failure (with short contributing 50%, and intermittent contributing 40%). Failure accelerating stresses contributing to failure modes of opens and intermittents are temperature cycling, vibration, and corrosion from exposure to humidity or contaminants. Additionally, the mating cycling rate highly influences reliability. When the cycling rate is very low, a cleaning action takes place counteracting the formation of corrosion or oxide films without causing excessive wear. Conversely, as the cycling rate increases, wearout failure mechanisms become very significant.

There are two critical manufacturing aspects which must be maintained to produce a reliable connector. For electrical and signal connectors, contact plating, contact form and physical dimensions are critical variables. For optical connectors, physical dimensioning and alignment are important design and manufacturing variables. For a reliable connector, there must be a consistent connection between its male and female components. This consistent connection must be maintained despite vibration and temperature cycling which can result in small amounts of movement and corrosion. Without sufficient contact force and plating, corrosion can cause increased resistance between contacts leading to failure.

There are a number of connector designs which can be used for a specific environmental application. For example, if the application for a circular connector were in a high temperature environment, the insert insulating material can be specified as vitreous glass or alumina ceramic which will maintain it's mechanical integrity up to 250°C. However, as is the case with other component types being modeled, it is assumed that the parts are operating below their maximum ratings. If not, the models are invalid.

For vibration or corrosive environments, special platings or contact configurations can be utilized along with sealing procedures to optimize reliability. An example of precautions taken in the design of a connector is the positive locking ring on circular connectors which creates a positive mating and seals the device to contamination and vibration.

The failure rate and failure mechanisms for edge-board PCB connectors are distinct from pin and socket PCB connectors. For edge board connectors, the connector mates with the edge of a PCB to provide electrical connection. For many applications, including airborne environments, the use of edge board connectors is restricted because of their greater frequency of failure.

Environmental contamination, vibration, temperature cycling and altitude tests are often performed on connectors. Plating procedures and the even dispersement of plating are other concerns resulting in the qualifications of connectors. Only military connectors are typically subjected to formal qualification tests, but commercial grade connectors are often subjected to functional tests to determine design integrity.

The dominant application variables affecting the failure rate of connectors are vibration, temperature cycling, mating and unmating cycles, and contamination. To a lesser extent, application variables affecting connector failure rates are the loads passing through the connector. If the loads are properly specified by gauge versus current carrying capacity, this factor is of relatively small influence.

Connectors have been a leading cause of reliability problems for many avionic electronic systems. Due to the space constraints in high performance aircraft equipment bays, is it often necessary to remove/replace several electronic boxes during flight-line maintenance simply for the failed box to become accessible. As a result, many equipments are being repeatedly removed and connectors are being stressed by mating/unmating cycles.

4.6.1 Connector Failure Modes/Mechanisms

Table 4.6-1 summarizes failure modes/mechanisms, their accelerating stresses and percent occurrence for connectors. This data is based on Reference 13 and is a summary of all connector types for which data existed. It is a generic listing and will vary depending on connector type, application, manufacturer, etc.

TABLE 4.6-1:
CONNECTOR FAILURE MODES/MECHANISMS

Failure Mode/Mechanism	Accelerating Stress	% Occurrence
Contact Resistance	Temperature Contamination	9%
Intermittent	Vibration Wear	22%
Mechanical Damage	Vibration Wear	24%
Open	Temperature Contamination Vibration Wear	36%
Short	Contamination Abuse	9%

Accelerating Stresses: Accelerating factors that degrade the reliability of electrical and fiber optic connectors can be identified by temperature, environment, and mechanical stresses. Separately, each causes specific degradation mechanisms and modes, but realistically they are interrelated to induce combined acceleration of failure factors.

Temperature: Temperature cycling in some applications causes the expansion and contraction of the mated connectors. If the temperature cycling is prolonged, then there is a possibility of the mated connectors to loosen and separate, causing intermittent anomalies and open failures. This condition would be further accelerated in high-vibration applications such as aircraft or with connectors that do not have screw-type mating or mated connector support such as D-sub or DIN connectors.

Another type of temperature accelerating factor is high contact resistance. This is caused by increased temperatures accelerating the diffusion of inner plating materials such as silver, tin and palladium-based metals to diffuse through the outer plating materials such as silver or gold.

Environmental: Environmental stresses are usually confined to acidic or caustic environments. These types of environmental stresses will accelerate corrosion in all non-gold plated connectors. The combination of temperature with environmental acceleration factors will induce the acceleration of contact corrosion. Initially, early degradation will develop a thin film on the outer plating layer which will require higher current potential to penetrate through to the contact. Later stages will induce corrosion on all non-gold plated connectors.

Mechanical: Mechanical stress is confined to three areas of stress: Cyclic mating/unmating, pin insertion stresses, and vibration stress. Cyclic mating and unmating and vibrational stresses are the more important areas to address. Failures caused by pin plating deficiencies are directly related to connector mating/unmating. Gold-plated connectors are standard for military applications while commercial applications may use less expensive silver or tin plated connectors.

Gold, by definition, is a soft noble metal. Prolonged mating/unmating cycles will erode the gold outer plating off of the connector pins, causing the tin, nickel or palladium-based inner plating to be exposed to the temperature and environmental accelerating stresses listed above. Another mechanism created by constant mating cycles is the loss of tension in female pin receptacles. The results of this mechanism is a loose mating connection and high probability of an open connector failure or intermittent anomalies in a high vibration environment.

Acceleration of connector failures due to insertion stresses are mostly human induced. Many of the insertion stresses are caused by pin misalignment which will usually lead to broken pins or shorting them against other pins. This type of failure would be most prevalent in high pin count connectors.

The following outline summarizes in more detail potential failure modes and factors affecting their prevalence.

Universal Connector Failure Modes:

- Deterioration of Insert Material
    - Total current passing through active contacts
    - Contact resistance
    - Contact density/geometry
    - Amount of conduction cooling available

Connector Failure Modes (Cont'd):

- Moisture Intrusion
    - Inadequate sealing of the internal structure

- Pin/Receptacle Damage
    - Use of probes
    - Connector Misalignment
    - Connector mismating
    - Relative connector movement due to vibration

- Vibration damage
    - Absence of positive screw-type couplings
    - Inadequate support of cables or wire bundles

Plating Specific Failure Modes:

- Silver Plating
    - High resistance/intermittent contact failure
        - Silver suifide build-up on contact surface
        - Wear-through of silver to contact base metal
    - Silver oxidation

- Gold over silver plating
    - High resistance/intermittent contact failure
        - Silver diffusion through gold over-plating (due to similar atomic lattice structure) forming silver sulfide contaminants on contact surface

- Rhodium plating
    - Hard open contact failure
        - Rhodium's inherent poor corrosion resistance
        - Galvanic corrosion caused by Rhodium to gold connector mating
        - Mating/Demating

Plating Specific Failure Modes (Cont'd):

- Tin plating
  - Contact surface melting
    - Heat generation
  - Increased contact resistance
    - Oxidation
    - Creep
    - Tin's inherent low-current capability
    - Contact mating/relaxation

- Gold over (nickel or copper) plating
  - High resistance or intermittent contact failures
    - Connector wear-through to nickel under-plating
      - Mating/demating of thin-gold plated
      - Relative connector movement due to vibration and/or thermal excursions
    - Contact oxidation
      - Oxidation of exposed nickel under-plating
      - High temperature for extended time periods
        - Diffusion of nickel and/or cobalt additives in some gold connectors. The additives then form oxides on gold surface.

4.6.2 MIL-HDBK-217E Connector Model Review

The current MIL-HDBK-217E failure rate model for connectors has been reviewed and the following observations have been made:

(1) The connector factor for active contacts needs revising. The existing factor increases somewhat gradually for pin counts up to 150 pins and then increases rapidly from 150 to 200 pins. As connector manufacturing and design becomes more advanced, the relationship between pin count and failure rate is expected to have changed since the connector models were last revised in the 1970s. Additionally, connectors are now available with greater than 200 pins.

(2) The current cycling rate factor should be reviewed with respect to the cycling stresses to which many connectors are being exposed.

(3) Models need to be updated to incorporate newer technologies in connector design. There have been advances in connector housing material and contact form, including zero insertion force connectors.

(4) Additional connectors which should be included in MIL-HDBK-217E are:

- Ribbon cable connectors
- Fiber optic couplers and connectors
- Leadless chip carriers

(5) The effects of connector mating and unmating should be reviewed.

(6) Fiber optic technology is increasing in popularity, especially where weight and reliability are concerned. The Navy uses fiber optic technology on shipboard radar systems to effectively reduce retrofit costs, save weight and space, and increase the performance capabilities of their systems.

4.6.3 Connector Model Development

4.6.3.1 Hypothesized Connector Model

The hypothesized connector model for connectors is as follows:

$$\lambda_p = \lambda_b \pi_T \pi_E \pi_Q \pi_C \pi_P \pi_K$$

λ_b = Base Failure Rate (function of connector type)
π_T = Temperature Factor
π_E = Environment Factor
π_Q = Quality Factor
π_C = Contact Plating Factor
π_P = Pin Count Factor (Complexity)
π_K = Mating/Unmating Frequency Factor

4.6.3.2 Connector Model Development

4.6.3.2.1 Connectors

Initial analysis of the connector dataset revealed several limitations. First, there was insufficient data to quantify several variables, including quality and insert material. Quality again could not be quantified due to the high correlation between quality and environment. Therefore, the current quality factor of 2:1 between military and commercial connectors were assumed to be correct and the observed failure rates were adjusted (divided by) this factor and quality was not used in subsequent regression analysis.

The next variables analyzed were environment, connector type and connector plating material. Since the precise temperature of all observed failure rates was not known, the temperature factor for each was calculated using a $E_a = .14$ and the default temperatures of MIL-HDBK-217E. The value of .14 eV was derived from the current MIL-HDBK-217 temperature factor and the observed failure rates were then normalized to this value.

After several iterations of combining various environment categories to obtain consistent and intuitively logical results, the following environmental factors were obtained in Table 4 6-2:

TABLE 4.6-2:
OBSERVED ENVIRONMENT FACTOR

Environment	π_E
Ground	1
Airborne	5.53
N_{SB}	1

Although all the specific environment categories could not be quantified from the available data, the above factors are consistent with the current MIL-HDBK-217E factors for MIL-Spec. connectors. Therefore the connector environment factors should be kept intact without modification.

The factor for gold plated connectors were observed to be 1.27 times better than copper although it was statistically a relatively insignificant factor and will not be used in the model.

The mating/unmating frequency factor was the next-variable analyzed. Since the failure rate data indicates that the reliability of connectors in general is very high, wearout failures due to mating/unmating are not prevalent in the data set. If they were prevalent, the observed failure rates would be much higher due to the fact that wearout mechanisms are common cause, indicating they would effect a large percentage of the population.

Although a mating/unmating factor cannot be derived from the data, it is an important reliability driver for connectors and should be accounted for in the model. However, since wearout failures have not been observed to be prevalent, in contrast to switches, a separate additive failure rate to model them is not warranted. It will however be included in the model as a multiplicative factor, which implies the mating/unmating action can accelerate non-wearout, defect related failure mechanisms. For these reasons, the current factor will be kept intact.

The base failure rates for various connector types were then derived from the regression analysis by compensating the observed failure rates for the quality, temperature, environment, and mating/unmating frequency factors previously described.

The base failure rates for the various types of connectors are given in Table 4.6-3 (after compensating for the percentage of hours associated with 0 failures).

TABLE 4.6-3:
CONNECTOR BASE FAILURE RATES

Type	λ_b (Regression)	% Hours with Failure Records	λ_b
Signal	.000086	5.04	.0000044
Rectangular	.054	85.2	.046
Elastomeric	.074	9.5	.0071
Edge Card	.040	99.9	.040
Cylindrical	.048	2.13	.0010
RF	.0060	6.85	.00041
Hexagonal	.776	18.8	.146
Rack and Panel	.776	2.67	.021
D-Subminiature	.776	85.2	.66
Telephone	.103	7.35	.0075

Also analyzed in the regression was the number of pins. There was a statistically insignificant relationship between number of pins and failure rate and when forced into the equation, it indicated that failure rate was inversely proportional to pin count. Since this is not intuitive, the factor for pin count was therefore discarded from the model.

4.6.3.2.2 Connections

To be consistent with MIL-HDBK-217E, connections are considered to be a single individual electrical connection, separate from a connection within a connector assembly. Examples of connections are wirewrap, crimp, weld, clip termination, and solder. The model form for connectors is;

$$\lambda_p = \lambda_b \pi_Q \pi_E$$

where λ_b is the base failure rate as a function of connection type. Since the predominant failure modes are similar for connectors and connections, the environment factors for connectors will also be used for connections. The initial regressions also indicated that there was not a significant difference between military and commercial connections. This is not surprising since the technology is essentially the same.

The only connection type quality is considered important is crimp types. For these the current factor will be kept. For all others quality is not a model variable.

Table 4.6-4 presents the results of this analysis and includes, for each connection type, the 217E λ_b, the observed λ_b and the proposed λ_b. Observed failure rates were corrected for environment and then averaged to obtain the observed λ_b.

TABLE 4.6-4:
CONNECTION BASE FAILURE RATES

Connection Type	217E λ_b	Observed λ_b	Proposed λ_b
Hand Solder w/o wrapping	.0026	<.000011	.000011
Hand Solder w/ wrapping	.00014	--	.00014
Crimp	.00026	--	.00026
Weld	.00005	<.000015	.000015
Solderless wirewrap	.0000035	.0000068	.0000068
Clip Termination	.00012	--	.00012
Reflow Solder	.000069	<.00012	.000069
Spring Contact	--	.168	.168
Terminal	--	.062	.062

*Zero failures observed, λ calculated from assuming 1 failure.

The connection model will therefore be kept unchanged with the exception of the modification of the base failure rates and addition of the terminal and contact spring categories. If the new data for which there were zero failures (indicated with a "<" symbol) suggested the worst case failure rate (calculated with assuming one failure) is lower than the current value, the new worst case number was used. If the current number is less than the worst case assumed value, the current number was kept. Only one failure rate, for solderless wire wrap, was increased.

4.6.3.2.3 Sockets

All data records available for which there existed observed failures on sockets were from a ground benign commercial environment. Therefore, the quality and environment factors could not be derived from this dataset and therefore the connector factors will be used. The models will be normalized to ground benign environment and commercial quality level. The socket failure rate model is:

$$\lambda_p = \lambda_b \pi_E \pi_Q$$

where λ_b is the base failure rate as a function of socket type.

Since there was insufficient data to quantify the environment factor specifically for sockets, the environment factor previously described for connectors will be used.

The observed failure rates for the socket types (for which there existed failures) are given in Table 4.6-5.

TABLE 4.6-5:
OBSERVED FAILURE RATES FOR SOCKETS

Socket Type	Failure Rate
DIP	.00064
Relay	.037
Transistor	.0051
Tube	<.011
Chip Carrier	<.0024
Pin Grid Array	<.014
SIP	<.0030

Since all failure data was from the same environment and quality level, a regression analysis was not necessary and the above failure rates were computed by summing the failures and hours for all ground benign, commercial data.

The failure rates preceded by a "<" sign are of device types for which there was no observed failures. For these, the upper limit of failure rate presented was calculated by dividing one failure by the observed number of operating hours.

Although there was no observed failures for military sockets, there was a substantial number of observed hours for Military DIP Sockets. Table 4.6-6 summarizes the DIP data.

TABLE 4.6-6:
DIP SOCKET DATA

	Commercial	Military
Failures/Hours	$8/12441 \times 10^6$	$0/5002 \times 10^6$
Failure Rate	.00064	<.0002

The number of total operating hours for the military data was calculated by adjusting for the environment by multiplying each data records hours by π_E. This indicates that there is at least a .3:1 difference in military vs. commercial DIP sockets. Therefore, this ratio will be used for the π_Q.

While there was not enough failure data to quantify the failure rate of Chip Carriers, Pin Grid Arrays, or SIP's, there was a significant number of observed hours associated with them. Therefore, the upper limit values in Table 4.6-4 will be used. Additionally, there was insufficient data to quantify the effects of the number of active pins.

Therefore a summary of the complete socket model is:

$\lambda_p = \lambda_b \pi_E \pi_Q$

λ_b = .00064 for DIP Sockets

= .0024 for Chip Carrier Sockets

= .014 for Pin Grid Array Sockets

= .0030 for SIP Sockets

= .037 for Relay Sockets

= .0051 for Transistor Sockets

= .011 for Tube Sockets

π_E = Environment Factor from Connectors

π_Q = .3 Military

1 Commercial

4.7 INTERCONNECTION ASSEMBLIES/PRINTED WIRING BOARDS

Interconnection assemblies are the medium which provides electrical connections to the components which collectively form an electrical circuit. The circuit board can be various combinations of multi-layer or double-sided, printed wiring or discrete wiring and components can be mounted to the board using either Plated Through Hole (PTH) or Surface Mount Technology (SMT). A Surface Mount Technology (SMT) interconnection assembly typically is comprised of a circuit board and solder connections which both physically and electrically connect the components to the board. PTH technology uses the solder joint for electrical connection only. There are various methods for forming solder connections including wave solder, hand or vapor phase soldering.

Most soldering operations for military systems utilize wave soldering. Wave soldering systems for printed wiring assemblies generally produce more reliable connections due to less variability in the process. These systems can apply the flux, dry and preheat the board, solder components, and clean the completed assembly. Some of the systems have special features where the flux is applied by passing through a wave, by spraying, by rolling or by dipping. Several systems employ oil mixed with the solder to aid in the elimination of icicles and bridging between conductor paths. Vapor phase or IR soldering is typically used for the reliable soldering of Surface Mount Boards.

4.7.1 Interconnection Assembly Failure Modes and Mechanisms

For interconnection assemblies using plated through hole (PTH) technology, fracture of the PTH is the primary cause of failure. For these types of circuit boards, holes are drilled through the pads of the inner layers of a multilayer printed circuit board. Drilling exposes a rim of copper around the entire circumference of the hole. The copper on the individual layers in the PTH is connected by copper plating. Plated through holes are also used for interconnection on some types of discrete wiring assemblies. The discrete wiring boards are plated in an electroless copper bath where copper is deposited to form the component holes and make connections to the discrete wires.

PTH barrel stresses are significantly higher in the central portion of the PTH when the assembly is exposed to thermal cycling. Internal circuit planes which inhibit free expansion of the PTH and additive loading on PTH lands have been considered to be the principal reasons for higher centralized stresses. As the number of internal circuit planes increase on a printed wiring board, the stresses in the central plated through hole region become larger and more failures are expected.

One advantage of surface mount technology is its ability to minimize board real estate. For surface mount devices, the component is attached directly to the surface of the printed wiring board. Even when surface mount technology is predominantly used, it is still necessary to use via PTHs to provide electrical connection between circuit planes. Via holes are also subject to barrel cracking but, the physics of failure are different due to the absence of an inserted lead. The absence of this lead changes the mechanical strength and TCE of the via. Also the integrity of the via is a strong function of the completeness which the hole is filled.

Manufacturing difficulties can accelerate the formation of PTH barrel cracks. The formation of barrel cracks is generally due either to imperfections in the PTH barrel wall which greatly amplify the level of axial strains or very poor effective ductility of the copper plating. Poor drilling or excessive acid etching during the hole wall cleaning process can lead to rough barrel walls. A level but thin plating on the rough barrel wall may then lead to localized stress concentrations and large plastic strains. Even if the PTH walls are smooth, variable electroplating processes may yield copper of very low conductivity.

In addition to surface mount or plated through hole printed wiring boards, design options for circuit boards include discrete wiring boards and flexible boards. These technologies are sometimes used in specific instances justified by particular design requirements.

Flexible circuit boards are not restricted by a rigid substrate and are commonly used in many electronic systems. They are sometimes used in place of interconnect cabling to connect between moving assemblies, or when a flexible board is required for volume or enclosure shape reasons. Since they are not rigid, their reliability concerns differ from those of rigid boards. More specifically of concern is the integrity of the solder joints when the board is exposed to movement or vibration. Additionally since the mechanical and thermal properties of the board substrate is different than rigid board, their behavior under temperature cycling conditions is expected to be different.

The most common form of discrete wiring boards are Multiwire boards (trademark name). In this technology, small wires are imbedded in the laminate in lieu of printed wiring. For these designs, it is possible to cross paths on a single circuit plane due to the insulation on the wire. Two distinct failure mode areas for Multiwire assemblies are the wire crossover points and where the PTH interfaces with the wire. The wire crossover potentially can be a source of failure. When one wire crosses another, there is typically 0.0012 inch of polyimide insulation between them. The typical breakdown voltage at a single crossover is 1,500 - 2,000 volts. The wire is ordinarily tested by the manufacturer to determine its ability to maintain insulation integrity under extreme conditions. Environmental testing at several testing laboratories has not shown degradation of the insulation resistance between crossovers; however more detailed analyses are required. Although a limited amount of test data that is available has indicated that the connection of the wire end to the copper plating in the PTH is reliable, there is another reliability concern in the use of multiwire technology that relates to the drilling and etching operation. Specifically, the wires are prone to overetching, causing the wire to withdraw thus exposing it for potential shorting to other circuit elements or stressing it such that opens can occur. Therefore, quality control procedures are critical in the fabrication of these boards.

The advent of surface mount technology has had a dramatic impact on the reliability of interconnection assemblies. The printed circuit board design and manufacturing process of SMD boards require much greater attention to produce reliable solder connections. To produce a reliable surface mount solder connection, it is necessary to tailor the thermal coefficient of expansion (TCE) of the printed circuit boards substrate to the TCE of the device in order to minimize thermal fatigue in the solder connection. The distinction between "tailoring" and "matching" TCEs is important because of the localized heating of the electrical component when power is applied.

Solder Joint Fatigue: A prime reliability issue associated with SMT assemblies involves the solder joint integrity between the surface-mounted component and the printed wiring board.

Thermal stress results when materials with different TCEs (Printed wiring board and chip carrier) are joined and exposed to variations in temperature. When the materials respond to fluctuations, each at their own rate, the bond which ties them together (the solder joint) restricts their independent movement. The resulting damage to the solder joint is cumulative in nature; that is, as the number of temperature fluctuations increases, the solder joint progressively weakens and the probability of failure increases. A worst-case scenario for solder joint fatigue is power cycling with large temperature fluctuations. The substantial changes in temperature coupled with materials which have widely differing thermal coefficients of expansion produce an extreme fatigue environment.

When such stress is applied to the assembly, both the substrate and the component deviate from their original shape concurrent with their individual TCEs. The difference in TCE between the substrate and device results in stress on the solder joint. Solder cracking problems become significantly worse as the number of solder joints increases with package size and the power dissipation increases with die size and function. As a leadless chip carrier increases in size from 18 to 64 pins, the allowable TCE difference between the substrate and the chip carrier must decrease from the typical 7 ppm/degree C to 2 ppm/degree C in order to achieve the same solder joint cycles to failure.

Printed wiring board substrate designs can be produced from a variety of materials. Historically, epoxy glass boards have been the most popular for PTH technology. Other board materials are necessary for SMD technology since the TCE of glass epoxy is too high to produce reliable SMD boards surface mount technology. However, the use of the polyimide boards has long been proposed as an alternative for epoxy glass for PTH boards as well. Each board material has different TCE, drilling characteristics and other parameters which impact failure rate. A summary of various substrate materials and their TCE characteristics are given in Table 4.7-2 later in this section.

Electrically, active and passive elements are designed and fabricated with similar technology, reliability standards and manufacturing processes for both SMD applications and PTH applications. Therefore, the failure mechanisms of the active elements are also similar. The connections and packaging of these two device types, are however very different. Surface-mount components (SMCs) are not afforded the inherent internal board heat sink that PTH devices are, whose leads penetrate the board surface and thermally connect to internal metalization. SMCs often rely on thermal vias to transport heat away from the chip. Heat transfer by this mechanism can be efficient if the vias are located where heat concentration occurs. The heat sinking properties of the mounting technique along with the thermal properties of the package are important factors since the failure rate and reliability are heavily dependent on device operating temperature.

The poor solderability of printed wiring boards is estimated to cause 50% of the solder defects and approximately 20% are caused by the component lead solderability problems. The other 30% are possibly due to solder composition or processing methods but more likely due to the application of operating stresses.

Improper or defective solder joints may occur in response to a large variety of factors, including:

- Mechanical Considerations
  - Solder joint fatigue
  - Solder joint formation anomalous effects
- Metallurgical Considerations
  - Solder composition
  - Wettability of metallizations
  - Solder contamination
- Chemical Considerations
  - Oxide formation effects
  - Cleaning of flux residues

Solder Joint Formation Anomalous Effects: The formation of the solder joint is also an important factor in the reliability of the assembly. The alignment, location, the degree of parallelism between the package and the substrate as well as the amount and shape of the solder contained at each joint location all have a dramatic effect on how the solder joint reacts to stress.

Solder Composition: The solder alloys themselves have fatigue properties which are inherently characteristic of the alloy composition. Their behavior, therefore, is largely dependent upon how that composition reacts to the thermal-mechanical stresses to which it is exposed. Solder alloy selection is based on its strength characteristic and its metallurgical compatibility with the base metal with which it will form a bond. Over 90% of the solder used in the electronics industry is of a tin-lead composition. The tin-lead solders typically used in the soldering of surface mount assemblies are considered to be soft solders due to their physical behavior under stress conditions. Soft solders react to the mechanical tension by absorbing some of the stress; however, some deformation occurs with each stress load. After repeated load applications, the solder becomes permanently deformed which allows cracks to develop and propagate into failures.

Cases of insufficient solder amounts characteristically have cohesive solder failure as a typical failure mode. Cohesive solder failure is a failure where the lead has pulled out of the solder with solder remaining on both the lead and the substrate. Insufficient solder placement is often the cause of inadequately formed solder joints, whereby open connections and voids result. Excessive solder in a solder joint is responsible for solder bridges that develop between adjacent leads. This solder bridging creates a conduction path between leads which should be isolated.

Increasing the clearance or stand-off heights between the component and the board allows the strain which develops during cycling to be absorbed by the main body of the solder connection. A small stand-off height limits the area through which the strain can be absorbed which results in solder joint cracking.

Wettability of Metallizations: The formation of a good solder bond is based on a compromise in that the surface materials must dissolve partially in the molten solder in order to provide good wetting but not so much as to initiate intermetallic compound growth. The solder flux ideally acts to provide the required wetting between the surfaces being attached in typical solder connection processing. Poor solder joint formations can be the result of dewetting or inadequate surface preparation. This condition, also referred to as cold soldering, indicates that a lack of proper adhesion had occurred between solder surfaces. Cold solder connections often can be detected by visual inspection.

Solder Contamination: Surface mount terminations are generally formed from or coated with precious metals such as gold, silver, platinum, palladium, etc. These terminations are readily soluble in solder, and if left unprotected the terminations become contaminated when placed in contact with solder. The intermetallic compound formations which result from the interaction between the active solder components (tin) and the soluble metallization (precious metals) produce weak solder joints at elevated temperatures. The process of intermetallic compound formation can be controlled by proper heat treatment, choice of solder alloy or the use of an underlying film (nickel) as a barrier to inhibit the dissolution of materials. The use of barrier materials has been widely accepted as a means of providing an interface between the terminations and the solder, thereby protecting each from contamination.

The intermetallic compound formations produced by the dissolution of the component lead material into the solder is responsible for the contamination of the solder joint. Any precious metal which dissolves into the joint becomes a problem which is aggravated as the concentration of the metal increases. This is typically expressed as a solder joint which becomes consumed by the process of diffusion between the precious metal and the tin in the solder. This consumption process is initiated as the molten solder comes into contact with the surfaces to be joined but may also continue throughout the life of the joint.

This contamination process is responsible for producing rough or gritty surfaces which reduce the ductility of the solder joint. This loss in the plastic response behavior of typical solder can be influenced by a relatively small amount of contamination. The contamination reduces the yield point (i.e., the point on the stress-strain curve which separates elastic and inelastic deformation) and causes the solder connection to be sensitive to even smaller temperature fluctuations which negatively impacts the life of the solder joint.

This contamination is also responsible for the formation of brittle solder joints which fail characteristically at much lower temperatures than would ordinarily be expected. Additionally, the dissolution of these metals decreases the melting point of the solder itself, which makes assembly and rework difficult.

Oxide Formation Effects: Surface mounting relies on the component being supported during solder reflow by the surface tension forces of the solder. When molten solder is exposed to air it quickly forms and oxide skin which can reduce the surface tension plays an important part in successful soldering operations. Careful monitoring of the soldering process is required to ensure the application of quality solder. Reduced exposure to oxidizing agents and other contaminants is a must in the formation of reliable solder connections.

Cleaning of Flux Residues: The criticality of removing flux residues prior to performing the soldering process is evidenced by the number of voids formed in the solder. Trapped air and flux forcefully escape from the solder, leaving behind harmful voids. Defects such as voids in a solder joint have a large effect on the fatigue resistance of a solder joint. Voids become stress-concentration sites which alter the typical stress patterns.

Substrate Reliability: The primary failure mechanism plaguing substrate reliability have traditionally been due to the plated through holes required to accommodate inserted package leads. With the elimination of hole drilling for surface mount packaging and the size reduction in the holes drilled for thermal/electrical vias, surface mounted substrates have the potential for a corresponding increase in reliability.

The problems of mating materials with unlike thermal coefficient properties have been addressed at the board level. by manipulating substrate materials and constructions, the magnitude of the stress which develops in the solder joint has been substantially reduced.

The operation of the component mounted generates heat in the component package at a greater rate than the substrate during powered operation, and, therefore, the lag time of the substrate heating causes stress to develop in the solder bond which connects the component to the substrate.

A summary of the failure modes and mechanisms of Printed Circuit Boards, Multi-wire Boards and Wire Wrap Boards that have been reported in the literature are as follows:

Printed Circuit Boards:

- Single sided
  - Open
    - Open Run
    - Delamination
    - Lifted Pad
    - Excessive acid etching during cleaning
    - Thermal expansion of different materials
    - Cracked solder joint
    - Cracked board

  - Short
    - Delamination
    - Thermal expansion of different materials
    - Excessive solder

  - Intermittent
    - Thermal expansion of different materials
    - Delamination
    - Cracked solder joint
    - Cracked board

Printed Circuit Boards (Cont'd):

- Multi-layer Boards including double sided
  - Open
    - Plated through hole failure
      - Thermal expansion of different material
      - Poor drilling process
      - Excessive acid etching during cleaning
    - Open run
      - Delamination
      - Lifted pad
      - Excessive acid etching during cleaning
      - Thermal expansions of different materials
      - Cracked solder joint
      - Cracked board
  - Short
    - Delamination
    - Thermal expansion of different materials
    - Excessive solder
  - Intermittent
    - Thermal expansion of different materials
    - Delamination
    - Cracked solder joint
    - Cracked board

Multi-wire Boards

- Short
  - Shorted run @ crossover
    - Wire insulation & wire deformation
      - Vibration
      - Thermal cycling

Multi-wire Boards (Cont'd)

- Open
  - Open Run
    - Delamination
    - Lifted Pad
    - Excessive acid etching during cleaning
    - Thermal expansion of different materials
    - Cracked solder joint
    - Vibration
    - Thermal cycling
    - Cracked board

- Intermittent
  - Thermal expansion of different materials
  - Delamination
  - Cracked solder joint
  - Cracked board

Wire-wrap Interconnection Boards

- Open
  - Delamination
  - Thermal expansion of different materials
  - Cracked board

- Intermittent
  - Poor connection between wire & wire post
    - Insufficient tension of wire
      - High vibration environment
  - Cracked board

- Short
  - Wire insulation cold flow

4.7.2 Interconnection Assembly/Printed Wiring Board MIL-HDBK-217E Model Review

The existing MIL-HDBK-217E model has been reviewed and the following deficiencies have been noted:

(1) Board materials other than epoxy-glass (FR-4, G-10) need to be included.

(2) Via holes used to provide interconnection between circuit planes need to be handled differently than plated through holes.

(3) Models must be made compatible with surface mount devices.

(4) It must be clearly and definitively stated that the interconnection assembly model pertains to the failure rates of both the printed wiring board and the solder connections.

(5) Provisions for flexible circuit boards need to be included.

(6) Wearout failure mechanisms including solder fatigue from temperature cycling needs to be addressed for both Surface Mount Devices and Plated through Holes.

(7) The various lead configurations including leadless, Gull Wing and S-lead need to be accounted for.

(8) Temperature cycling effects from the various environments need to be defined and accounted for.

4.7.3 Interconnection Assembly Model Development

Most of the models developed in this effort were derived primarily from field failure experience. There are several problems however in deriving a circuit board model in this manner. First, it is almost impossible to collect meaningful field data on circuit boards due to the fact that most maintenance activities will trace the failure of a populated board to a specific component and rarely attribute the failure to the board itself or the solder connection. Secondly, the model being developed herein is extremely sensitive to the temperature variations and cycling rates of a particular application. Since this data is not available for any data collected in this effort, the resulting data is of limited value. For these reasons, and the fact that many researchers have been studying and modeling SMT and PTH, the model for circuit board developed herein was developed from theoretical considerations and from laboratory test data. The single exception to this is the fact that part of the existing MIL-HDBK-217 model is used to model defect related PTH failures.

From the research conducted in this model development effort, it was concluded that the primary failure mechanism of surface mount devices is a common cause wearout mechanism due to solder joint fatigue. Plated through holes on the other hand exhibit both wearout from temperature cycling of the PTH barrel and defect related early and mid life failures due to incomplete filling of the hole and subsequent mechanical stresses. This is not to say that SMD assemblies are not prone to failure from defects, only that the predominant failure mechanism is wearout related.

Additionally while there is data to support a defect related failure rate for PTH assemblies, the field data necessary to accomplish this is not available for SMD assemblies. It will be shown later in this section that the wearout term is based on the Weibull distribution whose parameters have been empirically derived from test data. The shape parameter therefore will be representative of the observed values and will include the effects of defects.

The hypothesized model is therefore:

$$\lambda_p = \lambda_1(\alpha_1) + \lambda_2(\alpha_2) + \lambda_3\pi_{C1}\pi_Q\pi_{C2}\pi_E$$

where $\lambda_1(\alpha_1)$ = Average Life Cycle Failure Rate due to Surface Mounted wearout, function of α_1 (characteristic life) and Design Life Cycle. α_1 is a function of:

- Substrate X-Y axis TCE
- Device TCE
- Lead configuration
- Device size
- Temperature change

$\lambda_2(\alpha_2)$ = Average Life Cycle Failure Rate due to PTH wearout, functions of α_2 and Life Cycle. α_2 is a function of:

- Substrate Z axis TCE

- PTH material
- Substrate thickness
- Temperature change
- Temperature cycling rate

λ_3 = Defect related PTH base failure rate

π_{C1} = Complexity factor, function of number of PTH's

π_Q = Quality factor

π_{C2} = Complexity factor, function of number of board layers

π_E = Environment factor

The premise of this model is that there are basically two types of failures possible for PWB's:

(1) Common Cause - i.e., as a result of X-Y expansion mismatch resulting in fatigue (and hence wearout).

(2) Special Cause - i.e., defects in plated through holes that result in early and mid-life failures.

Special Cause (defect related) failures tend to have β's (from the Weibull distribution) close to 1 and therefore can be modeled with a constant failure rate. The probability of defect related failure mechanisms occurring is strongly a function of the quality of the fabrication process. Additionally, the screens for defect related failure mechanisms are typically very effective, indicating that the field failure rate is a strong function of both quality of the fabrication process and the screening to which the board is subjected.

Another premise of this model is that temperature cycling is the primary failure accelerating stress. While shock and vibration can also accelerate some failure mechanisms, it typically is only an issue in cases where the board is exposed to severe conditions of shock and vibration. These conditions can occur if the board is not damped enough or rigid enough and the applied stresses causes a resonance. While these are important reliability considerations, they are unpredictable due to the fact that they are special cause design problems and not related to the inherent reliability of the board itself. For this reason, the only stress the wearout failure mechanisms are a function of is temperature cycling. The environmental effects are, however, accounted for in the environment factor for defect related PTH failure rate.

Based on the assumption that PTH and via cracks are a function of defects, the failure rate contribution is treated in this model as exponential, corroborated by the conclusions in Reference 54. The solder joint fatigue contribution to the failure rate is a function of X-Y plane TCE matching and is treated in the model as a wearout item. The factors for this portion of the model are based on the Coffin-Manson model.

The methodology for performing the prediction is therefore:

(1) Identify the device on the board exhibiting the worst characteristic life. This will be a function of material (substrate and device) device dimensions, and solder height.

(2) Predict the characteristic life for this component and translate to a failure rate per the methodology in Section 2.3.

(3) Calculate λ_2.

(4) Calculate λ_3.

(5) Add failure rates to yield prediction of entire board.

The wearout failure rate is only calculated for the part exhibiting the lowest predicted number of cycles to failure. This occurs for the largest device exhibiting the largest mismatch in TCE. This was done simply for usability and to expedite the performance of reliability predictions using the model, and to avoid calculations which have little or no impact on the final predicted result. Reference 62 confirms this by stating that there is little risk from small passive devices and the predominant reliability risk comes from large ceramic chip carriers.

The via and PTH are separated since their reliability characteristics vary due to the fact that the PTH typically has a component lead through it and the via does not (solder only). This results in different thermal response characteristics.

Iannuyzelli (Reference 53) has shown that the manufacturing process can impact field reliability. This is based on the fact that damage is cumulative and that the manufacturing process exposes the assembly to the highest level of stress that will ever be seen. He concludes that the least to most damaging method is as follows:

- Wave Soldering
- SMT Repair
- Vapor Phase Soldering

Quantification of how these processes affect the field reliability of assemblies is not possible and therefore they will not explicitly be accounted for in the model.

The characteristic life α_1 and α_2 are based on the unmodified Coffin Manson model:

$$N_f = \frac{1}{2}\left(\frac{\Delta\gamma}{2\,\varepsilon_f'}\right)^{\frac{1}{c}}$$

where:

N_f = Mean number of temperature cycles to failure

$\Delta\gamma$ = Cyclic strain range

ε_f' = Fatigue ductility coefficient

c = Fatigue ductility exponent

The fatigue ductility exponent, c, is a constant in the unmodified version of the Coffin Manson model. Englemaier (Reference 62) has proposed a modified version of the Coffin-Manson model in which c, instead of being a constant, takes the following form:

$$c = -.442 - .0006T_S + .00174\ \ln(1+f)$$

where:

T_S = Mean cycle solder joint temperature

f = Cycling frequency

After reviewing this model and consulting with various industry experts, it was concluded that although the modified Coffin Manson model appears to be valid under some conditions, the unmodified version appears to be more universally accepted and applicable to a wider range of situations. For this reason, and to keep the models as simple as possible, the unmodified version is used in these models.

Generally accepted values of $2\varepsilon_f$ and $1/c$ are .65 and -2.26, respectively. Using these values, the mean number of cycles to failure can then be rewritten as:

$$N_f = \frac{1}{2}\left(\frac{\Delta\gamma}{.65}\right)^{-2.26} = N_{b(SMT)}\left(\frac{\Delta\gamma}{.65}\right)^{-2.26}$$

Here, $N_{b(SMT)}$ has been included in place of the constant $\frac{1}{2}$ since, as will be discussed later, it will be fit to empirical data.

The strain range, $\Delta\gamma$, is:

$$\Delta\gamma = \frac{d}{h}\left[\alpha_S(T_{SS} - T_o) - \alpha_{CC}(T_{CC} - T_o)\right]$$

d	=	Distance from neutral point (center of package) to solder joint
h	=	Solder joint height
α_S	=	TCE of substrate (board)
α_{CC}	=	TCE of chip (device)
T_o	=	Lower cycle extreme temp. (Pwr. off)
T_{CC}	=	Upper device temperature (Pwr. on)
T_{SS}	=	Upper substrate temp.

To use this model for failure rate predictions, values for TCE's (α_S, α_{CC}) and temperatures (T_o, T_{CC}, T_{SS}) must be derived as a function of operating environment. Ideally, the prediction would be performed based on knowledge of the actual values of a given application. Since this is rarely the case, however, default values must be available. The following discussion summarizes the derivation of these default values.

Temperature

A simplified thermal model for a surface mount device is as follows:

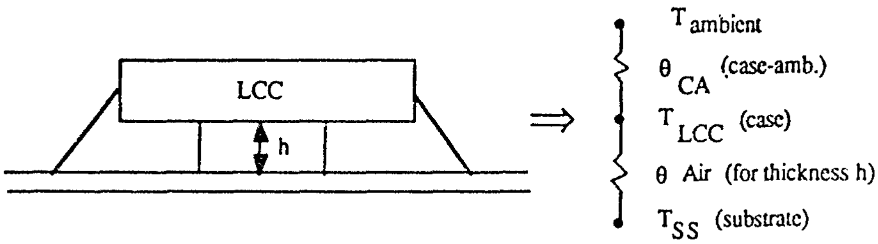


FIGURE 4.7-1:
THERMAL MODEL

The thermal resistance between the junction and case (θ_{JC}) is much lower than the thermal resistance of the case to ambient (i.e., $\theta_{JC} << \theta_{CA}$), which is obvious by examining typical θ_{JC} and θ_{JA} values ($\theta_{JA} << \theta_{JC}$). This indicates that the case temperature (T_{CC}) will be higher than the substrate temperature by an amount of temperature rise due to power dissipation. This temperature rise can be calculated in two ways, as is currently done in MIL-HDBK-217 models:

$$T_{RISE} = P\,\theta_{JC}$$

where:

P = Power dissipated by device.

θ_{JC} = Thermal impedance between the junction and case.

or:

$$T_{RISE} = (\Delta T)(S)$$

where:

S = The electrical stress on the device divided by its maximum rated stress.

ΔT = Temperature difference between zero stress and full rated stress.

Figure 4.7-2 illustrates the thermal profile for this situation as a function of time.

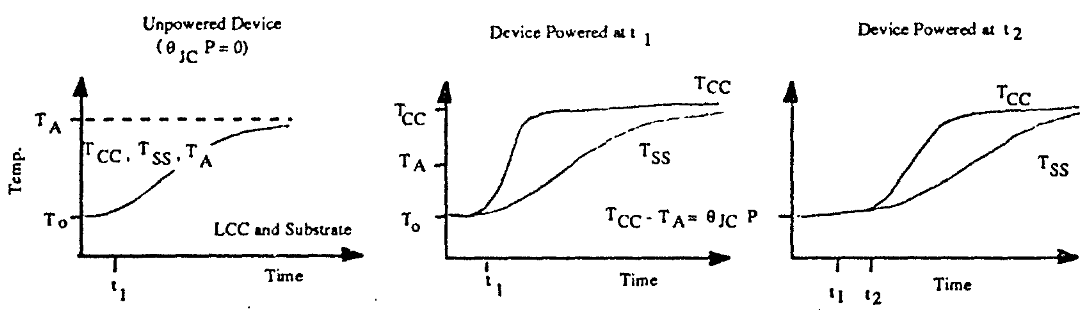


FIGURE 4.7-2: THERMAL PROFILE

t_1 = Time assembly is introduced into higher ambient temperature.

The worst case difference between the case and substrate temperature is θ_{JC} P:

$$T_{CC} - T_{SS} = \theta_{JC}P$$

Therefore, if T_A is the ambient temperature in the use environment, T_o is the ambient temperature when the equipment is in the dormant state:

$$T_{CC} = T_A + \theta_{JC}P$$
$$T_{SS} = T_A$$

The strain range can therefore be rewritten as:

$$\Delta\gamma = \frac{d}{h}\left[\alpha_S(T_A - T_o) - \alpha_{CC}(T_A + \theta_{JC}P - T_o)\right]$$

Reference 55 has derived default values of ΔT as a function of application environment. (In the analysis herein $\Delta T = T_A - T_o$). The ΔT values in Reference 55 are being proposed with the exception of the ground application environments. For these, ΔT is approximately 5°C for temperature controlled volumes and 10°C for uncontrolled volumes. In any case however, the temperature rise from a nearby heat source must be accounted for. For example the ΔT for an underhood G_M environment is much greater than other G_M environments where there is no heat source. Table 4.7-1 summarizes the ΔT from Reference 55, the T_A, T_o and ΔT values determined herein as a function of environment.

TABLE 4.7-1:
ENVIRONMENT ΔT VALUES

Proposed Environment	MIL-HDBK-217E Environment	ΔT (Ref. #55 Recommended)	T_A	T_o	ΔT
G_B	G_B, G_{MS}	30	30	23	7
G_F	G_F	55	40	14	26
G_M	G_M, M_P	55	35.	14	11
A_{IC}	A_{IC}, A_{IB}, A_{IT}	30	55	14	31
A_{UC}	A_{UC}, A_{UT}, A_{UB}	55	71	14	57
A_{IF}	A_{IA}, A_{IF}	30	55	14	31
A_{UF}	A_{UF}, A_{UA}	55	71	14	57
A_{RW}	A_{RW}	30	55	14	31
N_U	N_U, N_{UU}, N_H	55	75	14	61
N_S	N_{BS}, N_S	50	40	14	26
M_L	U_{SL}, M_L	50	55	14	31
M_F	M_{FF}, M_{FA}	50	45	14	31
C_L	C_L	50	40	14	26

T_A, obtained from MIL-HDBK-217E, defines default ambient temperatures as a function of application environment. These are worst case values and the actual ambient operating temperature should be used to calculated ΔT if possible. Also temperature rise from a nearby heat source must be accounted for.

T_o is the ambient temperature when the equipment is not in operation. Ref. #65 has determined that the average outdoor ambient temperature in the continental U.S. is 14°C. Therefore, 14°C will be used for T_o in uncontrolled outdoor environments. With the exception of ground benign , all environments are considered in this category. Ground benign is a controlled environment for which an ambient temperature is typically 23°C.

With the exception of G_B and G_F environments, the ΔT values arrived at agree very well with the recommended ΔT values published in Reference 55, thus lending a degree of confidence in the values.

The number of cycles to failure is therefore:

$$N_f = N_{b(SMT)}\left(\frac{d}{.65h}\,|\,\alpha_S(T_{SS}-T_o) - \alpha_{CC}(T_{CC} - T_o)\,|\times 10^{-6}\right)^{-2.26}$$

or:

$$N_f = N_{b(SMT)}\left(\frac{d}{.65h}\,|\,\alpha_S\,(\Delta T) - \alpha_{CC}\,(\Delta T + T_{RISE})\,|\times 10^{-6}\right)^{-2.26}$$

where:

α_S = Circuit board substrate TCE

ΔT = Environmental ΔT

α_{CC} = Device TCE

T_{RISE} = Temperature rise due to power dissipation

Although the above equation is specifically applicable to SMT solder joints, it will be extended to model PTH wearout failures.

Table 4.7-2 summarizes the X-Y thermal expansion coefficient for various circuit board substrate materials (extracted from References 56-63). Table 4.7-3 summarizes the TCE's of package material, Table 4.7-4 summarizes the PTH/via material TCE's, and Table 4.7-5 summarizes the TCE values of the Z axis.

TABLE 4.7-2: X-Y TCE VALUES

Substrate Material	TCE $\left(\frac{PPM}{°C}\right)$	Reference	Average Val .e
FR-4 Laminate	12-24	63	18
FR-4 MLB	16-24	63	20
FR-4 MLB w/Cc pper Clad Invar	86-14	63	11.3
Ceramic MLB	6.0-8.3	63	7.15
Copper Clad Invar	6.4 5 3-6	57 56 62	5.1
Copper Clad Molybdenum	5	56	5
Carbon-Fiber/Epoxy Composite	-.5-+2	56	.75
Kevlar Fiber	(-2)-(-4)	56	-3
Quartz Fiber	.54	56	.54
Glass Fiber	4-5	56	4.5
Epoxy/Glass Laminate	14-18 13-18 12-16	58,60 62 56,57	15.17
Polyimid/Glass Laminate	12-16 11-14	62,58,60 56	13.25
Polyimid/Kevlar Laminate	4-8 3-7	57 56	5.5
Polyimid/Quartz Laminate	6-8 6-12 6-9	62,57 58,60 56	7.8

TABLE 4.7-2: X-Y TCE VALUES (CONT'D)

Substrate Material	TCE $\left(\frac{PPM}{°C}\right)$	Reference	Average Value
Epoxy/Kevlar Laminate	6-8 6-7	57 56	6.75
Aluminum (Ceramic)	6.5	57	6.5
Epoxy Aramid Fiber	6-8	62,60,58	7
Polyimid Aramid Fiber	3-7 5-8	62 60,58	5.75
Epoxy-Quartz	6-12	60,58	9
Fiberglass Teflon Laminates	20	62,60,58	20
Porcelainized Copper Clad Invar	6-7	58	6.5
Fiberglass Ceramid Fiber	5-8	60	6.5

TABLE 4.7-3:
TCE'S OF PACKAGE MATERIALS

Substrate Material	TCE $\left(\frac{PPM}{°C}\right)$	Reference	Average Value
Plastic Chip Carriers	6-7	56	6.5
Ceramic Chip Carrier	5-7	56	5.6

TABLE 4.7-4:
PTH/VIA MATERIAL TCE VALUES

Material	TCE (ppm/°C)
Solder	27
Copper	17

TABLE 4.7-5:
Z AXIS TCE VALUES

Material	TCE (ppm/°C)
Epoxy Glass Laminate	175
Kevlar	20

Lead Configuration Factor

Reference 66 has performed a Finite Element Evaluation of stresses induced in solder connections of various styles lead configuration. Using these calculated stresses and the Coffin Manson Model, a number of cycles to failure was estimated. These results from Reference 66 are given in Table 4.7-6.

TABLE 4.7-6:
LEAD CONFIGURATION N_f (REF. #66)

Lead Configuration	N_f	Geometric Mean
S Lead	11,500-60,000	26,000
Leadless	120-260	175
Gull Wing	400,000-2,000,000	895,000

The geometric mean of these ranges can be used in the model developed herein as a relative figure of merit between lead configurations. This factor is normalized to the leadless configuration since the model developed herein is normalized to the leadless configuration. Therefore, the lead configuration modification factor is given in Table 4.7-7.

TABLE 4.7-7:
LEAD CONFIGURATION FACTOR

Lead Configuration	π_{LC}
Leadless	1
S Lead	150
Gull Wing	5,000

The study producing these values (Reference 66) used an 8 mil solder joint height for the leadless configuration. Since the model is normalized to the leadless configuration, predictions for S Lead and Gull Wing Configurations should use h = 8 in the equations.

The PWB model yields a failure rate in failures per calendar time since the accelerating stresses are power cycling related and not related to operational time. Therefore, the mean cycles to failure predicted must be converted to mean hours to failure. This is done first by identifying the number of temperature cycles per calendar hour for a given application. The conversion is therefore:

$$\alpha \text{ (Calendar Time, } 10^6 \text{ hrs.)} = N_f \times \text{(Cycling Period)}$$

where:

α is the characteristic life, in 10^6 hrs.

N_f is the predicted mean cycles to failure

Cycling Period = Average calendar time per temperature cycle (in 10^6 hrs./cycles)

If the actual cycling period is not known, the default periods listed in Table 4.7-8 should be used. These values are obtained from Reference 55.

TABLE 4.7-8: CYCLING RATE VALUES

Equipment Type	Number of Cycles per 10^6 hrs.
Consumer	4200
Computers	170,000
Telecommunications	4200
Commercial Aircraft	340,000
Industrial	21,000
Military Ground Applications	30,000
Military Aircraft	115,000

It would be desirable to define the absolute values of MTTF and β based on empirical data for a given process since there can be large degrees of variability as a function of the manufacturing process. Theoretical models, such as the Coffin Manson model, although based on sound physics of failure principals, do not necessarily offer an accurate absolute measure of the number of cycles to failure. Additionally, they provide only MTTF information and do not estimate the variance or Weibull shape parameter (β) in a given process. For situations in which the circuit board design is robust enough to function reliably in a given application for long periods of time, the failure rate is highly dependent on the value of β. Although the β is highly process dependent, and can indeed vary significantly within a given process, a worst case value should be used unless it can be shown through empirical data that another β value is appropriate for a given process. Using a conservative β will also serve to account for some of the early life defect related failure mechanisms.

PTH Wearout Modeling

PTH wearout modeling is accomplished in essentially the same manner as surface mount devices since the predominant failure mechanism is also mechanical fatigue due to TCE mismatches. The differences is that instead of the fatigue occurring in the solder joint, the fatigue occurs in the Z-axis between the board material and PTH material. Therefore, for this situation the number of cycles to failure model becomes:

$$N_f = \left(\frac{X}{T} \left| [\alpha_{SZ}(\Delta T) - \alpha_2(\Delta T + T_{RISE})] \right|\right)^{-2.26}$$

where:

X = Constant to be fitted to observed time to failure data.

T = The board thickness (in mils)

α_{SZ} = The Z axis TCE of the substrate

α_2 = The TCE of the PTH material

Table 4.7-9 summarizes the data set for PTH wearout. Detailed cycles-to-failure data was available for a variety of conditions. This data was plotted on Weibull paper to derive the characteristic life and β. Contained in this table is the board thickness in mils, T_o (-55°C), T_S (125°C), ΔT, TCE of the board, TCE of the PTH material, observed MCTF (Mean Cycles to Failure), the characteristic life (Weibull α), Weibull shape parameter (β), the strain gauge (excluding d, h), and the calculated value of X. This value of X was derived such that the observed MCTF is equal to the predicted. The geometric mean of these values of X is .0061. Therefore the predicted PTH wearout number of cycles to failure is:

$$N_{f(PTH)} = \left[\frac{.0061}{T} \left| (\alpha_{SZ}(\Delta T) - \alpha_2(\Delta T + T_{RISE})) \right|\right]^{-2.26}$$

TABLE 4.7-9: PTH DATA

Board Thickness (Mils)	T_o (°C)	T_s (°C)	ΔT (°C)	α_s TCE (subst.)	α_c TCE (copper)	Observed MCTF	Characteristic Life (Cycles)	β	$\left[\left(\alpha_s(\Delta T) - \alpha_c(\Delta T)^{2.26}\right)\right]$ (10^{-9})	x
100	-55	125	180	7.2	17	112	104	3.1	46	.0071
100	-55	125	180	7.2	17	153	128	4.0	46	.0062
100	-55	125	180	7.2	17	183	128	1.6	46	.0057
100	-55	125	180	20.9	17	98	96	5.0	369	.019
100	-55	125	180	20.9	17	113	112	2.5	369	.018
100	-55	125	180	20.9	17	240	235	2.6	369	.013
100	-55	125	180	8.1	17	360	410	2.6	57	.0046
100	-55	125	180	8.1	17	360	345	3.0	57	.0046
100	-55	125	180	8.1	17	312	300	4.5	57	.0049
100	-55	125	180	7.7	17	337	410	3.5	51	.0046
100	-55	125	180	7.7	17	–	> 1050	-	51	-----
100	-55	125	180	7.7	17	–	> 1050	-	51	-----
100	-55	125	180	---	17	120	112	4.5	–	-----
100	-55	125	180	---	17	170	155	4.0	–	-----
100	-55	125	180	---	17	602	560	4.0	–	-----
62	-55	125	180	9.1	17	242	230	2.6	75	.0039
62	-55	125	180	9.1	17	228	220	3.5	75	.0040
62	-55	125	180	9.1	17	113	88	3.0	75	.0054
40	-55	125	180	10.1	17	127	92	1.7	102	.0038
40	-55	125	180	10.1	17	265	250	4.8	102	.0027
40	-55	125	180	10.1	17	50	50	> 10	102	.0058
50	-55	125	180	8.1	17	144	145	2.9	57	.0035
50	-55	125	180	8.1	17	145	130	3.5	57	.0035
50	-55	125	180	8.1	17	190	150	1.5	57	.0025

SMT Wearout Modelling

As stated previously, the MCTF for surface mounted devices is:

$$N_{f(SMT)} = N_{b(SMT)} \left(\left[\frac{d}{.65h} \left| (\alpha_S(\Delta T) - \alpha_{CC}(\Delta T + T_{RISE})) \right| \right] \times 10^{-6} \right)$$

$N_{b\ SMT}$ has been added as a replacement to the 1.32 constant to adjust the model in accordance with the best data available. The 10^{-6} factor has also been included to account for units used. Table 4.7-10 summarizes the data used and includes d (in mils), h (in mils), ΔT, TCE of the substrate (α_S), TCE of the ceramic package (α_{CC}), observed mean cycles to failure (MCTF), Weibull characteristic life (α), Weibull shape parameter β, and the $N_{b(SMT)}$ calculated such that the observed MCTF equals the predicted for each data point.

The characteristic life differs from the mean cycles to failure primarily due to the fact that in some cases there were large variances in the data, and the best fit Weibull line often yields a characteristic life which differs from the true MCTF.

As can be seen from this data that there is a large degree of variation between the predicted MCTF and the observed. Part of this variation is a result of the uncertainty in the TCE of both the substrate and device and part is due to the inherent variation in the observed MCTF. As can be seen in Table 4.7-10, there are several values of $N_{b(SMT)}$ that are significantly higher than the rest of the population. Therefore, the model may be more sensitive to the input variables than is indicated by the data. Since these outlier datapoints significantly increased the calculated $N_{b(SMT)}$ value, they were discarded from the dataset and the geometric mean was calculated. This resulted in a $N_{b(SMT)}$ value of 3.5, which will be used in the model. This effort also highlights the fact that the model is extremely sensitive to the TCE values and suggests that, to obtain accurate results, accurate data must be supplied.

The final wearout model for SMT wearout is therefore:

$$N_{f\ (SMT)} = 3.5 \left[\frac{d}{.65\ h} \left| (\alpha_s(\Delta T) - \alpha_{CC}(\Delta T + T_{RISE})) \right| \times 10^{-6} \right]^{-2.26}$$

To use the wearout modeling methodology proposed in this study, a representative Weibull shape parameter β must be derived. The histograms in Figures 4.7-3 and 4.7-4 summarize the distribution of observed β's from the data presented previously for both PTH's and SMT's.

TABLE 4.7-10: SUMMARY OF LCC WEAROUT DATA

d (Mils)	h (Mils)	ΔT (°C)	α_s (ppm/°C)	α_{cc} (ppm/°C)	MCTF	Characteristic Life (α)	β	$\left[\frac{d}{.65h}\left(\alpha_s(\Delta T) - \alpha_{cc}(\Delta T + T_{RISE})\right)10^{-6}\right]^{2.26}$	$N_{b(SMT)}$ MCTF/Strain Gauge
740	3	155	15.2	6	747	750	6	4.01	187
600	3	155	15.2	6	970	1000	5	6.4	151
740	3	155	15.2	6	624	700	3.8	4.01	156
600	3	155	15.2	6	767	760	5	6.4	120
740	3	155	6.75	6	453	420	3	8.1	56
600	3	155	6.75	6	678	620	2.4	1858	.36
740	3	155	6.75	6	256			1157	.22
600	3	155	6.75	6	362			1858	.19
740	3	155	6.75	6	306			1157	.26
600	3	155	6.75	6	267			1858	.14
740	3	180	15.2	6	810			.0067	120, 895
740	3	180	15.2	6	700			.0067	104, 478
600	3	180	15.2	6	888			4.6	193
740	3	180	15.2	6	698	560	2.3	2.8	150
600	3	180	15.2	6	1050	1050	5	4.6	228
740	3	180	15.2	6	847			2.8	302
600	3	180	15.2	6	1138			4.6	247
740	3	180	6.75	6	432			825	.52
600	3	181	6.75	6	488			1325	.36
740	3	180	6.75	6	716			825	.87
600	3	180	6.75	6	1020			1325	.77
740	3	180	6.75	6	292	310	1.8	825	.35
600	3	180	6.75	6	352	440	1.3	1325	.26
740	3	180	6.75	6	147			825	.18
600	3	180	6.75	6	306			1325	.32
740	3	180	15.2	6	475	560	4.5	.0067	70,000
600	3	180	15.2	6	660	700	4.5	4.6	143
740	3	180	15.2	6	526			.0067	78,000
600	3	180	15.2	6	667			4.6	145
740	3	180	15.2	6	564			.0067	84,000
600	3	180	15.2	6	653			4.6	142
740	3	180	6.75	6	426			825	.51
600	3	180	6.75	6	340			1325	.25
740	3	180	6.75	6	428			825	.52
740	3	180	6.75	6	223			825	.27
600	3	180	6.75	6	292			1325	.22
740	3	180	6.75	6	53			825	.064
600	3	180	6.75	6	213			1325	.16

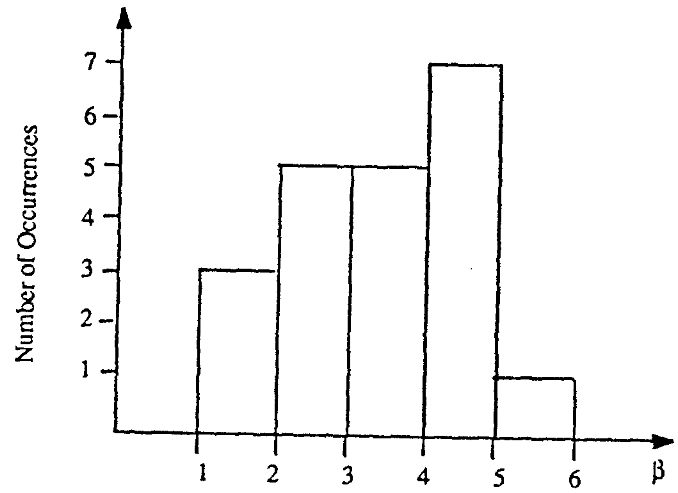


FIGURE 4.7-3: PTH β DISTRIBUTION

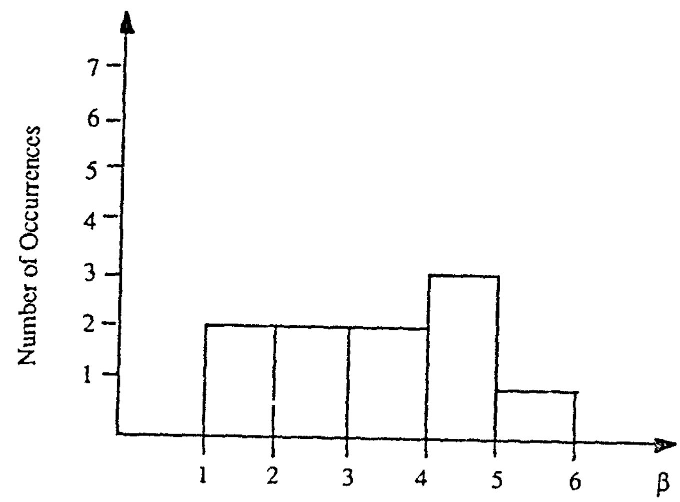


FIGURE 4.7-4: SMT β DISTRIBUTION

The mean value of PTH β's is 3.3 and the mean value for SMT β's is 3.7. The fact that there is such a wide variation in values for a single manufacturing process indicates the variability inherent in this modeling process. However, conservative β's of 3 for both cases will be used as representative values.

Defect Related Failure Rates

The defect related failure rate term is modeled as a constant failure rate. For these failure mechanisms, the screening effectiveness tends to be very high, indicating that a quality factor is applicable. The model currently contained in MIL-HDBK-217E contains provisions for all necessary model variables associated with early and mid life failures. It also indicates that there is a linear relationship between failure rate and number of PTH's. Reference 67 presents data indicating that the reject rate of both double sided and multilayer boards is directly proportional to both the board area and the number of holes. This indicates that the number of defects are also directly related to the number of holes. This observations lends an additional degree of confidence in the current model to be used herein for modeling defects.

Since inadequate field data was collected during this study, the current model is used as a baseline. The derivation methodology was to assume that a percentage of the current MIL-HDBK-217 failure rate are actually failures accounted for by the wearout modeling discussed previously. This percentage was derived by calculating a PTH wearout failure rate for a typical printed wiring board used in a typical application. The parameters for this calculation is as follows:

Board Thickness = 100 mils

$\Delta T = 30°C$

$\alpha_S = 14$ (Glass Epoxy)

$\alpha = 17$ (Copper)

Number of PTH's = 700

Life Cycle = 5 years*

MIL Spec. Quality

A_{IF} Environment

8% Rework

4 Circuit Planes

All PTH's Wave Soldered

$\theta_{JC}P = 10°C$

(*5 years is used for the life cycle since it is the approximate time period over which the original data was collected in support of the current MIL-HDBK-217 model).

The PTH wearout prediction is therefore:

$$N_f = \left(\frac{.0061}{100} \mid [14\ (30) - 17\ (30 + 10)] \mid\right)^{-2.26}$$

$$N_{f\,PTH} = 11{,}676 \text{ cycles}$$

The expected cycling rate in the use environment is 360 cycles per year. Equating the MCTF to mean-time-to-failure yields:

$$\alpha = \frac{11676 \text{ (cycles)}}{360 \frac{\text{cycles}}{\text{year}}} = 32 \text{ year MTTF (calendar time)}$$

λ_1 = .15 (using the table in Section 2.3 with $\beta = 3$ and $LC/\alpha = \frac{5}{32} = .2$ (rounded up))

$$\lambda = \frac{.15}{\alpha} = \frac{.15}{32 \text{ years}} = \frac{.15}{.28 \times 10^6} = .5\ F/10^6 \text{ hrs.}$$

The prediction using the current MIL-HDBK-217E model is:

$$\lambda_p = \lambda_b \pi_Q \pi_E \left[n_1\, \pi_C + n_2\, (\pi_C + 13) \right]$$

$$= (.000041)(1)(10)\ [700\ (2 + 100\ (2 + 13))]$$

$$= 1.19\ F/10^6 \text{ hrs.}$$

Therefore, an average of 42% $\left(\frac{.5}{1.19}\right)$ of the current models failure rate is accounted for in the PTH wearout failure rate. The current models base failure rate is therefore scaled in accordance with this percentage and, with this exception, is left largely intact. The primary assumption made in this model is that the defect rates have not changed dramatically since the current model was developed. While this may not be entirely true for conventional low complexity board types, newer boards of higher complexity can have higher defect rates. There was no evidence however to refute the fact that, on the average, board defect rates have stayed relatively constant. A summary of the defect (PTH) model is as follows:

The failure rate model for plated through hole (PTH) assemblies is:

$$\lambda_p = \lambda_b \pi_Q \pi_E \left[n_1 \pi_C + n_2 (\pi_C + 13) \right] \cdot DC$$ (failures/10^6 calendar hours/assembly)

where:

λ_p	=	Base failure rate in F/10^6 hrs., Table 4.7-11
π_Q	=	Quality factor, Table 4.7-12
π_E	=	Environment factor, Table 4.7-14
n_1	=	Quantity of wave soldered functional PTH's
n_2	=	Quantity of hand soldered PTH's
π_C	=	Complexity factor, Table 4.7-13
DC	=	Duty cycle, % of calendar time the circuit is operating. (necessary to convert to failures per calendar time so it can be added to λ_{PTH}, and λ_{SMT})

TABLE 4.7-11: BASE FAILURE RATE λ_b

Technology	λ_b (Failures/10^6 Hours)
Printed Wiring Assemblies	.000017
Discrete Wiring w/Electroless Deposited PTH*	.00011

*Applies to two or less levels of circuitry.

TABLE 4.7-12: QUALITY FACTOR π_Q

Quality Grade	π_Q
Manufactured to MIL-SPEC. or comparable IPC Standards	1
Lower Quality	2

TABLE 4.7-13:
COMPLEXITY FACTOR π_C

Number of Circuit Planes	π_C
≤ 2	1
3	1.3
4	1.5
5	1.8
6	2.0
7	2.2
8	2.4
9	2.6
10	2.7
11	2.9
12	3.1
13	3.2
14	3.4
15	3.5
16	3.7
Discrete Wiring w/PTH	1

For greater than 16 circuit planes,

π_C = $.65\ C^{.63}$

C = quantity of circuit planes

TABLE 4.7-14:
ENVIRONMENTAL MODE FACTORS

Environment	π_E
G_B	1
G_F	2.0
G_M	7.0
N_S	13
N_U	5.0
A_{IC}	5.0
A_{IF}	8.0
A_{UC}	16
A_{UF}	28
S_F	.5
M_F	10
M_L	27
C_L	500

4.8 ROTATING DEVICES

Rotating devices are energy-converting devices used in a variety of applications. These devices fall into the general categories of motors and generators. Motors convert electrical energy into mechanical torque, and generators convert mechanical torque energy into electrical energy. For each design there are several variations which are used depending on the application. The list below identifies types of generators and motors:

Motors:
- Induction
- Direct current
- Single-phase
- Poly-phase

Generators:
- Single-phase
- Poly-phase
- Externally excited
- Internally excited

The devices are generic categories of rotating devices. Within each category there are a variety of device styles and types which have specific operating characteristics for a given application. For example, the use of poly-phase motors has the widest general application of any type of motor because of its characteristics of good speed regulation and high starting torque. More importantly the simplicity of the poly-phase motor construction results in less maintenance and higher reliability.

4.8.1 Rotating Device Failure Modes and Mechanisms

The life limiting components affecting the failure rate of rotating devices are bearings, windings and brushes. The primary failure accelerating stress acting on these components is temperature. Sources of the damaging temperature are the environment and the load requirements of the driven device in the case of a motor, or the required electrical load in the case of a generator. Temperature cycling stresses degrade the insulation material on the field windings and armature windings resulting in the reduction of magnetic efficiency and increase of temperature rise. Temperature affects the viscosity of the lubrication necessary for long bearing life. As temperature cycling occurs at an increasing rate the reliability of the bearings will decrease. Brush wear increases as a function of armature speed, temperature, and electrical power transfer which is the most dominant of these stresses.

There are several manufacturing procedures which must be monitored to ensure an efficient and reliable rotating device. Bearing alignment, and armature and field (or permanent magnet) matching is critical to the efficiency because of the lines of flux being cut at precise distances through the rotational area. Clearances between the armature and fields correlate to the efficiency of the rotating device. The closer the tolerance, the more efficiently the flux lines are cut resulting in the higher output levels. Misalignment of the bearings or non-parallelism of the armature and fields can cause internal heat build-up amplified with additional load requirements and resulting in acceleration of the degradation process.

Device variations for rotating devices are based on the load requirements. The design variations which primarily affect reliability are complexity and size. Full horsepower vs. fractional horsepower motors require a completely different approach to design. Full horsepower motors, designed for higher loads, tend to experience additional bearing loads and generate more internal heat. Complexity of the rotating devices directly affects reliability. Motors needing assistance in initial start-up (including capacitive start motors) are more complex and have a higher failure rate. DC or AC rotating devices with brushes have additional design complexities which affect failure rate.

Typical qualification tests performed on a sample of motors or generators are functional in nature. Types of testing performed include torque generating, electrical power generation, speed control and temperature rise. These tests are effective methods in determining the quality of manufacturing when collated into a comprehensive monitoring program.

If properly designed, rotating devices are selected for specific applications and should provide reliable service. There are, however, application variables which do have a negative effect on reliability. On-off cycling or cyclic loads create internal heat generation resulting in accelerated degradation of starting components and windings. Environmental effects of contamination and ambient temperature including temperature cycling also have a negative effect on reliability.

The primary failure mechanisms for all types of motors are a function of the electrical or mechanical stresses that the windings and bearings experience. Windings experience degradation of their insulation and hence their ability to produce a sufficient magnetic field. The primary accelerating factor for insulation degradation is temperature. More specifically, the temperature rise in the winding during motor operation. According to Reference 80, "If two motors are running with a 10°C differential in temperature, the hotter motor's service life expectancy is reduced by one-half."

The class of insulation (A through F) designates the operating temperature limit the insulation can operate at and still maintain its integrity. Reference 80 indicates, "A motor operating within Class B temperature limitations and having a Class F insulation system that has a higher temperature rating is operating below its temperature rating. The cooler motor's insulation will be subject to a much lower degradation than that of the hotter running motor and will experience a longer life." Therefore, the conclusion derived from information collected is that the primary accelerating factor for windings in motors is ambient temperature and temperature rise. This is entirely consistent with the current MIL-HDBK-217E model.

Bearing failure mechanisms, such as galling or branell hardening are caused by the lack of lubrication. Lubrication loss can be traced to two operating characteristics, load and speed. These characteristics generate heat which increases the failure acceleration process. Load and speed influence reliability, but are normally designed for a specific application. Temperature again is the primary failure accelerating stress which results in the loss of the protective film on the bearing surface. Most susceptible to this occurrence are motors with heavy loads requiring frequent starts and stops. As stated by Lincoln manufacturing, "Bearings fail primarily because of heat. Contamination from a minute particle of dust, dirt or even cigarette ash will cause the bearing to run hot enough to melt the grease that will then run out ... grease that is moisture resistant and has a operating range from -35° to 350°F ... and bearing sized for 40 to 50,000 hours of life is the standard design criteria for most motors."

In summary, temperature, reducing the motor life by as much as 1/2 per 10°C rise, is the dominant accelerating factor for motors.

4.8.2 Current MIL-HDBK-217E Motor Model Review

Shaker Research (Reference 79) had developed the current MIL-HDBK-217E model. In that study the failure data collected are predominantly comprised of life test results. It was analyzed by means of a Weibull cumulative distribution analysis of each individual test population. The results provided a linear regression best fit Weibull slope and characteristic life for each test group of motors. Additional regression techniques are applied to determine the influence of parameters such as temperature, speed, bearing lubricant, motor type, etc., on characteristic life.

The current model considers bearing and winding to be the dominant factors in motor failure. These failure mechanisms are predominantly accelerated by temperature. The data collected during this study indicates that there are three major failure modes, they are:

Bearings failures	80.85%
Electrical failures	16.55%
Mechanical failures	2.60%

It is apparent that bearing failures are the dominant failure mode. This finding also explains why the Reference 79 model emphasizes the bearings and windings only for their model. Although temperature is the primary failure accelerating stress, additional variables include: bearing size, quality code and grease type. Among these variables the most dominant is grease.

Additional observations from review of the current MIL-HDBK-217 model are as follows:

(1) Full Horsepower (FLHP) rotating devices should be considered as an addition to the present reliability model. Brushes, as an additional failure mechanism, should also be considered.

(2) When considering FLHP motors, a distinction must be made based on the loading characteristics and power consumption affecting temperature life limiting characteristics.

(3) Technology has changed in the form of newer materials, resulting in increased efficiency of rotating devices. These changes should be accounted for in the models. These newer materials include:

- Insulation materials with higher temperature ratings.
- Higher magnetic density in permanent magnets.
- Brush material advances resulting in less wear and increases in power delivery.

(4) A major flaw in the current 217 motor model is that it uses a hazard rate for the failure rate. This is accurate if the total cumulative percent fail of a given population, for a given life cycle, is relatively low. If it is not, then it is very inaccurate (and pessimistic) since the hazard rate provides the instantaneous failure rate on the condition that the part has not yet failed. This results in predicted failure rates approaching infinity where in reality it reaches

an asymptotic value. Figure 4.8-1 illustrates this concept. The point the two curves begin to depart are approximately at a time equal to one α.

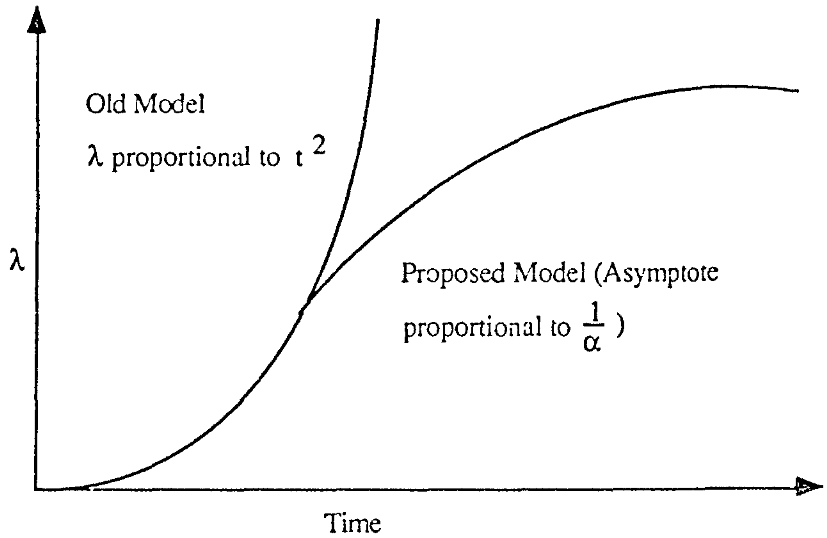


FIGURE 4.8-1:
FAILURE RATE FOR NEW AND EXISTING MOTOR MODEL

4.8.3 Rotating Device Model Development

4.8.3.1 Hypothesized Motor Model

Since both bearing and winding failures are normally wearout failures, they will be modeled in accordance with the methodology outlined in Section 2.3. The hypothesized model is therefore:

$$\lambda_p = \left(\frac{\lambda_{CB}}{\alpha_{BP}}\right) + \left(\frac{\lambda_{CW}}{\alpha_{WP}}\right)$$

λ_{CB} = Cumulative average failure rate for bearings as a function of LC/α and β

α_{BP} = Weibull characteristic life predicted for bearings

$= \alpha_{BB}\pi_T\pi_L\pi_{HP}\pi_R$

α_{BB} = Base characteristic life, function of generic motor type

π_T = Temperature factor

π_{HP} = Rated horse power

π_R = Rotation rate factor

λ_{CW} = Cumulative average failure rate for windings as a function of LC/α and β

α_{WP} = Weibull characteristic life predicted for windings

= $\alpha_W \pi_T \pi_I$

π_T = Temperature factor

π_L = Load (mechanical) factor

π_I = Insulation class factor

4.8.3.2 Motor Data Analysis

The collected motor data was analyzed in an attempt to quantify the motor life times and failure rates as a function of the parameters outlined in the hypothesized model. Unfortunately, the effects of actual mechanical load stress, rated horsepower, and rotation rate factor could not be quantified due to the fact that these quantities were not known for most of the observed data points. The bearing characteristic life (α) and failure rate is therefore a function of only generic motor type and operating temperature.

The model developed in Reference 79 was based on thorough research and a good set of data and therefore the temperature dependence of the model should be accurate. The approach therefore was to use the current base failure rate as a function of temperature and scale the model for each generic type of motor for which data existed.

The following items summarize the assumptions and methodologies used:

- Ambient temperatures for each environment from Reference 64 were assumed.

- The LC/α ratio was assumed to be $\leq .1$ for commercial data (since it is from 1st year warranty and the fact that the observed failure rates were low). In this case the LC is the time period over which the data is collected.

- The LC/α ratio was assumed to be >2 for military data since it is generally data from systems that have been fielded for years and the fact that the observed failure rates are generally high. This assumes the failure rate has reached its asymptotic value (see Section 2.3).

- The calculations assume that 20% of the observed motor failures are due to windings and 80% bearings.

- The observed β values from Reference 79 are generally between 2 and 3. A value of 3 will be used in this model.

Table 4.8-1 summarizes the data and analysis for motors. The α was calculated in the following manner:

$$\lambda_{obs} = \frac{\lambda_1}{\alpha}$$

$$\alpha = \frac{\lambda_1}{\lambda_{obs}}$$

λ_1 = Cumulative average failure rate over time period from which data was taken (from table in Section 2.3)

TABLE 4.8-1: MOTOR DATA ANALYSIS

Motor Type	Environment	Hours (10^6)	Failures	$\frac{LC}{\alpha}$	Temp.	Characteristic Life from Current Model α_B	α_w	Observed λ ($F/10^6$) Bearing λ ($.8\lambda_{obs}$)	Winding λ ($.2\lambda_{obs}$)	Calculated Base α's $\alpha_{B(obs)}$	$\lambda_{w(obs)}$	Observed (217E Predicted Ratio) $\frac{\alpha_{B(obs)}}{\alpha_{B(217E)}}$	$\frac{\alpha_{w(obs)}}{\alpha_{w(271E)}}$
Electric	A_U	5.085	785	2	71	21,700	1.1×10^5	123.5	30.9	8,130	32,360	.375	.294
	A_I, A_{RW}	4.69	68	2	55	43,800	2.3×10^5	11.6	2.90	86,207	344,800	1.97	.667
	G_B	294.98	104	.1	30	78,300	8.9×10^5	.28	.07	3.5×10^6	14×10^6	44.7	15.7
	G_F	189.52	457	2	40	80,200	5.0×10^5	1.93	.48	518,000	2.08×10^6	6.46	4.16
	N_S	8.164	173	2	40	80,200	5.0×10^5	16.9	4.24	59,000	235,800	.736	.47
	N_U	.049	6	2	75	17,300	8.8×10^4	97.9	24.5	10,200	40,800	.590	.464
	G_M	.145	4	2	55	43,800	2.3×10^5	22.1	5.5	45,200	181,800	1.03	.787
Sensor	A_U	2.77	1150	2	71	21,700	1.1×10^5	332	83.0	3012	12,048	.139	.109
	A_I, A_{RW}	6.37	985	2	55	43,800	2.3×10^5	112	28.1	8928	35,590	.204	.155
	G_F	11.94	49	2	40	80,200	5.0×10^5	3.28	.82	304,800	1.22×10^6	3.80	2.44
	S_F	.159	5	2	30	78,300	8.9×10^5	25.1	6.29	39,840	158,980	.509	.179
Servo	A_U	.391	6	2	71	21,700	1.1×10^5	12.3	3.07	81,300	325,700	3.75	2.96
	A_I, A_{RW}	4.53	60	2	55	43,800	2.3×10^5	10.6	2.65	94,340	377,360	2.15	1.64
	G_F	2.046	28	2	40	80,200	5.0×10^5	10.9	2.73	91,740	366,300	1.14	.732
	G_M	2.835	12	2	55	43,800	2.3×10^5	3.39	.847	294,980	1.18×10^6	6.73	5.13
	N_S	58.45	702	2	40	80,200	5.0×10^5	9.68	2.4	103,300	416,670	1.29	.832
Stepper	A_{UF}	3.75	30	2	71	21,700	1.1×10^5	6.4	1.60	156,250	625,000	7.43	2.41
	G_F	1.45	2	2	40	80,200	5.0×10^5	1.10	.276	909,000	3.62×10^6	11.4	7.24
	G_M	.300	4	2	55	43,800	2.3×10^5	10.7	2.67	93,450	374,500	2.16	1.63
	G_B	436.9	84	.1	30	78,300	8.9×10^5	.15	.038	6.67×10^6	26.3×10^6	85.5	29.2

The λ_{obs}/λ (217E) ratio was also calculated and is summarized in Table 4.8-1. The geometric means of this ratio as a function of motor type and failure mode (bearings, windings) is given in Table 4.8-2:

TABLE 4.8-2: $\frac{\alpha \text{ (observed)}}{\alpha \text{ (217E)}}$

Type	Bearing	Windings
Electric (General)	1.92	1.12
Servo	.48	.29
Stepper	11.2	5.4

These values can therefore be used as multipliers to adjust the current 217E model α's in accordance with observed field data and as a function of motor type.

The next analysis conducted on motors was in an attempt to determine the relationship between failure rate and horsepower rating. For this analysis, data was extracted from the same generic environment (Ground), in an attempt to minimize uncontrolled variables. The data in Figure 4.8-2 summarizes this data.

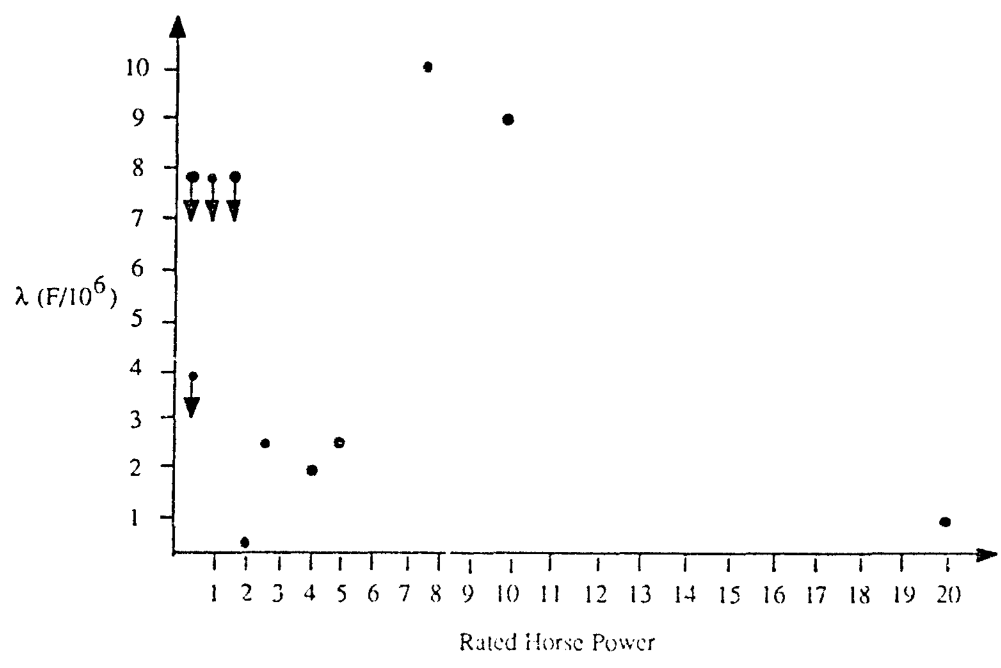


FIGURE 4.8-2:
FAILURE RATES VS. HORSE POWER RATING

The arrows in this figure are indicative of datapoints with zero failures. For these, one failure was assumed to establish an upper bound on the failure rate. This graph indicates that a horse power rating cannot be derived from this dataset, and therefore will not be included in the model.

The motor model therefore is as follows:

$$\lambda_p = \left(\frac{\lambda_1}{A\alpha_B} + \frac{\lambda_2}{B\alpha_W}\right) (x\ 10^6)\ (F/10^6)$$

where:

λ_1 is a function of Design Life Cycle (operating hours) and characteristic life for bearings and is summarized in Table 4.8-3 (α_B must be calculated first)

λ_2 is a function of Design Life Cycle and characteristic life for windings and is in Table 4.8-3 (α_W must be calculated first)

A,B are constants in Table 4.8-4

α_B = Base characteristic life of bearings in hours, in Table 4.8-5

α_W = Base characteristic life of windings in hours, in Table 4.8-5

TABLE 4.8-3:
CUMULATIVE AVERAGE FAILURE RATE

LC/α_B, LC/α_W	λ_1, λ_2
0-.10	.13
.11-.20	.15
.21-.30	.23
.31-.40	.31
.41-.50	.41
.51-.60	.51
.61-.70	.61
.71-.80	.68
.81-.90	.76
.91-1.0	.82
>1.0	1.0

TABLE 4.8-4:
A,B CONSTANTS

Motor Type	A	B
Electrical (General)	1.92	1.12
Sensor	.48	.29
Servo	2.4	1.7
Stepper	11.2	5.4

TABLE 4.8-5:
BEARING & WINDING CHARACTERISTICS
LIFE, α_B & α_W, vs. AMBIENT TEMPERATURE, T

T (°C.)	α_B* (Hr.)	α_W** (Hr.)	T (°C.)	α_B* (Hr.)	α_W** (Hr.)
-40	305	$1.9(10)^8$	55	43800	$2.3(10)^5$
-35	312	1.2 "	60	34600	1.8 "
-30	330	$7.4(10)^7$	65	27300	1.4 "
-25	372	4.7 "	70	21700	1.1 "
-20	463	3.1 "	75	17300	$8.8(10)^4$
-15	661	2.0 "	80	13900	7.0 "
-10	1080	1.4 "	85	11200	5.7 "
-5	1920	$9.2(10)^6$	90	9100	4.6 "
0	3570	6.4 "	95	7430	3.8 "
5	6750	4.5 "	100	6100	3.1 "
10	12600	3.2 "	105	5030	2.5 "
15	22800	2.3 "	110	4710	2.1 "
20	38800	1.6 "	115	3470	1.8 "
25	59600	1.2 "	120	2910	1.5 "
30	78300	$8.9(10)^5$	125	2440	1.2 "
35	85600	6.6 "	130	2060	1.0 "
40	80200	5.0 "	135	1750	$8.9(10)^3$
45	68200	3.8 "	140	1490	7.5 "
50	55200	2.9 "			

$$*\alpha_B = \left\{ 10^{\left(2.534 - \frac{2357}{T+273}\right)} + 1/\left[10^{\left(20 - \frac{4500}{T+273}\right)} + 300\right] \right\}^{-1}$$

$$**\alpha_W = 10^{\frac{2357}{T+273} - 1.83}$$

where T is ambient temperature in °C.

5.0 MODEL SUMMARY AND SAMPLE CALCULATIONS

5.1 MODEL SUMMARY

This section of the report summarizes the complete models being proposed for inclusion into MIL-HDBK-217.

CAPACITORS

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_C \pi_V \pi_{SR}$$

BASE FAILURE RATE - λ_b

Capacitor Type	Applicable Specifications	λ_b (F/10^6)
Paper	MIL-C-12889 MIL-C-25 MIL-C-18312	.00037
Plastic	MIL-C-19978 MIL-C-39022 MIL-C-55514	.00051
Mica, Glass	MIL-C-10950 MIL-C-39001 MIL-C-23269	.00076
Ceramic	MIL-C-11015 MIL-C-39014 MIL-C-20	.00099
Ceramic Chip	MIL-C-55681	.00195
Al Electrolytic	MIL-C-39118	.00012
Ta Electrolytic (Solid and Wet)	MIL-C-39006 MIL-C-39003	.00040
Tantalum Chip	MIL-C-55365	.00005
Variable, Air	MIL-C-92	.0000072
Variable, Ceramic	MIL-C-81	.0079
Variable, Glass	MIL-C-14409	.0060

TEMPERATURE (π_T), CAPACITANCE (π_C), VOLTAGE (π_V), AND SERIES RESISTANCE (π_{SR}) FACTORS

Capacitor Type	π_T	π_C	π_V	π_{SR}
Paper	$\exp\left[-2550\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.09}$	$\left(\frac{S}{.6}\right)^{4.5} + 1$	1
Plastic	$\exp\left[-2550\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.09}$	$\left(\frac{S}{.6}\right)^{6} + 1$	1
Mica, Glass	$\exp\left[-4290\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.09}$	$\left(\frac{S}{.6}\right)^{10} + 1$	1
Ceramic	$\exp\left[-3940\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.09}$	$\left(\frac{S}{.6}\right)^{3} + 1$	1
Ceramic Chip	$\exp\left[-3940\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.09}$	$\left(\frac{S}{.6}\right)^{3} + 1$	1
Al Electrolytic	$\exp\left[-5215\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.23}$	$\left(\frac{S}{.6}\right)^{5} + 1$	1
Ta Electrolytic, Solid	$\exp\left[-2200\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.23}$	$\left(\frac{S}{.6}\right)^{17} + 1$	π_{SR}
Ta Electrolytic, (Non-Solid)	$\exp\left[-2200\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.23}$	$\left(\frac{S}{.6}\right)^{17} + 1$	1
Tantalum Chip, (Solid)	$\exp\left[-2200\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.23}$	$\left(\frac{S}{.6}\right)^{17} + 1$	π_{SR}
Variable, Air	$\exp\left[-2900\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.09}$	$\left(\frac{S}{.5}\right)^{3} + 1$	1
Variable, Ceramic	$\exp\left[-3940\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.09}$	$\left(\frac{S}{.5}\right)^{1} + 1$	1
Variable, Glass	$\exp\left[-4290\left(\frac{1}{T_A+273}\right) - \frac{1}{298}\right]$	$C^{.09}$	$\left(\frac{S}{.5}\right)^{3} + 1$	1
	T_A = ambient temperature (in °C)	C is the capacitance in µF for variable types, it is the upper range.	$S = \frac{V}{V_R}$ V = actual max. voltage V_R = rated voltage	π_{SR} applicable to solid tantalum capacitors only.

CAPACITORS (CONT'D)

QUALITY FACTOR - π_Q

Quality	π_Q
D	.001
C	.01
S, B	.03
R	.1
P	.3
M	1
L	3
Non ER	3
Lower	10

ENVIRONMENT FACTOR - π_E

Environment	π_E
G_B	1
G_F	10
G_M	20
N_S	7
N_U	15
A_{IC}	12
A_{IF}	15
A_{UC}	25
A_{UF}	30
A_{RW}	40
S_F	.5
M_F	20
M_L	50
C_L	570

Series Resistance Factor - π_{SR}

Circuit Resistance, SR (ohms/volt)	π_{SR}
>0.8	.66
>0.6 to 0.8	1.0
>0.4 to 0.6	1.3
>0.2 to 0.4	2.0
>0.1 to 0.2	2.7
0 to 0.1	3.3

$$SR = \frac{\text{Eff. Res. Between Cap. and Pwr. Supply}}{\text{Voltage Applied to Capacitor}}$$

RESISTORS

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_p$$

BASE FAILURE RATE - λ_b, TEMPERATURE FACTOR - π_T

Resistor Type	Applicable Specifications	λ_b (F/10^6 hrs.)	π_T
Composition	MIL-R-39008	.0017	1
Film	MIL-R-39017 MIL-R-55182 MIL-R-55432	.0037	1
Network	MIL-R-83401	.0019	1
Wirewound	MIL-R-39005 MIL-R-39007 MIL-R-39009	.0024	1
Thermistor	MIL-R-23648	.0019	1
Varistor		.0023	1
Variable Wirewound	MIL-R-19 MIL-R-22 MIL-R-12934	.0024	$\exp\left[-2660\left(\frac{1}{T+273} - \frac{1}{298}\right)\right]$
Variable Non-Wirewound	MIL-R-94 MIL-R-23285	.0037	$\exp\left[-2660\left(\frac{1}{T+273} - \frac{1}{298}\right)\right]$
			T = Resistor operating Temp = $T_A + \theta_{JA} P$

RESISTORS (CONT'D)

QUALITY FACTOR - π_Q

Quality	π_Q
S	.03
R	.1
P	.3
M	1
Lower	10

ENVIRONMENT FACTOR - π_E

Environment	π_E
G_B	1
G_F	4.0
G_M	16
A_{IC}	18
A_{UC}	31
A_{IF}	23
A_{UF}	43
A_{RW}	63
N_U	42
N_S	12
M_L	87
M_F	37
C_L	1728
S_F	.5

POWER FACTOR - π_p

$\pi_p = P^{.39}$

P = Rated Resistor Power

TRANSFORMERS

Specification	Description
MIL-T-27	Audio Power and High Power Pulse
MIL-T-21038	Low Power Pulse
MIL-T-55631	IF, RF and Discriminator

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T$$

BASE FAILURE RATE - λ_b

Transformer	λ_b (F/10^6 hrs.)
Switching	.00057
Flyback	.0054
Audio	.0137
Power	.0486
RF	.133

QUALITY FACTOR - π_Q

Quality	λ_Q
MIL-Spec.	1
Lower	3

TRANSFORMERS (CONTD)

ENVIRONMENT - π_E

Environment	π_E
G_B	1.0
G_F	6.0
G_M	12
N_S	5.0
N_U	16
A_{IC}	6.0
A_{IF}	8.0
A_{UC}	7.0
A_{UF}	9.0
A_{RW}	24
S_F	.50
M_F	13
M_L	34
C_L	610

Temperature Factor - π_T

$$\pi_T = \exp\left[-1275\left(\frac{1}{T_{HS}+273} - \frac{1}{298}\right)\right]$$

where T_{HS} = Hot Spot Temperature (in °C)

INDUCTORS

Specification	Description
MIL-C-15305	Fixed and Variable RF
MIL-C-39010	Molded RF, Est. Rel.

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T$$

BASE FAILURE RATE λ_b

Inductor Type	λ_b F/10^6 hrs.
Inductor, General	.000025
Variable Inductor	.000050
Choke	.000030

QUALITY FACTOR - π_Q

Quality	λ_Q
MIL-Spec.	1
Lower	3

INDUCTORS (CONT'D)

ENVIRONMENT - π_E

Environment	π_E
G_B	1.0
G_F	6.0
G_M	12
N_S	5.0
N_U	16
A_{IC}	6.0
A_{IF}	8.0
A_{UC}	7.0
A_{UF}	9.0
A_{RW}	24
S_F	.50
M_F	13
M_L	34
C_L	610

$$\pi_T = \exp\left[-1275\left(\frac{1}{T_{HS}+273} - \frac{1}{298}\right)\right]$$

T_{HS} = Hot Spot Temperature (°C)

Hot Spot temperature can be estimated as follows:

$$T_{HS} = T_A + 1.1\,(\Delta T)$$

where:

T_{HS}	=	Hot Spot Temperature (°C)
T_A	=	Inductive Device Ambient Operating Temperature (°C)
ΔT	=	Average Temperature Rise Above Ambient (°C)

DT can either be determined by the appropriate "Temperature Rise" Test Method paragraph in the device base specification (e.g., paragraph 4.8.12 for MIL-T-27E), or by approximation using one of the procedures described below.

ΔT Approximation

Information Known	ΔT Approximation
1. MIL-C-39010 Slash Sheet Number MIL-C-39010/IC-3C, 5C, 7C, 9A, 10A, 13, 14 MIL-C-39010/4C, 6C, 8A, 11, 12	 $\Delta T = 15°C$ $\Delta T = 35°C$
2. Power Loss Case Radiating Surface Area	$\Delta T = 125\ W_L/A$
3. Power Loss Transformer Weight	$\Delta T = 11.5\ W_L/(wt.)^{.6766}$
4. Input Power Transformer Weight (Assumes 80% Efficiency)	$\Delta T = 2.1\ W_I/(wt.)^{.6766}$

W_L	=	Power Loss (W)
A	=	Radiating Surface Area of Case (in^2), See below for MIL-T-27 Case Areas
Wt.	=	Transformer Weight (lbs.)
W_I	=	Input Power (W)

NOTE: Methods are listed in preferred order (i.e., most to least accurate). MIL-C-39010 are microminiature devices with surface areas less than 1 in^2. Equations 2-4 are applicable to devices with surface areas from 3 in^2 to 150 in^2. Do not include the mounting surface when determining radiating surface area.

MIL-T-27 Case Radiating Areas (Excludes Mounting Surface)

Case	Area (in^2)	Case	Area (in^2)	Case	Area (in^2)
AF	4	GB	33	LB	82
AG	7	GA	43	LA	98
AH	11	HB	42	MB	98
AJ	18	HA	53	MA	115
EB	21	JB	58	NP	117
EA	23	JA	71	NA	139
FB	25	KB	72	OA	146
FA	31	KA	84		

SWITCHES

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_C + \lambda_U$$

BASE FAILURE RATE - λ_b

Switch Type	Applicable Specifications	λ_b F/10^6 hrs.
Rocker		.023
Slide		.003
Push Button/Toggle	MIL-S-22885 MIL-S-24317 MIL-S-3950 MIL-S-9419 MIL-S-13735	.102
Reed	MIL-S-55433	.001
DIP	MIL-S-83504	.00012
Sensitive	MIL-S-8805 MIL-S-25345	.49
Pressure	MIL-S-8932 MIL-S-12211	2.8
Limit	MIL-S-8805/39,40 41, 42, 43, 48, 49, 65, 70, 72, 73, 74, 80, 85, 100, 104, 114 MS-25253	4.3
Centrifugal		3.4
Microwave (Waveguide)		1.7
Liquid Level		2.3
Rotary	MIL-S-3786 MIL-S-15743 MIL-S-21604 MIL-S-22710	.11
Thumbwheel	MIL-S-22710	.18

SWITCHES (CONT'D)

QUALITY FACTOR - π_Q

Quality	λ_Q
MIL-Spec.	1
Lower	2

ENVIRONMENT - π_E

Environment	π_E
G_B	1.0
G_F	3.0
G_M	18
N_S	8.0
N_U	29
A_{IC}	10
A_{IF}	18
A_{UC}	13
A_{UF}	22
A_{RW}	46
S_F	.50
M_F	25
M_L	67
C_L	1200

CONTACT CONFIGURATION FACTOR - π_C

$\pi_C = (N_C)^{.33}$
N_C = Number of Contacts
Ex: SPST = 1
DPDT = 4
3PST = 3

λ_U = Wearout failure rate due to switch utilization.

$$\lambda_U = \frac{\lambda_1}{\alpha_c}$$

λ_1 = Cumulative average base failure rate over the life cycle (LC) time (desired life expectancy or preventative maintenance interval) as a function of α

LC = Life cycle time

α_a = Weibull characteristic life (in 10^6 actuations) as a function of load

α_c = Weibull characteristic life in (10^6 hours)

$$\alpha_c = \alpha_a \left(\frac{1}{SR}\right)$$

SR = Switching rate in actuations per 10^6 calendar hours (necessary to convert α to a time scale)

SWITCHES (CONT'D)

α_a CONTACT LIFE EXPECTANCY (10^6 ACTUATIONS)

Contact Current Rating (Amps)	α_a (AC Resistive Load)	α_a (DC Load)
0-4	$\frac{29.08}{V^{.75} I^{1.14}}$	$\frac{26.323}{V^{1.33} I^{1.3} e^{130 L/R}}$
>4-8	$\frac{103.45}{V^{.75} I^{1.14}}$	$\frac{123.187}{V^{1.33} I^{1.3} e^{130 LR}}$
>8	$\frac{219.74}{V^{.75} I^{1.14}}$	$\frac{307.94}{V^{1.33} I^{1.3} e^{130 L/R}}$

V = Applied voltage in volts

I = Applied current in amps

L = Load inductance

R = Load resistance

SWITCHES (CONT'D)

AVERAGE CUMULATIVE BASE FAILURE RATE - λ_1

$\frac{LC}{\alpha_c}$	λ_1
0-.1	.13
.11-.20	.15
.21-.30	.23
.31-.40	.31
.41-.50	.41
.51-.60	.51
.61-.70	.61
.71-.80	.68
.81-.90	.76
>.9	1.0

CIRCUIT BREAKERS

APPLICABLE SPECIFICATIONS

MIL-C-55629
MIL-C-83383
MIL-C-39018
MS-24510
MS-25244

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_C \text{ (F/10}^6\text{ hrs.)}$$

BASE FAILURE RATE - λ_b

Type	λ_b F/10^6 hrs.
Magnetic	.34
Thermal	.34
Power Switch	.85

QUALITY FACTOR - π_Q

Quality	π_Q
MIL-Spec.	1.0
Lower	8.4

ENVIRONMENT - π_E

Environment	π_E
G_B	1.0
G_F	2.0
G_M	15
N_S	8.0
N_U	27
A_{IC}	7.0
A_{IF}	9.0
A_{UC}	11
A_{UF}	12
A_{RW}	46
S_F	.50
M_F	25
M_L	66
C_L	N/A

CONTACT CONFIGURATION FACTOR - π_C

Configuration	π_C
SPST	1.0
DPST	2.0
3PST	3.0
4PST	4.0

THERMAL SWITCHES

Specifications
MIL-S-12285
MIL-S-24236

$\lambda_p = .031\ \pi_Q \pi_E$ (F/10^6 hrs.)

QUALITY FACTOR π_Q

Quality	π_Q
Military	1
Lower	2

ENVIRONMENT - π_E

Environment	π_E
G_B	1.0
G_F	3.0
G_M	18
N_S	8.0
N_U	29
A_{IC}	10
A_{IF}	18
A_{UC}	13
A_{UF}	22
A_{RW}	46
S_F	.50
M_F	25
M_L	67
C_L	1200

RELAYS, ELECTROMECHANICAL

Specifications
MIL-R-27745
MIL-R-39016
MIL-R-5757
MIL-R-6106
MIL-R-83726

$$\lambda_p = \lambda_b \pi_Q \pi_E + \lambda_U$$

BASE FAILURE RATE - λ_b

Relay Type	λ_b (F/10^6 hrs.)
General Purpose (all types except reed, time delay, and solid state)	.020
Reed	.10
Time Delay	.09

QUALITY FACTOR - π_Q

Quality	π_Q
MIL-Spec.	1
Lower	1.9

ENVIRONMENT - π_E

Environment	π_E
G_B	1
G_F	8.3
G_M	64
A_{IC}	168
A_{UC}	264
A_{IF}	216
A_{UF}	288
A_{RW}	833
N_U	27
N_S	8.2
M_L	1584
M_F	600
C_L	N/A
S_F	.82

λ_U = Wearout failure rate due to relay utilization.

$$\lambda_U = \frac{\lambda_1}{\alpha_c}$$

λ_1 = Cumulative average base failure rate over the life cycle time (desired life expectancy or preventative maintenance interval) as a function of α_c

LC = Life cycle time

$$\alpha_c = \alpha_a\left(\frac{1}{SR}\right)$$

α_a = Weibull Characteristic life (in 10^6 actuations) as a function of load

α_c = Weibull characteristic life

SR = Switching rate in actuations per 10^6 hours, (necessary to convert α to a time scale)

RELAYS, ELECTROMECHANICAL (CONT'D)

α_a - CONTACT LIFE EXPECTANCY (10^6 ACTUATIONS)

Contact Current Rating (Amps)	α_a (AC Resistive Load)	α_a (DC Load)
0-4	$\frac{29.08}{V^{.75} I^{1.14}}$	$\frac{26.323}{V^{1.33} I^{1.3} e^{130 L/R}}$
>4-8	$\frac{103.45}{V^{.75} I^{1.14}}$	$\frac{123.187}{V^{1.33} I^{1.3} e^{130 LR}}$
>8	$\frac{219.74}{V^{.75} I^{1.14}}$	$\frac{307.94}{V^{1.33} I^{1.3} e^{130 L/R}}$

AVERAGE CUMULATIVE BASE FAILURE RATE - λ_1

$\frac{LC}{\alpha_c}$	λ_1
0-.1	.13
.11-.20	.15
.21-.30	.23
.31-.40	.31
.41-.50	.41
.51-.60	.51
.61-.70	.61
.71-.80	.68
.81-.90	.76
>.9	1.0

RELAYS, SOLID STATE

Specifications
MIL-R-28750

$\lambda_p = .029\ \pi_Q \pi_E$ (F/10^6 hrs.)

QUALITY FACTOR - π_Q

Quality	π_Q
MIL-Spec.	1
Lower	1.9

ENVIRONMENT FACTOR - π_E

Environment	π_E
G_B	1.0
G_F	3.0
G_M	12
N_S	6.0
N_U	17
A_{IC}	12
A_{IF}	19
A_{UC}	21
A_{UF}	32
A_{RW}	23
S_F	.40
M_F	12
M_L	33
C_L	590

CONNECTORS

SPECIFICATIONS

CONNECTORS	
MIL-C-21097	MIL-C-21907
MIL-C-22857	MIL-C-23353
MIL-C-24308	MIL-C-26482
MIL-C-28748	MIL-C-3643
MIL-C-3767	MIL-C-38999
MIL-C-39012	MIL-C-39024
MIL-C-5015	MIL-C-55302
MIL-C-81511	MIL-C-83723
MIL-C-83733	

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_K$$

BASE FAILURE RATE - λ_b

Type	λ_b (F/10^6 hrs.)
Signal	.0000044
Rectangular	.046
Elastomeric	.0071
Edge Card	.040
Cylindrical	.0010
RF	.00041
Hexagonal	.146
Rack and Panel	.021
D-Subminiature	.66
Telephone	.0075

CONNECTORS (CONT'D)

QUALITY FACTOR - π_Q

Quality	π_Q
MIL-Spec.	1
Lower	2

ENVIRONMENT FACTOR - π_E

Environment	π_E
G_B	1.0
G_F	1.0
G_M	8.0
N_S	5.0
N_U	13
A_{IC}	3.0
A_{IF}	5.0
A_{UC}	8.0
A_{UF}	12
A_{RW}	19
S_F	.50
M_F	10
M_L	27
C_L	490

TEMPERATURE FACTOR - π_T

$$\pi_T = \exp\left[-1625\left(\frac{1}{T_o+273} - \frac{1}{298}\right)\right]$$

T_o = Ambient temperature + ΔT (°C)

CONNECTORS (CONT'D)

Insert Temperature Rise (ΔT °C) Determination

Amperes Per Contact	Contact Gauge 22	20	16	12
2	4	2	1	0
3	8	5	2	1
4	13	8	4	1
5	19	13	5	2
6	27	18	8	3
7	36	23	10	4
8	46	30	13	5
9	57	37	16	6
10	70	45	19	7
15		96	41	15
20			70	26
25			106	39
30				54
35				72
40				92

$\Delta T = 0.989\,(i)^{1.85}$ 22 Gauge Contacts

$\Delta T = 0.640\,(i)^{1.85}$ 20 Gauge Contacts

$\Delta T = 0.274\,(i)^{1.85}$ 16 Gauge Contacts

$\Delta T = 0.100\,(i)^{1.85}$ 12 Gauge Contacts

ΔT = Insert Temperature Rise

i = Amperes per Contact

RF Coaxial Connectors $\Delta T = 5°C$

RF Coaxial Connectors
(High Power Applications) $\Delta T = 50°C$

MATING/UNMATING FACTOR - π_K

Mating/Unmating Cycles* (per 1000 hours)	π_K
0 to .05	1.0
> .05 to 5	1.5
> .5 to 5	2.0
> 5 to 50	3.0
> 50	4.0

*One cycle includes both connect and disconnect.

SOCKETS

Specifications
MIL-S-83734
MS-25328
MS-27400

$$\lambda_p = \lambda_b \pi_Q \pi_E \text{ (F/10}^6\text{ hrs.)}$$

BASE FAILURE RATE - λ_b

Socket Type	λ_b (F/10^6 hrs.)
DIP	.00064
Chip Carrier	.0024
Pin Grid Array	.014
SIP	.0030
Relay	.037
Transistor	.0051
Tube	.011

QUALITY FACTOR - π_Q

Quality	π_Q
MIL-Spec.	.3
Lower	1

SOCKETS (CONT'D)

ENVIRONMENT FACTOR - π_E

Environment	MIL-SPEC
G_B	1.0
G_F	1.0
G_M	8.0
N_S	5.0
N_U	13
A_{IC}	3.0
A_{IF}	5.0
A_{UC}	8.0
A_{UF}	12
A_{RW}	19
S_F	.50
M_F	10
M_L	27
C_L	490

CONNECTIONS

DESCRIPTION
Connections Used on All Assemblies Except Those Using Plated Through Holes (PTH) or Surface Mounted Technology (SMTs)

APPLICATION NOTE: The failure rate model in this section applies to connections used on all assemblies except those using plated through holes or Surface Mounted Technology. Use the Interconnection Assembly Model to account for connections to a circuit board using PTH or SMT. The failure rate of the structure which supports the connections and parts, e.g., non-plated-through hole boards and terminal straps, is considered to be zero. Solderless wrap connections are characterized by solid wire wrapped under tension around a post, whereas hand soldering with wrapping does not depend on a tension induced connection.

$$\lambda_p = \lambda_b \pi_Q \pi_E \, n \text{ Failures/10}^6 \text{ Hours}$$

n = number of connections

Base Failure Rate - λ_b

Connection Type	λ_b (F/10^6 hrs)
Hand Solder, w/o Wrapping	.000011
Hand Solder, w/Wrapping	.00014
Crimp	.00026
Weld	.000015
Solderless Wrap	.0000068
Clip Termination	.00012
Reflow Solder	.000069
Spring Contact	.168
Terminal	.062

Quality Factor - π_Q

Quality Grade	π_Q	Comments
Crimp Types		
Automated	1.0	Daily pull tests recommended.
Manual		
Upper	1.0	Only MIL-SPEC or equivalent tools and terminals, pull test at beginning and end of each shift, color coded tools and terminations.
Standard	2.0	MIL-SPEC tools, pull test at beginning of each shift.
Lower	20.0	Anything less than standard criteria.
All Types Except Crimp	1.0	

Environment Factor - π_E

Environment	π_E
G_B	1.0
G_F	2.0
G_M	7.0
N_S	4.0
N_U	11
A_{IC}	4.0
A_{IF}	6.0
A_{UC}	6.0
A_{UF}	8.0
A_{RW}	16
S_F	.50
M_F	9.0
M_L	24
C_L	420

INTERCONNECTION ASSEMBLIES WITH PLATED THROUGH HOLES AND/OR SURFACE MOUNT CONNECTIONS

$$\lambda_p = \lambda_{SMT} + \lambda_{PTH1} + \lambda_{PTH2}$$

λ_{SMT} = Average failure rate over the expected equipment life cycle due to surface mount device wearout. This failure rate may be calculated only for the Surface Mount Device exhibiting the highest value of the strain range;

$$\left[\left| \left(\alpha_s \Delta T - \alpha_{CC} (\Delta T + T_{RISE}) \right) \right| \times 10^{-6} \right]$$

λ_{PTH1} = Average failure rate over the expected equipment life cycle due to plated through hole wearout (F/10^6 hrs.)

λ_{PTH2} = Failure rate from PTH defects (F/10^6 hrs.)

$$\lambda_{SMT} = \frac{\lambda_1}{\alpha_{SMT}}$$

$$\alpha_{SMT} = \left[3.5 \left[\frac{d}{.65\ h} \left| (\alpha_s \Delta T - \alpha_{CC}(\Delta T + T_{RISE})) \right| \times 10^{-6} \right]^{-2.26} \right] \frac{\pi_{LC}}{CR}$$

where:

d = Distance from center of device to the furthest solder joint

h = Solder joint height for leadless devices, use h=8 for compliant lead configurations

α_S = Circuit board substrate TCE

ΔT = Environmental ΔT

T_{RISE} = Temperature rise due to power dissipation = $\Theta_{JC} P$

CR = Temperature cycling rate in cycles per 10^6 calendar hours

INTERCONNECTION ASSEMBLIES WITH PLATED THROUGH HOLES AND/OR SURFACE MOUNT CONNECTIONS (CONT'D)

λ_1 = Cumulative average base failure rate over the life cycle time (desired life expectancy or preventative maintenance interval) as a function of α. This value is:

AVERAGE CUMULATIVE BASE FAILURE RATE - λ_1

$\frac{LC}{\alpha_{SMT}}$	λ_1
0-.1	.13
.11-.20	.15
.21-.30	.23
.31-.40	.31
.41-.50	.41
.51-.60	.51
.61-.70	.61
.71-.80	.68
.81-.90	.76
>.9	1.0

LC = Design life cycle of the equipment in which the circuit board is operating.

LEAD CONFIGURATION FACTOR - π_{LC}

Lead Configuration	π_{LC}
Leadless	1
S Lead	150
Gull Wing	5,000

INTERCONNECTION ASSEMBLIES WITH PLATED THROUGH HOLES AND/OR SURFACE MOUNT CONNECTIONS (CONT'D)

$$\lambda_{PTH\ 1} = \frac{\lambda_1}{\alpha_{PTH}}$$

$$\alpha_{PTH} = \left[\frac{.0061}{T} \left| (\alpha_{SZ}(\Delta T) - \alpha_2 (\Delta T + T_{RISE})) \right| \right]^{-2.26} \left[\frac{1}{CR}\right]$$

where:

T = The board thickness (in mils.)

α_{SZ} = The Z axis TCE of the substrate

α_2 = The TCE of the PTH material

λ_1 = Cumulative average base failure rate over the life cycle time (desired life expectancy or preventative maintenance interval) as a function of α. This value is as follows:

AVERAGE CUMULATIVE BASE FAILURE RATE - λ_1

$\frac{LC}{\alpha_{PTH}}$	λ_1
0-.1	.13
.11-.20	.15
.21-.30	.23
.31-.40	.31
.41-.50	.41
.51-.60	.51
.61-.70	.61
.71-.80	.68
.81-.90	.76
>.9	1.0

INTERCONNECTION ASSEMBLIES WITH PLATED THROUGH HOLES AND/OR SURFACE MOUNT CONNECTIONS (CONT'D)

The failure rate model for plated through holes (PTH) assemblies is:

$$\lambda_{PTH2} = \lambda_b \pi_Q \pi_E \left[n_1 \pi_C + n_2 (\pi_C + 13) \right] \cdot DC \quad \text{(failures/}10^6 \text{ calendar hours/assembly)}$$

where:

λ_b = Base failure rate

λ_Q = Quality factor

π_E = Environment factor

n_1 = Quantity of wave soldered functional PTH's

n_2 = Quantity of hand soldered PTH's

π_C = Complexity factor

DC = Duty cycle, % of calendar time the circuit is operating

BASE FAILURE RATE λ_b

Technology	λ_b (Failures/10^6 Hours)
Printed Wiring Assemblies	.000017
Discrete Wiring w/Electroless Deposited PTH*	.00011

*Applies to two or less levels of circuitry.

QUALITY FACTOR π_Q

Quality Grade	π_Q
Manufactured to MIL-Spec. or comparable IPC Standards	1
Lower Quality	2

INTERCONNECTION ASSEMBLIES WITH PLATED THROUGH HOLES AND/OR SURFACE MOUNT CONNECTIONS (CONT'D)

COMPLEXITY FACTOR π_C

Number of Circuit Planes	π_C
≤ 2	1
3	1.3
4	1.5
5	1.8
6	2.0
7	2.2
8	2.4
9	2.6
10	2.7
11	2.9
12	3.1
13	3.2
14	3.4
15	3.5
16	3.7
Discrete Wiring w/PTH	1

For greater than 16 circuit planes,

$\pi_C = .65C^{.63}$

C = quantity of circuit planes

ENVIRONMENTAL MODE FACTORS

Environment	π_E
G_B	1
G_F	2
G_M	7
N_S	13
N_U	5
A_{IC}	5
A_{IF}	8
A_{UC}	16
A_{UF}	28
S_F	.5
M_F	10
M_L	27
C_L	500

INTERCONNECTION ASSEMBLIES WITH PLATED THROUGH HOLES AND/OR SURFACE MOUNT CONNECTIONS (CONT'D)

If actual values of α_S, α_{CC}, ΔT, or CR cannot be determined use the following:

ΔT VALUES

Env.	ΔT
G_B	7
G_F	26
G_M	11
A_{IC}	31
A_{UC}	57
A_{IF}	31
A_{UF}	57
A_{RW}	31
N_U	61
N_S	26
M_L	31
M_F	31
C_L	26

α_S VALUES

Substrate Material	α_S
FR-4 Laminate	18
FR-4 MLB	20
FR-4 MLB w/Copper Clad Invar	11.3
Ceramic MLB	7.15
Copper Clad Invar	5.1
Copper Clad Molybdenum	5
Carbon-Fiber/Epoxy Composite	.75
Kevlar Fiber	-3
Quartz Fiber	.54
Glass Fiber	4.5
Epoxy/Glass Laminate	15.17
Polyimid/Glass Laminate	13.25
Polyimid/Kevlar Laminate	5.5
Polyimid/Quartz Laminate	7.8
Epoxy/Kevlar Laminate	6.75
Aluminum (Ceramic)	6.5
Epoxy Aramid Fiber	7
Polyimid Aramid Fiber	5.75
Epoxy-Quartz	9
Fiberglass Teflon Laminates	20
Porcelainized Copper Clad Invar	6.5
Fiberglass Ceramid Fiber	6.5

INTERCONNECTION ASSEMBLIES WITH PLATED THROUGH HOLES AND/OR SURFACE MOUNT CONNECTIONS (CONT'D)

TCE'S OF PACKAGE MATERIALS

Substrate Material	α_{CC} Average Value
Plastic	6.5
Ceramic	5.6

CR - CYCLING RATE VALUES

Equipment Type	Number of Cycles per 10^6 hrs.
Consumer	4200
Computers	170,000
Telecommunications	4200
Commercial Aircraft	340,000
Industrial	21,000
Military Ground Applications	30,000
Military Aircraft	115,000

$$\lambda_p = \left(\frac{\lambda_1}{A\,\alpha_B} + \frac{\lambda_2}{B\,\alpha_W}\right)(x\ 10^6)\left(\frac{F}{10^6\ \text{hrs.}}\right)$$

λ_1 = Design life cycle or preventative maintenance interval divided by the characteristic life (α_B). In the case where preventive maintenance is not performed, the design life is the total operating time that the system in which the motor is operating has been designed to last, times the duty cycle of the motor. For example if a motor is used continuously in a military system with a life expectancy of 20 years without preventive maintenance, the value of LC is 20 years. If the duty cycle of that motor is .5, the LC value is 10 years.

If that same motor is replaced every 5 years a preventive maintenance schedule, LC = 5 years times its duty cycle. The characteristic life (α_B) must be calculated before λ_1 can be calculated. The value of λ_1 as a function of the LC/α_B ratio is given in the following table. If this ratio is not known use λ_1 = 1.

$\frac{LC}{\alpha_B}$	λ_1
0-.10	.13
.11-.20	.15
.21-.30	.23
.31-.40	.31
.41-.50	.41
.51-.60	.51
.61-.70	.61
.71-.80	.68
.81-.90	.76
>1.0	1.0

λ_2 = Design life cycle of the equipment in which the motor is operating (or preventative maintenance interval) divided by the winding characteristic life (α_W)

$\frac{LC}{\alpha_W}$	λ_2
0-.10	.13
.11-.20	.15
.21-.30	.23
.31-.40	.31
.41-.50	.41
.51-.60	.51
.61-.70	.61
.71-.80	.68
.81-.90	.76
>1.0	1.0

A,B = Function of Motor Type:

A,B CONSTANTS

Motor Type	A	B
Electrical (General)	1.92	1.12
Sensor	.48	.29
Servo	2.4	1.7
Stepper	11.2	5.4

BEARING & WINDING CHARACTERISTICS
LIFE, α_B & α_W, vs. AMBIENT TEMPERATURE, T

T (°C.)	α_B* (Hr.)	α_W** (Hr.)	T (°C.)	α_B* (Hr.)	α_W* (Hr.)
-40	305	$1.9(10)^8$	55	43800	$2.3(10)^5$
-35	312	1.2 "	60	34600	1.8 "
-30	330	$7.4(10)^7$	65	27300	1.4 "
-25	372	4.7 "	70	21700	1.1 "
-20	463	3.1 "	75	17300	$8.8(10)^4$
-15	661	2.0 "	80	13900	7.0 "
-10	1080	1.4 "	85	11200	5.7 "
-5	1920	$9.2(10)^6$	90	9100	4.6 "
0	3570	6.4 "	95	7430	3.8 "
5	5750	4.5 "	100	6100	3.1 "
10	12600	3.2 "	105	5030	2.5 "
15	22800	2.3 "	110	4710	2.1 "
20	38800	1.6 "	115	3470	1.8 "
25	59600	1.2 "	120	2910	1.5 "
30	78300	$8.9(10)^5$	125	2440	1.2 "
35	85600	6.6 "	130	2060	1.0 "
40	80200	5.0 "	135	1750	$8.9(10)^3$
45	68200	3.8 "	140	1490	7.5 "
50	55200	2.9 "			

$$^*\alpha_B = \left\{ 10^{\left(2.534 - \frac{2357}{T+273}\right)} + 1/\left[10^{\left(20-\frac{4500}{T+273}\right)} + 300\right] \right\}^{-1}$$

$$^{**}\alpha_W = 10^{\frac{2357}{T+273} - 1.83}$$

where T is ambient temperature in °C.

5.2 SAMPLE CALCULATIONS

Capacitors

Conditions:
- 100 microfarad solid tantalum electrolytic capacitor
- Ambient temp (T_A) = 35°C
- 100 volt rated. 50V applied
- Series resistance of .5 ohms/volt as applied in circuit
- Military quality M
- Ground Fixed Environment

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_C \pi_V \pi_{SR}$$

$$\lambda_b = .0004 \ (F/10^6)$$

$$\pi_Q = 1$$

$$\pi_E = 10$$

$$\pi_T = \exp\left[-2200\left(\frac{1}{35 + 273} - \frac{1}{298}\right)\right] = 1.27$$

$$\pi_C = (100)^{.23} = 2.88$$

$$\pi_V = \left[\frac{\left(\frac{50}{100}\right)}{.6}\right]^{17} + 1 = 1.045$$

$$\pi_{SR} = 1.3$$

$$\lambda_p = (.0004)(1)(10)(1.27)(2.88)(1.045)(1.3) = .0198 \ F/10^6$$

Resistors

Conditions:
- Fixed resistor network (MIL-R-83401)
- Mil. quality M
- Ground Benign Environment
- Power rating (per resistor) = .25W

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_P$$

λ_b = .0019 (F/10^6)

π_Q = 1

π_E = 1

π_T = 1

π_P = $(.25)^{.39}$ = .58

$$\lambda_p = (.0019)(1)(1)(1)(.58) = .0011\ F/10^6$$

Transformers

Conditions:
- Audio transformer (MIL-T-27)
- Commercial quality
- A_{IF} environment
- ΔT rise = 15°C
- T_A = 40°C

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T$$

λ_b = .0137 (F/10^6)

π_Q = 3

π_E = 8.0

$$\pi_T = \exp\left[-1275\left(\frac{1}{56.5 + 273} - \frac{1}{298}\right)\right] = 1.5$$

$(T_{HS} = T_A + 1.1(\Delta T) = 56.5)$

$$\lambda_p = (.0137)(3)(8.0)(1.5) = .49\ F/10^6\ \text{hrs.}$$

Switches

Conditions:
- Toggle switch, 5 amp rating
  Mil. quality
- G_F environment
- DPDT configuration
- Design life (LC) for the equipment in which the switch is operating = .1752 x 10^6 hrs. (20 years) (no preventive maintenance)
- AC resistive load, 24 volts, 2 amps.
- Switching rate (SR) = 100,000 per 10^6 calendar hours

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_C + \lambda_u$$

$$\lambda_b = .102$$

$$\pi_Q = 1$$

$$\pi_E = 3.0$$

$$\pi_C = (4)^{.33} = 1.58$$

$$\lambda_u = \frac{\lambda_1}{\alpha_c}$$

$$\alpha_c = \alpha_a\left(\frac{1}{SR}\right)$$

$$\alpha_a = \frac{103.45}{V^{.75}\, I^{1.14}} = \frac{103.45}{24^{.75}\, 2^{1.14}} = 4.33 \times 10^6 \text{ actuations}$$

$$SR = \text{Switching rate} = 100{,}000\ \frac{\text{actuations}}{10^6 \text{ hrs.}}$$

$$\alpha_c = \alpha_a\left(\frac{1}{SR}\right) = 4.33\left(10^6 \text{ hrs.}\right)\left(\frac{1}{.1}\right) = 43.3\left(10^6 \text{ hrs.}\right)$$

$$\frac{LC}{\alpha} = \frac{.1752\ (10^6 \text{ hrs.})}{4.33\left(10^6 \text{ hrs.}\right)}$$

$$= .004$$

$$\lambda_1 = .13 \text{ (from Table)}$$

$$\lambda_u = \frac{\lambda_1}{\alpha_c} = \frac{.13}{43.3\ (10^6 \text{ hrs.})} = .003\ F/10^6$$

$$\lambda_p = (.102)(1)(3.0)(1.58) + .003 = .483\ F/10^6$$

Circuit Breakers

Conditions:
- Magnetic type
- Mil. quality
- A_{UC} environment
- SPST configuration

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_C$$

λ_b = .34 F/10^6 hrs.

π_Q = 1

π_E = 11

π_C = 1

$$\lambda_p = (.34)(1)(11)(1) = 3.74 \text{ F}/10^6$$

Thermal Switches

Conditions:
- Thermal switch (MIL-S-12285)
- Mil. quality
- S_F environment

$$\lambda_p = .031 \text{ (F}/10^6 \text{ hrs.)}\ \pi_Q\ \pi_E$$

π_Q = 1

π_E = .5

$$\lambda_p = (.031)(1)(.5) = .0155 \text{ F}/10^6$$

Relays

Conditions:
- General purpose electromagnetic relay (2 amp. Rating)
- Commercial quality
- G_B environment
- Equipment design life (LC) = 5 years = .0438 x 10^6 hrs.
- AC resistive load, 120 Volts, 1.5 amps applied
- Switching rate = 10 x 10^6 actuations per 10^6 hrs.

$$\lambda_p = \lambda_b \pi_Q \pi_E + \lambda_u$$

$$\lambda_b = .020 \text{ F}/10^6$$

$$\pi_Q = 1.9$$

$$\pi_E = 1$$

$$\lambda_u = \frac{\lambda_1}{\alpha_c}$$

$$\alpha_c = \alpha_a\left(\frac{1}{SR}\right)$$

$$\alpha_a = \frac{29.08\ (10^6)}{V^{.75}\ I^{1.14}} = \frac{29.08\ (10^6)}{120^{.75}\ 2^{1.14}} = .364 \times 10^6 \text{ actuations}$$

$$SR = 10 \times 10^6 \text{ (actuations}/10^6 \text{ hrs.)}$$

$$\alpha_c = \alpha_a\left(\frac{1}{SR}\right) = .364\left(10^6 \text{ hr.}\right)\left(\frac{1}{10}\right) = .0364\left(10^6 \text{ hr.}\right)$$

$$\frac{LC}{\alpha_c} = \frac{.0438\left(10^6\right)}{.0364\left(10^6\right)}$$

$$= 1.2$$

$$\lambda_1 = 1.0 \text{ (from table)}$$

$$\lambda_u = \frac{\lambda_1}{\alpha_c} = \frac{1.0}{.0364\left(10^6\right)} = 27.5 \text{ F}/10^6$$

$$\lambda_p = (.020)(1.9)(1) + 27.5 = 27.54 \text{ F}/10^6$$

Relay, Solid State

Conditions:
- Solid state relay (MIL-R-28750)
- Mil. spec.
- A_{UF} env.

$$\lambda_p = .029\ \pi_Q \pi_E\ F/10^6$$

$$\pi_Q = 1$$

$$\pi_E = 32$$

$$\lambda_p = (.029)(1)(32) = .93\ F/10^6$$

Connectors

Conditions:
- Edge card connector
- G_F environment
- Mil. quality
- 20 gauge contacts carrying .050 amperes per contact
- 2 mating/unmating Cycles per 1000 hrs.
- Ambient temperature = 35°C

$$\lambda_p = \lambda_b \pi_Q \pi_E \pi_T \pi_K$$

$$\lambda_b = .040\ (F/10^6)$$

$$\pi_Q = 1$$

$$\pi_E = 1$$

$$\pi_T = \exp\left[-1625\left(\frac{1}{T_o + 273} - \frac{1}{298}\right)\right]$$

$$= \exp\left[-1625\left(\frac{1}{35 + 273} - \frac{1}{298}\right)\right] = 1.19$$

$$\left(T_o = T_A + \Delta T = 35°C + .64(.05)^{1.85} = 35°C\right)$$

$$\pi_K = 1.5$$

$$\lambda_p = (.040)(1)(1)(1.19)(1.5) = .0714\ F/10^6$$

Sockets

Conditions:
- 144 pin grid array socket
- Socket commercial quality
- G_B environment

$$\lambda_p = \lambda_b \pi_Q \pi_E$$

λ_b = .014 F/10^6

π_Q = 1

π_E = 1

$$\lambda_p = (.014)(1)(1) = .014\ F/10^6$$

Connections

Conditions:
- A solderless wire wrap circuit board consists of 350 connections
- AIF environment

$$\lambda_p = 350\,\lambda_b \pi_Q \pi_E$$

λ_b = .0000068 F/10^6

π_Q = 1

π_E = 6.0

$$\lambda_p = (350)(.0000068)(1)(6.0) = .0143\ F/10^6$$

Interconnect Assemblies

Conditions:
- Epoxy-glass printed wiring assembly
- Four circuit planes
- 500 wave soldered PTHs
- No hand soldered PTHs
- Manufactured to MIL-spec. quality
- A_{IF} environment
- ICs are plastic encapsulated leadless chip carriers (LCC) for which the largest package is 740 mils between the center and corner pin
- The solder joint height for the LCC devices is 5 mils.
- The power dissipation for the largest LCC package is 5 watts and $\theta_{JC} = 20$
- The design life (LC) is 20 years (.1752 x 10^6 hrs.)
- Board thickness is 50 mils.
- The duty cycle of the circuit is .04 (30 hours/month)
- The cycling rate is 115,000 cycles per 10^6 hours

$$\lambda_p = \lambda_{SMT} + \lambda_{PTH1} + \lambda_{PTH2}$$

λ_{SMT}

Since all surface mounted devices are plastic encapsulated, the one exhibiting the largest value of strain gauge is the largest package, with d = 740 mils. Therefore the calculation of λ_{SMT} will be based on this device.

The predicted characteristic life of this LCC device is;

$$\alpha_{SMT} = \left[3.5\left(\frac{d}{.65h}\left|(\alpha_s \Delta T - \alpha_{cc}(\Delta T + T_{RISE})\right| \times 10^6)\right)\right]^{-2.26} \frac{\pi_{LC}}{CR}$$

d = 740 mils.
h = 5 mils.
α_s = 15.17
ΔT = 31°C (default for A_{IF} env.)
α_{cc} = 6.5
T_{RISE} = $\theta_{JC}P = 20(.5) = 10°C$
π_{LC} = 1 (leadless)
CR = 115,000 (cycles/10^6 hr.)

$$\alpha_{SMT} = 3.5\left[\frac{740}{(.65)(5)}\left|(15.17(31) - 6.5(31+10))\right| \times 10^{-6}\right]^{-2.26} \frac{1}{115{,}000\left(\frac{cyc}{10^6\ hrs.}\right)}$$

$$= .0314 \times 10^6 \text{ hrs. (calendar time)}$$

$$\frac{LC}{\alpha_{SMT}} = \frac{(.1752 \text{ hrs.})}{.0314\ (10^6) \text{ hrs.}}$$

$$= 5.58$$

$$\lambda_1 = 1 \text{ (from table)}$$

$$\lambda_{SMT} = \frac{\lambda_1}{\alpha_{SMT}} = \frac{1}{.0314} = 31.8\ F/10^6$$

$\underline{\lambda_{PTH1}}$

$$\alpha_{PTH} = \left[\frac{.0061}{T} \mid (\alpha_{SZ}\,\Delta T - \alpha_2(\Delta T + T_{RISE})) \mid \right]^{-2.26} \frac{1}{CR}$$

T = 50 Mils.

α_{SZ} = 20 (TCE of Epoxy - Glass Z axis)

α_2 = 17 (TCE of Copper PTH)

(all other factors as calculated for λ_{SMT})

$$\alpha_{PTH} = \left[\frac{.0061}{50} \mid (20\ (31) - 17\ (31 + 10)) \mid \right]^{-2.26} \frac{1}{.115}$$

$= .33 \times 10^6$ hrs.

$$\frac{LC}{\alpha_{PTH}} = \frac{(.1752)\left(10^6\right)}{.33\left(10^6\right)} = .53$$

λ_1 = .51 (from table)

$$\lambda_{PHT1} = \frac{\lambda_1}{\alpha_{PTH}} = \frac{(.51)}{.33\left(10^6 \text{ hr.}\right)} = 1.55\ F/10^6$$

$\underline{\lambda_{PTH2}}$

$$\lambda_{PTH2} = \lambda_b \pi_Q \pi_E \left[n_1 \pi_c + n_2(\pi_c + 13)\right] DC$$

λ_b = .000025

π_Q = 1

π_E = 8.0

n_1 = 500

π_c = 1.5

n_2 = 0

DC = .04

λ_{PTH2} = .000017 (1)(8)[500(1.6) + 0 (1.6+13)] .04

= .0043 F/10^6 hrs.

Therefore, the total interconnect assembly failure rate is;

$\lambda_p = \lambda_{SMT} + \lambda_{PTH1} + \lambda_{PTH2}$

λ_p = 31.8 + 1.55 + .0043 = 33.35 F/10^6

Rotating Devices

Conditions: - Electric motor, 1 HP
Ambient temperature = 40°C
Design life (LC) = 10 years (87,600 hrs.)

$$\lambda_p = \frac{\lambda_1}{A\alpha_B} \cdot \frac{\lambda_2}{B\alpha_W}$$

A = 1.92 (from table)

α_B = 80,200 (from table)

$$\frac{LC}{\alpha_B} = \frac{87,600}{80,200} = >1$$

Therefore, λ_1 = 1.0 (from table)

$$\frac{\lambda_1}{A\alpha_B} = \frac{1}{1.92\ (80,200)} = 6.5 \times 10^{-6}\ \text{F/hr.}$$

$$= 6.5\ \text{F}/10^6\ \text{hrs.}$$

B = 1.12 (from table)

α_W = 5×10^5 (from table)

$$\frac{(LC)}{\alpha_W} = 87,600/5\times10^5 = .175$$

Therefore, λ_2 = .15 (from table)

$$\frac{\lambda_2}{B\alpha_W} = \frac{.15}{1.12\ (5\times10^5)} = .3 \times 10^{-6}\ \frac{F}{hr.}$$

$$= .3\ \text{F}/10^6$$

$$\lambda_p = \frac{\lambda_1}{A\alpha_B} + \frac{\lambda_2}{B\alpha_W} = 6.5 + .3 = 6.8\ (\text{F}/10^6\ \text{hrs.})$$

6.0 MODEL COMPARISON

This section compares a sampling of the models developed in this effort to the existing MIL-HDBK-217E, Notice 1, models. Table 6.0-1 summarizes this comparison and presents the predicted failure rates for each and the ratio under both benign conditions and severe conditions. Benign conditions used in these calculations are:

Environment = G_B

Stress = .5

Quality = MIL-Spec.

T_A = 25°C

The severe conditions are:

Environment = A_{UF}

Stress = .9

Quality = MIL-Spec.

T_A = 70°C

TABLE 6.0-1:
MODEL COMPARISON

Part Type	Benign Conditions			Severe Conditions			Assumption
	New Model	*217E Model	New/217E Ratio	New Model	217E Model	New/217E Ratio	
Capacitors							
Paper	.0011	.0114	.10	.59	15.3	.039	.1μF
Plastic	.0020	.0093	.21	.15	7.8	.019	.1μF
Mica	.0011	.0042	.27	11.0	3.19	3.45	100pF
Ceramic	.0008	.0080	.10	.018	.045	.43	100pF
Al Elec.	.00029	.037	.008	.46	30.8	.015	10μF
Ta Elec.	.000031	.0017	.018	1.76	.011	160	10μF
Resistors							
Film	.0037	.0014	2.6	.16	.048	3.3	
Network	.0019	.0066	.29	.082	.039	2.1	$N_R = 10$
Transformers							
Audio	.013	.0072	1.8	.21	.22	.95	
Power	.048	.019	2.7	.76	.60	1.3	
Pulse/Switching	.00057	.0036	.16	.009	.112	.09	
Inductors	.00025	.00044	.57	.0022	.018	.12	
Switches							
Toggle	.102	.00045	226	2.2	.0098	224	(Resistive Load)
Relays	.016	.009	1.8	4.8	.608	7.9	
Magnetic Circuit Breakers	.34	.02	17	4.1	.24	17	
Connector	.001	.016	.06	.024	.34	.07	20 Pin
DIP Socket	.00019	.0014	.13	.0023	.018	.13	16 Pin

*Prediction performed to MIL-HDBK-217E, Notice 1.

6.1 MODEL COMPARISON OBSERVATIONS

From this analysis, several conclusions can be drawn relative to the current MIL-HDBK-217E models:

(1) Failure rates for capacitors are generally lower.

(2) Tantalum capacitor failure rates exhibit a very high dependency on applied voltage, making their predicted failure rate lower at low voltages and higher at higher voltages.

(3) Resistors are relatively consistent with current models.

(4) Inductors and transformers are generally consistent.

(5) Switches and relay failure rates in general are very much higher and have a much higher dependence on environment.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The objective of this effort was to develop or modify the MIL-HDBK-217 failure rate models for Capacitors, Resistors, Inductive Devices, Switches, Relays, Connectors, Interconnection Assemblies/Printed Wiring Boards, and Rotating Devices. This was accomplished with the statistical analysis of field failure rate data or from laboratory test results. A new methodology was also developed to predict failure rates of items exhibiting wearout characteristics. More specifically the objectives of these models are that:

(1) They be reflective of state-of-the-art manufacturing technologies.

(2) They be based on data available to design engineers during equipment design phases.

(3) They are inclusive of all part types used in military systems.

(4) They be as accurate as possible and be based on sound physics of failure principals.

(5) Their complexity be consistent with their precision and accuracy.

The failure rate models developed in this effort and summarized in Section 5.0 of this report meet all objectives listed above.

It was also apparent after developing these models that the failure rates predicted with them in some cases differed significantly from existing MIL-HDBK-217E models being either higher or lower. Additionally, new part types not included in MIL-HDBK-217E are included in the proposed models. Examples of these include:

- Ceramic Chip Capacitors
- Tantalum Chip Capacitors
- Pressure Switches
- Limit Switches
- Float Switches
- Centrifugal Switches
- Humidity Switches
- Waveguide Switches
- Various Connector Styles

- Various Socket Types
- Surface Mount Technology
- Full Horse Power Motors

It is recommended that efforts be continued to collect and analyze reliability data to continuously update models in MIL-HDBK-217. All data collected under government sponsored programs should be submitted to central repositories such as the Reliability Analysis Center.

It is also recommended that methodologies be developed to derive models without the statistical analysis of field failure rate data. Such methodologies could be based on physics of failure information, screening results, life test results, etc. Such models could then be modified as necessary once field data becomes available. Implementation of this approach would result in models representing state-of-the-art component types in a more timely manner than relying solely on field experience data.

8.0 REFERENCES

(1) Morrison, J.D., "Reliability Modelling of Tantalum Capacitors," 1988 CART Proceedings, p. 128.

(2) Draper, N., Smith H., "Applied Regression Analysis," Second Edition, Wiley.

(3) Priore, Mary G., "Discrete Semiconductor Device Reliability," RAC publication number DSR-4, 1988.

(4) Yudewitz N. "Predicting Relay Life Mathematically," 26th Relay Conferences, 1978.

(5) Moynihan, "Theory, Design and Application of Electrolytic Capacitors," CARTS Workshop, 1982.

(6) B.D. Hatch, et al., "Technical Information Series No. R6250 196," PT Missile and Space Div., G.E. Co.

(7) Word P., "Considerations In Design and Use of Multilayer Ceramic Capacitors in Surface Mounting," 1987 CARTS Proceedings, p. 79.

(8) Burnham, J., "Weibull Life Tests of KEMET Solid Tantalum Chip Capacitors at Highly Accelerated Voltages," 22nd Electronic Components Conference.

(9) Campbell and Hayes, "An Analysis of the Field Failure of Passive and Active Components," Loughborough University of Technology, June 1989.

(10) Air Force Maintenance Data

(11) "MTBF and Stability Data for Hy-Cal Engineering Platinum Resistance Temperature Sensors," Hy-Cal Engineering Report No. CF-393.2.

(12) Coit, David W., and Mary G. Priore, "Impact of Nonoperating Periods on Equipment Reliability," RADC-TR-85-91.

(13) Rossi, Michael, "Nonelectronics Parts Reliability Data," RAC publication number NPRD-3, 1985.

(14) Minford, W.J., "Accelerated Life Testing of High K Multilayer Ceramic Capacitors," NASA Conference Publication 2186.

(15) Corning Electronics, "In-House Life Testing"

(16) Bora, "Long Term Performance Studies of Electronic Component at Rated Electrical Stress," Microelectronics and Reliability, Vol. 26, N5, pp. 989-991.

(17) "Expressing Capacitor Reliability Accurately," Union Carbide Electronics, Report No. F-1884.

(18) Burnham, "Weibull Life Tests of Kemet Solid Ta Chip Capacitors at High Accelerated Voltages," Hughes Aircraft, 22nd Electronics Components Conference, 1982, pp. 439-455.

(19) Brodsky, et al., "Reliability and Application of Leaded Plastic Chip Carriers," Electronic Packaging and Production, Nov. 1981.

(20) Smeby, "Solder Joint Behavior in HCC/PWB Interconnects," 1984 Proceedings 34th Electronic Components Conference.

(21) Chappen and Banas, "Integrating Surface Mounted Technology into Manufacturing," 1984 Electronic Components Conference.

(22) Reynolds, "SMDs Invade Military and Commercial Equipment," Electronic Packaging and Production, Feb. 1985.

(23) Wright, "Thermal Shock Testing of Ceramic Thick Film Substrate," 1984 International Symposium on Microelectronics.

(24) Baron, R.V., Weingarten, D.H., "A Reliability Assessment of Polycarbonate Film Capacitors," 1986 CARTS Symposium, p. 117.

(25) Danielson, "Chip Carriers on Ceramic Thick Film Multilayer Boards in High Reliability Applications," 1984 International Symposium on Microelectronics.

(26) Isaacson, et. al., "Implementing Copper Thick Film Substrates for Surface Mount Technology," April 1985.

(27) Wright and Wolverton, "The Effect of the Solder Reflow Method and Joint Design on the Thermal Fatigue Life of Leadless Chip Carrier Solder Joint," 1984 Electronic Components Conference, 1984.

(28) Gray, "Substrates for Chip Carrier Interconnections," Surface Mount Technology: ISHM Technical Monograph series 6984-002, 1984.

(29) Caswell, "Vapor Phase Soldering of SMDs: Reliability Characteristics," Circuit World, 1985.

(30) Foldman, "An Unsymmetric Metal Base PWB: Design Parameters and Thermal Considerations," Circuit World, 1985.

(31) Walker, "Surface Mounted Device: Hybrid Module Technology Trade-offs in Communications Equipment," 1983 International Microelectronics Symposium, 1983.

(32) Brice-Heames, "Direct Attachment of Leadless Chip Carriers to Various PWB Material," 1984 International Symposium on Microelectronics, 1984.

(33) Chen and Verulle, "Direct Mounting of Ceramic Leadless Chip Carrier into Glass Epoxy Circuit Board," 1983 International Microelectronics Symposium, 1983.

(34) Greer, "Post Molded Leaded Chip Carrier," Texas Instruments, 1983.

(35) Denson, K. and P. Brusius, "VHSIC/VHSIC-Like Reliability Prediction Modeling," RADC-TR-89-177.

(36) Rivard, W.H., "Performance Characteristics of Gold vs. Tin Plated Relay and Socket Terminals."

(37) Maher, G.H., Hofmaier, R., Neumun, J., Love. G.R., "Accelerated Life Testing and Reliability of X7R Multilayer Ceramic Capacitor with a PLET Dielectric" 1986 CARTS Symposium, p. 1.

(38) Stockman, S. and D. Coit, "Surface Mount Technology: A Reliability Review," Reliability Analysis Center, 1986.

(39) Reliability Prediction of Electronic Equipment, MIL-HDBK-217E, Oct. 1986.

(40) Belcore TA-000-23620-84-01, "Reliability Prediction Procedure for Electronic, "Issue, 1984.

(41) "Handbook of Reliability Data for Electronic Component Used in Telecommunications Systems," British Telecon Handbook HDR3, 1984.

(42) ReLueil deDonnees deFiabilite du CNET, Tome 1: Portie Composants Electroniques, Centre National d'Etudes des Telecommunications, 1983.

(43) "Standard Reliability Table for Semiconductor Devices," Nippon Telegraphanel Telephone Public Corp., 1982.

(44) PREL$_{TM}$, Society of Automotive Engineers, 1989.

(45) Spencer, J., "The High and Lows of Reliability Predictions," 1986 R&M Symposium Proceedings, 1986, pp. 156-162.

(46) Denson, W.K.., et. al., "Development of Reliability Prediction Models for Electronic Components in Automotive Applications," SAE paper 840486, 1984.

(47) Blanks, H., "Reliability Prediction: A Constructive Critique of MIL-HDBK-217E," Q&RE International, V4, 1988, pp. 227-234.

(48) Priore, M., and W. Denson, "Automative Electronic Reliability Prediction," SAE Paper 870050, 1987.

(49) "Components Technology and Standardization," General Electric, Genium Publishing Corporation.

(50) "Reliability and Maintainability Data for Computer, Telephone and Electronic Parts and Equipment," TD-86-37, A.P. Harris and Associates.

(51) MIL-HDBK-338 "Electronic Reliability Design Handbook."

(52) Lauber, A., "Aluminum Electrolytic Capacitors Reliability Expected Life, and Shelf Capability," Sprague Technical Paper TP83-9, Dec. 1985.

(53) Lannuyzelli, R.J., "Effects of Manufacturing on Plated through Hole Reliability."

(54) Coit, D., "Printed Wiring Assembly and Interconnect Reliability" Sept. 1981, RADC-TR-81-318.

(55) Whelan, S., Pecht, M., Dasgupta, A., "Operational Temperature Cycle Values for Application Environment Categories," International Journal for Hybrid Microcircuit Vol. 13 Num 1, March 90.

(56) "Surface Mount Technology: A Reliability Review," RAC Publication SOAR-5.

(57) "How to Use Surface Mount Technology," TI Report No. SSYZ001.

(58) "Guidelines for Surface Mounting and Interconnecting Chip Carriers," IPC-CM-78, (1983).

(59) Reimer, D.E., Saulsburry, Boeing Aerospace "Power Cycling of Ceramic Chip Carriers on Ceramic Substrates".

(60) Lau, J.H., Rice, D.W., "Solder Joint Fatigue in Surface Mount Technology: State of the Art" Solid State Technology, Oct. 1985.

(61) Anderson, R., et. al., "Manufacturing Technology for High Reliability Packaging Using Hermetic Chip Carriers (HCC) on Compatible Printed Wiring Boards (PWBs)," Interim Technical Report, Jan 88 through April 88.

(62) Hinch, S.W., "Handbook of Surface Mount Technology," Pubished by Longman Scientific and Technical 1988.

(63) Surface Mount Technology, ISHM Technical Monograph Series 6984-002.

(64) Coit, D.W., Priore, M.P., "Reliability Prediction Models for Discrete Semiconductor Devices" RADC-TR-88-97, April 1988.

(65) Denson, W.K , Priore, M.G., "Automotive Electronic Reliability Prediction," SAE publication 870050, February 1987.

(66) Bivens, G.A., "Predicting Time to Failure Using Finite Element Analysis," 1990 R/M Symposium Proceedings.

(67) Weyde, B., "High Failure Rates of Printed Circuit Boards Demonstrate the Need for Bare Board Testing," IPC Report Number IPC-TP-493, 1983.

(68) Schindhelm, K.H., "The Evolution of High Pressure Polystyrene Capacitors with Extended Upper Catagory Temperature and Higher Reliability," 1987 CARTS Europe Symposium, p. 144.

(69) Burton, L., "Voltage Dependence of Activation Energy for MLC Capacitors."

(70) Prince, M.D.H., Hayes, J.A., "A Reliability Analysis of Multilayer Ceramic Capacitors Under Voltage and Temperature Acceleration," 1987 CARTS Europe, p. 195.

(71) Waser, K., "Accelerated Life Testing and Long Term Reliability of Multilayer Ceramic Capacitors," 1987 CARTS Europe Symposium, p. 189.

(72) Mogilevsky, B.M., Shirm, G.A "Accelerated Life Tests of Ceramic Capacitors," 1988 Electronic Components Conference, p. 362.

(73) Cornell Dublier Literature "SRC Capacitors", 209,75N.

(74) Tieman, B.M., "The Characteristic Life of a Dry Reed Contact - The influence of Switching Phenomena," 29th Relay Conference, 1981.

(75) KEMET Technical Data MR 50A.

(76) Eskin, D.J., "Reliability Derating Procedures," RADC-TR-84-254 (ADA153268).

(77) Sutherland, E.F., "Quality and Reliability Considerations for Dry Reed Relays," Evaluation Engineering, November 1989.

(78) Kimura, K., Ishino, M., Matsui, K., and Mitani, S., "Resistance Increase of Gold-Plated Silver Contacts by Carbon and its Acceleration Factor," 27th Relay Conference, 1979.

(79) Wilson, D.S., Smith, R., "Electric Motor Reliability Model," RADC-TR-77-408 (AD A050179) December 1977.

(80) "Lincoln Motor Briefs,," Lincoln Electric Company, July 1987.

(81) "Heres why Motors Fail," Lincoln Electric Company.

(82) Munikoti, R. and Dhar, P., "Highly Accelerated Life Testing (HALT) For Multilayer Ceramic Capacitor Qualification."

(83) Cozzolino, M.J., and R.C. Straessle, "Design, Characteristics and Failure Mechanisms of Tantalum Capacitors," 1988 CARTS Symposium, p. 98.

APPENDIX A:
DETAILED DATA

Part Type	Qual	DType	Env	Dielectric	Voltage		
	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Capacitor, Unknown				Unknown	Unk		
	M	FLD	AIC	0	112800.0H	188	1
	M	FLD	AIF	1	0.0H	2	2
	M	FLD	GF	6	258277240.0H	0	2
Capacitor, Unknown				Al Electrolytic	Unk		
	M	FLD	GF	0	12808120.0H	516	1
	M	FLD	GF	1	21854228.0H	0	1
Capacitor, Unknown				Al Foil, Solid	Unk		
	M	FLD	G	10	800000000.0H	0	1
Capacitor, Unknown				Al Foil, Wet	Unk		
	M	FLD	G	0	5000000.0H	0	1
Capacitor, Unknown				Al Sintered, Solid	Unk		
	M	FLD	G	0	16000.0H	0	1
Capacitor, Unknown				Ceramic	Unk		
	M	FLD	AIF	8	0.0H	280	3
	M	FLD	GF	2	71522928.0H	0	1
Capacitor, Unknown				Ceramic	50.00d		
	M	FLD	AIF	18	0.0H	161	5
Capacitor, Unknown				Ceramic	100.00d		
	M	FLD	AIF	12	0.0H	186	11
Capacitor, Unknown				Ceramic	200.00d		
	M	FLD	AIF	0	0.0H	38	8
Capacitor, Unknown				Ceramic (Disc)	Unk		
	M	FLD	G	3	300000000.0H	0	1
Capacitor, Unknown				Ceramic (Multilayer)	Unk		
	M	FLD	G	24	10000000000.0H	0	1
Capacitor, Unknown				Ceramic Class II	Unk		
	C	LAB	N/R	134	16512000.0H	4126	3
Capacitor, Unknown				Glass	Unk		
	M	FLD	G	0	40000.0H	0	1
Capacitor, Unknown				Mica (Metallised)	Unk		
	M	FLD	G	1	200000000.0H	0	1
Capacitor, Unknown				Paper (Metallised)	Unk		
	M	FLD	G	0	40000.0H	0	1
Capacitor, Unknown				Paper Plastic	30.00d		
	M	FLD	AIF	1	0.0H	32	3
Capacitor, Unknown				Paper Plastic Foil	Unk		
	M	FLD	G	0	3000.0H	0	1
Capacitor, Unknown				Paper Plastic Metal	Unk		
	M	FLD	G	0	700000.0H	0	1
Capacitor, Unknown				Polycarbonate Foil	Unk		
	M	FLD	G	0	20000000.0H	0	1
Capacitor, Unknown				Polycarbonate Metal	Unk		
	M	FLD	G	0	2000000000.0H	0	1
Capacitor, Unknown				Polyester Metallise	Unk		
	M	FLD	G	4	2000000000.0H	0	1
Capacitor, Unknown				Polystyrene Foil	Unk		
	M	FLD	G	10	300000000.0H	0	1
Capacitor, Unknown				Preset	Unk		
	M	FLD	G	0	8000000.0H	0	1
Capacitor, Unknown				Ta Electrolytic	Unk		

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
	M	FLD	AIF	0	0.0H	2	1
Capacitor, Unknown				Ta Electrolytic	20.00d		
	M	FLD	AIF	35	0.0H	94	4
Capacitor, Unknown				Ta Electrolytic	35.00d		
	M	FLD	AIF	2	0.0H	33	4
Capacitor, Unknown				Ta Electrolytic	50.000		
	M	FLD	GF	0	16010150.0H	645	1
Capacitor, Unknown				Ta Electrolytic	50.00d		
	M	FLD	AIF	43	0.0H	125	10
Capacitor, Unknown				Ta Electrolytic	75.00d		
	M	FLD	AIF	0	0.0H	1	1
Capacitor, Unknown				Ta Foil, Wet	Unk		
	M	FLD	G	5	7000000.0H	0	1
Capacitor, Unknown				Ta Sintered, Solid	Unk		
	M	FLD	G	5	3000000000.0H	0	1
Capacitor, Unknown				Ta Sintered, Wet	Unk		
	M	FLD	G	0	40000000.0H	0	1
Capacitor, Unknown				Ta Solid Elctltic	Unk		
	M	FLD	AIC	0	789600.0H	1316	3
Capacitor, Unknown				Tuner/Timmer	Unk		
	M	FLD	G	10	200000000.0H	0	1
Capacitor, Fixed				Unknown	Unk		
	M	FLD	AIA	0	1239972.0H	2664	4
	M	FLD	AIC	0	676800.0H	1128	4
	U	NOP	AIF	0	51901000.0H	2008	1
	U	NOP	GF	0	104843000.0H	7366	3
Capacitor, Fixed				Unknown	0.00v		
	C	FLD	GBC	12	3742221600.0H	2878632	66
Capacitor, Fixed				Unknown	25.00v		
	C	FLD	GBC	8	1005347200.0H	773344	26
Capacitor, Fixed				Unknown	30.00v		
	C	FLD	GBC	0	23056800.0H	17736	9
Capacitor, Fixed				Unknown	50.000		
	M	FLD	AIA	0	2066620.0H	4440	1
	M	FLD	AIC	0	1128000.0H	1880	1
Capacitor, Fixed				Unknown	50.00v		
	C	FLD	GBC	140	145875121600.0H	********	364
Capacitor, Fixed				Unknown	63.00v		
	C	FLD	GBC	0	5116800.0H	3936	1
Capacitor, Fixed				Unknown	75.00v		
	C	FLD	GBC	4	421200.0H	324	1
Capacitor, Fixed				Unknown	100.00v		
	C	FLD	GBC	120	128721387600.0H	99016452	367
Capacitor, Fixed				Unknown	200.000		
	M	FLD	AU	0	3054136.0H	7246	1
	M	FLD	AUA	0	206662.0H	888	1
	M	FLD	AUF	0	117032.0H	930	1
Capacitor, Fixed				Unknown	200.00v		
	C	FLD	GBC	32	13382605600.0H	10294312	151
Capacitor, Fixed				Unknown	250.00v		
	C	FLD	GBC	4	520728000.0H	400560	15

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
Capacitor, Fixed				Unknown	300.00v		
	C	FLD	GBC	0	3842800.0H	2956	5
Capacitor, Fixed				Unknown	400.00v		
	C	FLD	GBC	0	346585200.0H	266604	4
Capacitor, Fixed				Unknown	500.00v		
	C	FLD	GBC	12	4624531600.0H	3557332	135
Capacitor, Fixed				Unknown	600.00v		
	C	FLD	GBC	0	437195200.0H	336304	5
Capacitor, Fixed				Unknown	1000.00v		
	C	FLD	GBC	4	5230981600.0H	4023832	51
Capacitor, Fixed				Unknown	1600.00v		
	C	FLD	GBC	0	39187200.0H	30144	1
Capacitor, Fixed				Unknown	2000.00v		
	C	FLD	GBC	0	28407600.0H	21852	3
Capacitor, Fixed				Unknown	2500.00v		
	C	FLD	GBC	0	31200.0H	24	1
Capacitor, Fixed				Unknown	3000.00v		
	C	FLD	GBC	0	171267200.0H	131744	10
Capacitor, Fixed				Unknown	4000.00v		
	C	FLD	GBC	0	12656800.0H	9736	4
Capacitor, Fixed				Unknown	5000.00v		
	C	FLD	GBC	4	15116400.0H	11628	3
Capacitor, Fixed				Unknown	6000.00v		
	C	FLD	GBC	0	69451200.0H	53424	3
Capacitor, Fixed				Unknown	7500.00v		
	C	FLD	GBC	0	88400000.0H	68000	1
Capacitor, Fixed				Unknown	8000.00v		
	C	FLD	GBC	0	4555200.0H	3504	1
Capacitor, Fixed				Unknown	250000.00v		
	C	FLD	GBC	0	89050000.0H	68500	2
Capacitor, Fixed				Al Electrolytic	0.00v		
	C	FLD	GBC	0	21548800.0H	16576	2
Capacitor, Fixed				Al Electrolytic	2.50v		
	C	FLD	GBC	4	5990400.0H	4608	2
Capacitor, Fixed				Al Electrolytic	3.00v		
	C	FLD	GBC	0	29224000.0H	22480	5
Capacitor, Fixed				Al Electrolytic	6.00v		
	C	FLD	GBC	0	43508400.0H	33468	7
Capacitor, Fixed				Al Electrolytic	6.30v		
	C	FLD	GBC	0	635102000.0H	488540	12
Capacitor, Fixed				Al Electrolytic	7.50v		
	C	FLD	GBC	0	47304400.0H	36388	9
Capacitor, Fixed				Al Electrolytic	10.00v		
	C	FLD	GPC	0	610547600.0H	469652	31
Capacitor, Fixed				Al Electrolytic	12.00v		
	C	FLD	GBC	4	314511600.0H	241932	20
Capacitor, Fixed				Al Electrolytic	15.00v		
	C	FLD	GBC	8	244082800.0H	187756	50
Capacitor, Fixed				Al Electrolytic	16.00v		
	C	FLD	GBC	8	1808528800.0H	1391176	66
Capacitor, Fixed				Al Electrolytic	20.00v		

Part Type	Qual	DType	Env	Dielectric / Tot. Fail	Voltage / Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	8	209679600.0H	161292	38
Capacitor, Fixed				Al Electrolytic	25.00v		
	C	FLD	GBC	24	6356428000.0H	4889560	117
Capacitor, Fixed				Al Electrolytic	28.00v		
	C	FLD	GBC	4	19791200.0H	15224	2
Capacitor, Fixed				Al Electrolytic	30.000		
	M	FLD	GF	1	6404060.0H	258	1
Capacitor, Fixed				Al Electrolytic	30.00v		
	C	FLD	GBC	20	270784800.0H	208296	40
Capacitor, Fixed				Al Electrolytic	35.00v		
	C	FLD	GBC	8	1257074000.0H	966980	58
Capacitor, Fixed				Al Electrolytic	40.000		
	M	FLD	AU	0	9162408.0H	21738	1
	M	FLD	AUA	0	206662.0H	2664	1
	M	FLD	AUF	0	117032.0H	2790	1
Capacitor, Fixed				Al Electrolytic	40.00v		
	C	FLD	GBC	20	887312400.0H	682548	79
Capacitor, Fixed				Al Electrolytic	45.00v		
	C	FLD	GBC	4	48406800.0H	37236	4
Capacitor, Fixed				Al Electrolytic	50.000		
	M	FLD	GF	6	25616240.0H	1032	3
Capacitor, Fixed				Al Electrolytic	50.00v		
	C	FLD	GBC	12	7329795200.0H	5638304	144
Capacitor, Fixed				Al Electrolytic	55.00v		
	C	FLD	GBC	0	270400.0H	208	1
Capacitor, Fixed				Al Electrolytic	60.00v		
	C	FLD	GBC	4	147534400.0H	113488	7
Capacitor, Fixed				Al Electrolytic	63.00v		
	C	FLD	GBC	0	299686400.0H	230528	29
Capacitor, Fixed				Al Electrolytic	65.00v		
	C	FLD	GBC	0	65546000.0H	50420	4
Capacitor, Fixed				Al Electrolytic	75.00v		
	C	FLD	GBC	4	212019600.0H	163092	36
Capacitor, Fixed				Al Electrolytic	80.00v		
	C	FLD	GBC	0	4986800.0H	3836	4
Capacitor, Fixed				Al Electrolytic	85.00v		
	C	FLD	GBC	0	81208400.0H	62468	4
Capacitor, Fixed				Al Electrolytic	100.00v		
	C	FLD	GBC	4	284341200.0H	218724	38
Capacitor, Fixed				Al Electrolytic	120.00v		
	C	FLD	GBC	0	10400.0H	8	1
Capacitor, Fixed				Al Electrolytic	125.00v		
	C	FLD	GBC	0	8756800.0H	6736	3
Capacitor, Fixed				Al Electrolytic	140.00v		
	C	FLD	GBC	0	1414400.0H	1088	1
Capacitor, Fixed				Al Electrolytic	150.00v		
	C	FLD	GBC	8	462971600.0H	356132	25
Capacitor, Fixed				Al Electrolytic	160.00v		
	C	FLD	GBC	0	399724000.0H	307480	2
Capacitor, Fixed				Al Electrolytic	200.00v		
	C	FLD	GBC	76	354629600.0H	272792	34

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
Capacitor, Fixed				Al Electrolytic	225.00v		
	C	FLD	GBC	0	925600.0H	712	1
Capacitor, Fixed				Al Electrolytic	250.000		
	M	FLD	GF	3	3202030.0H	129	1
Capacitor, Fixed				Al Electrolytic	250.00v		
	C	FLD	GBC	4	256058400.0H	196968	32
Capacitor, Fixed				Al Electrolytic	255.00v		
	C	FLD	GBC	0	167757200.0H	129044	2
Capacitor, Fixed				Al Electrolytic	300.00v		
	C	FLD	GBC	12	88925200.0H	68404	9
Capacitor, Fixed				Al Electrolytic	350.00v		
	C	FLD	GBC	0	415994800.0H	319996	5
Capacitor, Fixed				Al Electrolytic	400.00v		
	C	FLD	GBC	0	439212800.0H	337856	5
Capacitor, Fixed				Al Electrolytic	450.00v		
	C	FLD	GBC	0	19151600.0H	14732	11
Capacitor, Fixed				Al Electrolytic	475.00v		
	C	FLD	GBC	0	1466400.0H	1128	2
Capacitor, Fixed				Carbon	5.00v		
	C	FLD	GBC	0	44995600.0H	34612	3
Capacitor, Fixed				Ceramic	Unk		
	C	NOP	GF	4	17045374000.0H	824051	29
	M	FLD	AIA	0	17566270.0H	37740	7
	M	FLD	AIC	0	18950400.0H	31584	12
	M	NOP	AIF	4	207602000.0H	8032	7
	M	NOP	GF	9	5400497000.0H	147706	60
	U	NOP	AIF	10	3703389000.0H	177206	7
	U	NOP	GF	0	96760000.0H	874	2
Capacitor, Fixed				Ceramic	50.000		
	M	FLD	AIA	0	25626088.0H	55056	23
	M	FLD	AIC	2	18612000.0H	32712	31
	M	FLD	AU	16	302359464.0H	717354	23
	M	FLD	AUA	1	4753226.0H	87912	23
	M	FLD	AUF	2	2691736.0H	92070	23
	M	FLD	GF	4	209733000.0H	9066	12
Capacitor, Fixed				Ceramic	50.00d		
	M	FLD	GF	0	19212180.0H	774	1
Capacitor, Fixed				Ceramic	75.000		
	M	FLD	AU	0	13743612.0H	32607	4
		FLD	AUA	0	826648.0H	3996	4
	M	FLD	AUF	4	468128.0H	4185	4
	M	FLD	GF	0	3202030.0H	129	1
Capacitor, Fixed				Ceramic	100.000		
	M	FLD	AIA	0	26452736.0H	56832	24
	M	FLD	AIC	2	22334400.0H	37154	25
	M	FLD	AU	25	375658728.0H	891258	30
	M	FLD	AUA	1	6199860.0H	109224	30
	M	FLD	AUF	11	3510960.0H	114390	30
	M	FLD	GF	0	193[illegible]21800.0H	7740	5
Capacitor, Fixed				Ceramic	200.000		
	M	FLD	AIA	0	57452036.0H	123432	17

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
	M	FLD	AIC	3	48052800.0H	80088	19
	M	FLD	AU	3	189356432.0H	449252	13
	M	FLD	AUA	0	2686606.0H	55056	13
	M	FLD	AUF	0	1521416.0H	57660	13
	M	FLD	GF	3	140889320.0H	5712	4
Capacitor, Fixed				Ceramic	300.000		
	M	FLD	AU	0	6108272.0H	14492	2
	M	FLD	AUA	0	413324.0H	1776	2
	M	FLD	AUF	0	234064.0H	1860	2
Capacitor, Fixed				Ceramic	500.000		
	M	FLD	AIA	0	2066620.0H	4440	6
	M	FLD	AIC	0	1579200.0H	2445	7
	M	FLD	AU	2	22906020.0H	54345	3
	M	FLD	AUA	0	619936.0H	6660	3
	M	FLD	AUF	1	351096.0H	6975	3
	M	FLD	GF	6	124879170.0H	5031	5
Capacitor, Fixed				Ceramic	600.000		
	M	FLD	AIA	0	206662.0H	444	1
	M	FLD	AIC	0	112800.0H	188	1
Capacitor, Fixed				Electrolytic	Unk		
	C	NOP	GF	9	14599409000.0H	744373	59
	M	NOP	GF	18	3755797000.0H	57288	54
	U	NOP	AIF	2	1012060000.0H	39152	2
Capacitor, Fixed				Electrolytic	6.000		
	M	FLD	AU	5	21378952.0H	50722	5
	M	FLD	AUA	2	1033310.0H	6216	5
	M	FLD	AUF	2	585160.0H	6510	5
Capacitor, Fixed				Electrolytic	10.000		
	M	FLD	AIA	0	1653296.0H	3552	3
	M	FLD	AIC	0	902400.0H	1504	3
	M	FLD	AU	1	47339108.0H	112313	4
	M	FLD	AUA	0	826648.0H	13764	4
	M	FLD	AUF	0	468128.0H	14415	4
Capacitor, Fixed				Electrolytic	15.000		
	M	FLD	AIA	0	619986.0H	1332	1
	M	FLD	AIC	0	338400.0H	564	1
	M	FLD	AU	6	33595496.0H	79706	6
	M	FLD	AUA	0	1239972.0H	9768	6
	M	FLD	AUF	0	702192.0H	10230	6
Capacitor, Fixed				Electrolytic	20.000		
	M	FLD	AIA	0	1239972.0H	2664	3
	M	FLD	AIC	0	676800.0H	1128	3
	M	FLD	AU	23	105367692.0H	249987	8
	M	FLD	AUA	0	1653296.0H	30636	8
	M	FLD	AUF	0	936256.0H	32085	8
	M	FLD	GF	0	16010150.0H	645	1
Capacitor, Fixed				Electrolytic	25.000		
	M	FLD	AU	4	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Capacitor, Fixed				Electrolytic	30.000		

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
	M	FLD	AU	1	12216544.0H	28984	2
	M	FLD	AUA	0	413324.0H	3552	2
	M	FLD	AUF	0	234064.0H	3720	2
	M	FLD	GF	0	3202030.0H	129	1
Capacitor, Fixed				Electrolytic	33.500		
	M	FLD	GF	0	3202030.0H	129	1
Capacitor, Fixed				Electrolytic	35.000		
	M	FLD	AIA	0	619986.0H	1332	1
	M	FLD	AIC	0	338400.0H	564	1
	M	FLD	AU	0	27487224.0H	65214	4
	M	FLD	AUA	0	826648.0H	7992	4
	M	FLD	AUF	0	468128.0H	8370	4
Capacitor, Fixed				Electrolytic	40.000		
	M	FLD	AU	0	3054136.0H	7246	2
	M	FLD	AUA	0	413324.0H	888	2
	M	FLD	AUF	0	234064.0H	930	2
Capacitor, Fixed				Electrolytic	50.000		
	M	FLD	AIA	0	619986.0H	1332	2
	M	FLD	AIC	0	338400.0H	564	2
	M	FLD	AU	8	87042876.0H	206511	11
	M	FLD	AUA	7	2273282.0H	25308	11
	M	FLD	AUF	12	1287352.0H	26505	11
	M	FLD	GF	17	6404060.0H	258	2
Capacitor, Fixed				Electrolytic	60.000		
	M	FLD	AU	17	10689476.0H	25361	3
	M	FLD	AUA	13	619986.0H	3108	3
	M	FLD	AUF	17	351096.0H	3255	3
Capacitor, Fixed				Electrolytic	75.000		
	M	FLD	AIA	0	413324.0H	888	1
	M	FLD	AIC	0	225600.0H	376	1
	M	FLD	AU	3	27487224.0H	65214	5
	M	FLD	AUA	4	1033310.0H	7992	5
	M	FLD	AUF	0	585160.0H	8370	5
Capacitor, Fixed				Electrolytic	100.000		
	M	FLD	AIA	0	619986.0H	1332	1
	M	FLD	AIC	0	338400.0H	564	1
	M	FLD	AU	17	7635340.0H	18115	4
	M	FLD	AUA	2	826648.0H	2220	4
	M	FLD	AUF	5	468128.0H	2325	4
Capacitor, Fixed				Electrolytic	150.000		
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Capacitor, Fixed				Glass	Unk		
	C	NOP	GF	0	367235000.0H	5903	4
	M	NOP	GF	0	1128910000.0H	81282	36
	U	NOP	AIF	0	25950000.0H	1004	1
Capacitor, Fixed				Glass	50.000		
	M	FLD	AIA	0	619986.0H	1332	1
	M	FLD	AIC	0	338400.0H	564	1
Capacitor, Fixed				Glass	200.000		

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
	M	FLD	AIA	0	1653296.0H	3552	1
	M	FLD	AIC	0	902400.0H	1504	1
Capacitor, Fixed				Glass	300.00v		
	C	FLD	GBC	0	78327600.0H	60252	3
Capacitor, Fixed				Glass	500.000		
	M	FLD	AIA	0	4959888.0H	10656	11
	M	FLD	AIC	0	2932800.0H	4888	12
Capacitor, Fixed				Glass	500.00v		
	C	FLD	GBC	0	5200.0H	4	1
Capacitor, Fixed				Mica	Unk		
	C	NOP	GF	2	3632712000.0H	254544	29
	M	NOP	GF	0	906554000.0H	38456	17
Capacitor, Fixed				Mica	0.00v		
	C	FLD	GBC	0	30737200.0H	23644	5
Capacitor, Fixed				Mica	50.000		
	M	FLD	AU	148	64136856.0H	152166	19
	M	FLD	AUA	4	3926578.0H	18648	19
	M	FLD	AUF	6	2223608.0H	19530	19
	M	FLD	GF	0	38424360.0H	1548	8
Capacitor, Fixed				Mica	100.000		
	M	FLD	AU	7	13743612.0H	32607	4
	M	FLD	AUA	0	826648.0H	3996	4
	M	FLD	AUF	0	468128.0H	4185	4
	M	FLD	GF	2	9606090.0H	387	2
Capacitor, Fixed				Mica	100.00v		
	C	FLD	GBC	0	2094060800.0H	1610816	71
Capacitor, Fixed				Mica	250.000		
	M	FLD	AU	0	9162408.0H	21738	1
	M	FLD	AUA	0	206662.0H	2664	1
	M	FLD	AUF	0	117032.0H	2790	1
	M	FLD	GF	0	3202030.0H	129	1
Capacitor, Fixed				Mica	250.00v		
	C	FLD	GBC	0	17680000.0H	13600	5
Capacitor, Fixed				Mica	300.000		
	M	FLD	AU	4	13743612.0H	32607	5
	M	FLD	AUA	1	1033310.0H	3996	5
	M	FLD	AUF	2	585160.0H	4185	5
	M	FLD	GF	0	9606090.0H	387	2
Capacitor, Fixed				Mica	300.00v		
	C	FLD	GBC	20	8487221600.0H	6528632	200
Capacitor, Fixed				Mica	330.00v		
	C	FLD	GBC	0	3978000.0H	3060	1
Capacitor, Fixed				Mica	500.000		
	M	FLD	AIA	0	206662.0H	444	1
	M	FLD	AIC	0	112800.0H	188	1
	M	FLD	GF	0	89656840.0H	3612	20
Capacitor, Fixed				Mica	500.00v		
	C	FLD	GBC	4	1384614400.0H	1065088	103
Capacitor, Fixed				Paper	600.000		
	M	FLD	GF	6	6404060.0H	258	1
Capacitor, Fixed				Paper Foil	600.00v		

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	0	4102800.0H	3156	1
Capacitor, Fixed				Paper Metal	0.00v		
	C	FLD	GBC	0	2921042800.0H	2246956	15
Capacitor, Fixed				Paper Metal	240.00v		
	C	FLD	GBC	0	587600.0H	452	1
Capacitor, Fixed				Paper Plastic	Unk		
	C	NOP	GF	4	1281264000.0H	90284	23
	M	NOP	GF	9	2256014000.0H	120612	79
Capacitor, Fixed				Paper Polyest. Metal	200.00v		
	C	FLD	GBC	0	3369600.0H	2592	1
Capacitor, Fixed				Paper Polyest. Metal	400.00v		
	C	FLD	GBC	0	1450800.0H	1116	1
Capacitor, Fixed				Paper Polyester Foil	400.00v		
	C	FLD	GBC	0	1445600.0H	1112	1
Capacitor, Fixed				Paper Polyester Foil	1000.00v		
	C	FLD	GBC	0	904800.0H	696	1
Capacitor, Fixed				Plastic	50.000		
	M	FLD	AU	6	27487224.0H	65214	12
	M	FLD	AUA	0	2479944.0H	7992	12
	M	FLD	AUF	0	1404384.0H	8370	12
Capacitor, Fixed				Plastic	80.000		
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
	M	FLD	GF	0	3202030.0H	129	1
Capacitor, Fixed				Plastic	100.000		
	M	FLD	AU	21	7635340.0H	18115	4
	M	FLD	AUA	0	826648.0H	2220	4
	M	FLD	AUF	0	468128.0H	2325	4
Capacitor, Fixed				Plastic	150.000		
	M	FLD	AU	0	3054136.0H	7246	2
	M	FLD	AUA	0	413324.0H	888	2
	M	FLD	AUF	0	234064.0H	930	2
	M	FLD	GF	0	9606090.0H	387	1
Capacitor, Fixed				Plastic	400.000		
	M	FLD	AU	1	3054136.0H	7246	1
	M	FLD	AUA	1	206662.0H	888	1
	M	FLD	AUF	0	117032.0H	930	1
Capacitor, Fixed				Plastic	500.000		
	M	FLD	AU	0	3054136.0H	7246	1
	M	FLD	AUA	0	206662.0H	888	1
	M	FLD	AUF	2	117032.0H	930	1
Capacitor, Fixed				Polycarbonate Foil	50.00v		
	C	FLD	GBC	0	98800.0H	76	2
Capacitor, Fixed				Polycarbonate Foil	63.00v		
	C	FLD	GBC	0	18995600.0H	14612	4
Capacitor, Fixed				Polycarbonate Foil	100.00v		
	C	FLD	GBC	0	16749200.0H	12884	2
Capacitor, Fixed				Polycarbonate Foil	400.00v		
	C	FLD	GBC	0	1710800.0H	1316	1
Capacitor, Fixed				Polycarbonate Metal	Unk		

Part Type	Dielectric	Voltage	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
			M	LAB	N/R	0	560000.0H	280	14
Capacitor, Fixed	Polycarbonate Metal	40.00v	C	FLD	GBC	8	296233600.0H	227872	15
Capacitor, Fixed	Polycarbonate Metal	50.00v	C	FLD	GBC	0	1236773200.0H	951364	72
Capacitor, Fixed	Polycarbonate Metal	63.00v	C	FLD	GBC	0	72529600.0H	55792	18
Capacitor, Fixed	Polycarbonate Metal	75.00v	C	FLD	GBC	0	3775200.0H	2904	2
Capacitor, Fixed	Polycarbonate Metal	100.00v	C	FLD	GBC	0	496017600.0H	381552	28
Capacitor, Fixed	Polycarbonate Metal	160.00v	C	FLD	GBC	0	278558300.0H	214276	13
Capacitor, Fixed	Polycarbonate Metal	200.00v	C	FLD	GBC	4	415318800.0H	319476	35
Capacitor, Fixed	Polycarbonate Metal	250.00v	C	FLD	GBC	0	563378400.0H	433368	24
Capacitor, Fixed	Polycarbonate Metal	400.00v	C	FLD	GBC	0	91327600.0H	70252	8
Capacitor, Fixed	Polycarbonate Metal	630.00v	C	FLD	GBC	0	76757200.0H	59044	2
Capacitor, Fixed	Polyesther Foil	30.00v	C	FLD	GBC	0	4154800.0H	3196	2
Capacitor, Fixed	Polyesther Foil	50.00v	C	FLD	GBC	0	230952800.0H	177656	18
Capacitor, Fixed	Polyesther Foil	80.00v	C	FLD	GBC	0	599575600.0H	461212	11
Capacitor, Fixed	Polyesther Foil	100.00v	C	FLD	GBC	0	216590400.0H	166608	9
Capacitor, Fixed	Polyesther Foil	150.00v	C	FLD	GBC	0	816400.0H	628	1
Capacitor, Fixed	Polyesther Foil	200.00v	C	FLD	GBC	16	4565210000.0H	3511700	58
Capacitor, Fixed	Polyesther Foil	250.00v	C	FLD	GBC	0	5761600.0H	4432	1
Capacitor, Fixed	Polyesther Foil	400.00v	C	FLD	GBC	0	75114000.0H	57780	11
Capacitor, Fixed	Polyesther Foil	600.00v	C	FLD	GBC	0	48141600.0H	37032	9
Capacitor, Fixed	Polyesther Foil	800.00v	C	FLD	GBC	0	306800.0H	236	1
Capacitor, Fixed	Polyesther Metal	0.00v	C	FLD	GBC	8	58988800.0H	45376	11
Capacitor, Fixed	Polyesther Metal	35.00v	C	FLD	GBC	0	4004000.0H	3080	1
Capacitor, Fixed	Polyesther Metal	50.00v	C	FLD	GBC	4	4117453600.0H	3167272	24
Capacitor, Fixed	Polyesther Metal	63.00v	C	FLD	GBC	0	1243803600.0H	956772	15
Capacitor, Fixed	Polyesther Metal	100.00v	C	FLD	GBC	0	694574400.0H	534288	23

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
Capacitor, Fixed				Polyesther Metal	150.00v		
	C	FLD	GBC	0	306800.0H	236	1
Capacitor, Fixed				Polyesther Metal	160.00v		
	C	FLD	GBC	0	2298400.0H	1768	1
Capacitor, Fixed				Polyesther Metal	200.00v		
	C	FLD	GBC	0	154996400.0H	119228	8
Capacitor, Fixed				Polyesther Metal	250.00v		
	C	FLD	GBC	0	158839200.0H	122184	10
Capacitor, Fixed				Polyesther Metal	400.00v		
	C	FLD	GBC	0	763224800.0H	587096	15
Capacitor, Fixed				Polyesther Metal	600.00v		
	C	FLD	GBC	0	10426000.0H	8020	3
Capacitor, Fixed				Polyesther Metal	630.00v		
	C	FLD	GBC	4	172780400.0H	132908	3
Capacitor, Fixed				Polyesther Metal	4000.00v		
	C	FLD	GBC	0	255580000.0H	196600	9
Capacitor, Fixed				Polyesther Metal	6000.00v		
	C	FLD	GBC	0	87037600.0H	66952	5
Capacitor, Fixed				Polyesther Metal	8000.00v		
	C	FLD	GBC	0	42593200.0H	32764	1
Capacitor, Fixed				Polyesther Metal	15000.00v		
	C	FLD	GBC	0	130000.0H	100	1
Capacitor, Fixed				Polypropelene	400.000		
	M	FLD	AU	0	3054136.0H	7246	1
	M	FLD	AUA	0	206662.0H	888	1
	M	FLD	AUF	0	117032.0H	930	1
Capacitor, Fixed				Polypropelene	600.000		
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Capacitor, Fixed				Polypropelene Foil	50.00v		
	C	FLD	GBC	0	61198800.0H	47076	5
Capacitor, Fixed				Polypropelene Foil	63.00v		
	C	FLD	GBC	0	4087200.0H	3144	2
Capacitor, Fixed				Polypropelene Foil	100.00v		
	C	FLD	GBC	0	349018800.0H	268476	22
Capacitor, Fixed				Polypropelene Foil	150.00v		
	C	FLD	GBC	0	2735200.0H	2104	1
Capacitor, Fixed				Polypropelene Foil	160.00v		
	C	FLD	GBC	0	106797600.0H	82152	7
Capacitor, Fixed				Polypropelene Foil	200.00v		
	C	FLD	GBC	0	44200000.0H	34000	8
Capacitor, Fixed				Polypropelene Foil	250.00v		
	C	FLD	GBC	0	399058400.0H	306968	2
Capacitor, Fixed				Polypropelene Foil	400.00v		
	C	FLD	GBC	0	82841200.0H	63724	3
Capacitor, Fixed				Polypropelene Foil	500.00v		
	C	FLD	GBC	0	10940800.0H	8416	3
Capacitor, Fixed				Polypropelene Foil	600.00v		
	C	FLD	GBC	0	14294800.0H	10996	1
Capacitor, Fixed				Polypropelene Foil	630.00v		

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	0	410612800.0H	315856	7
Capacitor, Fixed				Polypropelene Foil	800.00v		
	C	FLD	GBC	0	38818000.0H	29860	1
Capacitor, Fixed				Polypropelene Foil	1000.00v		
	C	FLD	GBC	0	646755200.0H	497504	5
Capacitor, Fixed				Polypropelene Foil	1500.00v		
	C	FLD	GBC	0	91052000.0H	70040	3
Capacitor, Fixed				Polypropelene Foil	1600.00v		
	C	FLD	GBC	0	306800.0H	236	1
Capacitor, Fixed				Polypropelene Foil	2000.00v		
	C	FLD	GBC	0	1040000.0H	800	1
Capacitor, Fixed				Polypropelene Metal	0.00v		
	C	FLD	GBC	0	124800.0H	96	1
Capacitor, Fixed				Polypropelene Metal	50.00v		
	C	FLD	GBC	0	33893600.0H	26072	2
Capacitor, Fixed				Polypropelene Metal	100.00v		
	C	FLD	GBC	0	301854800.0H	232196	19
Capacitor, Fixed				Polypropelene Metal	160.00v		
	C	FLD	GBC	0	53970800.0H	41516	3
Capacitor, Fixed				Polypropelene Metal	200.00v		
	C	FLD	GBC	0	78681200.0H	60524	13
Capacitor, Fixed				Polypropelene Metal	250.00v		
	C	FLD	GBC	0	7030400.0H	5408	2
Capacitor, Fixed				Polypropelene Metal	400.00v		
	C	FLD	GBC	0	463174400.0H	356288	5
Capacitor, Fixed				Polypropelene Metal	800.00v		
	C	FLD	GBC	0	93600.0H	72	1
Capacitor, Fixed				Polypropelene Metal	1500.00v		
	C	FLD	GBC	0	51833600.0H	39872	1
Capacitor, Fixed				Polypropelene Metal	2000.00v		
	C	FLD	GBC	0	17128800.0H	13176	1
Capacitor, Fixed				Polystyrene Foil	50.00v		
	C	FLD	GBC	0	17908800.0H	13776	3
Capacitor, Fixed				Polystyrene Foil	63.00v		
	C	FLD	GBC	8	113479600.0H	87292	45
Capacitor, Fixed				Polystyrene Foil	100.00v		
	C	FLD	GBC	8	65644800.0H	50496	5
Capacitor, Fixed				Polystyrene Foil	160.00v		
	C	FLD	GBC	0	691600.0H	532	1
Capacitor, Fixed				Polystyrene Foil	200.00v		
	C	FLD	GBC	0	1320800.0H	1016	1
Capacitor, Fixed				Polystyrene Foil	600.00v		
	C	FLD	GBC	0	1648400.0H	1268	1
Capacitor, Fixed				Polystyrene Metal	100.00v		
	C	FLD	GBC	0	20893600.0H	16072	2
Capacitor, Fixed				Porcelain	0.00v		
	C	FLD	GBC	0	3109600.0H	2392	1
Capacitor, Fixed				Porcelain	50.00v		
	C	FLD	GBC	0	3936400.0H	3028	2
Capacitor, Fixed				Porcelain	350.00v		
	C	FLD	GBC	0	4908800.0H	3776	2

Part Type	Qual	Dtype	Env	Tot. Fail	Dielectric	Voltage	Total Duration	Total Pop.	No. Rec.
Capacitor, Fixed	C	FLD	GBC	0	Porcelain	500.00v	130254800.0H	100196	16
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	2.00v	41600.0H	32	1
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	3.00v	16525600.0H	12712	1
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	4.00v	65733200.0H	50564	1
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	6.00v	1356908800.0H	1043776	18
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	6.30v	1544400.0H	1188	1
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	8.00v	38968800.0H	29976	4
Capacitor, Fixed	M	FLD	GF	0	Ta Electrolytic	10.000	12808120.0H	516	4
Capacitor, Fixed	C	FLD	GBC	8	Ta Electrolytic	10.00v	6298879600.0H	4845292	43
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	13.00v	14300000.0H	11000	1
Capacitor, Fixed	M	FLD	GF	0	Ta Electrolytic	15.000	12808120.0H	516	2
Capacitor, Fixed	C	FLD	GBC	16	Ta Electrolytic	15.00v	3944865600.0H	3034512	18
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	16.00v	91260000.0H	70200	4
Capacitor, Fixed	M	FLD	GF	0	Ta Electrolytic	20.000	35222330.0H	1419	5
Capacitor, Fixed	C	FLD	GBC	68	Ta Electrolytic	20.00v	12327842800.0H	9482956	39
Capacitor, Fixed	C	FLD	GBC	24	Ta Electrolytic	25.00v	2600670800.0H	2000516	22
Capacitor, Fixed	C	FLD	GBC	4	Ta Electrolytic	30.00v	178146800.0H	137036	10
Capacitor, Fixed	M	FLD	GF	1	Ta Electrolytic	35.000	38424360.0H	1548	4
Capacitor, Fixed	C	FLD	GBC	52	Ta Electrolytic	35.00v	15652956800.0H	12040736	73
Capacitor, Fixed	M	FLD	GF	2	Ta Electrolytic	50.000	51232480.0H	2064	4
Capacitor, Fixed	M	FLD	AIF	0	Ta Electrolytic	50.00d	0.0H	32	1
Capacitor, Fixed	C	FLD	GBC	48	Ta Electrolytic	50.00v	2493270000.0H	1917900	20
Capacitor, Fixed	C	FLD	GBC	4	Ta Electrolytic	60.00v	70751200.0H	54424	2
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	75.00v	176893600.0H	136072	11
Capacitor, Fixed	C	FLD	GBC	0	Ta Electrolytic	100.00v	11923800.0H	9176	3
Capacitor, Fixed					Ta Solid Electric	10.000			

Part Type	Qual	DType	Env	Dielectric / Tot. Fail	Voltage / Total Duration	Total Pop.	No. Rec.
	M	FLD	GF	0	12808120.0H	516	2
Capacitor, Fixed				Ta Solid Elctltic	15.000		
	M	FLD	AIC	0	225600.0H	376	1
Capacitor, Fixed				Ta Solid Elctltic	35.000		
	M	FLD	AIC	1	1128000.0H	1880	1
Capacitor, Fixed				Ta Solid Elctltic	50.000		
	M	FLD	AIA	0	206662.0H	444	1
	M	FLD	AIC	0	112800.0H	188	1
Capacitor, Fixed				Teflon	100.00v		
	C	FLD	GBC	0	2943200.0H	2264	4
Capacitor, Fixed				Unknown (Mis)	50.00v		
	C	FLD	GBC	0	90324000.0H	69480	2
Capacitor, Fixed				Unknown (Mis)	100.00v		
	C	FLD	GBC	0	7618000.0H	5860	2
Capacitor, Fixed				Unknown (Mis)	150.00v		
	C	FLD	GBC	0	6900400.0H	5308	2
Capacitor, Fixed				Unknown (Ti Diox)	500.00v		
	C	FLD	GBC	0	120738800.0H	92876	12
Capacitor, Variable				Unknown	Unk		
	C	NOP	GF	2	144186000.0H	6155	7
	M	FLD	DOR	1	49470000.0H	0	4
	M	NOP	GF	0	84000000.0H	0	1
Capacitor, Variable				Unknown	50.00v		
	C	FLD	GBC	0	25188800.0H	19376	1
Capacitor, Variable				Unknown	63.00v		
	C	FLD	GBC	0	509501200.0H	391924	10
Capacitor, Variable				Unknown	100.000		
	M	FLD	AIA	0	1239972.0H	2664	1
	M	FLD	AIC	0	1128000.0H	1880	2
Capacitor, Variable				Unknown	100.00v		
	C	FLD	GBC	4	129417600.0H	99552	5
Capacitor, Variable				Unknown	160.00v		
	C	FLD	GBC	0	235211600.0H	180932	6
Capacitor, Variable				Unknown	200.00v		
	C	FLD	GBC	0	693659200.0H	533584	5
Capacitor, Variable				Unknown	250.000		
	M	FLD	AIA	0	1239972.0H	2664	1
	M	FLD	AIC	0	1128000.0H	1880	2
Capacitor, Variable				Unknown	250.00v		
	C	FLD	GBC	8	101925200.0H	78404	8
Capacitor, Variable				Unknown	350.00v		
	C	FLD	GCC	16	695255600.0H	534812	13
Capacitor, Variable				Unknown	400.00v		
	C	FLD	GBC	0	2574000.0H	1980	1
Capacitor, Variable				Unknown	500.00v		
	C	FLD	GBC	0	3406000.0H	2620	2
Capacitor, Variable				Unknown	750.00v		
	C	FLD	GBC	0	1190800.0H	916	1
Capacitor, Variable				Air	0.00v		
	C	FLD	GBC	0	88400.0H	68	1
Capacitor, Variable				Air	50.00v		

Part Type	Qual	DType	Env	Dielectric / Tot. Fail	Voltage / Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	0	43305600.0H	33312	1
Capacitor, Variable				Air	175.00v		
	C	FLD	GBC	0	641622800.0H	493556	6
Capacitor, Variable				Air	250.000		
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
	M	FLD	GF	1	3202030.0H	129	1
Capacitor, Variable				Air	250.00v		
	C	FLD	GBC	0	126906000.0H	97620	5
Capacitor, Variable				Air	350.00v		
	C	FLD	GBC	0	84286800.0H	64836	10
Capacitor, Variable				Air	500.00v		
	C	FLD	GBC	0	1227200.0H	944	1
Capacitor, Variable				Ceramic	100.000		
	M	FLD	AIA	0	2066620.0H	4440	1
	M	FLD	AIC	0	1128000.0H	1880	1
	M	FLD	AU	28	18324816.0H	43476	4
	M	FLD	AUA	42	826648.0H	5328	4
	M	FLD	AUF	20	468128.0H	5580	4
Capacitor, Variable				Ceramic	200.000		
	M	FLD	AU	0	3054136.0H	7246	1
	M	FLD	AUA	0	206662.0H	888	1
	M	FLD	AUF	0	117032.0H	930	1
	M	FLD	GF	0	12808120.0H	516	1
Capacitor, Variable				Ceramic	250.000		
	M	FLD	AIA	0	206662.0H	444	1
	M	FLD	AIC	0	112800.0H	188	1
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Capacitor, Variable				Ceramic	350.000		
	M	FLD	AU	2	7635340.0H	18115	3
	M	FLD	AUA	1	619986.0H	2220	3
	M	FLD	AUF	2	351096.0H	2325	3
	M	FLD	GF	0	28818270.0H	1161	3
Capacitor, Variable				Glass	250.00v		
	C	FLD	GBC	0	13280800.0H	10216	1
Capacitor, Variable				Glass	750.00v		
	C	FLD	GBC	0	81348800.0H	62576	4
Capacitor, Variable				Mica	175.00v		
	C	FLD	GBC	0	20878000.0H	16060	4
Capacitor, Variable				Polycarbonate Foil	100.00v		
	C	FLD	GBC	0	18085600.0H	13912	1
Capacitor, Variable				Polypropelene Metal	100.00v		
	C	FLD	GBC	0	58775600.0H	45212	2
Capacitor, Variable				Polypropelene Metal	150.00v		
	C	FLD	GBC	0	3374800.0H	2596	1
Capacitor, Variable				Teflon	200.00v		
	C	FLD	GBC	0	676000.0H	520	1
Capacitor, Variable				Unknown (Fep)	100.00v		

Part Type	Qual	DType	Env	Dielectric Tot. Fail	Voltage Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	0	17482400.0H	13448	1
Capacitor, Variable				Unknown (Fep)	300.00v		
	C	FLD	GBC	0	56648800.0H	43576	1
Capacitor, Variable				Unknown (Fep)	600.00v		
	C	FLD	GBC	0	107983200.0H	83064	2
Capacitor, Variable				Unknown (Fep)	1000.00v		
	C	FLD	GBC	0	1029600.0H	792	1
Capacitor, Variable				Unknown(Polyimid-Fl)	50.00v		
	C	FLD	GBC	0	4908800.0H	3776	1
Capacitor, Variable				Unknown(Polyphe-Fl)	600.00v		
	C	FLD	GBC	0	18668000.0H	14360	1

Part Type	Contact Config.	Rated Current	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Circuit Breaker, Unknown	Unknown	Unk							
			C	FLD	A	0	84000.0H	3	1
			C	FLD	GF	9	792000.0H	36	3
			C	FLD	HEL	2	70000.0H	0	1
			M	FLD	A	379	121252883.0H	564	38
			M	FLD	AI	0	17200.0H	2	1
			M	FLD	GF	63	108930290.0H	1266	3
			M	FLD	GM	33	8165210.0H	1949	20
			M	FLD	GMW	30	40125000.0H	0	2
			M	FLD	NBS	68	1636000.0H	0	2
			M	FLD	NS	1	3737488.0H	55	2
			M	FLD	NSB	0	31886400.0H	858	20
			M	FLD	SF	4	8937000.0H	1216	2
			U	FLD	A	0	0.0H	0	1
			U	FLD	ARW	0	0.0H	0	1
			U	FLD	GM	0	0.0H	0	1
			U	FLD	N	0	0.0H	0	1
			U	FLD	NSB	0	0.0H	0	1
			U	FLD	SF	0	0.0H	0	1
Circuit Breaker, Unknown	Unknown	3.00a							
			M	FLD	A	2	22650.0H	1	1
Circuit Breaker, Unknown	3P	20.00a							
			C	FLD	GBC	0	728000.0H	560	1
Circuit Breaker, Unknown	3PST	10.00a							
			M	FLD	NSB	1	569400.0H	13	1
Circuit Breaker, Unknown	3PST	100.00a							
			M	FLD	GM	1	1989.0H	64	1
Circuit Breaker, Unknown	DP	2.50a							
			C	FLD	GBC	0	5652400.0H	4348	1
Circuit Breaker, Unknown	DP	7.50a							
			C	FLD	GBC	0	11996400.0H	9228	1
Circuit Breaker, Unknown	DP	10.00a							
			C	FLD	GBC	0	691600.0H	532	3
Circuit Breaker, Unknown	DP	11.00a							
			C	FLD	GBC	0	499200.0H	384	1
Circuit Breaker, Unknown	DP	12.50a							
			C	FLD	GBC	0	1263600.0H	972	1
Circuit Breaker, Unknown	DP	15.00a							
			C	FLD	GBC	0	1851200.0H	1424	3
Circuit Breaker, Unknown	DP	20.00a							
			C	FLD	GBC	0	14580800.0H	11216	6
Circuit Breaker, Unknown	DP	25.00a							
			C	FLD	GBC	0	3801200.0H	2924	1
Circuit Breaker, Unknown	DP	30.00a							
			C	FLD	GBC	0	369200.0H	284	2
Circuit Breaker, Unknown	SP	1.20a							
			C	FLD	GBC	0	1882400.0H	1448	1
Circuit Breaker, Unknown	SP	3.00a							
			C	FLD	GBC	0	2163200.0H	1664	1
Circuit Breaker, Unknown	SP	6.00a							
			C	FLD	GBC	0	3692000.0H	2840	1

Part Type	Qual	DType	Env	Contact Config. / Tot. Fail	Rated Current / Total Duration	Total Pop.	No. Rec.
Circuit Breaker, Unknown				SP	7.50a		
	C	FLD	GBC	0	5881200.0H	4524	1
Circuit Breaker, Unknown				SP	20.00a		
	C	FLD	GBC	0	1341600.0H	1032	1
Circuit Breaker, Unknown				SP	25.00a		
	C	FLD	GBC	0	14383200.0H	11064	1
Circuit Breaker, Unknown				SPST	5.00a		
	M	FLD	NSB	1	1078200.0H	39	1
Circuit Breaker, Unknown				SPST	10.00a		
	M	FLD	NSB	2	3416400.0H	78	1
Circuit Breaker, 3-Pole				Unknown	Unk		
	U	FLD	G	0	0.0H	0	1
	U	FLD	GM	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	1
	U	FLD	SF	0	0.0H	0	1
Circuit Breaker, Current Trip				Unknown	Unk		
	U	FLD	GF	5	1215091.0H	265	3
	U	FLD	GM	21	2937495.0H	1816	4
	U	FLD	NS	12	2298769.0H	834	3
	U	FLD	NU	4	799870.0H	285	2
Circuit Breaker, Current/Voltage Trip				Unknown	Unk		
	U	FLD	GF	11	1107781.0H	889	2
	U	FLD	NS	15	250000.0H	125	1
	U	FLD	NSB	1	38000.0H	236	4
Circuit Breaker, Magnetic				Unknown	Unk		
	M	FLD	GF	0	114048.0H	4	4
	M	FLD	GM	0	369000.0H	21	1
	M	FLD	NC	0	211418.0H	53	1
	M	FLD	NS	0	632616.0H	155	3
	U	FLD	GF	190	69571000.0H	6617	5
Circuit Breaker, Magnetic				Unknown	0.20a		
	M	FLD	GF	0	313632.0H	11	4
Circuit Breaker, Magnetic				3PST	Unk		
	M	FLD	GF	1	10707000.0H	0	1
	M	FLD	GM	0	276000.0H	14	1
	M	FLD	NBS	1	111000.0H	0	1
Circuit Breaker, Magnetic				3PST	5.00a		
	M	FLD	GF	0	28512.0H	1	1
	M	FLD	GM	0	246000.0H	14	1
Circuit Breaker, Magnetic				3PST	20.00a		
	M	FLD	GF	0	28512.0H	1	1
Circuit Breaker, Magnetic				3PST	35.00a		
	M	FLD	GM	0	246000.0H	14	1
Circuit Breaker, Magnetic				3PST	50.00a		
	M	FLD	GM	0	123000.0H	7	1
Circuit Breaker, Magnetic				3PST	60.00a		
	M	FLD	GM	0	123000.0H	7	1
Circuit Breaker, Magnetic				DPST	Unk		
	M	FLD	GF	0	28512.0H	1	1
	M	FLD	GM	0	123000.0H	7	1
Circuit Breaker, Magnetic				DPST	0.20a		

Part Type	Qual	DType	Env	Contact Config.	Tot. Fail	Rated Current	Total Duration	Total Pop.	No. Rec.
	M	FLD	GF		0		114048.0H	4	4
Circuit Breaker, Magnetic				DPST		5.00a			
	M	FLD	GM		0		3690000.0H	210	1
Circuit Breaker, Magnetic				DPST		10.00a			
	M	FLD	GM		0		123000.0H	7	1
Circuit Breaker, Magnetic				SPST		0.20a			
	M	FLD	GF		0		142560.0H	5	2
Circuit Breaker, Magnetic				SPST		1.00a			
	M	FLD	GM		0		123000.0H	7	1
Circuit Breaker, Magnetic				SPST		2.00a			
	M	FLD	GF		0		355902.0H	0	1
	M	FLD	GM		0		246000.0H	14	1
Circuit Breaker, Magnetic				SPST		3.00a			
	M	FLD	GM		0		123000.0H	7	1
Circuit Breaker, Magnetic				SPST		4.00a			
	M	FLD	GM		0		246000.0H	14	1
Circuit Breaker, Magnetic				SPST		5.00a			
	M	FLD	GM		0		123000.0H	7	1
Circuit Breaker, Magnetic				SPST		8.00a			
	M	FLD	GM		0		123000.0H	7	1
Circuit Breaker, Magnetic				SPST		10.00a			
	M	FLD	GF		0		355902.0H	0	1
	M	FLD	GM		0		123000.0H	7	1
Circuit Breaker, Magnetic				SPST		20.00a			
	M	FLD	GF		0		355902.0H	0	1
	M	FLD	GM		0		123000.0H	7	1
Circuit Breaker, Magnetic				SPST		30.00a			
	M	FLD	GF		0		711804.0H	0	2
Circuit Breaker, Magnetic				SPST		50.00a			
	M	FLD	GF		0		1067706.0H	0	1
Circuit Breaker, Molded Case				3PST		15.00a			
	M	FLD	GF		4		6341952.0H	1322	6
Circuit Breaker, Molded Case				3PST		70.00a			
	M	FLD	GF		0		1477520.0H	80	1
Circuit Breaker, Molded Case				3PST		125.00a			
	M	FLD	GF		6		4944480.0H	280	3
Circuit Breaker, Molded Case				DPST		15.00a			
	M	FLD	GF		8		6392880.0H	1010	2
Circuit Breaker, Molded Case				SPST		15.00a			
	M	FLD	GF		11		7029216.0H	1172	2
Circuit Breaker, Power Switch				Unknown		Unk			
	U	FLD	GF		70		43219000.0H	3888	7
Circuit Breaker, Power Switch				3PST		200.00a			
	M	FLD	GF		6		2083968.0H	216	3
Circuit Breaker, Thermal				Unknown		Unk			
	U	FLD	GF		3		6944000.0H	675	2
Circuit Breaker, Thermal				SPST		7.50a			
	M	FLD	GM		0		26116.0H	69	1
Circuit Breaker, Thermal				SPST		15.00a			
	M	FLD	GM		0		52232.0H	138	1
Circuit Breaker, Thermal				SPST		20.00a			

Part Type	Qual	DType	Env	Contact Config. Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
	M	FLD	GM	0	26116.0H	69	1
Circuit Breaker, Under Voltage				Unknown	Unk		
	M	FLD	GF	8	4275000.0H	350	2

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Connector, Unknown, ,							
	M	FLD	A	162	2480955.0H	430	74
	M	FLD	AIA	0	1653296.0H	3552	5
	M	FLD	AIT	0	902400.0H	1504	5
	M	FLD	GF	12	6404060.0H	258	2
	M	FLD	GM	0	2503749.0H	9	1
	M	FLD	NH	8	9265.0H	0	1
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	0.0H	0	1
	U	FLD	N	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	1
	U	FLD	SF	0	0.0H	0	1
Connector, Electrical, ,							
	C	FLD	A	0	1028595000.0H	9	4
	C	FLD	AI	0	233000.0H	0	15
	C	FLD	AUT	0	2368000.0H	0	5
	C	FLD	GBC	0	213870800.0H	164516	23
	C	FLD	GF	0	1451388.0H	384	1
	C	FLD	GM	0	7000.0H	0	1
	C	FLD	GMW	0	3380000.0H	1	1
	M	FLD	A	32	603853.0H	40	17
	M	FLD	AI	0	328000.0H	0	5
	M	FLD	AIA	0	1653296.0H	3552	5
	M	FLD	AIF	0	65574875.0H	860826	923
	M	FLD	AIT	0	2170042.0H	7510	6
	M	FLD	AU	1	45812040.0H	108690	25
	M	FLD	AUA	2	5166550.0H	13320	25
	M	FLD	AUF	1	2925800.0H	13950	25
	M	FLD	DOR	[illegible]	11624755000.0H	135063	13
	M	FLD	G	6	420000000.0H	0	4
	M	FLD	GF	1	5109130350.0H	23486	61
	M	FLD	GM	3	39901283.0H	77590	294
	M	FLD	[illegible]	0	1850000.0H	0	1
	M	FLD	MP	0	3889520.0H	64492	38
	M	FLD	NBS	0	240973400.0H	0	63
	M	FLD	NS	0	79339190.0H	19552	52
	M	FLD	NSB	2	2842055378.0H	66413	305
	M	FLD	SF	0	40633000.0H	0	2
	M	LAB	N/R	0	40000.0H	20	1
Connector, Electrical, AC,							
	C	FLD	GBC	0	834766400.0H	642128	32
Connector, Electrical, AMP,							
	C	FLD	GBC	0	2366000.0H	1820	1
Connector, Electrical, Adapter,							
	C	FLD	GBC	40	842041200.0H	647724	68
Connector, Electrical, Amphenol,							
	C	FLD	GBC	0	275600.0H	212	1
Connector, Electrical, Anode,							
	C	FLD	GBC	0	14138800.0H	10876	2

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Connector, Electrical, Assembly,							
	C	FLD	GBC	4	1237600.0H	952	3
	M	FLD	AU	0	4581204.0H	10869	1
	M	FLD	AUA	0	206662.0H	1332	1
	M	FLD	AUF	0	117032.0H	1395	1
Connector, Electrical, Battery,							
	C	FLD	GBC	0	18033600.0H	13872	1
Connector, Electrical, Battery, Clip							
	C	FLD	GBC	0	10899200.0H	8384	1
Connector, Electrical, Circular,							
	C	FLD	GBC	0	260925600.0H	200712	34
	U	FLD	A	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	N	0	0.0H	0	1
Connector, Electrical, Circular, Audio							
	C	FLD	GBC	0	67350400.0H	51808	22
Connector, Electrical, Circular, KPT							
	C	FLD	GBC	0	790400.0H	608	2
Connector, Electrical, Circular, Special							
	C	FLD	GBC	0	7472400.0H	5748	5
Connector, Electrical, Coaxial,							
	C	FLD	A	0	49531000.0H	0	1
	C	FLD	GF	0	48700000.0H	0	5
	C	FLD	HEL	0	100000.0H	0	1
	C	FLD	SF	0	11026500.0H	0	6
	M	FLD	A	0	27562000.0H	0	1
	M	FLD	AIA	0	206662.0H	444	1
	M	FLD	AIF	0	901800.0H	17316	1
	M	FLD	AIT	0	112800.0H	188	1
	M	FLD	AU	1	65276680.0H	36230	10
	M	FLD	AUA	1	1653296.0H	4440	8
	M	FLD	AUF	10	936256.0H	4650	8
	M	FLD	GF	0	173242554.0H	1735	33
	M	FLD	GM	0	67626.0H	2176	2
	M	FLD	NS	0	57608942.0H	570	7
	M	FLD	SF	0	32233500.0H	394	6
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	66506000.0H	0	1
	U	FLD	N	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	1
	U	FLD	SF	0	0.0H	0	1
Connector, Electrical, Coaxial, Rack and Panel							
	M	FLD	GF	0	684283.0H	24	1
Connector, Electrical, Coaxial, Termination							
	C	FLD	GBC	4	545610000.0H	419700	27
Connector, Electrical, Connector Pins,							
	M	FLD	AIT	0	10130000.0H	9370	1
	M	FLD	DOR	0	2798310000.0H	7200	1
	M	FLD	GF	0	1514246000.0H	0	1

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pcp.	No. Rec.
	M	FLD	SF	0	2208930000.0H	7200	2
Connector, Electrical, Contact,							
	C	FLD	GBC	0	25150372000.0H	19346440	214
Connector, Electrical, Cover,							
	C	FLD	GBC	0	174044000.0H	133880	23
Connector, Electrical, Cylindrical,							
	C	FLD	SF	0	5851977000.0H	92360	8
	M	FLD	A	0	1520264100.0H	2598	6
	M	FLD	AI	0	310000.0H	0	30
	M	FLD	AU	0	1115507000.0H	0	6
	M	FLD	AUF	0	1188000.0H	0	8
	M	FLD	DOR	0	69253400.0H	4080	2
	M	FLD	G	12	200000000.0H	0	1
	M	FLD	GF	0	388689304.0H	8571	33
	M	FLD	GM	0	682784.0H	1656	15
	M	FLD	NBS	0	926700.0H	0	79
	M	FLD	NS	0	8300.0C	0	1
	M	FLD	NS	0	197465569.0H	5967	81
	M	FLD	SF	0	25482000.0H	840	3
Connector, Electrical, DIN,							
	C	FLD	GBC	0	2704000.0H	2080	1
Connector, Electrical, DIP Adapter,							
	C	FLD	GBC	0	46373600.0H	35672	8
Connector, Electrical, Edge Card,							
	M	FLD	AIA	0	206662.0H	444	1
	M	FLD	AIT	0	112800.0H	188	1
	M	FLD	G	31	600000000.0H	0	1
Connector, Electrical, Elastomeric,							
	C	FLD	GBC	16	168594400.0H	129688	18
Connector, Electrical, Flat Cable,							
	M	FLD	GM	0	15714000.0H	0	1
	M	FLD	NBS	0	44000.0H	0	2
Connector, Electrical, Flex Cable,							
	C	FLD	GBC	0	6895200.0H	5304	4
Connector, Electrical, Hexagonal,							
	C	FLD	GBC	4	8554000.0H	6580	7
Connector, Electrical, High Voltage,							
	C	FLD	GBC	0	390000.0H	300	2
Connector, Electrical, Jones Type,							
	C	FLD	GBC	0	15600.0H	12	2
Connector, Electrical, Kit, 3 Subassemblies							
	C	FLD	GBC	0	7904000.0H	6080	1
Connector, Electrical, Metric CIS,							
	C	FLD	GBC	0	3676400.0H	2828	1
Connector, Electrical, Micro,							
	C	FLD	GBC	0	9921600.0H	7632	3
Connector, Electrical, Micro, Ribbon							
	C	FLD	GBC	0	1190800.0H	916	1
Connector, Electrical, PC,							
	C	FLD	GBC	0	10940800.0H	8416	4
Connector, Electrical, PC, Edge							

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	20	6838826800.0H	5260636	227
Connector, Electrical, PWB,							
	M	FLD	AI	0	5860000.0H	0	2
	M	FLD	AIA	0	3099930.0H	6660	8
	M	FLD	AIF	3	39627209.0H	39524	58
	M	FLD	AIT	0	1353600.0H	2820	8
	M	FLD	DOR	0	14140410.0H	833	1
	M	FLD	GF	0	8269388.0H	104	12
	M	FLD	GM	0	21031000.0H	0	1
	M	FLD	NBS	0	32000.0H	0	2
	M	FLD	NS	0	176678246.0H	1919	2
	M	FLD	SF	0	20796500.0H	342	2
Connector, Electrical, Phono,							
	C	FLD	GBC	0	667338800.0H	513376	4
Connector, Electrical, Phono, Jack							
	C	FLD	GBC	0	78234000.0H	60180	2
Connector, Electrical, Piercing,							
	C	FLD	GBC	0	129714000.0H	99780	2
Connector, Electrical, Pin,							
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	0.0H	0	1
Connector, Electrical, Power,							
	C	FLD	GBC	0	332800.0H	256	4
	M	FLD	AIF	0	626250.0H	12025	4
	M	FLD	GF	0	6772100.0H	0	2
Connector, Electrical, Power Lock,							
	C	FLD	GBC	0	1965600.0H	1512	2
Connector, Electrical, Pressure Type,							
	C	FLD	GBC	0	8668400.0H	6668	4
Connector, Electrical, RF,							
	C	FLD	GBC	28	15067218400.0H	11590168	264
	M	FLD	GF	0	434534099.0H	14849	1
Connector, Electrical, RF, BNC							
	C	FLD	GBC	20	2119332800.0H	1630256	61
Connector, Electrical, RF, BNC/TNC Clamp							
	C	FLD	GBC	0	736886800.0H	566836	2
Connector, Electrical, RF, Body							
	C	FLD	GBC	0	1641645200.0H	1262804	25
Connector, Electrical, RF, Contact							
	C	FLD	GBC	20	1784156400.0H	1372428	24
Connector, Electrical, RF, Contact Assembly							
	C	FLD	GBC	4	10218000.0H	7860	1
Connector, Electrical, RF, Mounting Collar							
	C	FLD	GBC	0	1820000.0H	1400	1
Connector, Electrical, RF, Retainer							
	C	FLD	GBC	0	2111200.0H	1624	1
Connector, Electrical, RF, Subminiature							
	C	FLD	GBC	0	100365200.0H	77204	4
Connector, Electrical, RF, Termination-Open							
	C	FLD	GBC	0	384800.0H	296	2
Connector, Electrical, Rack and Panel,							

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
	M	FLD	AI	0	1707000.0H	0	20
	M	FLD	AIA	5	1446634.0H	3108	6
	M	FLD	AIF	0	1242320.0H	279	8
	M	FLD	AIT	1	789600.0H	1316	6
	M	FLD	AU	0	71343204.0H	10869	3
	M	FLD	AUA	0	413324.0H	1332	2
	M	FLD	AUF	0	234064.0H	1395	2
	M	FLD	GF	2	67721358.0H	530	18
	M	FLD	GM	0	765665.0H	0	7
	M	FLD	NBS	0	310000.0H	0	10
	M	FLD	SF	0	829000.0H	0	1
Connector, Electrical, Receptacle,							
	C	FLD	GBC	0	114192000.0H	87840	8
Connector, Electrical, Receptacle, Blue Ribbon							
	C	FLD	GBC	0	17222400.0H	13248	8
Connector, Electrical, Receptacle, D-Microminiature							
	C	FLD	GBC	0	665600.0H	512	3
Connector, Electrical, Receptacle, D-Subminiature							
	C	FLD	GBC	4	2225995200.0H	1712304	173
Connector, Electrical, Receptacle, Microribbon							
	C	FLD	GBC	0	922937600.0H	709952	76
Connector, Electrical, Rectangular,							
	C	FLD	A	0	68699000.0H	0	2
	C	FLD	GBC	0	136224400.0H	104788	27
	C	FLD	GF	0	140018000.0H	0	1
	M	FLD	AIA	0	206667.0H	444	1
	M	FLD	AIT	0	112800.0H	188	1
	M	FLD	G	139	2000000000.0H	0	1
	M	FLD	SF	0	1450400.0H	0	2
	U	FLD	A	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
Connector, Electrical, Round,							
	C	FLD	GBC	0	176800.0H	136	1
Connector, Electrical, Signal,							
	C	FLD	GBC	8	72148185200.0H	55498604	150
Connector, Electrical, Signal, ONISC							
	C	FLD	GBC	0	3943966000.0H	3033820	90
Connector, Electrical, Special Purpose,							
	C	FLD	GBC	4	119532400.0H	91948	9
Connector, Electrical, Telephone,							
	C	FLD	GBC	8	242216000.0H	186320	29
	M	FLD	GF	0	1954560.0H	509	2
	M	FLD	AP	0	1093560.0H	18226	7
	M	FLD	NS	0	460340.0H	10	1
Connector, Electrical, Test Adapter,							
	C	FLD	GBC	0	1523600.0H	1172	1
Connector, Electrical, Test Point,							
	M	FLD	AIF	0	7715400.0H	148148	1
	M	FLD	GF	0	4515304772.0H	301931	6
	M	FLD	NS	0	844486163.0H	18440	1
Connector, Electrical, Utitly,							

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	0	1755579600.0H	1504292	191
Connector, Electrical, Winch JF,	C	FLD	GBC	0	4414800.0H	3396	3
Connector, Electrical, Zero Insertion Force,	C	FLD	GBC	0	20763600.0H	15972	1

Part Type	Qual	QType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Connection, Assembly,							
	M	FLD	AIF	0	0.0H	1	1
Connection, Connector Post,							
	C	FLD	AI	53	270000.0H	0	1
	C	FLD	GBC	8	35533383600.0H	27333372	1896
Connection, Contact, Spring							
	C	FLD	GBC	4	23805600.0H	18312	1
Connection, Solder,							
	M	FLD	A	0	5995553000.0H	0	1
	M	FLD	AIF	0	6287550.0H	121693	2
	M	FLD	DOR	0	34900000000.0H	0	1
	M	FLD	GF	0	162329440000.0H	0	2
	M	FLD	NS	0	1640528000.0H	0	1
	U	FLD	A	0	0.0H	0	2
	U	FLD	G	0	0.0H	0	2
	U	FLD	GF	0	0.0H	0	2
	U	FLD	N	0	0.0H	0	2
Connection, Solder, Hand Lap							
	M	FLD	DOR	0	52594180000.0H	0	1
	M	FLD	SF	0	39610000000.0H	0	1
Connection, Solder, Reflow							
	M	FLD	GF	0	8835115000.0H	0	1
Connection, Solder, Wave							
	M	FLD	NS	0	57835239168.0H	935482	1
Connection, Terminal,							
	C	FLD	A	0	28000.0H	*	1
	M	FLD	A	158	31948000.0H	0	1
	M	FLD	AIF	0	27699516.0H	612404	165
	M	FLD	AIT	0	2535284.0H	16107	2
	M	FLD	AU	0	3054136.0H	7246	1
	M	FLD	AUA	0	206662.0H	888	1
	M	FLD	AUF	0	117032.0H	930	1
	M	FLD	GM	0	2629458.0H	84608	37
	M	FLD	MP	0	252360.0H	4206	2
	M	FLD	NS	0	7384888.0H	1819	27
	M	FLD	NSB	0	95089800.0H	2121	32
Connection, Terminal, Barrier Block							
	C	FLD	GBC	20	731848000.0H	562960	98
Connection, Terminal, Block							
	C	FLD	GBC	0	68411200.0H	52624	11
Connection, Terminal, Board							
	C	FLD	GBC	0	644800.0H	496	2
	M	FLD	AU	0	13743612.0H	32607	9
	M	FLD	AUA	0	1859958.0H	3996	9
	M	FLD	AUF	0	1053288.0H	4185	9
	U	FLD	A	0	0.0H	0	1
	U	FLD	AUT	4	732784.0H	1856	1
	U	FLD	CF	9	2340646.0H	2063	5
	U	FLD	GM	17	7894728.0H	4371	4
	U	FLD	NS	26	23662586.0H	6071	4
	U	FLD	NSB	5	658800.0H	954	3

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
	U	FLD	NU	1	99560.0H	92	1
Connection, Terminal, Crimp							
	C	FLD	GBC	0	4249949600.0H	3269192	140
Connection, Terminal, Feed Through							
	M	FLD	AIA	0	1033310.0H	2220	1
	M	FLD	AIF	0	5960959.0H	45725	31
	M	FLD	AIT	0	564000.0H	940	1
	M	FLD	AU	0	256547424.0H	608664	9
	M	FLD	AUA	0	1859958.0H	74592	9
	M	FLD	AUF	0	1053288.0H	78120	9
	M	FLD	GM	0	5967.0H	192	2
Connection, Terminal, Lug							
	M	FLD	AIF	0	4951870.0H	86427	74
	M	FLD	AIT	0	1267642.0H	1911	1
	M	FLD	AU	0	85515808.0H	202888	9
	M	FLD	AUA	0	1859958.0H	24864	9
	M	FLD	AUF	0	1053288.0H	26040	9
	M	FLD	GM	0	3815890.0H	122816	67
	M	FLD	MP	0	504720.0H	8412	4
	M	FLD	NS	0	1688068.0H	416	8
	U	FLD	GBC	4	4108213200.0H	3160164	81
Connection, Terminal, Metal Sleeve							
	C	FLD	GBC	0	1453181600.0H	1117832	40
Connection, Terminal, Screw							
	C	FLD	GBC	0	1658800.0H	1276	3
Connection, Terminal, Stand-off							
	M	FLD	AU	0	85515808.0H	202888	4
	M	FLD	AUA	0	826648.0H	24864	4
	M	FLD	AUF	0	468128.0H	26040	4
Connection, Terminal, Strip							
	C	FLD	GBC	0	447657600.0H	344352	27
Connection, Terminal, Stud							
	C	FLD	GBC	4	5769010000.0H	4437700	69
	M	FLD	AIA	0	6819846.0H	14652	4
	M	FLD	AIF	0	15458610.0H	160782	47
	M	FLD	AIT	0	3722400.0H	6204	4
	M	FLD	AU	0	171031616.0H	405776	5
	M	FLD	AUA	0	1033310.0H	49728	5
	M	FLD	AUF	0	585160.0H	52080	5
	M	FLD	GM	0	1182726.0H	38336	30
	M	FLD	MP	0	3364800.0H	56080	7
Connection, Terminal, Tab							
	C	FLD	GBC	0	46113600.0H	35472	5
Connection, Terminal, Test Point							
	C	FLD	GBC	0	3982908800.0H	3063776	4
Connection, Weld Joint,							
	C	FLD	GF	0	490600000.0H	0	1
	M	FLD	A	0	157063000.0H	0	1
	M	FLD	GF	0	65259910000.0H	0	2
	M	FLD	GM	0	529200000.0H	21168	1
	U	FLD	A	0	0.0H	0	2

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
	U	FLD	G	0	0.0H	0	2
Connection, Wire, Joke							
	C	FLD	GBC	0	61510800.0H	47316	2
Connection, Wire Wrap,							
	M	FLD	A	0	100000000.0H	0	1
	M	FLD	GF	0	556809888000.0H	128	3
	U	FLD	A	0	0.0H	0	2
	U	FLD	G	0	0.0H	0	2
Connection, Wire Wrap, Solder							
	M	FLD	GF	0	3056630000.0H	0	3
Connection, Wire Wrap, Solderless							
	M	FLD	AUT	0	456105000.0H	0	2
	M	FLD	NSB	4	32500000000.0H	0	1

Part Type	Qual	DType	Env	Tot. Fail	HP Total Duration	Total Pop.	No. Rec.
Electrical Motor, Unknown,					Unk		
	C	FLD	AU	681	4530000.0H	0	4
	C	FLD	GBC	104	294268000.0H	226360	13
	C	FLD	GF	154	102788971.0H	53535	1
	M	FLD	AI	16	3313422.0H	0	1
	M	FLD	AIC	31	1267642.0H	546	1
	M	FLD	ARW	21	110000.0H	0	1
	M	FLD	AU	104	555000.0H	0	1
	M	FLD	GF	13	680000.0C	0	1
	M	FLD	GF	258	49242263.0H	1418	10
	M	FLD	NH	89	40140.0H	0	1
	M	FLD	NS	41	4016870.0H	8	7
	M	FLD	NSB	22	701000.0H	0	2
	M	FLD	SF	2	2295000.0H	0	2
Electrical Motor, Unknown,					0.0200HP		
	C	FLD	GBC	0	260000.0H	200	1
Electrical Motor, Unknown,					0.0360HP		
	C	FLD	GBC	0	130000.0H	100	1
Electrical Motor, Unknown,					0.0670HP		
	C	FLD	GBC	0	130000.0H	100	1
Electrical Motor, Unknown,					0.7500HP		
	C	FLD	GBC	0	130000.0H	100	1
Electrical Motor, Unknown,					2.0000HP		
	M	FLD	GF	8	26793440.0H	648	5
Electrical Motor, Unknown,					3.0000HP		
	M	FLD	GF	3	1172000.0H	0	2
	M	NOP	DOR	1	2004000.0H	2	1
Electrical Motor, Unknown,					4.0000HP		
	U	FLD	A	0	0.0H	0	4
	U	FLD	ARW	0	0.0H	0	2
	U	FLD	G	0	0.0H	0	16
	U	FLD	GB	0	38634.0H	72	2
	U	FLD	GF	6	3180000.0H	180	4
	U	FLD	GM	4	144962.0H	56	10
	U	FLD	N	0	0.0H	0	2
	U	FLD	NS	110	3443660.0H	238	6
	U	FLD	NSB	0	0.0H	0	4
	U	FLD	NU	6	49020.0H	14	2
	U	FLD	SF	0	0.0H	0	2
Electrical Motor, Unknown,					5.0000HP		
	M	FLD	GF	5	1889560.0H	270	2
Electrical Motor, Unknown,					7.5000HP		
	M	FLD	GF	1	99000.0H	0	1
Electrical Motor, Unknown,					10.0000HP		
	M	FLD	GF	8	863000.0H	0	2
Electrical Motor, Unknown,					20.0000HP		
	M	FLD	GF	1	829000.0H	0	1
Electrical Motor, Brush,					Unk		
	C	FLD	GBC	0	3785600.0H	2912	3
	U	FLD	AUT	0	48924.0H	116	1
	U	FLD	GF	1	500000.0H	60	1

Part Type	Qual	DType	Env	Tot. Fail	HP Total Duration	Total Pop.	No. Rec.
	U	FLD	GM	4	676752.0H	444	4
	U	FLD	NS	0	52400.0H	48	1
Electrical Motor, Brushless,					0.0010HP		
	C	FLD	GBC	0	889200.0H	684	1
Electrical Motor, Brushless,					0.0560HP		
	C	FLD	GBC	0	130000.0H	100	1
Electrical Motor, Commutator,					Unk		
	C	FLD	GBC	0	1892800.0H	1456	3
Electrical Motor, Hydraulic,					Unk		
	U	FLD	A	0	0.0H	0	2
	U	FLD	ARW	0	0.0H	0	2
	U	FLD	AUT	12	195696.0H	464	2
	U	FLD	G	0	0.0H	0	2
	U	FLD	GF	2	18000.0H	120	2
	U	FLD	N	0	0.0H	0	2
Electrical Motor, Induction,					Unk		
	M	FLD	GF	0	62000.0H	0	1
	U	FLD	G	0	0.0H	0	2
	U	FLD	NSB	0	0.0H	0	2
Electrical Motor, Instrumentation,					Unk		
	U	FLD	GF	0	0.0H	0	2
Electrical Motor, Permanent Magent,					Unk		
	C	FLD	GBC	44	167518000.0H	128860	5
	M	FLD	GF	0	218000.0H	0	1
Electrical Motor, Permanent Magent,					0.0200HP		
	C	FLD	GBC	0	3764800.0H	2896	1
Electrical Motor, Rotary Solenoid,					Unk		
	M	FLD	DOR	0	385000.0H	26	1
	M	FLD	SF	0	26975000.0H	5	1
Electrical Motor, Sensor,					Unk		
	C	FLD	AI	191	2140000.0H	0	2
	C	FLD	AU	44	870000.0H	0	1
	C	FLD	GF	2	33000.0H	0	1
	M	FLD	A	794	4238000.0H	0	4
	M	FLD	ARW	38	496000.0H	0	5
	M	FLD	AU	1106	1900000.0H	960	3
	M	FLD	DOR	10	18340000.0H	0	1
	M	FLD	GF	47	11915220.0H	724	10
	M	FLD	SF	5	159000.0H	0	2
Electrical Motor, Servo,					Unk		
	C	FLD	A	3	368000.0H	0	1
	M	FLD	A	4	81000.0H	0	1
	M	FLD	GF	0	46000.0H	0	1
	M	FLD	GM	2	2524000.0H	0	1
	M	FLD	NS	0	2357427.0H	0	1
	M	FLD	NSB	702	56104000.0H	0	2
	U	FLD	A	0	0.0H	0	2
	U	FLD	AIF	8	274310.0H	1462	2
	U	FLD	ARW	52	4260268.0H	3988	2
	U	FLD	AUT	6	391392.0H	928	2
	U	FLD	G	0	0.0H	0	2

Part Type	Qual	DType	Env	Tot. Fail	HP / Total Duration	Total Pop.	No. Rec.
	U	FLD	GF	28	1999508.0H	280	4
	U	FLD	GM	10	315196.0H	390	10
	U	FLD	NSB	0	0.0H	0	2
	U	FLD	NU	0	49020.0H	14	2
Electrical Motor, Shaded-P,					Unk		
	C	FLD	GBC	4	6406400.0H	4928	2
Electrical Motor, Shaded-P,					0.0007HP		
	C	FLD	GBC	0	286000.0H	220	1
Electrical Motor, Shaded-P,					0.0010HP		
	C	FLD	GBC	0	1367600.0H	1052	1
Electrical Motor, Stepper,					Unk		
	C	FLD	GBC	48	269230000.0H	207100	10
	C	FLD	GF	2	1451388.0H	32	1
	U	FLD	AUF	30	3756444.0H	0	2
	U	FLD	GM	4	300376.0H	156	4
Electrical Motor, Stepper,					0.8000HP		
	C	FLD	GBC	0	530400.0H	408	1
Electrical Motor, Stepper, Permanent Magnet					Unk		
	C	FLD	GBC	36	167174800.0H	128596	5
Electrical Motor, Synchronous,					Unk		
	M	FLD	AIC	11	1267642.0H	546	1
Electrical Motor, Tachometer,					Unk		
	C	FLD	GBC	4	1934400.0H	1488	1
Electrical Motor, Torque,					Unk		
	M	FLD	AIC	0	1267642.0H	273	1
	M	FLD	AIF	4	155252.0H	3524	6
	M	FLD	DOR	0	4158000.0H	0	1
	M	FLD	GM	0	219000.0H	0	1
	U	FLD	G	0	0.0H	0	2
	U	FLD	GF	0	0.0H	0	2
	U	FLD	NSB	0	0.0H	0	2

Part Type	Qual	DType	Env	Operating Freq. / Tot. Fail	Total Duration	Total Pop.	No. Rec.
Inductor, Unknown				Unknown			
	C	FLD	GBC	4	51958400.0H	39968	16
	C	NOP	GF	14	883400000.0H	0	5
	M	FLD	AIA	0	10333100.0H	22200	35
	M	FLD	AIT	1	5640000.0H	9400	35
	M	FLD	AU	0	6108272.0H	14492	2
	M	FLD	AUA	0	413324.0H	1776	2
	M	FLD	AUF	0	234064.0H	1860	2
	M	NOP	AIF	0	103801000.0H	4016	3
	M	NOP	GF	0	408621000.0H	33120	2
	U	NOP	AIF	5	531978000.0H	20582	12
	U	NOP	GB	1	659490000.0H	75284	1
	U	NOP	GM	0	604606000.0H	41420	8
	U	NOP	N/R	0	165529473000.0H	1251800	11
Inductor, Unknown				RF			
	M	FLD	AIA	0	8836466.0H	19092	11
	M	FLD	AIT	0	6373200.0H	11468	16
Inductor, Bobbin				Unknown			
	C	FLD	GBC	0	1483024400.0H	1140788	168
Inductor, Choke				Unknown			
	C	FLD	GBC	0	31808400.0H	24468	9
Inductor, Choke				RF			
	C	FLD	GBC	12	16675516000.0H	12827320	211
Inductor, Core				Unknown			
	C	FLD	GBC	12	3689852400.0H	2838348	12
Inductor, Fixed				Unknown			
	C	FLD	GBC	8	4169635600.0H	3207412	298
	M	FLD	AU	5	109948896.0H	260856	29
	M	FLD	AUA	1	5993198.0H	31968	29
	M	FLD	AUF	0	3393928.0H	33480	29
	M	FLD	GF	5	22414210.0H	903	5
Inductor, Fixed				1-40Khz			
	C	FLD	GBC	0	10920000.0H	8400	1
Inductor, Fixed				1.25hz			
	M	FLD	AU	0	3054136.0H	7246	1
	M	FLD	AUA	0	206662.0H	888	1
	M	FLD	AUF	0	117032.0H	930	1
Inductor, Fixed				10Khz			
	C	FLD	GBC	0	88977200.0H	68444	9
Inductor, Fixed				110Uhz-25Khz			
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	1	117032.0H	465	1
Inductor, Fixed				120-1300hz			
	C	FLD	GBC	0	937835600.0H	721412	1
Inductor, Fixed				15.75 Khz			
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Inductor, Fixed				1Khz			
	C	FLD	GBC	0	40294800.0H	30996	2

Part Type	Qual	DType	Env	Operating Freq. Tot. Fail	Total Duration	Total Pop.	No. Rec.
Inductor, Fixed				20Khz			
	C	FLD	GBC	0	6952400.0H	5348	5
Inductor, Fixed				24Mhz			
	M	FLD	AU	3	12216544.0H	28984	[illegible]
	M	FLD	AUA	0	206662.0H	3552	[illegible]
	M	FLD	AUF	0	117032.0H	3720	1
Inductor, Fixed				350Khz			
	C	FLD	GBC	0	2974400.0H	2288	1
Inductor, Fixed				4hz			
	M	FLD	AU	2	3054136.0H	7246	1
	M	FLD	AUA	1	206662.0H	588	1
	M	FLD	AUF	0	117032.0H	930	1
Inductor, Fixed				800hz			
	C	FLD	GBC	0	187200.0H	144	1
Inductor, Fixed				RF			
	C	FLD	GBC	24	13800732400.0H	10615948	161
	M	FLD	GF	0	224485260.0H	5418	14
	M	NOP	AIF	0	51901000.0H	2008	1
	M	NOP	GF	0	409312000.0H	9699	8
	M	NOP	GM	2	935808000.0H	58905	3
	U	NOP	GM	0	1196000.0H	84	4
Inductor, Variable				Unknown			
	C	FLD	GBC	0	1272731200.0H	979024	76
Inductor, Variable				RF			
	C	FLD	GBC	0	2808000.0H	2160	1
Inductor, Yoke				Unknown			
	C	FLD	GBC	0	1487200.0H	1144	1

Part Type	Qual	DType	Env	Rated Current / Tot. Fail	Contact Config. / Total Duration	Total Pop.	No. Rec.
Relay, Unknown				Unk	Unknown		
	M	FLD	A	327	1493484.0H	184	48
	M	FLD	AIF	3	970340.0H	11195	15
	M	FLD	GF	13	59191512.0H	3730	1
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	0.0H	0	1
	U	FLD	N	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	2
	U	FLD	SF	0	0.0H	0	1
Relay, Unknown				Unk	DPDT		
	M	FLD	AIF	21	0.0H	20	1
Relay, Unknown				0.01a	1A		
	C	FLD	GBC	0	13811200.0H	10624	1
Relay, Unknown				0.01a	1C		
	C	FLD	GBC	0	806000.0H	620	1
Relay, Unknown				0.20a	2C		
	C	FLD	GBC	0	10472800.0H	8056	1
Relay, Unknown				0.25a	4C		
	C	FLD	GBC	0	88400.0H	68	1
Relay, Unknown				0.30a	1C		
	C	FLD	GBC	0	1837600.0H	1452	2
Relay, Unknown				0.50a	1C		
	C	FLD	GBC	0	16463200.0H	12664	1
Relay, Unknown				0.50a	2C		
	C	FLD	GBC	68	383562400.0H	295048	11
Relay, Unknown				1.00a	1C		
	C	FLD	GBC	0	99876400.0H	76828	9
Relay, Unknown				1.00a	2C		
	C	FLD	GBC	36	351686400.0H	270528	16
Relay, Unknown				1.00a	DPDT		
	M	FLD	AIF	11	0.0H	9	1
Relay, Unknown				2.00a	1C		
	C	FLD	GBC	0	136011200.0H	104624	8
Relay, Unknown				2.00a	2C		
	C	FLD	GBC	4	122241600.0H	94032	15
Relay, Unknown				2.00a	3A		
	C	FLD	GBC	0	75296000.0H	57920	1
Relay, Unknown				2.00a	4C		
	C	FLD	GBC	0	60439600.0H	46492	4
Relay, Unknown				2.00a	6C		
	C	FLD	GBC	0	670800.0H	516	2
Relay, Unknown				2.50a	1C		
	C	FLD	GBC	0	124800.0H	96	1
Relay, Unknown				3.00a	1A		
	C	FLD	GBC	0	4409600.0H	3392	1
Relay, Unknown				3.00a	2B		
	C	FLD	GBC	0	135200.0H	104	1
Relay, Unknown				3.00a	2C		
	C	FLD	GBC	0	37102000.0H	28540	3

Part Type	Rated Current	Contact Config.	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Relay, Unknown	3.00a	4C	C	FLD	GBC	0	629200.0H	484	1
Relay, Unknown	4.00a	1AB	C	FLD	GBC	0	4908800.0H	3776	1
Relay, Unknown	4.00a	2AB	C	FLD	GBC	8	171912000.0H	132240	3
Relay, Unknown	4.00a	3AB	C	FLD	GBC	0	41314000.0H	31780	1
Relay, Unknown	4.00a	4A	C	FLD	GBC	4	228129200.0H	175484	5
Relay, Unknown	5.00a	1A	C	FLD	GBC	0	2735200.0H	2104	1
Relay, Unknown	5.00a	2A	C	FLD	GBC	4	3364400.0H	2588	1
Relay, Unknown	5.00a	2C	C	FLD	GBC	12	72976800.0H	56136	10
Relay, Unknown	5.00a	4C	C	FLD	GBC	0	7534800.0H	5796	2
Relay, Unknown	5.00a	6A	C	FLD	GBC	28	6567600.0H	5052	1
Relay, Unknown	7.00a	1C	C	FLD	GBC	0	93600.0H	72	1
Relay, Unknown	7.00a	2C	C	FLD	GBC	0	140400.0H	108	1
Relay, Unknown	7.00a	3C	C	FLD	GBC	0	520000.0H	400	1
Relay, Unknown	7.50a	2C	C	FLD	GBC	0	6900400.0H	5308	1
Relay, Unknown	7.50a	4C	C	FLD	GBC	8	15709200.0H	12084	1
Relay, Unknown	8.00a	1C	C	FLD	GBC	0	1159600.0H	892	1
Relay, Unknown	8.00a	2A	C	FLD	GBC	0	270400.0H	208	1
Relay, Unknown	10.00a	1A	C	FLD	GBC	0	17518800.0H	13476	3
Relay, Unknown	10.00a	1C	C	FLD	GBC	0	32349200.0H	24884	3
Relay, Unknown	10.00a	2C	C	FLD	GBC	0	78000.0H	60	2
Relay, Unknown	10.00a	3A	C	FLD	GBC	0	1138800.0H	876	1
Relay, Unknown	10.00a	3C	C	FLD	GBC	0	1939600.0H	1492	2
Relay, Unknown	10.00a	4C	C	FLD	GBC	0	41600.0H	32	1
Relay, Unknown	12.00a	2C	C	FLD	GBC	0	2683200.0H	2064	1
Relay, Unknown	13.00a	1C	C	FLD	GBC	0	187200.0H	144	1
Relay, Unknown	15.00a	2C							

Part Type	Qual	DType	Env	Rated Current	Tot. Fail	Contact Config.	Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC		0		239200.0H	184	1
Relay, Unknown				16.00a		1A			
	C	FLD	GBC		0		5839600.0H	4492	2
Relay, Unknown				16.00a		1C			
	C	FLD	GBC		0		894400.0H	688	2
Relay, Unknown				20.00a		1A			
	C	FLD	GBC		0		5200.0H	4	1
Relay, Unknown				25.00a		2C			
	C	FLD	GBC		0		67600.0H	52	1
Relay, Unknown				30.00a		1A			
	C	FLD	GBC		0		46800.0H	36	1
Relay, Unknown				30.00a		2A			
	C	FLD	GBC		0		176800.0H	136	2
Relay, Unknown				30.00a		2C			
	C	FLD	GBC		4		15048800.0H	11576	2
Relay, Unknown				40.00a		3A			
	C	FLD	GBC		0		15600.0H	12	1
Relay, Unknown				40.00a		4A			
	C	FLD	GBC		0		10400.0H	8	1
Relay, Unknown				50.00a		3A			
	C	FLD	GBC		0		130000.0H	100	1
Relay, Unknown				60.00a		2A			
	C	FLD	GBC		0		182000.0H	140	1
Relay, Unknown				60.00a		3A			
	C	FLD	GBC		0		629200.0H	484	1
Relay, Unknown				125.00m		DPDT			
	M	FLD	AIF		0		0.0H	12	1
Relay, Unknown				200.00a		1A			
	C	FLD	GBC		0		728000.0H	560	1
Relay, Unknown				250.00a		DPDT			
	M	FLD	AIF		0		0.0H	1	1
Relay, Unknown				500.00m		DPDT			
	M	FLD	AIF		0		0.0H	1	1
Relay, Coaxial				Unk		Unknown			
	M	FLD	GF		0		233520.0H	14	1
Relay, Coil				8.00a		Unknown			
	C	FLD	GBC		0		494000.0H	380	1
Relay, Contactors				Unk		Unknown			
	C	FLD	GF		9		4390000.0H	106	3
	M	FLD	A		50		5262000.0H	0	1
	M	FLD	GF		7		6912000.0H	0	1
	M	FLD	GMW		6		856000.0H	0	2
	M	FLD	NS		0		46000.0H	0	1
	U	FLD	A		0		0.0H	0	1
	U	FLD	G		0		0.0H	0	1
	U	FLD	GM		0		0.0H	0	1
Relay, Electromechanical				Unk		Unknown			
	C	FLD	AIT		79		17860000.0H	26	6
	C	FLD	DOR		0		2000000.0H	8677	1
	C	FLD	GBC		0		1580800.0H	1216	2
	C	FLD	GF		130		27010200000.0C	0	3

Part Type	Qual	DType	Env	Rated Current Tot. Fail	Contact Config. Total Duration	Total Pop.	No. Rec.
	C	FLD	GF	792	499809958.0H	105073	53
	C	FLD	GM	0	26116.0H	69	1
	C	FLD	NS	15	13974000.0H	0	1
	M	FLD	AIF	32	583228.0H	8474	23
	M	FLD	AIT	8	5657642.0H	1362	3
	M	FLD	DOR	20	810038000.0H	0	9
	M	FLD	GF	31	33149000.0C	0	2
	M	FLD	GF	67	481635600.0H	3001	18
	M	FLD	GM	0	547076.0H	5376	25
	M	FLD	GMW	1	814000.0H	0	1
	M	FLD	HEL	157	2531000.0H	0	2
	M	FLD	MP	0	84120.0H	1402	1
	M	FLD	NBS	1	29500000.0C	15	1
	M	FLD	NBS	8224	11231986000.0H	0	11
	M	FLD	NS	225	715829897.0H	1094	18
	M	FLD	NSB	1	53799300.0H	1436	17
	M	FLD	SF	2	112100000.0C	0	2
	M	FLD	SF	1	132651000.0H	9976	11
	U	FLD	A	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	3
	U	FLD	GF	0	0.0H	0	2
	U	FLD	GM	0	0.0H	0	1
	U	FLD	N	0	0.0H	0	2
	U	FLD	NSB	0	0.0H	0	2
	U	FLD	SF	0	0.0H	0	1
Relay, Electromechanical				Unk	2A 1B		
	C	FLD	GBC	0	62400.0H	48	1
Relay, Electromechanical				Unk	3PDT		
	C	FLD	GF	2	30910000.0H	0	2
Relay, Electromechanical				Unk	4PDT		
	M	FLD	AI	1	23400000.0H	42	1
	M	FLD	AIT	0	12000.0H	0	2
	M	FLD	GF	0	10400.0H	0	1
	M	FLD	NBS	0	89000.0H	0	4
	M	FLD	NS	0	996156.0H	2	1
Relay, Electromechanical				Unk	4PST		
	C	FLD	GF	2	5109000.0H	0	1
Relay, Electromechanical				Unk	6PDT		
	M	FLD	GF	0	3774000.0H	0	2
Relay, Electromechanical				Unk	DPDT		
	C	FLD	GF	60	18096000.0H	0	2
	M	FLD	AIF	8	367832.0H	4097	5
	M	FLD	AIT	21	392000000.0H	0	1
	M	FLD	GM	3	406000.0H	100	4
	M	FLD	GMW	0	0.0	0	1
	M	FLD	NBS	0	136000.0H	0	5
	M	FLD	NS	1	3486546.0H	7	1
	M	FLD	SF	0	182000.0H	1	1
Relay, Electromechanical				Unk	SPST		
	C	FLD	GF	118	36700000.0H	0	3
	C	FLD	GM	1	4742000.0H	25	1

Part Type	Rated Current	Contact Config.	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
			M	FLD	GF	0	41600.0H	0	1
Relay, Electromechanical	0.10a	DPDT							
			M	FLD	NS8	1	13096000.0H	299	1
Relay, Electromechanical	0.75a	DPDT							
			M	FLD	NS8	1	2847000.0H	65	1
Relay, Electromechanical	1.00a	1A							
			C	FLD	GBC	52	474016400.0H	364628	7
Relay, Electromechanical	1.00a	1A DRY							
			C	FLD	GBC	0	572000.0H	440	2
Relay, Electromechanical	1.00a	1B							
			C	FLD	GBC	0	130000.0H	100	1
Relay, Electromechanical	1.00a	1C							
			C	FLD	GBC	0	7077200.0H	5444	2
Relay, Electromechanical	1.00a	2A							
			C	FLD	GBC	0	31938400.0H	24568	3
Relay, Electromechanical	1.00a	4PDT							
			M	FLD	AIT	16	294000000.0H	528	1
Relay, Electromechanical	1.00a	6PDT							
			M	FLD	NS8	1	2835000.0H	65	1
Relay, Electromechanical	1.00a	DPDT							
			M	FLD	AU	0	3054136.0H	7246	1
			M	FLD	AUA	0	206662.0H	888	1
			M	FLD	AUF	0	117032.0H	930	•
			M	FLD	GF	0	741312.0H	26	3
Relay, Electromechanical	2.00a	Unknown							
			M	FLD	GM	1	1989.0H	64	1
Relay, Electromechanical	2.00a	1A							
			C	FLD	GBC	0	13410800.0H	10316	1
Relay, Electromechanical	2.00a	1C							
			C	FLD	GBC	0	1861600.0H	1432	1
Relay, Electromechanical	2.00a	1D							
			C	FLD	GBC	0	83200.0H	64	1
Relay, Electromechanical	2.00a	2A							
			C	FLD	GBC	0	25584000.0H	19680	1
Relay, Electromechanical	2.00a	3A							
			C	FLD	GBC	0	18345600.0H	14112	:
Relay, Electromechanical	2.00a	3PST							
			M	FLD	GM	1	5967.0H	192	1
Relay, Electromechanical	2.00a	DPDT							
			M	FLD	AIT	5	98000000.0H	175	1
			M	FLD	GF	1	826848.0H	29	2
			M	FLD	NS	0	15938496.0H	32	1
			M	FLD	NS8	1	2277600.0H	52	1
Relay, Electromechanical	3.00m	1A							
			C	FLD	GBC	0	104000.0H	80	1
Relay, Electromechanical	3.00m	2A							
			C	FLD	GBC	4	36129600.0H	27792	1
Relay, Electromechanical	5.00a	Unknown							
			M	FLD	NS8	2	4535200.0H	104	1
Relay, Electromechanical	5.00a	2D							
			C	FLD	GBC	4	665600.0H	512	1

Part Type	Qual	DType	Env	Rated Current	Tot. Fail	Contact Config.	Total Duration	Total Pop.	No. Rec.
Relay, Electromechanical				5.00a		4PDT			
	M	FLD	NS		2		498073.0H	1	1
	M	FLD	NSB		4		2277600.0H	52	1
Relay, Electromechanical				5.00a		6PDT			
	M	FLD	GF		0		37024.0H	2	1
Relay, Electromechanical				6.00a		DPDT			
	M	FLD	GM		0		156696.0H	414	1
Relay, Electromechanical				10.00a		4PDT			
	M	FLD	NS		3		1220808.0H	4	2
	M	FLD	NSB		9		376372200.0H	8593	3
Relay, Electromechanical				10.00a		DPDT			
	M	FLD	GF		0		85536.0H	3	1
Relay, Electromechanical				10.00a		SPST			
	C	FLD	GM		0		26116.0H	69	1
Relay, Electromechanical				10.00m		1A			
	C	FLD	GBC		0		31200.0H	24	1
Relay, Electromechanical				10.00m		2A			
	C	FLD	GBC		8		5876000.0H	4520	1
Relay, Electromechanical				25.00a		3PST			
	M	FLD	GF		0		1368576.0H	48	2
	M	FLD	NSB		1		7402200.0H	169	1
Relay, Electromechanical				25.00m		1C			
	C	FLD	GBC		0		22016800.0H	16936	1
Relay, Electromechanical				50.00a		3PST			
	M	FLD	GF		4		1368576.0H	48	1
Relay, Electromechanical				50.00a		SPST			
	M	FLD	GM		0		26116.0H	69	1
Relay, Electromechanical				75.00m		1C			
	C	FLD	GBC		0		5246800.0H	4036	1
Relay, Electromechanical				100.00m		1A			
	C	FLD	GBC		0		9526400.0H	7328	2
Relay, Electromechanical				100.00m		1A DRY			
	C	FLD	GBC		0		494000.0H	380	1
Relay, Electromechanical				200.00m		2A			
	C	FLD	GBC		0		650000.0H	500	1
Relay, Electromechanical				250.00m		1A			
	C	FLD	GBC		0		31881200.0H	24524	4
Relay, Electromechanical				250.00m		1B			
	C	FLD	GBC		0		1029600.0H	792	1
Relay, Electromechanical				250.00m		1C			
	C	FLD	GBC		12		211203200.0H	162464	11
Relay, Electromechanical				250.00m		2A			
	C	FLD	GBC		4		300913600.0H	231472	5
Relay, Electromechanical				250.00m		2B			
	C	FLD	GBC		0		67600.0H	52	1
Relay, Electromechanical				250.00m		2C			
	C	FLD	GBC		4		24481600.0H	18832	3
Relay, Electromechanical				250.00m		3A			
	C	FLD	GBC		0		166400.0H	128	1
Relay, Electromechanical				300.00m		1A DRY			
	C	FLD	GBC		0		5200.0H	4	1

Part Type	Qual	DType	Env	Rated Current / Tot. Fail	Contact Config. / Total Duration	Total Pop.	No. Rec.
Relay, Electromechanical				350.00m	1C		
	C	FLD	GBC	8	11533600.0H	8872	1
Relay, Electromechanical				500.00a	1A		
	C	FLD	GBC	0	2392000.0H	1840	1
Relay, Electromechanical				500.00m	1A		
	C	FLD	GBC	112	1131618800.0H	870476	37
Relay, Electromechanical				500.00m	1B		
	C	FLD	GBC	0	10878400.0H	8368	4
Relay, Electromechanical				500.00m	1C		
	C	FLD	GBC	0	8559200.0H	6584	3
Relay, Electromechanical				500.00m	2A		
	C	FLD	GBC	0	45760000.0H	35200	5
Relay, Electromechanical				500.00m	2C		
	C	FLD	GBC	0	34668400.0H	26668	1
Relay, Electromechanical				500.00m	SPDT		
	M	FLD	GF	0	31200.0H	0	1
	M	FLD	NBS	0	23000.0H	0	2
Relay, Electromechanical				750.00m	4A		
	C	FLD	GBC	0	41600.0H	32	1
Relay, Electronic				Unk	Unknown		
	C	FLD	GBC	0	23722400.0H	18248	5
	C	FLD	GF	1	210000.0H	12	3
	M	FLD	A	5	69358.0H	10	2
	M	FLD	GF	0	724000.0H	0	1
Relay, Electronic				Unk	SPST		
	C	FLD	GF	702	23842080000.0H	0	3
	C	FLD	NBS	0	38000.0H	0	1
	M	FLD	GF	7	24091000.0H	0	2
	M	FLD	NBS	0	249000.0H	0	2
Relay, Electronic				3.00a	Unknown		
	C	FLD	GBC	0	421200.0H	324	1
Relay, Electronic				10.00a	Unknown		
	C	FLD	GBC	0	166400.0H	128	1
Relay, Electronic				10.00a	SPST		
	C	FLD	GF	693	23827200000.0H	0	1
Relay, Electronic				50.00m	SPST		
	M	FLD	GF	0	10707000.0H	0	1
	M	FLD	NBS	0	111000.0H	0	1
Relay, Power				Unk	Unknown		
	C	FLD	GF	4	2550708.0H	648	2
	M	FLD	NS	3	15093770.0H	174	3
Relay, Power				Unk	3PST		
	M	FLD	GF	0	28512.0H	1	1
Relay, Power				Unk	4PDT		
	M	FLD	GF	0	28512.0H	1	1
Relay, Power				0.05a	Unknown		
	C	FLD	GF	2	829440.0H	54	1
Relay, Retainer				Unk	Unknown		
	C	FLD	GBC	0	10514400.0H	8088	4
Relay, Solenoid				Unk	Unknown		
	C	FLD	AIT	13	721000.0H	0	1

Part Type	Qual	DType	Env	Rated Current Tot. Fail	Contact Config. Total Duration	Total Pop.	No. Rec.
	C	FLD	GF	67	16220000.0H	1234	11
	C	FLD	GM	0	26116.0H	69	1
	M	FLD	A	617	9422650.0H	14	13
	M	FLD	DOR	0	3057000.0H	67	1
	M	FLD	GM	6	5242940.0H	25	2
	M	FLD	HEL	3	30000.0H	0	1
	M	FLD	NBS	6	234000.0H	0	1
	M	FLD	SF	1	1399000.0H	0	2
Relay, Strap				Unk	Unknown		
	C	FLD	GBC	0	50533600.0H	38872	1
Relay, TO-5 (Crystal Can)				Unk	Unknown		
	C	FLD	GF	17	132005000.0C	0	5
	C	FLD	GF	0	79178000.0H	0	3
	M	FLD	DOR	0	43469000.0H	0	1
	M	FLD	GF	8	45001000.0H	1242	2
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	0.0H	0	1
Relay, TO-5 (Crystal Can)				Unk	DPDT		
	C	FLD	GF	6	68480000.0C	0	3
	M	FLD	AIT	30	4050000.0C	81	2
	M	FLD	DOR	0	193000.0H	13	1
	M	FLD	NS	0	996156.0H	2	1
	M	FLD	SF	0	182000.0H	5	1
Relay, Thermal				Unk	Unknown		
	M	FLD	AI	1	39000.0H	0	1
	M	FLD	DOR	0	458000.0H	0	1
	M	FLD	GF	5	382000.0H	0	1
	M	FLD	GM	0	1989.0H	64	1
	M	FLD	NS	2	2680000.0H	0	1
	U	FLD	A	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	0.0H	0	1
	U	FLD	N	0	0.0H	0	1
Relay, Thermal				Unk	SPST		
	C	FLD	GF	2	4396000.0H	0	1
Relay, Time Delay				Unk	Unknown		
	C	FLD	GF	9	5829044.0H	384	7
	M	FLD	AIT	23	864000.0H	0	1
	M	FLD	AMF	0	469000.0H	0	1
	M	FLD	GF	11	7019000.0H	0	4
	M	FLD	GM	0	1989.0H	64	1
	M	FLD	GMW	2	471000.0H	0	1
	M	FLD	NBS	3	4450000.0H	0	1
	M	FLD	NS	55	34799233.0H	7	5
	U	FLD	A	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GM	0	0.0H	0	1
	U	FLD	N	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	1
Relay, Time Delay				Unk	DPDT		
	M	FLD	AUT	0	482400.0H	0	3

Part Type	Qual	DType	Env	Rated Current Tot. Fail	Contact Config. Total Duration	Total Pop.	No. Rec.
	M	FLD	GM	0	246000.0H	14	1
Relay, Time Delay				Unk	SPDT		
	M	FLD	AUT	1	321600.0H	0	1
Relay, Time Delay				Unk	SPST		
	M	FLD	NBS	0	500000.0H	0	1

Part Type	Qual	DType	Env	Tot. Fail	Rated Pwr Total Duration	Total Pop.	No. Rec.
Resistor, Unknown,					Unk		
	M	FLD	AIA	0	1446634.0H	3108	3
	M	FLD	AIT	0	789600.0H	1316	3
	M	FLD	G	86	34850002500.0H	0	7
	M	LAB	N/R	7	42587000.0H	0	5
	M	FLD	GF	1	32781342.0H	0	1
	M	FLD	GF	4	2768533333.0H	0	2
Resistor, Fixed,					Unk		
	.	FLD	AIF	0	0.0H	8	1
	M	FLD	AIA	0	2893268.0H	6216	7
	M	FLD	AIT	0	1579200.0H	2632	7
	M	FLD	GF	0	6404060.0H	258	1
Resistor, Fixed,					0.050w		
	.	FLD	AIA	0	619986.0H	1332	2
	.	FLD	AIT	0	338400.0H	564	2
Resistor, Fixed,					0.100w		
	.	FLD	AIA	0	2686606.0H	5772	11
	.	FLD	AIF	47	0.0H	2438	188
	.	FLD	AIT	1	1804800.0H	3008	14
	.	FLD	AIA	0	619986.0H	1332	3
	.	FLD	AIF	0	0.0H	36	1
	.	FLD	AIT	0	451200.0H	752	4
	1	FLD	AIF	0	0.0H	4	3
	M	FLD	AU	1	250439152.0H	594172	59
	M	FLD	AUA	0	12193058.0H	72816	59
	M	FLD	AUF	0	6904588.0H	76260	59
	M	FLD	GF	0	121677140.0H	4902	24
Resistor, Fixed,					0.125w		
	.	FLD	AIA	1	27072722.0H	58164	36
	.	FLD	AIT	0	14776800.0H	24628	36
	.	FLD	GF	0	67242630.0H	2709	11
	.	FLD	AIA	0	1033310.0H	2220	4
	.	FLD	AIF	2	0.0H	346	18
	.	FLD	AIT	0	564000.0H	940	4
	.	FLD	AIA	0	5166550.0H	11100	13
	.	FLD	AIT	0	3835200.0H	6392	17
	M	FLD	AIA	0	3513254.0H	7548	6
	M	FLD	AIT	0	1917600.0H	3196	6
	M	FLD	AU	32	1058258124.0H	2510739	196
	M	FLD	AUA	5	40505752.0H	307692	196
	M	FLD	AUF	0	22938272.0H	322245	196
	M	FLD	GF	2	1025930412.0H	41796	133
Resistor, Fixed,					0.250w		
	.	FLD	AIA	0	85971392.0H	184706	90
	.	FLD	AIF	18	0.0H	1379	46
	.	FLD	AIT	3	61363200.0H	102550	114
	.	FLD	GF	26	1194357190.0H	47861	58
	M	FLD	AU	7	1259831100.0H	2988975	77
	M	FLD	AUA	6	15912974.0H	366300	77
	M	FLD	AUF	4	9011464.0H	383625	77
Resistor, Fixed,					0.500w		

Part Type	Qual	DType	Env	Tot. Fail	Rated Pwr / Total Duration	Total Pop.	No. Rec.
	.	FLD	AIA	0	413324.0H	888	2
	.	FLD	AIF	0	0.0H	10	3
	.	FLD	AIT	0	225600.0H	376	2
	.	FLD	GF	3	22414210.0H	903	4
	M	FLD	AU	0	74826332.0H	177527	17
	M	FLD	AUA	0	3513254.0H	21756	17
	M	FLD	AUF	2	1989544.0H	22785	17
Resistor, Fixed,					1.000w		
	.	FLD	AIA	0	206662.0H	444	1
	.	FLD	AIF	2	0.0H	6	2
	.	FLD	AIT	0	112800.0H	188	1
	.	FLD	GF	0	9606090.0H	387	3
	.	FLD	AIA	0	1239972.0H	2664	4
	.	FLD	AIT	0	676800.0H	1128	4
	1	FLD	AIA	0	619986.0H	1332	3
	1	FLD	AIF	30	0.0H	54	5
	1	FLD	AIT	0	338400.0H	564	3
	1	FLD	GF	3	9606090.0H	387	3
	M	FLD	AU	1	73299264.0H	173904	16
	M	FLD	AUA	0	3306592.0H	21312	16
	M	FLD	AUF	0	1872512.0H	22320	16
	M	FLD	GF	2	6404060.0H	258	1
Resistor, Fixed,					1.250w		
	M	FLD	GF	1	6404060.0H	258	1
Resistor, Fixed,					2.000w		
	1	FLD	AIA	0	206662.0H	444	1
	1	FLD	AIT	0	112800.0H	188	1
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Resistor, Fixed,					2.500w		
	M	FLD	AU	1	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
	M	FLD	GF	4	28818270.0H	1161	8
Resistor, Fixed,					3.000w		
	M	FLD	AU	0	71772196.0H	170281	18
	M	FLD	AUA	1	3719916.0H	20868	18
	M	FLD	AUF	0	2106576.0H	21855	10
	M	FLD	GF	0	9606090.0H	387	2
Resistor, Fixed,					6.500w		
	M	FLD	AU	21	15270680.0H	36230	3
	M	FLD	AUA	2	619986.0H	4440	3
	M	FLD	AUF	0	351096.0H	4650	3
	M	FLD	GF	0	22414210.0H	903	4
Resistor, Fixed, Multiple					Unk		
	C	FLD	GBC	4	34070400.0H	26208	19
Resistor, Fixed, Single					Unk		
	C	FLD	GBC	8	6828608800.0H	5252776	113
Resistor, Fixed, Single					0.050w		
	C	FLD	GBC	140	38954047600.0H	29964652	264

Part Type	Qual	DType	Env	Tot. Fail	Rated Pwr / Total Duration	Total Pop.	No. Rec.
Resistor, Fixed, Single					0.062w		
	C	FLD	GBC	8	1528800.0H	1176	1
Resistor, Fixed, Single					0.063w		
	C	FLD	GBC	0	82336800.0H	63336	1
Resistor, Fixed, Single					0.075w		
	C	FLD	GBC	0	15022800.0H	11556	5
Resistor, Fixed, Single					0.100w		
	C	FLD	GBC	24	2781277200.0H	2139444	238
Resistor, Fixed, Single					0.125w		
	C	FLD	GBC	276	334440371200.0H	********	2111
Resistor, Fixed, Single					0.150w		
	C	FLD	GBC	4	40835600.0H	31412	8
Resistor, Fixed, Single					0.200w		
	C	FLD	GBC	0	10182936400.0H	7833028	138
Resistor, Fixed, Single					0.225w		
	C	FLD	GBC	0	38334400.0H	29488	8
Resistor, Fixed, Single					0.250w		
	C	FLD	GBC	104	109414791200.0H	84165224	704
Resistor, Fixed, Single					0.300w		
	C	FLD	GBC	0	139495200.0H	107304	16
Resistor, Fixed, Single					0.333w		
	C	FLD	GBC	0	396754800.0H	305196	10
Resistor, Fixed, Single					0.350w		
	C	FLD	GBC	0	29972800.0H	23056	4
Resistor, Fixed, Single					0.375w		
	C	FLD	GBC	0	19531200.0H	15024	3
Resistor, Fixed, Single					0.400w		
	C	FLD	GBC	0	25490400.0H	19608	2
Resistor, Fixed, Single					0.500w		
	C	FLD	GBC	76	14314591200.0H	11011224	584
Resistor, Fixed, Single					0.600w		
	C	FLD	GBC	0	135200.0H	104	2
Resistor, Fixed, Single					0.660w		
	C	FLD	GBC	0	1398800.0H	1076	1
Resistor, Fixed, Single					0.667w		
	C	FLD	GBC	0	322400.0H	248	1
Resistor, Fixed, Single					0.750w		
	C	FLD	GBC	0	52988000.0H	40760	11
Resistor, Fixed, Single					1.000w		
	C	FLD	GBC	28	2245063600.0H	1726972	175
Resistor, Fixed, Single					1.500w		
	C	FLD	GBC	0	390000.0H	300	1
Resistor, Fixed, Single					1.800w		
	C	FLD	GBC	0	35[illegible]800.0H	27736	1
Resistor, Fixed, Single					2.000w		
	C	FLD	GBC	56	5783278800.0H	4448676	163
Resistor, Fixed, Single					2.250w		
	C	FLD	GBC	0	17082000.0H	13140	3
Resistor, Fixed, Single					2.500w		
	C	FLD	GBC	0	8450000.0H	6500	3
Resistor, Fixed, Single					3.000w		

Part Type	Qual	DType	Env	Tot. Fail	Rated Pwr / Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	24	2131750400.0H	1639808	135
Resistor, Fixed, Single					3.250W		
	C	FLD	GBC	0	4102800.0H	3156	1
Resistor, Fixed, Single					4.000W		
	C	FLD	GBC	0	23441600.0H	18032	6
Resistor, Fixed, Single					5.000W		
	C	FLD	GBC	8	935719200.0H	719784	94
Resistor, Fixed, Single					6.000W		
	C	FLD	GBC	0	12573600.0H	9672	1
Resistor, Fixed, Single					7.000W		
	C	FLD	GBC	0	170794000.0H	131380	19
Resistor, Fixed, Single					7.500W		
	C	FLD	GBC	0	10389600.0H	7992	8
Resistor, Fixed, Single					8.000W		
	C	FLD	GBC	0	67340000.0H	51800	3
Resistor, Fixed, Single					9.000W		
	C	FLD	GBC	0	8741200.0H	6724	3
Resistor, Fixed, Single					10.000W		
	C	FLD	GBC	0	377977600.0H	290752	53
Resistor, Fixed, Single					12.000W		
	C	FLD	GBC	0	94754400.0H	72888	16
Resistor, Fixed, Single					15.000W		
	C	FLD	GBC	0	5844800.0H	4496	2
Resistor, Fixed, Single					17.000W		
	C	FLD	GBC	0	3754400.0H	2888	1
Resistor, Fixed, Single					20.000W		
	C	FLD	GBC	16	79284400.0H	6098[illegible]	12
Resistor, Fixed, Single					25.000W		
	C	FLD	GBC	4	42270800.0H	32516	15
Resistor, Fixed, Single					40.000W		
	C	FLD	GBC	0	2370[illegible].0H	18236	14
Resistor, Fixed, Single					50.000W		
	C	FLD	GBC	0	12053600.0H	9272	8
Resistor, Fixed, Single					55.000W		
	C	FLD	GBC	0	452400.0H	348	2
Resistor, Fixed, Single					75.000W		
	C	FLD	GBC	0	39624000.0H	30480	6
Resistor, Fixed, Single					100.000W		
	C	FLD	GBC	0	10400.0H	8	1
Resistor, Network,					Unk		
	M	FLD	AIF	3	0.0H	146	11
	M	FLD	AU	2	33595496.0H	79706	10
	M	FLD	AUA	0	2066620.0H	9768	10
	M	FLD	AUF	0	1170320.0H	10230	10
	M	FLD	G	10	1200000000.0H	0	1
	U	FLD	GBC	72	23473262800.0H	18056356	434
Resistor, Network,					0.250W		
	M	FLD	AIF	1	0.0H	21	5
Resistor, Network,					0.500W		
	M	FLD	AU	0	4581204.0H	10869	1
	M	FLD	AUA	0	206662.0H	1332	1

Part Type	Qual	DType	Env	Tot. Fail	Rated Pwr Total Duration	Total Pop.	No. Rec.
	M	FLD	AUF	0	117032.0H	1395	1
	M	FLD	GF	3	9606090.0H	387	2
Resistor, Network,					0.750w		
	M	FLD	AU	0	4581204.0H	10869	3
	M	FLD	AUA	0	619985.0H	1332	3
	M	FLD	AUF	0	351096.0H	1395	3
Resistor, Network,					1.000w		
	M	FLD	AIF	39	0.0H	396	39
	M	FLD	AU	0	29014292.0H	68837	11
	M	FLD	AUA	0	2273282.0H	8436	11
	M	FLD	AUF	0	1287352.0H	8835	11
Resistor, Network,					1.250w		
	M	FLD	AU	0	16797748.0H	39853	1
	M	FLD	AUA	0	206662.0H	4884	1
	M	FLD	AUF	0	117032.0H	5115	1
Resistor, Network,					1.600w		
	M	FLD	AIF	0	0.0H	1	1
Resistor, Network,					125.000w		
	M	FLD	AIF	1	0.0H	2	1
Resistor, Thermistor,					Unk		
	C	FLD	GBC	0	656614400.0H	505088	20
	M	FLD	AIA	0	6613154.0H	14208	9
	M	FLD	AIT	0	3609600.0H	6016	9
	M	FLD	G	0	6000000.0H	0	2
Resistor, Thermistor,					0.225w		
	C	FLD	GBC	0	2293200.0H	1764	1
Resistor, Thermistor,					0.250w		
	M	FLD	AU	2	3054136.0H	7246	2
	M	FLD	AUA	2	413324.0H	888	2
	M	FLD	AUF	2	234064.0H	930	2
Resistor, Thermistor,					0.500w		
	M	FLD	GF	0	12808120.0H	516	2
Resistor, Thermistor,					1.000w		
	M	FLD	AU	0	3054136.0H	7246	2
	M	FLD	AUA	0	413324.0H	888	2
	M	FLD	AUF	1	234064.0H	930	2
Resistor, Thermistor, Bead					Unk		
	C	FLD	GBC	0	72420400.0H	55708	13
Resistor, Thermistor, Disc					Unk		
	C	FLD	GBC	4	621327200.0H	477944	54
Resistor, Thermistor, PTC					Unk		
	C	FLD	GBC	0	224021200.0H	172324	7
Resistor, Thermistor, Probe					Unk		
	C	FLD	GBC	0	15277600.0H	11752	3
Resistor, Thermistor, Rod					Unk		
	C	FLD	GBC	0	143852800.0H	110656	3
Resistor, Thermistor, Tub					Unk		
	C	FLD	GBC	4	73158800.0H	56276	9
Resistor, Thermistor, WFR					Unk		
	C	FLD	GBC	0	10472800.0H	8056	3
Resistor, Variable,					Unk		

Part Type	Qual	DType	Env	Tot. Fail	Rated Pwr / Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	8	1616087200.0H	1243144	20
	M	FLD	AIA	2	1033310.0H	2220	3
	M	FLD	AIT	1	564000.0H	940	3
	M	FLD	G	32	442280000.0H	0	6
Resistor, Variable,					0.250w		
	M	FLD	AIA	11	206662.0H	444	1
	M	FLD	AIT	1	112800.0H	188	1
	M	FLD	GF	3	3202030.0H	129	1
Resistor, Variable,					0.500w		
	M	FLD	AIA	0	619986.0H	1332	2
	M	FLD	AIT	1	338400.0H	564	2
	M	FLD	AU	0	3054136.0H	7246	2
	M	FLD	AUA	0	413324.0H	888	2
	M	FLD	AUF	0	234064.0H	930	2
	M	FLD	GF	9	3202030.0H	129	1
Resistor, Variable,					0.750w		
	M	FLD	GF	1	25616240.0H	1032	4
Resistor, Variable,					1.000w		
	C	FLD	GBC	0	60954400.0H	46888	1
	M	FLD	AU	34	119111304.0H	282594	14
	M	FLD	AUA	2	2893268.0H	34632	14
	M	FLD	AUF	1	1638448.0H	36270	14
	M	FLD	GF	0	3202030.0H	129	1
Resistor, Variable, Single					Unk		
	C	FLD	GBC	68	1273079600.0H	979292	355
Resistor, Variable, Trimmer					Unk		
	C	FLD	GBC	84	17969016000.0H	13822320	320
Resistor, Variable, Trimmer					10.000w		
	C	FLD	GBC	0	7316400.0H	5628	1
Resistor, Varistor,					Unk		
	C	FLD	GBC	4	92554800.0H	71196	5
	M	FLD	G	7	600000000.0H	0	1

Part Type	Qual	DType	Env	Contact Config. Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
Rotary Switch, Unknown				Unknown	Unk		
	C	FLD	AIT	15	114000.0H	0	2
	C	FLD	GBC	4	257426000.0H	198020	130
	C	FLD	GF	1	109000.0H	0	1
	C	FLD	GM	0	52232.0H	138	2
	M	FLD	A	[illegible]61	14749000.0H	0	3
	M	FLD	AI	4	90000.0H	0	1
	M	FLD	AIA	4	619986.0H	1332	1
	M	FLD	AIF	0	3050541.0H	14810	32
	M	FLD	AIT	1	6066042.0H	845	3
	M	FLD	AU	6	3054136.0H	7246	1
	M	FLD	AUA	0	206662.0H	888	1
	M	FLD	AUF	0	117032.0H	930	1
	M	FLD	GF	50	68822093.0H	646	10
	M	FLD	GM	0	11934.0H	384	5
	M	FLD	GMW	0	98000.0H	0	8
	M	FLD	GRF	0	1700000.0C	0	2
	M	FLD	HEL	6	97000.0H	0	3
	M	FLD	MP	1	126180.0H	2103	3
	M	FLD	NBS	71	24838239.0H	0	17
	M	FLD	NS	84	57344938.0H	57	4
	M	FLD	NSB	1	46121560.0H	1053	20
	M	FLD	SF	1	2391000.0H	0	1
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	1	4610800.0H	0	2
	U	FLD	N	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	1
	U	FLD	SF	0	0.0H	0	1
Rotary Switch, Unknown				Unknown	0.20a		
	M	FLD	AI	0	172000.0H	2	1
Rotary Switch, Unknown				Unknown	0.25a		
	C	FLD	GMW	0	6760000.0H	2	2
Rotary Switch, Unknown				Unknown	2.00a		
	M	FLD	NSB	1	1708100.0H	39	1
Rotary Switch, Unknown				Unknown	50.00m		
	M	FLD	AU	2	1527068.0H	3623	1
	M	FLD	AUA	3	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Rotary Switch, Unknown				Unknown	200.00m		
	M	FLD	AU	0	3054136.0H	7246	1
	M	FLD	AUA	0	206662.0H	888	1
	M	FLD	AUF	0	117032.0H	930	1
Rotary Switch, Unknown				Unknown	750.00m		
	M	FLD	AIA	0	[illegible].0H	444	1
	M	FLD	AIT	0	112800.0H	183	1
Rotary Switch, Unknown					Unk		
	C	FLD	GBC	0	6240000.0H	4800	12
Rotary Switch, Unknown				4P4T,NS	Unk		
	C	FLD	GBC	0	88400.0H	68	1

Part Type	Qual	DType	Env	Contact Config.	Tot. Fail	Rated Current	Total Duration	Total Pop.	No. Rec.
Rotary Switch, Unknown				4PDT,NS		Unk			
	C	FLD	GBC		0		676000.0H	520	1
Rotary Switch, Unknown				DP13T,PS		Unk			
	C	FLD	GBC		0		4186000.0H	3220	1
Rotary Switch, Unknown				DP3T		500.00m			
	M	FLD	AIA		0		1239972.0H	2664	1
	M	FLD	AIT		0		676800.0H	1128	1
Rotary Switch, Unknown				DP4T		Unk			
	C	FLD	GBC		0		1352000.0H	1040	2
Rotary Switch, Unknown				DP4T		250.00m			
	M	FLD	AIA		0		206662.0H	444	1
	M	FLD	AIT		0		112800.0H	188	1
Rotary Switch, Unknown				DP4T,NS		Unk			
	C	FLD	GBC		0		2631200.0H	2024	1
Rotary Switch, Unknown				DP8T		Unk			
	C	FLD	GBC		0		691600.0H	532	1
Rotary Switch, Unknown				DPST,NS		Unk			
	C	FLD	GBC		0		5200.0H	4	1
Rotary Switch, Unknown				SP		Unk			
	C	FLD	GBC		0		156052000.0H	120040	9
Rotary Switch, Unknown				SP10T,NS		Unk			
	C	FLD	GBC		0		10311600.0H	7932	3
Rotary Switch, Unknown				SP12T		150.00m			
	M	FLD	AIA		0		206662.0H	444	1
	M	FLD	AIT		0		112800.0H	188	1
Rotary Switch, Unknown				SP16T,PS		Unk			
	C	FLD	GBC		0		8262800.0H	6356	1
Rotary Switch, Unknown				SP3T,NS		Unk			
	C	FLD	GBC		0		2631200.0H	2024	1
Rotary Switch, Unknown				SP4T		500.00m			
	M	FLD	AIA		0		206662.0H	444	1
	M	FLD	AIT		0		112800.0H	188	1
Rotary Switch, Unknown				SP5T		Unk			
	M	FLD	GF		2		6404060.0H	258	2
Rotary Switch, Unknown				SP7T,PS		Unk			
	C	FLD	GBC		0		2048800.0H	1576	2
Rotary Switch, Unknown				SP8T,NS		Unk			
	C	FLD	GBC		0		5262400.0H	4048	2
Rotary Switch, Unknown				SP9T,SS		Unk			
	C	FLD	GBC		0		1409200.0H	1084	1
Rotary Switch, Unknown				SPDT		250.00m			
	M	FLD	AIA		0		206662.0H	444	1
	M	FLD	AIT		0		112800.0H	188	1
Rotary Switch, Lever				Unknown		Unk			
	C	FLD	GBC		0		20919600.0H	16092	24
Rotary Switch, Lever				4P3T,NS		Unk			
	C	FLD	GBC		0		161200.0H	124	1
Rotary Switch, Lever				DP4T		Unk			
	C	[illegible]	[illegible]		0		686400.0H	528	1
Rotary Switch, Lever				[illegible]		Unk			
	C	FLD	GBC		0		[illegible]	392	1

Part Type	Qual	DType	Env	Contact Config. / Tot. Fail	Rated Current / Total Duration	Total Pop.	No. Rec.
Rotary Switch, Lever				DPDT	Unk		
	C	FLD	GBC	0	1352000.0H	1040	1
Rotary Switch, Shield				Unknown	Unk		
	C	FLD	GBC	0	88400.0H	68	1
Rotary Switch, Stepping				Unknown	Unk		
	M	FLD	[illegible]	2	5000000.0H	0	1
	M	FLD	NSS	5	234200.0H	0	1
	U	FLD	GF	[illegible]	[illegible].0H	[illegible]	1
	U	FLD	NSB	[illegible]	[illegible].0H	[illegible]	1
Rotary Switch, Thumbwheel				Unknown	Unk		
	C	FLD	AI	3	[illegible]	22	1
	C	FLD	GBC	[illegible]	[illegible]	46536	14
	M	FLD	[illegible]	3	[illegible]	384	3
	M	FLD	[illegible]	[illegible]	[illegible]	[illegible]	11
	U	FLD	GF	[illegible]	[illegible]	304	3
	U	FLD	GM	[illegible]	3700.0H	27	1
Rotary Switch, Thumbwheel				Unknown	[illegible]		
	C	FLD	GB	[illegible]	[illegible]	[illegible]	1
Rotary Switch, Thumbwheel				Unknown	[illegible]		
	C	FLD	GF	[illegible]	[illegible]	636	9
Rotary Switch, Thumbwheel				Unknown	3.00a		
	C	FLD	GM	[illegible]	[illegible]	224	1
	M	FLD	GF	[illegible]	[illegible]	0	1
	M	FLD	GM	[illegible]	[illegible]	308	8
	M	FLD	NBS	[illegible]	[illegible]	0	2
Rotary Switch, Thumbwheel					Unk		
	C	FLD	GBC	0	23550800.0H	18116	4
Rotary Switch, Thumbwheel				SP	Unk		
	C	FLD	GBC	0	4747600.0H	3652	3

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Socket, Unknown,							
	C	FLD	GBC	0	13202800.0H	10156	8
	M	FLD	AIF	0	16069404.0H	147158	56
	M	FLD	GF	0	1954560.0H	509	2
	M	FLD	NSB	0	384343800.0H	3775	7
Socket, Adapter,							
	C	FLD	GBC	0	199992000.0H	153840	5
Socket, Coax,							
	C	FLD	GBC	0	50585600.0H	38912	1
Socket, Crystal,							
	C	FLD	GBC	0	3920800.0H	3016	2
Socket, Crystal, HC-25/U							
	C	FLD	GBC	0	39296400.0H	30228	3
Socket, Crystal, HC-6/U							
	C	FLD	GBC	0	50819600.0H	39092	4
Socket, DIP,							
	C	FLD	GBC	8	10631020400.0H	8177708	147
	C	FLD	GF	0	1821936000.0H	483152	2
	M	FLD	GF	0	3225772183.0H	0	12
	M	FLD	NS	0	200500000.0H	40744	1
Socket, Display,							
	C	FLD	GBC	0	578156800.0H	444736	17
Socket, Ground,							
	C	FLD	GBC	0	165105200.0H	127004	1
Socket, Hi-density,							
	C	FLD	GBC	0	27752400.0H	21348	1
Socket, IC,							
	C	FLD	GBC	0	39150800.0H	30116	4
Socket, IC, Chip Carrier							
	C	FLD	GBC	0	418121600.0H	321632	5
Socket, IC, PGA							
	C	FLD	GBC	0	74001200.0H	56924	18
Socket, Lamp,							
	M	FLD	GF	0	124942090.0H	7859	1
	M	FLD	NS	0	762182311.0H	1656	1
Socket, Recepticle,							
	C	FLD	GBC	0	127114000.0H	97780	4
Socket, Relay,							
	C	FLD	GBC	4	98498400.0H	75768	15
	C	FLD	CM	0	52232.0H	133	1
	M	FLD	AIF	0	118444.0H	507	1
	M	FLD	NS	0	6343310.0H	138	1
Socket, SIP,							
	C	FLD	GBC	0	336044800.0H	258496	19
Socket, Spring,							
	C	FLD	GBC	0	2683200.0H	2064	1
Socket, Strip,							
	C	FLD	GBC	0	188130800.0H	144716	6
Socket, Strip, DIP							
	C	FLD	GBC	0	35406800.0H	27236	3
Socket, Strip, SIP							

Part Type	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	8	563602000.0H	433540	22
Socket, Strip, Square	C	FLD	GBC	0	2849600.0H	2192	1
Socket, Substrait,	C	FLD	GBC	0	795600.0H	612	1
Socket, Test,	C	FLD	GBC	0	3822000.0H	2940	1
Socket, Transistor,	C	FLD	GBC	4	395553600.0H	304272	5
Socket, Transistor, TO-18	C	FLD	GBC	0	12386400.0H	9528	2
Socket, Transistor, TO-3	C	FLD	GBC	0	299722800.0H	230556	15
Socket, Transistor, TO-5	C	FLD	GBC	0	64038000.0H	49260	4
Socket, Transistor, TO-66	C	FLD	GBC	0	18735600.0H	14412	4
Socket, Tube,	C	FLD	GBC	0	45884800.0H	35296	7
	M	FLD	GF	0	1921280.0H	128	1
Socket, Tube, CRT	C	FLD	GBC	0	34117200.0H	26244	3
Socket, Tube, Circular	C	FLD	GBC	0	6947200.0H	5344	2

Part Type	Qual	DType	Env	Tot. Fail	Rated Current / Total Duration	Total Pop.	No. Rec.
Switch, Unknown,					Unk		
	C	FLD	AI	2	3952000.0H	0	1
	C	FLD	AIT	1081	10075000.0H	0	2
	C	FLD	GF	1	3000000.0C	0	1
	C	FLD	GF	0	6778600.0H	0	3
	M	FLD	A	356	2155461.0H	142	64
	M	FLD	AIA	2	206662.0H	444	1
	M	FLD	AIF	0	136752.0H	609	3
	M	FLD	AIT	1	112800.0H	188	1
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
	M	FLD	DOR	0	44949000.0H	1601	5
	M	FLD	GF	2	666000.0C	20	2
	M	FLD	GF	21	10830821.0H	109	4
	M	FLD	GM	112	30041885.0H	7407	41
	M	FLD	HEL	348	3528000.0H	0	2
	M	FLD	NBS	2	3952000.0H	0	1
	M	FLD	NH	13	8028.0H	0	1
	M	FLD	NS	0	11997574.0H	13	7
	M	FLD	SF	4	7880000.0H	0	2
	U	FLD	G	6	900000.0H	0	1
Switch, Unknown,					5.000a		
	M	FLD	GF	0	142560.0H	5	2
	M	FLD	NS	0	498078.0H	1	1
Switch, Unknown,					10.000a		
	M	FLD	GF	0	31200.0H	0	2
	M	FLD	NS	0	996156.0H	2	2
Switch, Actuator,					Unk		
	C	FLD	GBC	0	10545600.0H	8112	1
Switch, Array,					Unk		
	C	FLD	GBC	0	109200.0H	84	1
Switch, Centrufugal,					Unk		
	M	FLD	AIT	2	65000.0H	0	1
	M	FLD	AU	237	671000.0H	0	1
	M	FLD	GF	3	1659000.0H	0	1
	M	FLD	HEL	59	439000.0H	0	2
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
Switch, Centrufugal,					120.000a		
	M	FLD	N/R	3	1658880.0H	108	1
Switch, Coaxial,					Unk		
	C	FLD	GF	2	4645000.0C	0	2
	M	FLD	GF	4	14030883.0H	113	3
	M	FLD	GM	0	9945.0H	320	2
	U	FLD	G	0	0.0H	0	1
Switch, Coaxial, Electromechanical					Unk		
	U	FLD	NS	10	277800.0H	18	1
Switch, Contact,					Unk		
	C	FLD	GBC	0	333257600.0H	256352	3

Part Type	Qual	DType	Env	Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
Switch, Control,					Unk		
	C	FLD	GBC	0	1019200.0H	784	1
Switch, Cover, Rooker Assembly					Unk		
	C	FLD	GBC	0	62400.0H	48	1
Switch, Crank,					Unk		
	C	FLD	GBC	0	202800.0H	156	1
Switch, DIP,					Unk		
	C	FLD	GBC	0	15620800.0H	12016	1
	C	FLD	GF	1	4229019.0H	2784	1
Switch, DIP,					100.000a		
	M	FLD	GF	0	114048.0H	4	2
Switch, DIP, Rocker					0.030a		
	C	FLD	GBC	0	25053600.0H	19272	1
Switch, DIP, Rocker					0.050a		
	C	FLD	GBC	0	894587200.0H	688144	28
Switch, DIP, Rocker					0.060a		
	C	FLD	GBC	0	22911200.0H	17624	2
Switch, DIP, Rocker					0.100a		
	C	FLD	GBC	0	132813200.0H	102164	12
Switch, DIP, Rocker					0.125a		
	C	FLD	GBC	0	301600.0H	232	1
Switch, DIP, Rocker					0.250a		
	C	FLD	GBC	0	5200.0H	4	1
Switch, DIP, Rocker					5.000a		
	C	FLD	GBC	0	114400.0H	88	1
Switch, DIP, Rotary					0.100a		
	C	FLD	GBC	0	5902000.0H	4540	1
Switch, DIP, Slide					0.050a		
	C	FLD	GBC	0	14606800.0H	11236	7
Switch, DIP, Slide					0.100a		
	C	FLD	GBC	0	868639200.0H	668184	36
Switch, DIP, Slide					0.250a		
	C	FLD	GBC	0	3172000.0H	2440	1
Switch, DIP, Surface Mount					0.100a		
	C	FLD	GBC	0	988000.0H	760	1
Switch, DIP, Toggle					0.050a		
	C	FLD	GBC	0	1383200.0H	1064	2
Switch, Display,					Unk		
	C	FLD	GBC	0	1783600.0H	1372	1
Switch, End Plate,					Unk		
	C	FLD	GBC	0	447200.0H	344	2
Switch, Float,					Unk		
	C	FLD	AU	0	50000.0H	0	1
	C	FLD	N/R	14	2786000.0H	189	1
	M	FLD	AU	2	7000.0H	0	1
	M	FLD	GF	2	334000.0C	0	1
	M	FLD	GM	2	21000.0H	0	1
	M	FLD	HEL	2	43000.0H	0	1
Switch, Float, Liquid Level Ind.					Unk		
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1

Part Type	Qual	DType	Env	Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
	U	FLD	GM	0	0.0H	0	1
Switch, Flow,					Unk		
	M	FLD	A	11	34679.0H	1	1
	M	FLD	GF	1	342144.0H	12	1
	M	FLD	GM	0	3978.0H	128	2
	M	FLD	NS	0	498078.0H	1	1
	M	FLD	NSB	0	3985800.0H	91	2
Switch, Flow,					0.500a		
	M	FLD	GF	10	2737152.0H	96	1
Switch, Flow, Liquid					Unk		
	M	FLD	NH	24	30252.0H	0	2
	U	FLD	GM	4	535968.0H	3260	2
	U	FLD	NS	7	1386117.0H	368	3
	U	FLD	NU	2	20960.0H	20	1
Switch, Flow, Paddle Type					Unk		
	M	FLD	GF	56	11612160.0H	740	3
Switch, Foot,					Unk		
	C	FLD	GBC	0	436800.0H	336	1
	M	FLD	A	13	25492.0H	1	1
Switch, Frame,					Unk		
	C	FLD	GBC	0	561600.0H	432	1
Switch, Humidity,					Unk		
	M	FLD	GF	4	238444.0H	54	1
Switch, Impact,					Unk		
	C	FLD	GBC	0	24637600.0H	18952	1
Switch, Inertial,					Unk		
	M	FLD	DOR	9	137100000.0H	649	1
	U	FLD	GF	0	0.0H	0	1
Switch, Interlock,					Unk		
	M	FLD	GF	3	15697000.0H	0	1
	U	FLD	GM	6	9500.0H	190	1
Switch, Interlock,					10.000a		
	M	FLD	GF	2	7584192.0H	266	1
	M	FLD	NS	1	1494234.0H	3	1
Switch, Keyboard,					Unk		
	C	FLD	GBC	0	68577600.0H	52752	3
	M	FLD	GMW	0	13882.0H	0	1
Switch, Keylock,					Unk		
	C	FLD	GBC	0	150800.0H	116	1
Switch, Keylock,					100.000a		
	C	FLD	GBC	0	338000.0H	260	1
Switch, Keyswitch,					Unk		
	C	FLD	GBC	0	171600.0H	132	1
Switch, Lever,					Unk		
	C	FLD	GBC	0	332800.0H	256	1
Switch, Limit,					Unk		
	M	FLD	A	296	11982000.0H	0	1
	M	FLD	AU	42	96000.0H	0	2
	M	FLD	GF	5	711000.0C	21	3
	M	FLD	GF	31	5265574.0H	305	5
	M	FLD	GM	0	5967.0H	192	1

Part Type	Qual	DType	Env	Tot. Fail	Rated Current	Total Duration	Total Pop.	No. Rec.
	M	FLD	GMW	1		21000.0H	0	1
	U	FLD	A	0		0.0H	0	1
	U	FLD	GM	0		0.0H	0	1
Switch, Link,					Unk			
	C	FLD	GBC	0		405600.0H	312	1
Switch, Liquid Level,					Unk			
	M	FLD	GF	2		424224.0H	54	1
Switch, Microwave,					Unk			
	C	FLD	GBC	56		50398400.0H	38768	11
Switch, Overcurrent, Alarm					Unk			
	M	FLD	GF	2		3504000.0H	200	1
Switch, Pressure,					Unk			
	C	FLD	AIT	433		10956000.0H	0	4
	C	FLD	GM	0		52232.0H	138	2
	M	FLD	A	561		1179064.0H	61	33
	M	FLD	AIF	85		760000.0H	3120	1
	M	FLD	AU	6		763000.0C	0	1
	M	FLD	AU	1383		21801000.0H	0	4
	M	FLD	DOR	96		57450000.0H	220	3
	M	FLD	GB	1		26000.0C	5	2
	M	FLD	GF	24		38589000.0H	0	5
	M	FLD	GM	0		5967.0H	192	3
	M	FLD	GMW	183		26390000.0H	4	5
	M	FLD	HEL	348		1047000.0H	0	5
	M	FLD	NBS	4		613000.0H	0	1
	M	FLD	NS	18		798000.0H	0	1
	M	FLD	NSB	0		569400.0H	13	1
	U	FLD	A	0		0.0H	0	1
	U	FLD	ARW	0		0.0H	0	1
	U	FLD	G	0		0.0H	0	1
	U	FLD	GF	0		0.0H	0	1
	U	FLD	GM	0		0.0H	0	1
	U	FLD	N	0		0.0H	0	1
	U	FLD	NSB	0		0.0H	0	1
Switch, Pressure, Air Flow					Unk			
	U	FLD	GF	9		2155190.0H	256	5
	U	FLD	GM	9		810421.0H	415	2
	U	FLD	ML	0		164.0H	0	1
	U	FLD	NS	38		4202120.0H	496	4
	U	FLD	NU	1		40000.0H	20	1
Switch, Pressure, Diaphragm					Unk			
	M	FLD	GF	19		5018112.0H	324	5
Switch, Pressure, Fuel					Unk			
	M	FLD	A	6		42000.0H	0	1
Switch, Pressure, Hydraulic					Unk			
	M	FLD	A	383		2776000.0H	0	3
	M	FLD	HEL	70		778000.0H	0	1
	U	FLD	A	0		0.0H	0	1
	U	FLD	ARW	0		0.0H	0	1
Switch, Pressure, Refrigerator					Unk			
	M	FLD	GF	2		320.0H	162	1

Part Type	Qual	DType	Env	Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
Switch, Programming,					Unk		
	C	FLD	GBC	0	260000.0H	200	1
Switch, Push Button,					Unk		
	C	FLD	AI	1	9921000.0H	0	3
	C	FLD	GBC	28	517155600.0H	397812	120
	C	FLD	GF	21096	775190305.0H	403444	2
	M	FLD	A	101	3624000.0H	0	2
	M	FLD	AIF	0	593157.0H	2289	5
	M	FLD	DOR	0	603000.0H	0	1
	M	FLD	GF	3	487407.0C	108	1
	M	FLD	GF	8	53928031.0H	1070	6
	M	FLD	GM	215	26520564.0H	1507	4
	M	FLD	GMW	0	34705.0H	0	1
	M	FLD	HEL	0	1286000.0H	0	1
	M	FLD	NBS	169	91747000.0H	0	6
	M	FLD	NS	57	150806612.0H	5744	14
	M	FLD	NSB	0	13096200.0H	299	10
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	0.0H	0	1
	U	FLD	N	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	1
Switch, Push Button,					0.010a		
	C	FLD	GBC	0	1388940800.0H	1068416	4
Switch, Push Button,					0.020a		
	C	FLD	GBC	0	59893600.0H	46072	10
Switch, Push Button,					0.040a		
	C	FLD	GBC	0	12901200.0H	9924	3
Switch, Push Button,					0.045a		
	C	FLD	GBC	0	6318000.0H	4860	1
Switch, Push Button,					0.050a		
	C	FLD	GBC	0	93043600.0H	71572	4
Switch, Push Button,					0.100a		
	C	FLD	GBC	52	724656400.0H	557428	8
Switch, Push Button,					0.125a		
	C	FLD	GBC	8	1416017200.0H	1089244	7
Switch, Push Button,					0.150a		
	C	FLD	GBC	0	9578400.0H	7368	1
Switch, Push Button,					0.250a		
	C	FLD	GBC	28	515996000.0H	396920	18
Switch, Push Button,					0.450a		
	C	FLD	GBC	0	40222000.0H	30940	10
Switch, Push Button,					0.500a		
	C	FLD	GBC	0	43648800.0H	33576	14
Switch, Push Button,					1.000a		
	C	FLD	GBC	8	39696800.0H	30536	22
Switch, Push Button,					1.500a		
	C	FLD	GBC	0	1367600.0H	1052	1
Switch, Push Button,					2.000a		
	M	FLD	AU	52	1527068.0H	3623	1

Part Type	Qual	DType	Env	Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Switch, Push Button,					2.500a		
	C	FLD	GBC	0	398855600.0H	306812	1
Switch, Push Button,					3.000a		
	M	FLD	NSB	4	56370500.0H	1287	2
Switch, Push Button,					4.000a		
	C	FLD	GBC	36	316742400.0H	243648	22
	M	FLD	GMW	0	7000.0H	0	1
Switch, Push Button,					5.000a		
	C	FLD	GBC	36	88342800.0H	67956	12
	M	FLD	AI	1	438600.0H	51	1
	M	FLD	AIA	5	413324.0H	888	2
	M	FLD	AIT	0	225600.0H	376	2
	M	FLD	GF	0	1509512.0H	51	18
	M	FLD	NS	0	29000.0H	0	1
Switch, Push Button,					6.000a		
	C	FLD	GBC	0	67787200.0H	52144	7
Switch, Push Button,					7.000a		
	C	FLD	GBC	0	1726400.0H	1328	1
Switch, Push Button,					10.000a		
	C	FLD	GBC	0	135200.0H	104	2
	M	FLD	GF	0	57024.0H	2	2
Switch, Push Button,					10.100a		
	C	FLD	GBC	0	18236400.0H	14028	2
Switch, Push Button,					10.500a		
	C	FLD	GBC	0	13462800.0H	10356	5
Switch, Push Button, Assembly					Unk		
	C	FLD	GBC	0	2958800.0H	2276	3
Switch, Push Button, Illuminated					Unk		
	M	FLD	GF	0	10400.0H	0	1
	M	FLD	NSB	0	1708200.0H	39	1
Switch, Push Button, Illuminated					2.000a		
	C	FLD	GF	6	1898650.0H	188	1
	M	FLD	NSB	2	1708200.0H	39	2
Switch, Push Button, Pendant-Hoist (Key)					Unk		
	M	FLD	A	88	504014.0H	27	14
Switch, Push Button, Pendant-Hoist (Key)					3.000a		
	C	FLD	GF	6	2589460.0H	6313	1
Switch, Push Button, Sensitive					Unk		
	M	FLD	NS	0	5832330.0H	1540	4
Switch, Push Button, Sensitive					1.000a		
	M	FLD	AU	1	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
Switch, Push Button, Sensitive					2.000a		
	M	FLD	AU	140	1527068.0H	3623	1
	M	FLD	AUA	10	206662.0H	444	1
	M	FLD	AUF	6	117032.0H	465	1
Switch, Push Button, Sensitive					5.000a		
	C	FLD	GM	0	26116.0H	60	1

Part Type	Rated Current	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Switch, Push Button, Switch Extender	Unk							
		C	FLD	GBC	0	1019200.0H	784	1
Switch, Pushwheel,	Unk							
		C	FLD	GBC	0	223600.0H	172	1
Switch, Reed,	Unk							
		C	FLD	GF	0	1200000000.0C	0	1
		C	FLD	GM	2	16252000.0H	0	1
		C	FLD	N/R	11	6827000.0H	424	1
		M	FLD	DOR	0	964000.0H	65	1
		M	FLD	SF	0	908000.0H	25	1
Switch, Rocker,	Unk							
		U	FLD	GF	19	1806200.0H	8521	2
Switch, Rocker,	0.020a							
		C	FLD	GBC	0	9573200.0H	7364	5
Switch, Rocker,	0.030a							
		C	FLD	GBC	8	22032400.0H	16948	1
Switch, Rocker,	0.100a							
		C	FLD	GBC	0	20155200.0H	15504	3
Switch, Rocker,	0.250a							
		C	FLD	GBC	4	90578800.0H	69676	1
Switch, Rocker,	2.000a							
		C	FLD	GBC	0	2152800.0H	1656	1
Switch, Rocker,	3.000a							
		C	FLD	GBC	0	51563200.0H	39664	5
Switch, Rocker,	4.000a							
		C	FLD	GBC	0	133889600.0H	102992	4
Switch, Rocker,	5.000a							
		C	FLD	GBC	0	7202000.0H	5540	6
Switch, Rocker,	6.000a							
		C	FLD	GBC	0	1102400.0H	848	2
Switch, Rocker,	10.000a							
		C	FLD	GBC	0	84198400.0H	64768	5
Switch, Rocker,	12.000a							
		C	FLD	GBC	0	374400.0H	288	1
Switch, Rocker,	16.000a							
		C	FLD	GBC	0	17399200.0H	13384	8
Switch, Rocker, Actuator	Unk							
		C	FLD	GBC	0	5673200.0H	4364	2
Switch, Section,	Unk							
		C	FLD	GBC	0	14617200.0H	11244	10
Switch, Sensitive (micro),	Unk							
		C	FLD	GM	0	26116.0H	69	1
		M	FLD	A	202	12707079.0H	10	6
		M	FLD	AIF	0	306952.0H	1188	2
		M	FLD	AIT	13	1267642.0H	1092	1
		M	FLD	AMF	2	8000.0H	0	1
		M	FLD	DOR	0	2237000.0H	3	3
		M	FLD	GF	16	32853320.0H	1503	4
		M	FLD	HEL	46	1010000.0H	0	2
		M	FLD	NBS	51	46202000.0H	0	2
		M	FLD	NS	3	7043469.0H	164	4

Part Type	Qual	DType	Env	Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
	M	FLD	NSB	0	27331600.0H	624	4
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	0.0H	0	1
	U	FLD	ML	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	1
Switch, Sensitive (micro),					0.100a		
	C	FLD	GBC	120	38781600.0H	29032	6
Switch, Sensitive (micro),					0.500a		
	C	FLD	GBC	0	6890000.0H	5300	2
Switch, Sensitive (micro),					1.000a		
	C	FLD	GBC	0	129880400.0H	99908	3
Switch, Sensitive (micro),					3.000a		
	C	FLD	GBC	0	1019200.0H	784	1
Switch, Sensitive (micro),					4.000a		
	C	FLD	GBC	4	15917200.0H	12244	2
Switch, Sensitive (micro),					5.000a		
	C	FLD	GBC	0	11965200.0H	9204	5
Switch, Sensitive (micro),					7.000a		
	C	FLD	GBC	0	1097200.0H	844	2
Switch, Sensitive (micro),					10.000a		
	M	FLD	NSB	1	10819000.0H	247	1
Switch, Sensitive (micro),					10.100a		
	C	FLD	GBC	0	312000.0H	240	1
Switch, Sensitive (micro),					15.000a		
	C	FLD	GBC	0	187200.0H	144	2
Switch, Shield,					Unk		
	C	FLD	GBC	0	12781600.0H	9832	3
Switch, Slide,					Unk		
	C	FLD	NBS	16	74050000.0H	0	1
	M	FLD	A	9	28100.0H	1	1
Switch, Slide,					0.020a		
	C	FLD	GBC	0	68629600.0H	52792	8
Switch, Slide,					0.030a		
	C	FLD	GBC	0	1955200.0H	1504	1
Switch, Slide,					0.100a		
	C	FLD	GBC	0	993200.0H	764	2
Switch, Slide,					0.300a		
	C	FLD	GBC	0	25604800.0H	19696	6
Switch, Slide,					0.500a		
	C	FLD	GBC	8	460236400.0H	354028	42
Switch, Slide,					1.000a		
	C	FLD	GBC	0	16452800.0H	12656	9
Switch, Slide,					1.500a		
	C	FLD	GBC	0	158802800.0H	122156	14
Switch, Slide,					2.000a		
	C	FLD	GBC	4	28657200.0H	22044	5
Switch, Slide,					3.000a		
	C	FLD	GBC	0	5532800.0H	4256	4
Switch, Slide,					5.000a		

Part Type	Rated Current	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
		C	FLD	GBC	8	531939200.0H	409184	19
Switch, Slide,	6.000a							
		C	FLD	GBC	0	920400.0H	708	2
Switch, Slide,	12.000a							
		C	FLD	GBC	0	135200.0H	104	1
Switch, Snap Disc,	Unk							
		C	FLD	GBC	0	97676800.0H	75136	2
Switch, Spacer,	Unk							
		C	FLD	GBC	0	179727600.0H	138252	2
Switch, Thermostatic,	Unk							
		C	FLD	AIT	17	3374000.0H	0	2
		C	FLD	GF	0	344000.04	0	1
		C	FLD	NBS	0	4137000.0H	0	2
		M	FLD	A	5	60171.0H	2	2
		M	FLD	AI	0	4000.0H	0	1
		M	FLD	AIF	0	38813.0H	881	3
		M	FLD	AU	8	2285000.0H	0	1
		M	FLD	DOR	0	5382000.0H	123	4
		M	FLD	GF	11	9259380.0H	344	5
		M	FLD	GM	9	13822225.0H	114	2
		M	FLD	GMW	0	1063000.0H	0	1
		M	FLD	HEL	9	218000.0H	0	2
		M	FLD	NBS	7	2233000.0H	0	2
		M	FLD	NS	29	53445760.0H	1305	18
		M	FLD	NSB	0	28470000.0H	650	10
		U	FLD	A	0	0.0H	0	1
		U	FLD	ARW	0	0.0H	0	1
		U	FLD	AUT	4	244620.0H	500	1
		U	FLD	G	0	0.0H	0	1
		U	FLD	GF	14	145549606.0H	30583	5
		U	FLD	GM	38	3655909.0H	1849	3
		U	FLD	N	0	0.0H	0	1
		U	FLD	NS	13	3135144.0H	795	3
		U	FLD	NSB	19	345600.0H	3212	5
		U	FLD	NU	3	200190.0H	98	3
Switch, Thermostatic,	4.000a							
		C	FLD	GF	0	28000.0H	0	3
Switch, Thermostatic, Bimetal	Unk							
		M	FLD	GF	6	2488320.0H	162	2
Switch, Thermostatic, Fire Detector	Unk							
		U	FLD	A	19	1064000.0H	0	1
Switch, Thermostatic, Remote Bulb	Unk							
		M	FLD	A	4	25492.0H	1	1
		M	FLD	GF	4	1658880.0H	108	1
Switch, Time,	Unk							
		C	FLD	GBC	0	1019200.0H	784	1
Switch, Toggle,	Unk							
		C	FLD	A	0	365000.0H	13	1
		C	FLD	GBC	0	10400.0H	8	2
		C	FLD	GF	0	25000.0H	30	1
		C	FLD	GM	1	26115.0H	69	1

Part Type	Qual	DType	Env	Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
	M	FLD	A	34	4573000.0A	0	1
	M	FLD	A	265	31353013.0H	79	27
	M	FLD	AIF	69	1911430.0H	22990	26
	M	FLD	AIT	1	1267642.0H	546	1
	M	FLD	DOR	0	1010000.0H	0	1
	M	FLD	GF	135	410367414.0H	11957	14
	M	FLD	GM	23	1317960.0H	68	3
	M	FLD	GMW	1	359000.0H	0	1
	M	FLD	HEL	8	430000.0H	0	1
	M	FLD	MP	0	42060.0H	701	1
	M	FLD	NAB	0	569400.0H	13	1
	M	FLD	NBS	18	442723000.0H	0	13
	M	FLD	NS	60	110706010.0H	4445	48
	M	FLD	NSB	0	37011200.0H	845	13
	M	FLD	SF	0	5480000.0H	0	1
	U	FLD	A	0	0.0H	0	1
	U	FLD	ARW	0	0.0H	0	1
	U	FLD	G	0	0.0H	0	1
	U	FLD	GF	0	0.0H	0	1
	U	FLD	GM	0	0.0H	0	1
	U	FLD	N	0	0.0H	0	1
Switch, Toggle,					0.020a		
	C	FLD	GBC	0	85472400.0H	65748	26
Switch, Toggle,					0.400a		
	C	FLD	GBC	0	8845200.0H	6804	1
Switch, Toggle,					0.500a		
	C	FLD	GBC	0	22984000.0H	17680	5
Switch, Toggle,					2.000a		
	C	FLD	GBC	0	103469600.0H	79592	25
Switch, Toggle,					3.000a		
	C	FLD	GBC	4	25844000.0H	[illegible]	5
Switch, Toggle,					4.000a		
	M	FLD	AI	6	197800.0H	23	5
	M	FLD	AIF	16	592220.0H	2535	2
Switch, Toggle,					5.000a		
	C	FLD	GBC	0	61594000.0H	47380	8
	M	FLD	AI	0	4000.0H	0	1
	M	FLD	AIF	1	236888.0H	1014	1
	M	FLD	GF	0	3341832.0H	111	2
	M	FLD	GMW	0	257000.0H	0	3
	M	FLD	NBS	0	453000.0H	0	5
Switch, Toggle,					6.000a		
	C	FLD	GBC	0	1669200.0H	1284	2
Switch, Toggle,					7.500a		
	C	FLD	GBC	0	5200.0H	4	1
Switch, Toggle,					10.000a		
	C	FLD	GBC	0	17539600.0H	13492	6
	C	FLD	GM	0	26116.0H	69	1
	M	FLD	GM	0	104464.0H	276	3
	M	FLD	NS	0	498073.0H	1	1
Switch, Toggle,					18.000a		

Part Type	Qual	DType	Env	Tot. Fail	Rated Current Total Duration	Total Pop.	No. [illegible]
	M	FLD	GM	0	26116.0H	69	[illegible]
Switch, Toggle,					20.000a		
	M	FLD	GF	0	1026432.0H	36	1
	M	FLD	GM	0	78348.0H	207	2
	M	FLD	NS	0	2490390.0H	5	1
Switch, Toggle,					25.000a		
	M	FLD	GM	0	120000.0H	[illegible]	1
Switch, Toggle,					28.000a		
	M	FLD	GF	0	684288.0H	24	
Switch, Toggle,					30.000a		
	C	FLD	GBC	0	1320800.0H	1016	[illegible]
Switch, Toggle, Alarm					Unk		
	M	FLD	AIF	0	77626.0H	1762	6
Switch, Toggle, Alarm					5.000a		
	M	FLD	GF	31	6404060.0H	258	1
Switch, Toggle, Alarm					20.000a		
	M	FLD	GF	4	6404060.0H	258	1
Switch, Toggle, Sensitive					Unk		
	M	FLD	AIF	0	38813.0H	881	3
	M	FLD	GF	1	180982000.0H	0	2
	M	FLD	MP	0	84120.0H	1402	1
	M	FLD	NS	2	9239000.0H	0	2
Switch, Toggle, Sensitive					7.000a		
	M	FLD	AIA	0	413324.0H	888	1
	M	FLD	AIT	0	225600.0H	376	1
Switch, Voltage,					Unk		
	C	FLD	GBC	0	1019200.0H	784	1
Switch, Wave Guide,					Unk		
	M	FLD	GF	1	580000.0H	0	1
	M	FLD	GF	4	1123512.0H	1	2
	U	FLD	GF	2	500000.0H	20	1
	U	FLD	GM	3	59481.0H	25	2
	U	FLD	NS	3	46200.0H	34	2

Part Type	Rated Temp.	Rated Current	Qual	DType	Env	Tot. Fail	Total Duration	Total Pop.	No. Rec.
Thermal Switch, Unknown	Unknown	Unk	M	FLD	A	14	84300.0H	3	3
Thermal Switch, Unknown	75.00C	13.30a	C	FLD	GBC	0	26000.0H	20	1
Thermal Switch, Fixed	Unknown	Unk	M	FLD	A	8	67415.0H	2	2
Thermal Switch, Fixed	Unknown	12.00a	C	FLD	GBC	0	561600.0H	432	1
Thermal Switch, Fixed	6.60C	15.00a	C	FLD	GBC	0	22989200.0H	17684	1
Thermal Switch, Fixed	4.40C	15.00a	C	FLD	GBC	0	2298400.0H	1768	1
Thermal Switch, Fixed	40.00C	1.00a	C	FLD	GBC	0	650000.0H	500	1
Thermal Switch, Fixed	45.00C	1.00a	C	FLD	GBC	0	5023200.0H	3864	1
Thermal Switch, Fixed	50.00C	8.00a	C	FLD	GBC	0	10400.0H	8	1
Thermal Switch, Fixed	50.00C	25.00a	C	FLD	GBC	4	62400.0H	48	1
Thermal Switch, Fixed	55.00C	1.00a	C	FLD	GBC	0	14086800.0H	10836	1
Thermal Switch, Fixed	55.00C	5.00a	C	FLD	GBC	0	15600.0H	12	1
Thermal Switch, Fixed	70.00C	1.00a	C	FLD	GBC	0	681200.0H	524	1
Thermal Switch, Fixed	71.00C	2.50a	C	FLD	GBC	0	1981200.0H	1524	1
Thermal Switch, Fixed	71.00C	12.00a	C	FLD	GBC	0	9245600.0H	7112	1
Thermal Switch, Fixed	73.00C	2.00a	C	FLD	GBC	0	83200.0H	64	1
Thermal Switch, Fixed	75.00C	1.00a	C	FLD	GBC	0	2735200.0H	2104	1
Thermal Switch, Fixed	75.00C	5.00a	C	FLD	GBC	0	1138800.0H	876	1
Thermal Switch, Fixed	75.00C	6.00a	C	FLD	GBC	0	3894800.0H	2996	1
Thermal Switch, Fixed	75.00C	15.00a	C	FLD	GBC	0	7352800.0H	5656	2
Thermal Switch, Fixed	80.00C	Unk	C	FLD	GBC	0	2433600.0H	1872	1
Thermal Switch, Fixed	80.00C	10.00a	C	FLD	GBC	0	2069600.0H	1592	1
Thermal Switch, Fixed	85.00C	1.00a	C	FLD	GBC	0	852800.0H	656	1
Thermal Switch, Fixed	85.00C	4.00a	C	FLD	GBC	0	5200.0H	4	1
Thermal Switch, Fixed	85.00C	15.00a	C	FLD	GBC	0	806000.0H	620	1
Thermal Switch, Fixed	86.00C	3.00a							

Part Type	Qual	DType	Env	Rated Temp. / Tot. Fail	Rated Current / Total Duration	Total Pop.	No. Rec.
	C	FLD	GBC	0	6640400.0H	5108	1
Thermal Switch, Fixed				89.00C	15.00a		
	C	FLD	GBC	0	9822800.0H	7556	2
Thermal Switch, Fixed				90.00C	Unk		
	C	FLD	GBC	0	7477600.0H	5752	1
Thermal Switch, Fixed				90.00C	1.00a		
	C	FLD	GBC	0	520000.0H	400	1
Thermal Switch, Fixed				90.00C	3.00a		
	C	FLD	GBC	0	8470800.0H	6516	1
Thermal Switch, Fixed				90.00C	6.00a		
	C	FLD	GBC	0	447200.0H	344	1
Thermal Switch, Fixed				90.00C	8.00a		
	C	FLD	GBC	0	1596400.0H	1228	1
Thermal Switch, Fixed				90.00C	10.00a		
	C	FLD	GBC	0	124800.0H	96	1
Thermal Switch, Fixed				92.00C	10.00a		
	C	FLD	GBC	0	3556800.0H	2736	2
Thermal Switch, Fixed				93.00C	0.75a		
	C	FLD	GBC	0	364000.0H	280	1
Thermal Switch, Fixed				93.00C	2.50a		
	C	FLD	GBC	0	62400.0H	48	1
Thermal Switch, Fixed				100.00C	2.50a		
	C	FLD	GBC	0	8268000.0H	6360	1
Thermal Switch, Fixed				100.00C	5.00a		
	C	FLD	GBC	0	514800.0H	396	1
Thermal Switch, Fixed				100.00C	8.00a		
	C	FLD	GBC	0	1903200.0H	1464	1
Thermal Switch, Fixed				100.00C	10.00a		
	C	FLD	GBC	4	22614800.0H	17396	2
Thermal Switch, Fixed				104.00C	8.00a		
	C	FLD	GBC	0	5808400.0H	4468	1
Thermal Switch, Fixed				105.00C	15.00a		
	C	FLD	GBC	0	3239600.0H	2492	1
Thermal Switch, Fixed				106.00C	15.00a		
	C	FLD	GBC	4	8741200.0H	6724	1
Thermal Switch, Fixed				110.00C	6.00a		
	C	FLD	GBC	0	5876000.0H	4320	1
Thermal Switch, Fixed				110.00C	13.30a		
	C	FLD	GBC	0	10134800.0H	7796	1
Thermal Switch, Fixed				110.00C	15.00a		
	C	FLD	GBC	0	10400.0H	8	1
Thermal Switch, Fixed				120.00C	6.00a		
	C	FLD	GBC	0	6718400.0H	5168	1
Thermal Switch, Fixed				120.00C	8.00a		
	C	FLD	GBC	0	1991600.0H	1532	1
Thermal Switch, Fixed				140.00C	6.30a		
	C	FLD	GBC	0	62400.0H	48	1
Thermal Switch, Fixed				371.00C	25.00a		
	C	FLD	GBC	0	62400.0H	48	1
Thermal Switch, Variable				Unknown	Unk		
	C	FLD	GBC	0	93600.0H	72	1

Part Type	Qual	DType	Env	Rated Temp. Tot. Fail	Rated Current Total Duration	Total Pop.	No. Rec.
Thermal Switch, Variable				Unknown	25.00a		
	C	FLD	GBC	0	478400.0H	368	1

Part Type	Qual	DType	Env	Tot. Fail	Sec. Current Total Duration	Total Pop.	No. Rec.
Transformer, Unknown,					Unk		
		FLD	GF	5	7842522.0H	447	6
	C	FLD	AIF	0	0.0H	28	7
	C	FLD	GBC	8	872840800.0H	671416	104
	C	NOP	GF	16	357000000.0H	0	4
	M	FLD	AIF	2	5507695.0H	52442	120
	M	FLD	AIT	11	1267642.0H	819	1
	M	FLD	AU	8	18324816.0H	43476	11
	M	FLD	AUA	0	2273282.0H	5328	11
	M	FLD	AUF	C	1287352.0H	5580	11
	M	FLD	GF	0	760320.0H	198	2
	M	FLD	GM	0	22414210.0H	903	6
	M	FLD	MP	0	2018880.0H	33648	36
	M	FLD	NS	0	3167994.0H	787	14
	M	FLD	NSB	3	68896700.0H	1703	37
	M	NOP	GF	12	3619035000.0H	12249	17
	M	NOP	GM	0	204176000.0H	12852	3
	U	NOP	GF	0	16000000.0H	0	1
	U	NOP	GM	0	131804000.0H	9129	25
Transformer, Unknown,					400.00m		
	M	FLD	GM	0	3202030.0H	129	1
Transformer, Audio,					Unk		
	C	FLD	GBC	0	39119600.0H	30092	11
	M	FLD	AIA	0	2479944.0H	5328	7
	M	FLD	AIT	0	1353600.0H	2256	7
	M	FLD	AU	4	1527068.0H	3623	1
	M	FLD	AUA	0	205662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
	M	FLD	GM	3	9606090.0H	387	2
	U	NOP	GM	0	25521000.0H	1748	1
Transformer, Driver,					Unk		
	M	FLD	NS	0	1265232.0H	310	6
Transformer, Flyback,					Unk		
	C	FLD	GBC	4	595795200.0H	458304	11
Transformer, Inverter,					Unk		
	C	FLD	GBC	0	5678400.0H	4368	3
Transformer, Inverter, Radar					Unk		
	M	FLD	GM	1	1989.0H	64	1
Transformer, Isolation,					Unk		
	C	FLD	GBC	0	45723600.0H	35172	9
Transformer, Motor,					Unk		
		FLD	GF	0	667000.0H	44	6
Transformer, Power,					Unk		
	C	FLD	GBC	96	590099600.0H	684692	266
	C	NOP	GF	2	16000000.0H	0	2
	M	FLD	AU	28	4581204.0H	10869	3
	M	FLD	AUA	2	619986.0H	1332	3
	M	FLD	AUF	0	351096.0H	1395	3
	M	FLD	GF	3	3973496.0H	0	1
	M	FLD	GM	2	6404060.0H	258	2
	M	FLD	NS	0	1431870.0H	354	7

Part Type	Qual	DType	Env	Tot. Fail	Sec. Current / Total Duration	Total Pop.	No. Rec.
	M	NOP	GF	0	17424000.0H	1431	5
	M	NOP	GM	0	17015000.0H	1071	1
	U	NOP	GM	0	15246000.0H	1068	21
Transformer, Power,					4.00a		
	M	FLD	GM	0	3202030.0H	129	1
Transformer, Power,					28.30m		
	C	FLD	AIF	0	0.0H	1	1
Transformer, Power,					33.10m		
	C	FLD	AIF	0	0.0H	3	3
Transformer, Power,					400.00m		
	C	FLD	AIF	0	0.0H	8	2
Transformer, Power, Phase					Unk		
	M	FLD	NS	0	525978.0H	111	2
Transformer, Power, Radar					Unk		
	M	FLD	GM	1	1989.0H	64	1
Transformer, Pulse,					Unk		
	C	FLD	GBC	0	306560800.0H	235816	23
	M	FLD	AIA	0	206662.0H	444	1
	M	FLD	AIT	0	112800.0H	188	1
	M	FLD	AU	0	1527068.0H	3623	1
	M	FLD	AUA	0	206662.0H	444	1
	M	FLD	AUF	0	117032.0H	465	1
	M	FLD	GF	2	39734960.0H	0	1
	M	FLD	NS	0	1265252.0H	310	3
Transformer, Pulse, Radar					Unk		
	M	FLD	GM	7	1989.0H	64	1
Transformer, Radar,					Unk		
	M	FLD	AIF	8	698634.0H	15858	45
	M	FLD	GM	0	109395.0H	3520	33
Transformer, Radar, Filament					Unk		
	M	FLD	GM	1	1939.0H	64	1
Transformer, Radio,					Unk		
	M	FLD	AIF	0	310504.0H	7048	21
	M	FLD	GF	0	5103360.0H	1329	2
Transformer, Switching,					Unk		
	C	FLD	GBC	4	437902400.0H	336848	8
Transformer, Toridal,					Unk		
	C	FLD	GBC	0	42343600.0H	32572	7
Transformer, Toridal, Pulse					Unk		
	C	FLD	GBC	0	33904000.0H	26080	1
Transformer, Trifilar,					Unk		
	C	FLD	GBC	0	4654000.0H	3580	1
	M	NOP	GM	0	17015000.0H	1071	1
Transformer, Variable,					Unk		
	C	FLD	GBC	0	5200.0H	4	1
	U	FLD	GF	0	0.0H	0	1
	U	FLD	NSB	0	0.0H	0	1

APPENDIX B:
PART PARAMETERS

RESISTORS

- Part number
- Spec. number
- Style designation
- Manufacturer
- Type
  - Fixed
  - Variable
    - Potentiometers
      - Single-turn
      - Multi-turn
    - Trimmer
    - Rheostat
  - Network
  - Chip
  - Thermistor
  - Varistor
- Material
  - Carbon composition
  - Film
    - Metal
    - Carbon
  - Cermet
  - Wirewound
- Part description
- Resistance value
- Package Type
  - Axial lead
  - SIP
  - DIP
  - Surface mount
- Package hermeticity
- Rated Power (in watts)
- Tolerance
- Rated temperature
- Quality level (failure rate level)

CAPACITORS

- Part number
- spec. number
- Style designation
- Manufacturer
- Type
    - Fixed
    - Variable
- Dielectric material
    - Paper
    - Mica
    - Electrolytic
        - Aluminum
        - Tantalum
            - Solid
            - Non-solid
        - Ceramic
        - Glass
        - Plastic
            - Polystyrene
            - Polypropelene
            - Polyester
            - Polycarbonate
- Package type
- Package material
    - Hermetic
    - Non-hermetic
- Polarization
    - Polarized
    - Non-polarized
- Tolerance
- Temperature range
- Capacitance value
- Voltage rating
- Quality level
- Series resistance

TRANSFORMERS

- Type
    - Power
    - Audio
    - Isolation
    - Auto
    - Pulse
- Part number
- Spec. number
- Style number
- Manufacturer
- Core material
    - Iron
    - Nickel
    - Cobalt
- Insulation material
- Operating frequency range
- Voltage rating
- Current rating
- Impedance
    - Primaty
    - Secondary
- Turns ratio
- Number of windings
- Case type
- Quality level

INDUCTORS

- Type
  - Fixed
  - Variable
- Part number
- Spec. number
- Style designation
- Manufacturer
- Core material
  - Iron
  - Nickel
  - Cobalt
- Insulation material
- Operating frequency range
- Voltage rating
- Current rating
- Number of windings
- Case type
- Quality level

ROTATING DEVICES

- Type
  - Full Horse Power
  - Fractional horse power
- Part number
- Specification number
- Style designation
- Manufacturer
- Function
  - Asyncronous
  - Syncronous
- Description
  - Single phase
  - Multi-phase
  - Induction
  - Capacitor
  - Shunt
  - Series
  - Compound
- Rated output
  - Motors (in hp)
  - Generators (in Kva)
- Brushes
  - Brushless
  - Commutator
  - Slip ring
- Bearing type
  - Roller
  - Ball
  - Bushing
- Lubrication
  - Sealed
  - Grease
  - Oil
- Winding material
- Rated temperature

RELAYS

- Type
  - Electromechanical
    - Contact type
      - Armature
      - Reed
      - Mercury wetted
    - Contact material
  - Electronic (solid state)
- Part number
- Specification number
- Style designation
- Manufacturer
- Voltage rating (contact)
- Current rating (contact)
- Mounting type
- Terminal type
  - solder lug
  - pin
  - stud
- Enclosure
  - Hermetic
  - Non-hermetic
- Temperature rating
- Configuration
  - SPST
  - DPST
  - 3PST
  - etc.
- Quality level

SWITCHES

- Type
  - Mechanical
    - Toggle
    - Push button
    - Sensitive
    - Rotary
    - Thumwheel
    - Circuit breakers
      - Magnetic
      - Thermal
      - Ground fault
      - Hydraulic
      - Trip free
    - Centrifugal
    - Capacitive touch
    - Membrane
    - Slide
  - Solid state
- Part number
- Specification number
- Style designation
- Manufacturer
- Contact configuration
  - SPST
  - DPDT
  - #PST
  - etc.
- Contact material
- Voltage rating
- Current rating
- Enclosure type
- Temperature rating
- Quality level

CONNECTORS

- Electrical
  - Coaxial
  - Twinaxial
  - DIN
  - D-subminiature
  - IC sockets
  - Rack and panel
  - Surface mounted
  - High voltage
  - Edge card
  - PWB
    - One piece
    - Two piece
  - Zoro insertion force
  - Mass termination
  - Phone
  - Multi pin circular
  - Press fit
  - RF
  - Rectangular
- Fiber optic
  - Tube
  - Straight sleeve
  - Double eccentric
  - Tapered sleeve
  - Multi rod
  - Couplers
- Part number
- Specification number
- Style designation
- Manufacturer
- Package
  - Sealed
  - Non-sealed
- Shield
  - Shielded
  - Non-shielded
- Contact material
- Insert material
- Number of active pins
- Current rating per pin
- Quality level

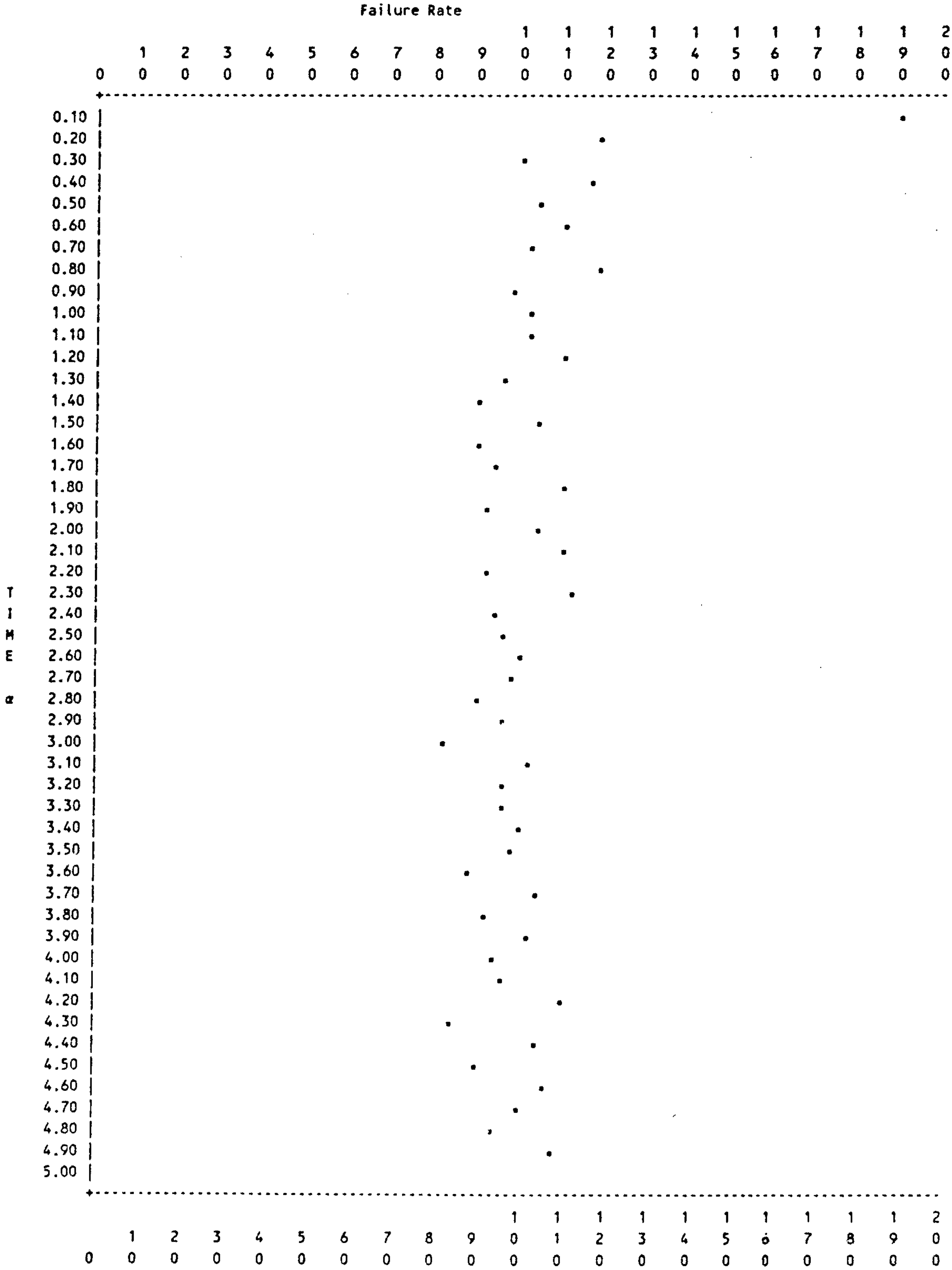
INTERCONNECT ASSEMBLIES/PWB's

- Type
  - Printed wiring assembly w/PTH's
  - Multiwire board
  - Flexible circuit board
  - Discrete wiring board w/PTH
  - Printed wiring board w/surface mount
- Part number
- Spec. number
- Style designation
- Manufacturer
- Interconnect type
  - Wave soldered
  - Hand soldered
  - Reflow soldered
  - Laser soldered
  - Vapor phase soldered
  - Wire wrapped
  - Wrapped and soldered
  - Discrete wiring assembly with electroless PTH's
  - Weld
  - Crimp
- Complexity
  - Number of circuit planes
  - Number of plated through holes
  - Cross sectional area of circuit trace
  - Distance between traces
- Substrate material
  - Flexible board
    - Teflon
    - Polymide
    - Polyester
    - Polyvinyl
    - Polypropelene
    - Polyethelene
    - Ceramic
    - Laminant
      - Glass cloth teflon
      - ?
      - Glass mat polyester-resin
  - Rigid board
    - Epoxy glass
    - Polymide-glass
    - Teflon-glass
    - Epoxy-kevlar
    - Polymide-kevlar
    - Epoxy quartz
    - Polymide-quartz
    - Thermoplastics
    - Alumina
    - Copper-invar-copper

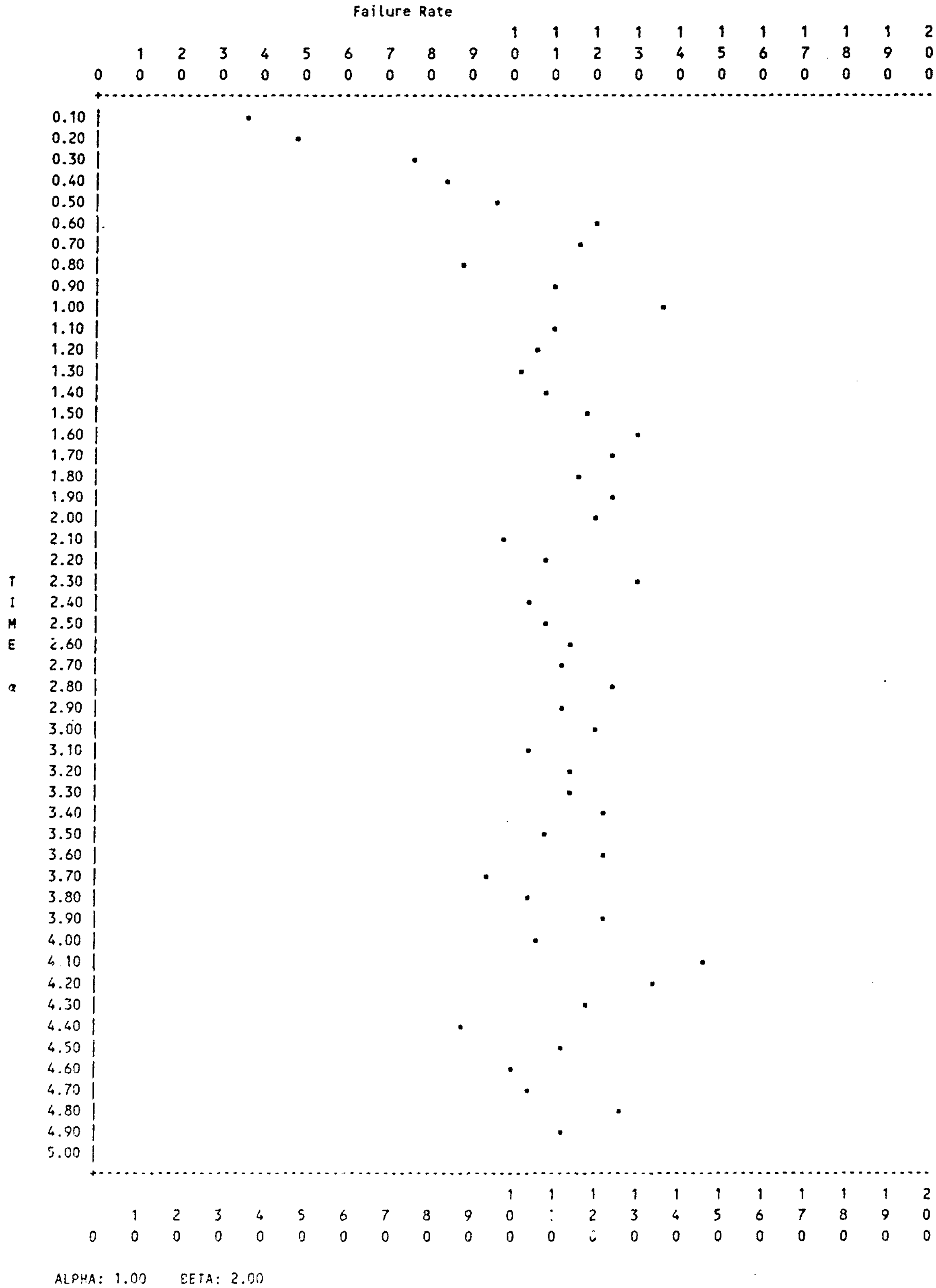
INTERCONNECT ASSEMBLIES/PWB's (CONT'D)

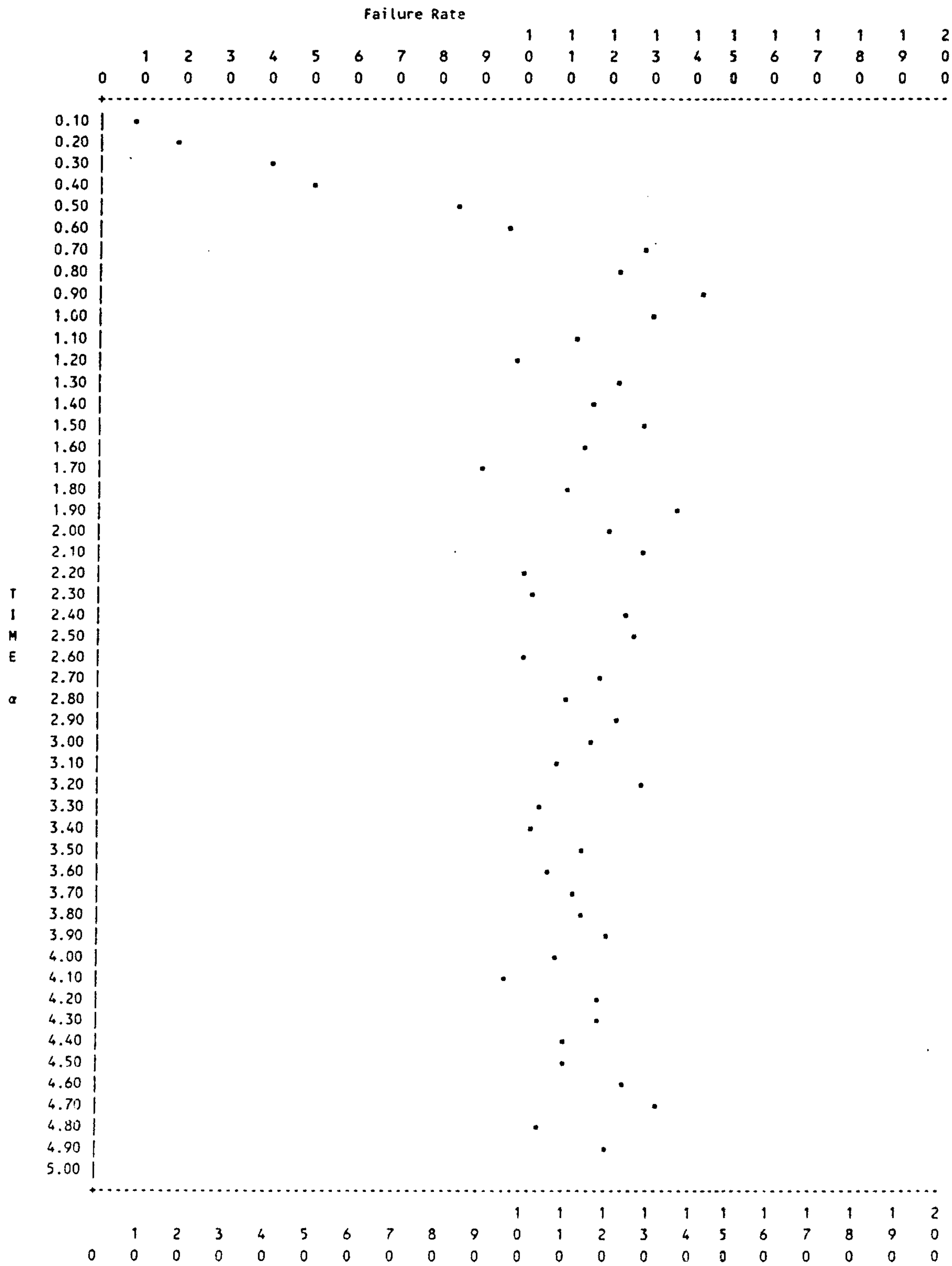
- Bonding adhesives
  - Vinyl
  - Modified epoxy
- Conductor
  - Copper
  - Aluminum
  - Steel
  - Tin
  - Silver
- Quality

APPENDIX C:
MONTE CARLO SIMULATIONS

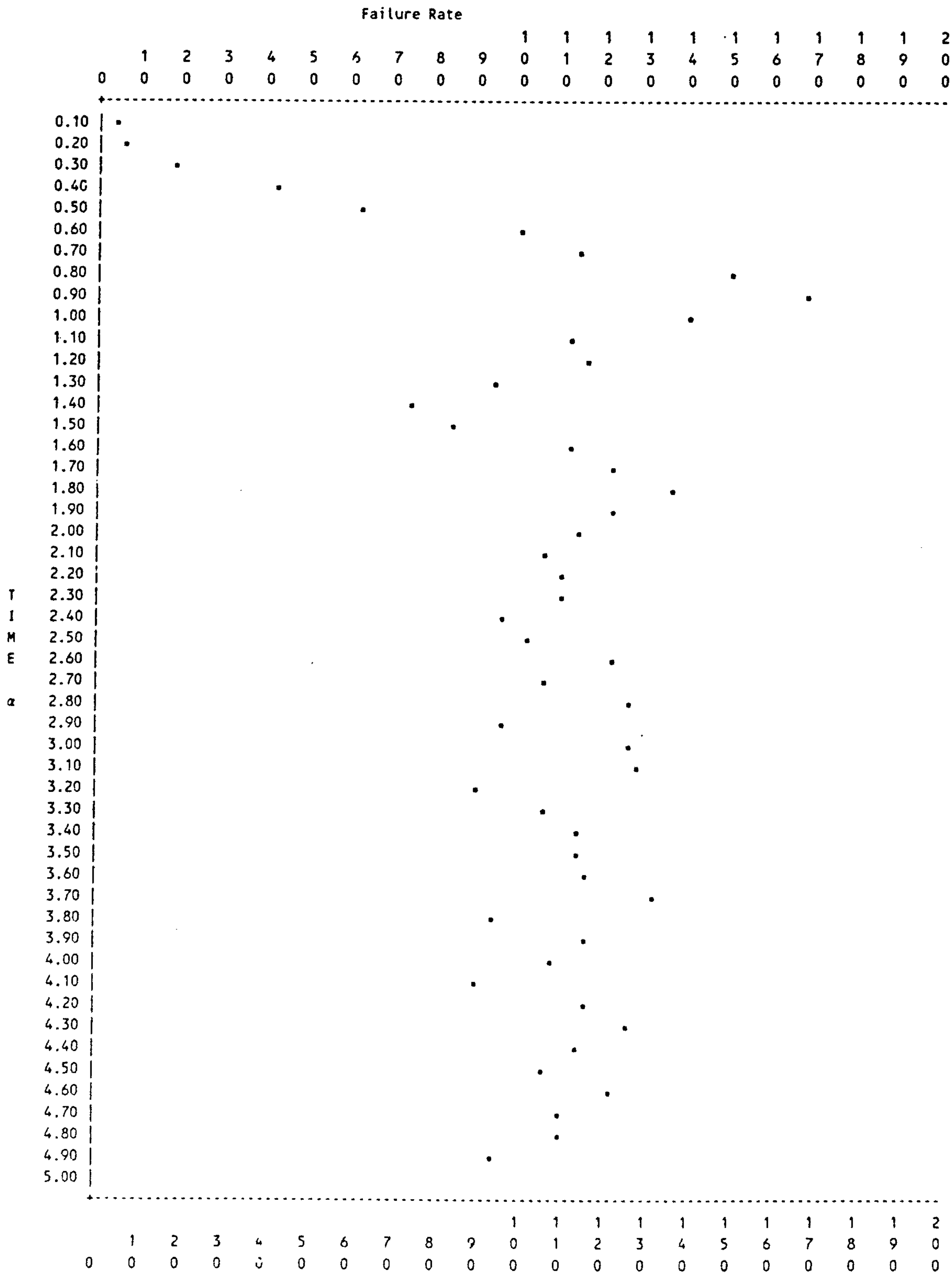


ALPHA: 1.00 BETA: 1.00

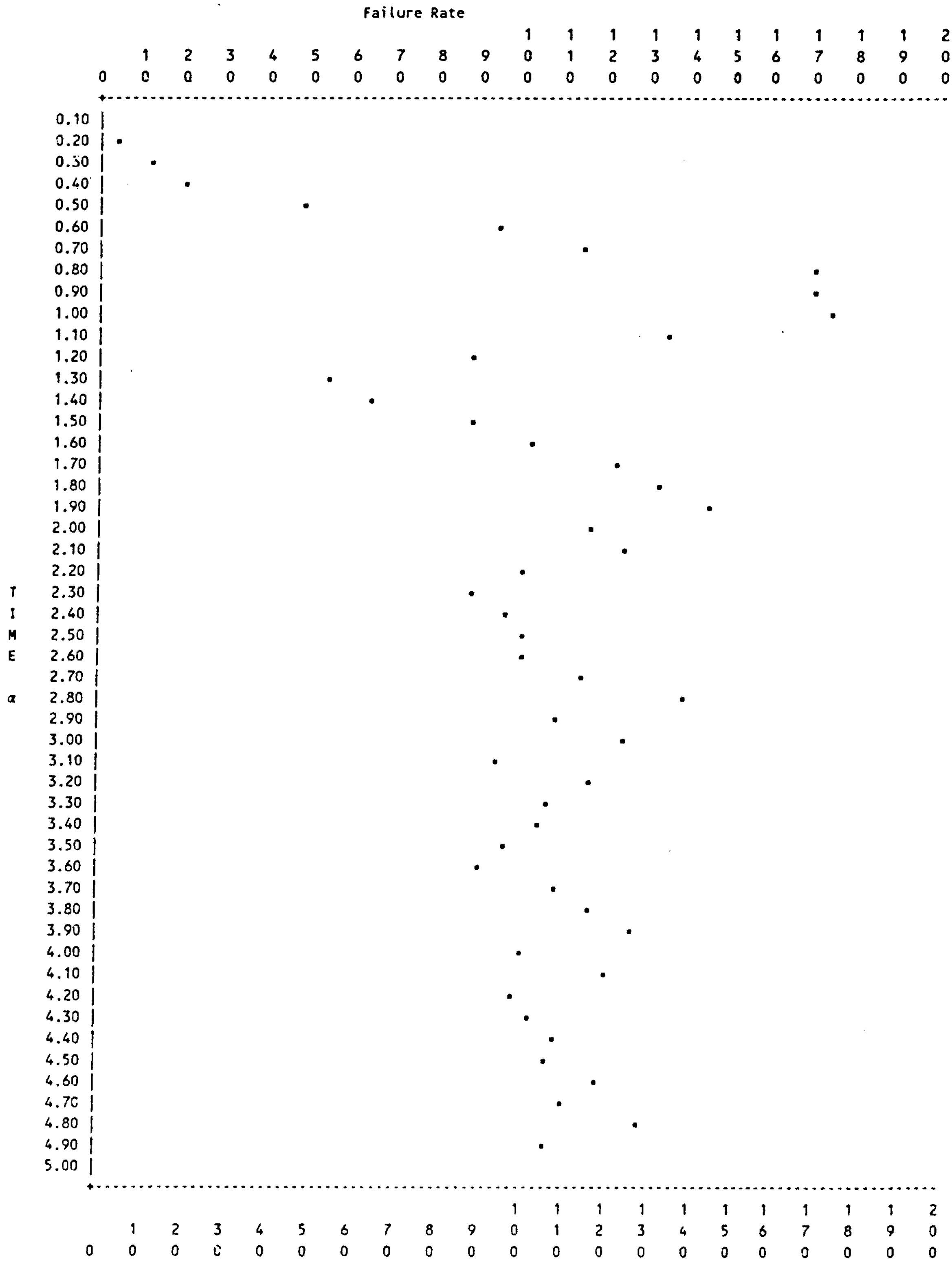

Failure Rate
TIME
ALPHA: 1.00 BETA: 2.00



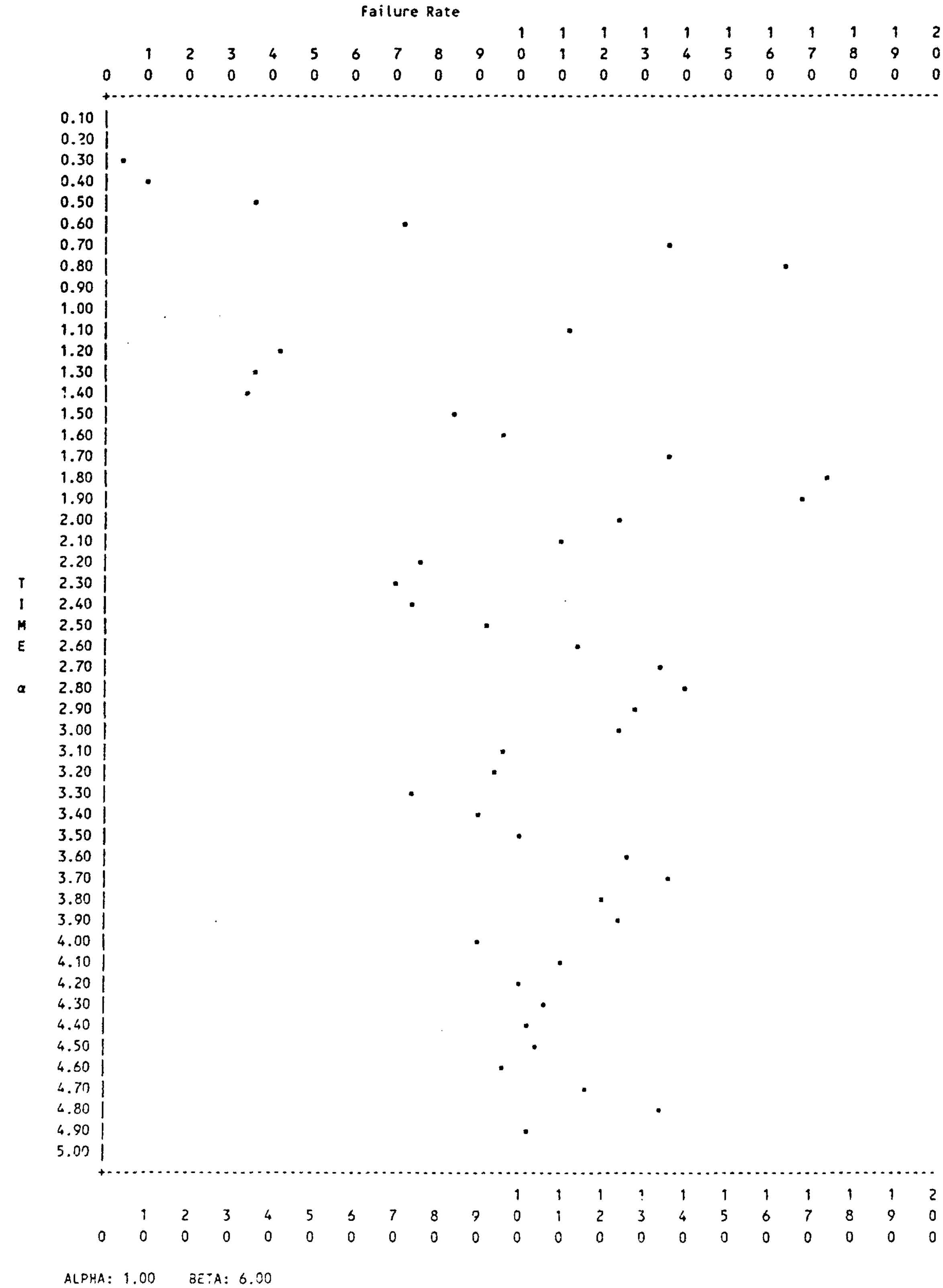
ALPHA: 1.00 BETA: 3.00

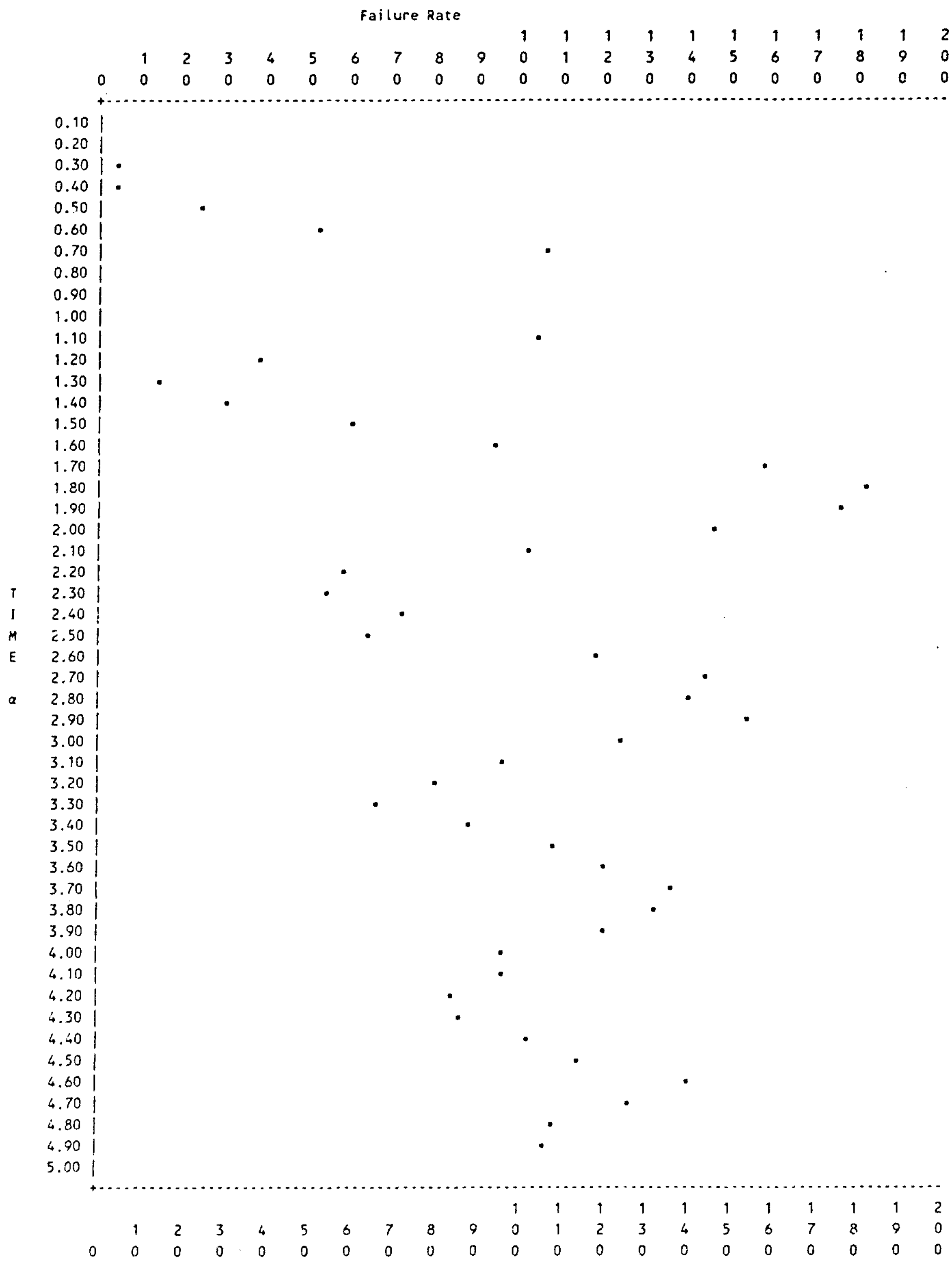


ALPHA: 1.00 BETA: 4.00

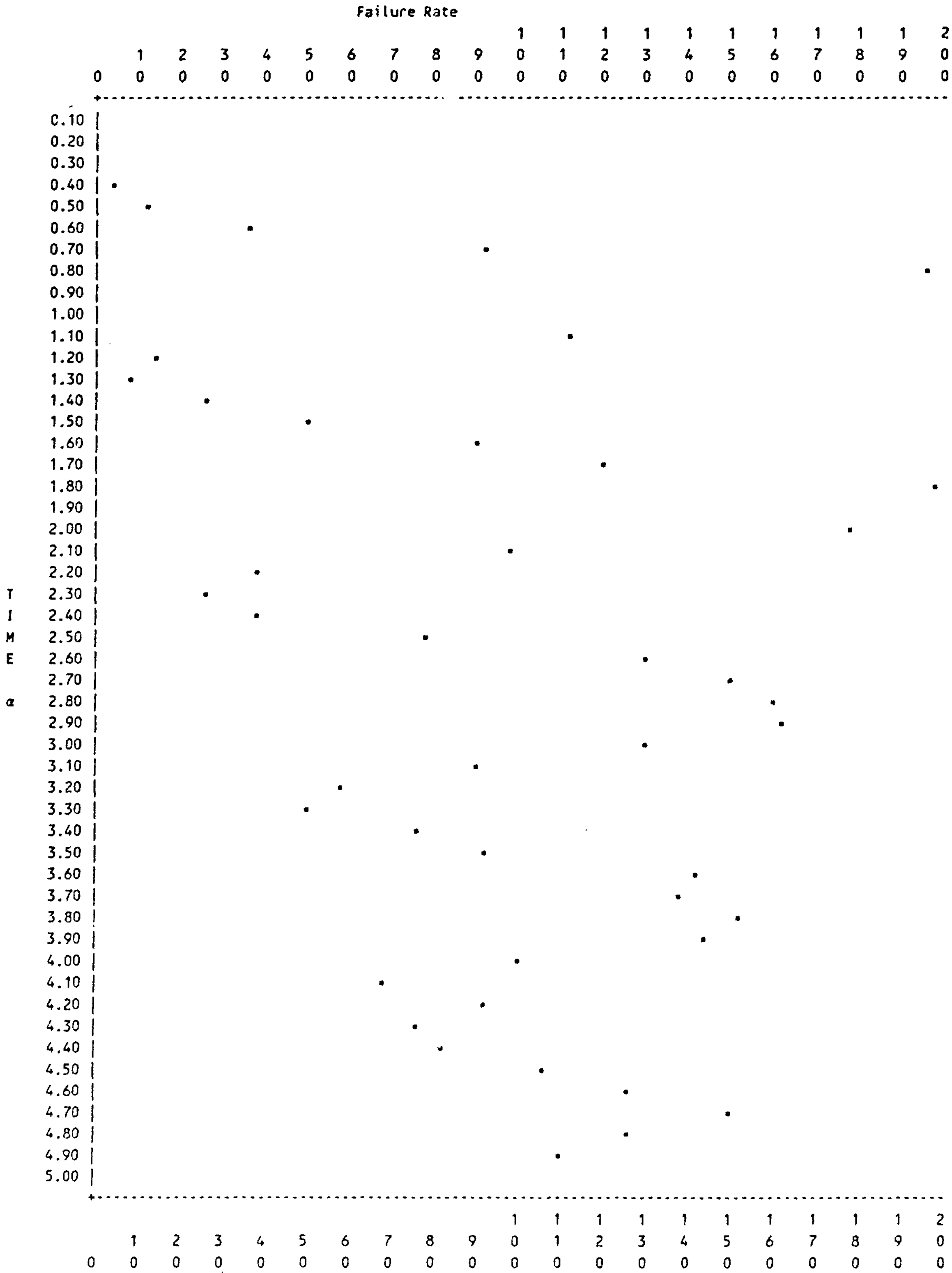


ALPHA: 1.00 BETA: 5.00

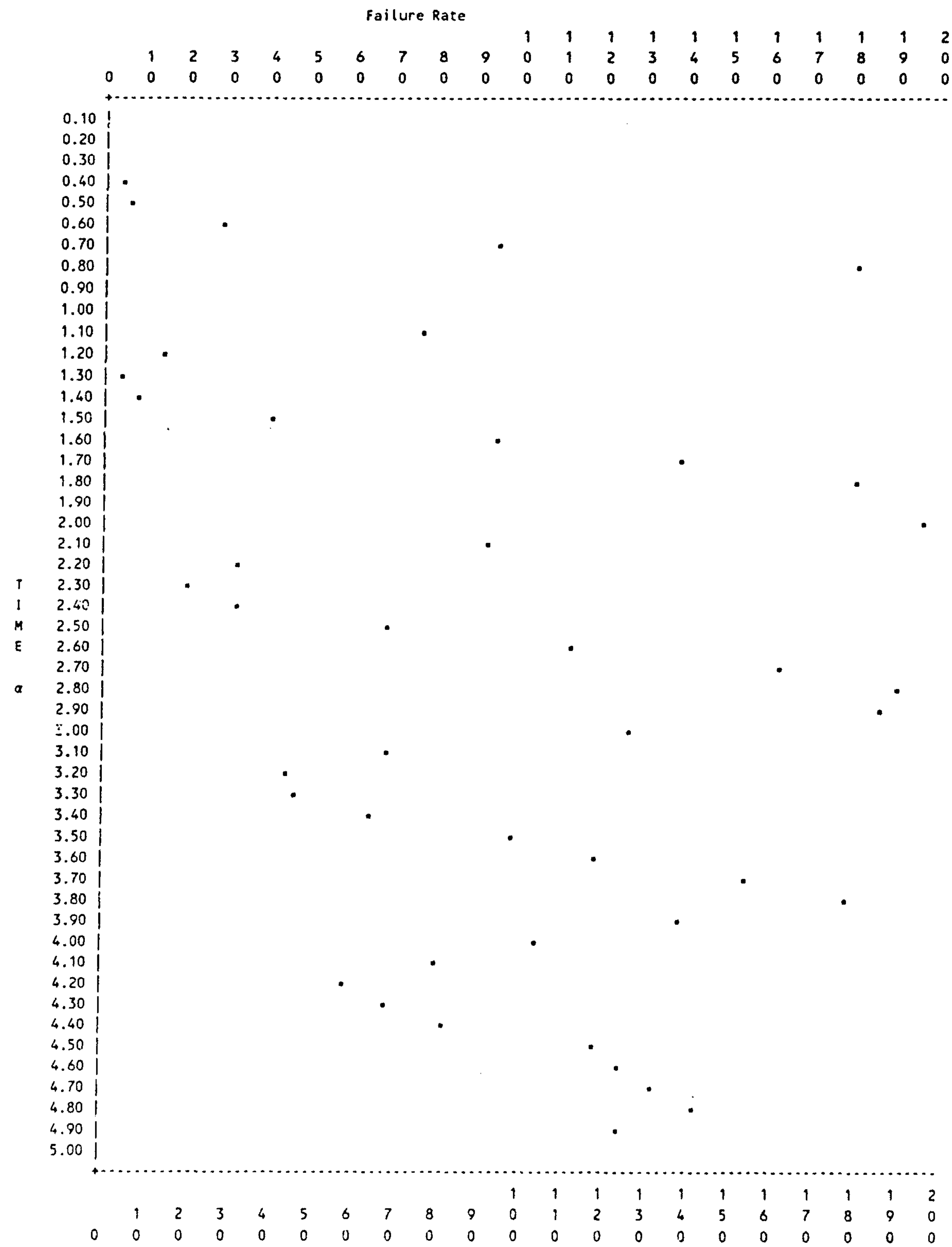

Failure Rate
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TIME α
0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70 1.80 1.90 2.00 2.10 2.20 2.30 2.40 2.50 2.60 2.70 2.80 2.90 3.00 3.10 3.20 3.30 3.40 3.50 3.60 3.70 3.80 3.90 4.00 4.10 4.20 4.30 4.40 4.50 4.60 4.70 4.80 4.90 5.00
ALPHA: 1.00 BETA: 6.00



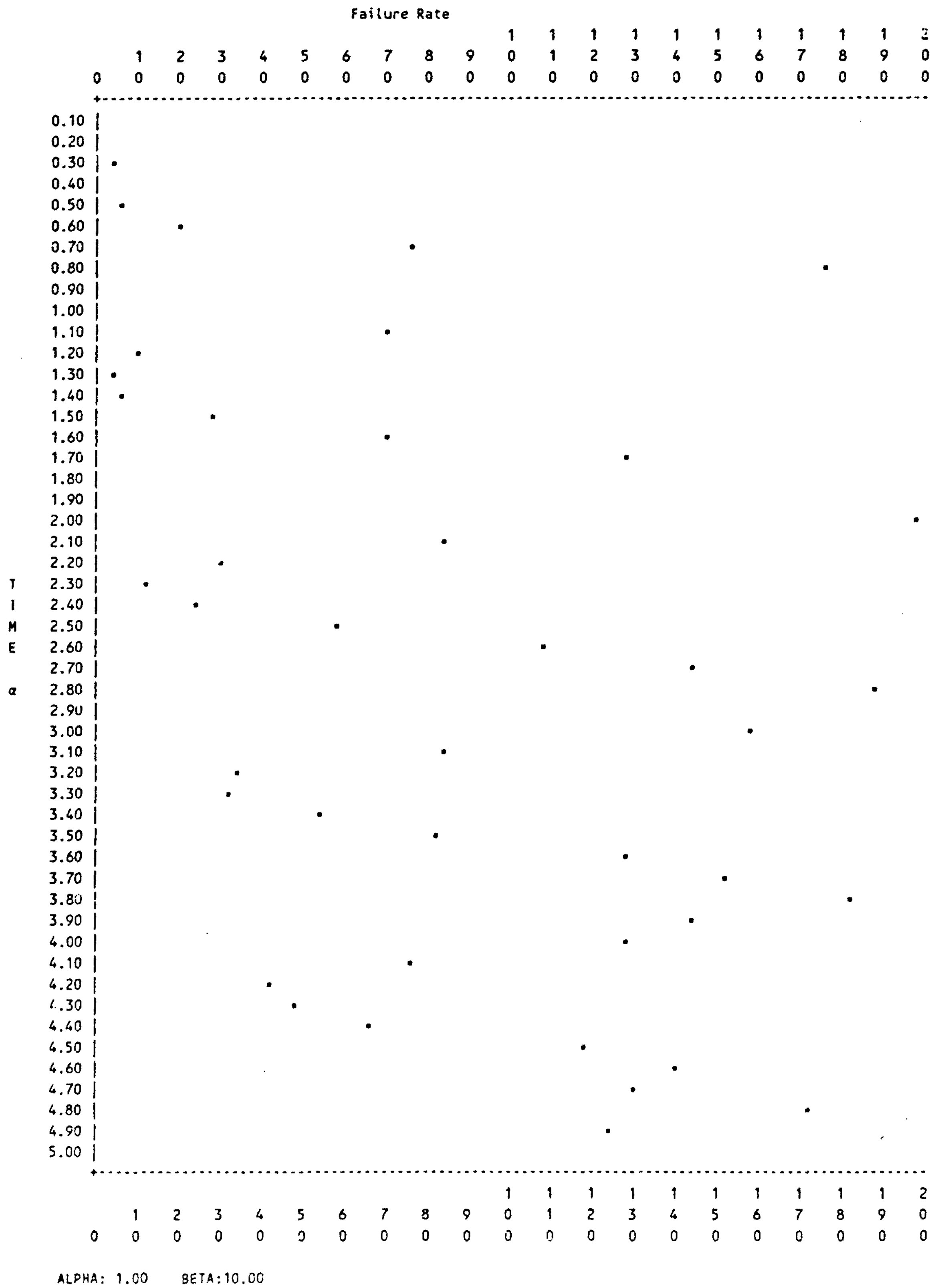
ALPHA: 1.00 BETA: 7.00



ALPHA: 1.00 BETA: 8.00



ALPHA: 1.00 BETA: 9.00


Failure Rate
TIME α
0.10
5.00
ALPHA: 1.00 BETA:10.00

APPENDIX D

REGRESSION RESULTS

This appendix presents the multiple regression results on which the reliability models developed in this study have been based. Using the regression analysis described in Section 2, the constants summarized in this appendix have formed the basis for both base failure rates and multiplicative model parameters. The results presented here are the results of the final regression runs, and as such may not include all factors present in the final model. The reason for this, as described in the model development Section (4), some model parameters needed to be derived independently from the final regression analysis. Examples of these parameters are quality and environment. Typically, these parameters were quantified with initial repression results along with any other information available. When the final parameters were derived, the regressions were re-run by compensating (dividing) the observed failure rate for these "given" values. Other parameters analyzed in this manner were typically continuous variables, such as switch current rating. The reason for this is that the entire dataset typically will not have values for those variables and with these "unknown" values, the regression yields erroneous results. A more efficient method to analyze the effect of such variables is to subset the database with those data points for which the parameter is known, then compensate the failure rate for the derived value and re-run the regressions. The final regression results, therefore, will be inclusive of the discrete variables which comprise the final model (see the discussions in Section 4 for the relevant initial parameters).

Since the logarithmic transformation was taken to yield a multiplicative model, the inverse ln must be taken for the values listed in the regression results. Also listed in this appendix are various statistics relevant to the regression analysis.

The variables listed under "variables not in the equation" are those determined by the analysis to be not significantly different than the variables to which the models are normalized. The normalizing variables are listed on the cover page corresponding to each part type.

Switches

Normalized to;

CoAx Switch
G_F Environment

Military Quality

VARIABLES IN THE EQUATION

Variable	B	SE B	95% Confidence	Interval B	Beta
C21 (waveguide)	1.18181	.89392	-.58124	2.94485	.08774
C6 (humidity)	2.78268	1.89416	-.95310	6.51846	.09330
C15 (reed)	-1.64047	1.34507	-4.29332	1.01237	-.07760
C11 (microwave)	1.91128	.95913	.01962	3.80293	.12723
C4 (float)	2.23130	.86143	.53233	3.93028	.16565
C5 (flow)	.79146	.81247	-.81095	2.39388	.06421
C9 (limit)	2.12044	.73403	.67274	3.56813	.18533
C13 (pressure)	1.83702	.37513	1.09716	2.57688	.32101
C18 (slide)	-1.86082	.86143	-3.55980	-.16185	-.13815
Q2 (unknown)	.88786	.46685	-.03289	1.80861	.12960
C1 (switch, NOC)	.60978	.48839	-.35345	1.57301	.08094
(Constant)	-13.77828	.17499	-14.12340	-13.43315	

VARIABLES IN THE EQUATION

Variable	Tolerance	T	Sig T
C21	.91247	1.322	.1877
C6	.99630	1.469	.1434
C15	.99271	-1.220	.2241
C11	.98586	1.993	.0477
C4	.98258	2.590	.0103
C5	.92508	.974	.3312
C9	.97634	2.889	.0043
C13	.93521	4.897	.0000
C18	.98258	-2.160	.0320
Q2	.86544	1.902	.0587
C1	.95618	1.249	.2133
(Constant)		-78.737	.0000

VARIABLES NOT IN THE EQUATION

Variable	Beta In	Partial	Tolerance	Min Tolerance	T	Sig T
C3 (DIP)	-.05003	-.05655	.99623	.86508	-.787	.4323
C7 (inertial)	- 02921	-.03302	.99623	.86508	-.459	.6468
C8 (interlock)	-9.355E-03	-.01049	.97931	.85925	-.146	.8843
C10 (liquid lev.)	.05118	.05786	.99623	.86508	.805	.4217
Q1 (commercial)	-.02787	-.02776	.77312	.77312	-.386	.7001
C12 (alarm)	-.02022	-.02286	.99623	.86508	-.318	.7511
C16 (rocker)	-.01243	-.01392	.97804	.85513	-.193	.8469
C17 (sensitive)	.05536	.06090	.94361	.85980	.848	.3977
C19 (thermostat)	.01112	.01140	.82024	.75997	.158	.8743
C20 (toggle)	-.01499	-.01596	.88335	.85309	-.222	.8248

VARIABLES NOT IN THE EQUATION

Variable	Beta In	Partial	Tolerance	Min Tolerance	T	Sig T
C1	.08094	.08928	.95618	.86544	1.249	.2133
C3	-.05253	-.05917	.99726	.86553	-.826	.4100
C7	-.03173	-.03575	.99726	.86553	-.498	.6189
C8	-.01432	-.01601	.98316	.85949	-.223	.8237
C10	.04858	.05472	.99726	.86553	.763	.4462
Q1	-.02831	-.02808	.77314	.77314	-.391	.6960
C12	-.02276	-.02564	.99726	.86553	-.357	.7213
C16	-.01665	-.01861	.98083	.85536	-.259	.7958
C17	.04420	.04883	.95909	.86069	.681	.4968
C19	-1.690E-03	-.00174	.83796	.76066	-.024	.9806
C20	-.02994	-.03231	.91538	.85474	-.450	.6530

Multiple R	.46944		
R Square	.22037	R Square Change	.00626
Adjusted R Square	.17616	F Change	1.55891
Standard Error	1.88606	Significant F Change	.2133

F = 4.98510 Significant F = .0000

Inductors

Normalized to;

Fixed Inductor
G_B Environment

Military/Commercial Quality of 20:1

VARIABLES IN THE EQUATION

Variable	B	SE B	95% Confidence	Interval B	Beta
E4 (A_U)	5.41444	.93505	3.44998	7.37890	.76098
E3 (A_I)	5.16250	1.58231	1.83818	8.48681	.41009
E1 (G_F)	4.01205	1.58231	.6873	7.33636	.31870
TT1 (nonop)	-3.03306	1.38116	-5.93476	-.13136	-.32558
T1 (choke)	-2.09691	1.29195	-4.81120	.61739	-.19952
E2 (G_M)	3.13001	2.34186	-1.79006	8.05008	.17959
(Constant)	-19.95780	.69058	-21.40865	-18.50695	

Multiple R	.88273		
R Square	.77921	R Square Change	.02191
Adjusted R Square	.70561	F Change	1.78636
Standard Error	1.89122	Significant F Change	.1980

F = 10.58762 Significant F = .0000

Transformers

Normalized to;

G_B Environment

Commercial Quality

Non-RF Transformers

VARIABLES IN THE EQUATION

Variable	B	SE B	95% Confidence	Interval B	Beta
T2 (flyback)	2.39812	1.37526	-.55152	5.34775	.27529
T1 (audio)	1.94490	.94426	-.08035	3.97014	.36686
T5 (power)	2.42700	.69738	.93126	3.92274	.65339
RF1 (RF)	2.56656	1.61891	-.90565	6.03877	.29463
E4 (A_U)	1.66182	.85412	-.17008	3.49372	.35176
E5 (A_{UA})	2.41511	1.35547	-.49209	5.32231	.27724
(Constant)	-18.05855	.51980	-19.17340	-16.94369	

VARIABLES IN THE EQUATION

Variable	Tolerance	T	Sig T
T2	.90000	1.744	.1031
T1	.70707	2.060	.0585
T5	.63636	3.480	.0037
RF1	.64948	1.585	.1352
E4	.68627	1.946	.0721
E5	.92647	1.782	.0965
(Constant)		-34.741	.0000

VARIABLES NOT IN THE EQUATION

Variable	Beta In	Partial	Tolerance	Min Tolerance	T	Sig T
T7 (switching)	-.09060	-.15123	.87500	.57273	-.552	.5906
TT1 (nonop)	.13091	.19972	.73088	.53505	.735	.4755
E8 (G_F)	.14310	.20640	.65333	.53455	.761	.4605
E10 (G_M)	.05003	.06098	.46667	.35897	.220	.8291

Multiple R	.82823		
R Square	.68596	R Square Change	.07121
Adjusted R Square	.55137	F Change	3.17463
Standard Error	1.27324	Signif F Change	.0965

F = 5.09677 Signif F = .0057

Resistors

Normalized to;

Military/Commercial Quality of 10:1
Carbon Composition
Ground Environment

VARIABLES IN THE EQUATION

Variable	B	SE B	95% Confidence	Interval B	Beta
E2 (A_U)	3.22433	.38810	2.45936	3.98930	.41646
E1 (A_I)	3.77398	.71393	2.36678	5.18119	.23119
M4 (thin film)	-2.80321	.36593	-3.52448	-2.08193	-.36983
M2 (carbon film)	-4.55193	.70504	-5.94161	-3.16225	-.27885
M5 (thick film)	-4.37189	.70504	-5.76157	-2.98220	-.43710
D6 (network)	1.40905	.94983	-.46312	3.28122	.11644
D1 (NOC)	-2.54579	.80304	-4.12864	-.96295	-.13817
M8 (film)	-1.33480	.56948	-2.45729	-.21231	-.10726
M3 (nichrome)	2.53446	.42628	-.27681	5.34574	.07436
M1 (unknown)	1.07049	.50971	.06582	2.07515	.12276
D5 (varistor)	-2.83596	.49492	-5.78252	.11061	-.08320
(Constant)	-16.99768	.24061	-17.47185	-16.52335	

VARIABLES IN THE EQUATION

Variable	Tolerance	T	Sig T
E2	.68299	8.308	.0000
E1	.89725	5.286	.0000
M4	.73635	-7.660	.0000
M2	.92001	-6.456	.0000
M5	.34540	-6.201	.0000
D6	.27859	1.483	.1394
D1	.90350	-3.170	.0017
M8	.81952	-2.344	.0200
M3	.98018	1.777	.0770
M1	.50228	2.100	.0369
D5	.89223	-1.897	.0592
(Constant)		-70.645	.0000

VARIABLES NOT IN THE EQUATION

Variable	Beta In	Partial	Tolerance	Min Tolerance	T	Sig T
D2 (variable)	.02223	.02935	.64322	.22712	.430	.6679
D4 (thermistor)	.02338	-.03052	.62876	.24631	-.447	.6556
M6 (non-wire)	.01173	-.01805	.87452	.27681	-.264	.7919
M7 (wire wound)	.04579	.06198	.67615	.27359	.908	.3647
M9 (metal film)	.01638	.02611	.93693	.27781	.382	.7028
M10 (metal)	.03640	.05520	.84881	.27758	.809	.4195
M11 (metal)	.03114	-.04971	.94006	.27777	-.728	.4674

VARIABLES NOT IN THE EQUATION

Variable	Beta In	Partial	Tolerance	Min Tolerance	T	Sig T
D2	.03464	.04576	.65457	.23574	.672	.5025
D4	-4.255E-05	-.00006	.66361	.25832	-.001	.9993
D5	-.08320	-.12831	.89223	.27859	-1.897	.0592
M6	-.01061	-.01620	.87468	.28308	-.238	.8124
M7	.04874	.06547	.67682	.27945	.962	.3371
M9	.01569	.02480	.93699	.28426	.364	.7164
M10	.03327	.05008	.84992	.28416	.735	.4630
M11	-.03134	-.04961	.94006	.28419	-.728	.4672

Multiple R	.79436		
R Square	.63101	R Square Change	.00618
Adjusted R Square	.61213	F Change	3.59886
Standard Error	1.98815	Significant F Change	.0592

F = 33.42487 Significant F = 0.0

Capacitors

Normalized to;

Fixed Paper Capacitor
Ceramic Package
G_B Environment
Operating Environment

VARIABLES IN THE EQUATION

Variable	B	SE B	95% Confidence	Interval B	Beta
D9 (ta elec.)	-1.69487	.35541	-2.39621	-.99354	-.19337
D7 (plastic)	1.18050	.50714	.17975	2.18125	.10396
D6 (mica)	.89810	.50994	-.10817	1.90438	.10749
D4 (electrolytic)	-.62003	.54582	-1.69709	.45703	-.08549
D3 (ceramic)	-.58884	.56212	-1.69807	.52040	-.08119
E6 (A_{UF})	6.27433	.54189	5.20502	7.34364	.67734
E5 (A_{UA})	5.31034	.56029	4.20472	6.41596	.53730
E2 (A_{IC})	7.34207	1.04160	5.28668	9.39747	.46586
P4 (metal package)	-1.46382	.91764	-3.27461	.34698	-.07076
F1 (variable)	2.08365	.56702	.96475	3.20256	.15677
E4 (A_U)	2.75466	.48584	1.79595	3.71337	.41869
E8 (G_F)	4.24595	.60044	3.06109	5.43080	.47600
TT1 (nonop.)	-4.71904	.77249	-6.24341	-3.19467	-.35504
E3 (A_{IF})	8.13377	1.45071	5.27108	10.99647	.27947
P5 (plastic package)	-1.57215	.92108	-3.38973	.24544	-.12372
D1 (air)	-2.43752	1.62391	-5.64199	.76694	-.05937
E7 (G)	-1.21026	1.08532	-3.35192	.93140	-.04158
(Constant)	-18.87137	.22402	-19.31344	-18.42931	

Multiple R	.89146		
R Square	.79470	R Square Change	.00143
Adjusted R Square	.77520	F Change	1.24349
Standard Error	1.38686	Significant F Change	.2663

F = 40.75764 Significant F = 0.0

Connectors

Normalized to;

COAX
Military Quality
Ground Environment

VARIABLES IN THE EQUATION

Variable	B
C15 (telephone)	-2.03
C13 (signal)	-9.10
C12 (rectangular)	-2.66
C6 (elastometeric)	-2.35
C5 (edge card)	-2.96
C4 (cylindrical)	-2.80
C9 (RF)	-4.87
C8 (PC edge)	-4.64
C1 (NOC)	-.95
E1 (airborne)	1.71
(Constant)	-14.00

VARIABLES NOT IN THE EQUATION

Variable	Tolerance
C3 (elect. assy)	.08
C7 (hexagonal)	.06
C10 (rack & panel)	.08
C11 (D-subminiature)	-.03
E2 (N_{SB})	-.03

VARIABLES NOT IN THE EQUATION

Relays

Normalized to;

Reed Relay
G_F Environment

Military Quality

VARIABLES IN THE EQUATION

Variable	B	SE B	95% Confidence	Interval B	Beta
E1 (airborne)	3.32291	.33980	2.65275	3.99307	.55481
E6 (A_{RW})	4.60798	.99443	2.64677	6.56919	.22847
E5 (G_M)	2.00302	.61817	.78386	3.22219	.16187
C2 (gen. purpose)	-1.64898	.37848	-2.39542	-.90255	-.23260
E9 (S_F)	-2.32449	.99137	-4.27967	-.36930	-.11525
E11 (G_{BC})	-2.14630	.55913	-3.24901	-1.04358	-.27242
C4 (latching)	-1.64931	.63982	-2.91118	-.38745	-.13329
C3 (armature)	-1.05752	.48636	-2.01671	-.09833	-.11508
C5 (electronic)	-1.83392	.90343	-3.61568	-.05216	-.10141
Q1 (commercial)	.63537	.42793	-.20860	1.47934	.10359
C9 (TO-5)	-1.55760	.99549	-3.52091	.40570	-.07723
C12 (non latching)	-2.73642	1.92936	-6.54152	1.06868	-.06833
E12 (dormant)	-1.86363	1.40239	-4.62943	.90217	-.06565
C11 (power)	-1.13389	1.00028	-3.10665	.83888	-.05622
(Constant)	-13.40188	.28374	-13.96147	-12.84229	

VARIABLES IN THE EQUATION

Variable	Tolerance	T	Sig T
E1	.70887	9.779	.0000
E6	.93860	4.634	.0000
E5	.91429	3.240	.0014
C2	.80059	-4.357	.0000
E9	.94439	-2.345	.0200
E11	.45304	-3.839	.0002
C4	.85346	-2.578	.0107
C3	.81463	-2.174	.0309
C5	.91419	-2.030	.0437
Q1	.46878	1.485	.1392
C9	.93660	-1.565	.1193
C12	.98305	-1.418	.1577
E12	.93480	-1.329	.1854
C11	.92764	-1.134	.2584
(Constant)		-47.233	.0000

VARIABLES NOT IN THE EQUATION

Variable	Beta In	Partial	Tolerance	Min Tolerance	T	Sig T
C1	.03465	.04119	.63292	.43283	.576	.5655
C6	-.03100	-.04324	.87134	.46850	-.604	.5463
C7	-.03708	-.05349	.93171	.46585	-.748	.4554
C8	.01013	.01395	.84918	.45576	.195	.8458
C10	.04818	.06682	.86133	.45990	.935	.3509
C11	-.05622	-.08091	.92764	.45304	-1.134	.2584
E7	-.02827	-.03158	.55914	.42614	-.441	.6595
E10	-.03131	-.04457	.90768	.47039	-.623	.5340
E14	-2.797E-03	-.00405	.94048	.47184	-.057	.9549

Multiple R	.74502		
R Square	.55506	R Square Change	.00293
Adjusted R Square	.52311	F Change	1.28497
Standard Error	1.90839	Significant F Change	.2584

F = 17.37548 Significant F = .0000

*U.S. GOVERNMENT PRINTING OFFICE: 1990-612-093-60030