1.0 INTRODUCTION

The purpose of this document is to provide empirical field failure rate data on electronic components. The component types for which data is presented in this document are Capacitors, Diodes, Integrated Circuits, Optoelectronic Devices, Resistors, Thryistors, Transformers, and Transistors.

Reliability data is required to perform reliability assessments of systems. The part types for which data is contained in this document are those contained in existing reliability prediction methodologies, such as MIL-HDBK-217. Whereas MIL-HDBK-217 contains mathematical models that have been derived from empirical field failure rate data, the data contained herein is historically observed field failure rates. This data can be used as an alternative to existing prediction methodologies.

Commercial quality components are becoming widely used in many applications, including military systems. Much of the data contained in this document relates to commercial quality components. It can, therefore, be used to predict reliability for both commercial and military systems containing commercial quality components.

This document, along with the RAC's document "Nonelectronic Parts Reliability Data," (NPRD-95), contains all (non-proprietary) component data that is in the RAC databases. These two documents are complementary and there is no duplication of data between them. Together they provide the capability of estimating the reliability of most component types used in electronic or mechanical systems.

1.1 <u>Background</u>

Accurate and timely reliability predictions are an important part of a well structured reliability program. If properly performed, they can provide insight into the design and maintenance of reliable systems.

A potential use for this document is to complement existing reliability prediction methodologies by providing failure rate data in a consistent format on various electronic component types. Although the data contained in this publication were collected from a wide variety of sources, The RAC has screened the data such that only high quality data is added to the database and presented in this document. In addition, only field failure rate data has been included.

The user of this document should note that the use of reliability prediction techniques such as MIL-HDBK-217, or the use of the data contained herein, should complement and not replace sound reliability engineering and design practices. This document is meant to provide historical reliability data on a wide variety of components to aid engineers in estimating reliability of systems. Sound reliability engineering practices must include a knowledge of the failure physics of all components, modules and interconnection assemblies in a system. A knowledge of life-limiting failure mechanisms, and how these mechanisms will behave in the intended use environment, is also necessary. Only in this manner can robust designs be ensured.

The intent of this introductory section is to provide the user with information to adequately interpret and use the data. Since the primary purpose of this document is to augment reliability prediction methodologies such as MIL-HDBK-217, a brief background of MIL-HDBK-217 will be given, along with a description of how the data in this document can be used to augment it. The following is an excerpt from the RAC's April 1990 Newsletter Technical Brief, written by Seymour Morris of Rome Laboratory.

WHAT IS THE PURPOSE OF PERFORMING A RELIABILITY PREDICTION?

Predictions have several purposes, among them are:

(1) feasibility evaluation
(2) comparing competing designs
(3) identification of potential reliability problems
(4) to provide reliability input to other R/M tasks

Feasibility evaluation involves evaluating the compatibility of a proposed design concept with the design reliability requirements. Early in the system formulation process a feasibility evaluation would typically take the form of a parts count type prediction (MIL-HDBK-217F, Appendix A) to determine "ballpark" compatibility with required reliability. Feasibility evaluation may also take the form of a detailed parts stress type analysis (MIL-HDBK-217F, Sections 5-23) for components used in very high quantities. One example might be for phase shifter modules on a phased array antenna. Feasibility evaluation is much more critical for totally new design concepts where no similar earlier system exists than for systems with known reliability performance.

Comparing competing designs is similar to the feasibility evaluation except that it extends through the design process and provides one input, the predicted reliability, to be used in making broader system level design trade-off decisions involving factors such as cost, weight, power, performance, etc. A parts stress type prediction is typically refined to provide a quantitative means of estimating the relative cost-benefit of these and other system level trade-off considerations.

Predictions which are properly performed provide a methodical means of checking all components for potential reliability problems. By focusing attention on lower quality, over-stressed or misapplied parts a relative means of evaluating the reliability impact of these potential problem areas can be performed. It should be emphasized that the prediction itself does not improve system reliability, it only provides a means for identifying potential problems that, if corrected, will lead to improved systems reliability. Therefore, predictions provide an excellent vehicle for government/contractor dialog in reviewing and evaluating the progress of the design prior to testing.

Predictions provide key input to other R/M tasks such as maintainability analysis, testability evaluation and failure modes and effects analysis (FMEA). Because predictions identify areas of relatively low reliability they provide key input to weigh the benefits of adding test points, making areas more readily accessible for maintenance or adding redundancy to reduce the effect of a particularly critical failure mode.

WHAT IS THE PURPOSE OF MIL-HDBK-217?

MIL-HDBK-217 is intended to provide a consistent and uniform data base for making reliability predictions when no substantial reliability experience exists for a particular equipment. It contains two basic methods of calculating component level failure rates, the "parts stress method" and the "parts count method." The parts count method requires only limited information such as component type, complexity and part quality to calculate a part failure rate. The parts count section of the handbook is derived by assigning model factors for more involved part stress method to slightly conservative estimates of what would typically be expected. All of the specific default values are provided in Appendix A of the handbook. The parts stress method requires significantly more information such as case or junction temperature and electrical operating and rated conditions to perform a failure rate calculation. Prior to the development of the handbook, each contractor would have its own unique set of data of which the source would have to be fully understood before meaningful design comparisons could be made.

It is not feasible for documents like MIL-HDBK-217 or other prediction methodologies to contain failure rate models on every conceivable type of component and assembly. Traditionally, reliability prediction models have been primarily applicable only for generic electronic components. Therefore, this document serves a variety of needs:

1) To provide failure rate data on commercial quality components.

2) To provide failure rates on state-of-the-art components in cases where data or analyses are not feasible or required.

3) To complement MIL-HDBK-217 or other prediction methodologies by providing data on part types not addressed by its models.

1.2 Data Collection

The failure rate data contained in this document represent a cumulative compilation from the early 1970's through October 1996. However, it should be noted that data is periodically purged from the database in the event that newer data of higher quality is obtained. The RAC is continuously soliciting new field data in an effort to keep the databases current. The goals of these data collection efforts are as follows:

1) To obtain data on relatively new part types and assemblies.

2) To collect as much data on as many different data sources, application environments, and quality levels as possible.

3) To identify as many characteristic details as possible, including both part and application parameters.

RAC utilized the following generic sources of data for this publication:

- Published reports and papers
- Data collected from government-sponsored studies
- Data collected from military maintenance data collection systems
- Data collected from commercial warranty repair systems
- Data from commercial/industrial maintenance databases
- Data submitted directly to RAC from military or commercial organizations that maintain failure databases

Brief descriptions are provided of the sources utilized in this document. Each summarized failure rate can be mapped to one of these data sources. An example of the process by which RAC identifies candidate systems and extracts reliability data on military systems is summarized in Table 1-1.

Table 1-1: Data Summarization Procedure

(1)	Identify System Based On:	• Environments/Quality • Age • Component Types • Availability of Quality Data
(2)	Build Parts List:	• Obtain Illustrated Parts Breakdown (IPB) • Ensure Correct Version of System Consistent with Maintenance Data • Identify Characteristics of Components (Part Numbers, Federal Stock Number,, Microfiche, Vendor Catalogs, etc.) • Enter Part Characteristics into Database
(3)	Obtain Failure Data:	• Reliability Improvement Warranty, 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
(5)	Transform Data to Common RAC Database Template	

Perhaps the most important aspect of this data collection process is identifying viable sources of high quality data. Large automated maintenance databases, such as the Air Force MODAS (or REMIS) system or the Navy's 3M system, typically will not provide accurate data on piece parts. They can, however, provide acceptable data on assemblies or LRUs, if used judiciously. Additionally, there are specific instances in which they can be used to obtain piece part data. Piece part data from these maintenance systems is used in the RAC's data collection efforts only when it can be verified that they accurately report data at this level. Reliability Improvement Warranty (RIW) data are another high quality data source which has been used by the RAC. Section 4 of this document contains a brief description of each data source used in this publication because the RAC believes it is important for the user to understand the types of data that were used in deriving the failure rates.

The RAC has done everything possible to ensure that only the best data available is published in this document. Completeness of data, consistency of data, equipment population tracking, failure verification, availability of parts breakdown structure, and characterization of operational histories are all used to determine the adequacy of the data. In many cases, data submitted to the RAC is discarded since a reasonable degree of credibility does not exist.

Inherent limitations in data collection efforts can result in errors and inaccuracies in summary data. Care must be taken to ensure that the following factors are considered when using a data source.

- There are many more factors affecting reliability than can be identified.

- There is a degree of uncertainty in any failure rate data collection effort. This uncertainty is due to the following factors:

  - Uncertainty as to whether the failure was inherent (common cause) or event-related (special cause).
  - Difficulty in separating primary and secondary failures.
  - Much data collected is generic and not manufacturer specific, indicating that variations in the manufacturing process are not accounted for.

- It is very difficult to distinguish between the effects of highly correlated variables. For example, the fact that higher quality components are typically used in the more severe environments makes it impossible to distinguish the effect each has on reliability.

- Operating hours can be reported inaccurately.

- Maintenance logs can be incomplete.

- Actual component stresses are rarely known. Even if nominal stresses are known, actual stresses which significantly impact reliability can vary significantly about this nominal value.

When collecting field failure data, a very important variable is the criteria used to detect and classify failures. Much of the failure data presented in this publication as identified by maintenance technicians performing a repair action, indicating that the criteria for failure is that a part in a particular application has failed in a manner that makes it apparent to the technician. In some data sources, the criteria for failure was that the component replacement must have remedied the failure symptom. A description of these such sources are given in Section 4 of this document.

1.3 Data Interpretation

Data contained in this document reflects industry average failure rates, especially the summary failure rates which were derived by combining several failure rates on similar parts/assemblies from various sources. In certain instances, reliability differences can be distinguished between manufacturers or between detailed part characteristics. Although the summary section cannot be used to identify these differences (since it presents summaries only by generic type, quality, environment, and data source), the listings in the detailed section contain all specific information that was known for each part and, therefore, can sometimes be used to identify such differences.

Data in the summary section of this document represent an "estimate" of the expected failure rate and the "true" value will lie in some confidence interval about that estimate. The traditional method of identifying confidence limits for components with exponentially distributed lifetimes has been the use of the Chi-Square distribution. This distribution relies on the observance of failures from a homogeneous population and, therefore, has limited applicability to merged data points from a variety of sources.

To give users of this document a better understanding of the confidence they can place in the presented failure rates, an analysis was performed on the variation in observed failure rates. It was concluded that, for a given generic part type, the natural logarithm of the observed failure rate is normally distributed with a sigma of 1.5. This indicates that 68 percent of actual failure rates will be between 0.22 and 4.5 times the mean value. Similarly, 90% of actual failure rates will be between 0.08 and 11.9 times the presented value. This type of precision is typical of probabilistic reliability prediction models and point estimate failure rates such as those contained herein. It should be noted that these precession is applicable to predicted failure rates at the component level and that the confidence will increase as the statistical distributions of components are combined when analyzing modules or systems.

The time period over which the data is collected is also an important attribute when interpreting the data. Many component types exhibit infant mortality behavior, which is characterized by a decreasing failure rate as a function of time. This observation is due to the fact that the failure rate of many component types are driven by defects which occur in a small percentage of the part population. Once these defects have manifested themselves as failures, the failure rate decreases. Therefore, the failure rate for component types exhibiting these infant mortality characteristics will appear higher if the data was collected in the early life compared to being collected later in the component’s life.

As a result, data collected from warranty repair records may exhibit failure rates higher than data collected from maintenance records throughout an equipment’s life because warranties are typically only applicable to the early life. The user of this document is therefore encouraged to review the description of the data sources in Section 4 to gain a better understanding of specific data points.

It is also necessary to understand its age when interpreting the data contained in this document. The reason for this is that many electronic part types have experienced reliability growth which has resulted from the reliability improvement efforts of the component manufacturers. Some components, such as integrated circuits, have experienced a large degree of growth, while others, such as resistors, have experienced a slower growth rate.

An analysis of the data has been performed to quantify the rate of reliability growth as a function of the year of component manufacture. A model of the following form was used to quantify the growth rate:

$$\lambda = \mathrm{A}e^{-\mathrm{Bt}}$$

where,

λ = Failure rate (F/10^6 hrs)
A = Constant
B = Growth rate
t = Time in years

Table 1-2 summarizes the values of B derived for various component types. As an example of how this growth effect can be interpreted, consider a plastic encapsulated microprocessor microcircuit whose B value is .526. In this example, the failure rate for these devices has improved between 1990 and 1995 by an average factor of:

$$e^{-.526(1995-1990)} = .072$$

It is suggested that the user of this data review the data source descriptions in Section 4 of this document to determine the age of specific data when it appears in the data source descriptions. The dates provided are indicative of the dates over which the data was collected, not the date of part manufacture. This data is provided so that the user of this data can quantify a "typical" reliability improvement from the time at which the data was collected to the present. While this data can be used to calculate an improvement factor and modify the failure rates presented herein accordingly, the user is cautioned that this procedure will add a degree of uncertainty in the resultant failure rate estimate. This is due to the assumption that the growth rate continues at a (logarithmically) constant rate in accordance with the above equation. Therefore, extrapolation of the failure rate increases the level of uncertainty, and the uncertainty increases with the extrapolation distance.

It should be stressed that the data in this document should not be used to form general conclusions or to guide policy decisions. For example, data for a particular device in the summary section may indicate that a lower quality level part is more reliable than a high quality part. This situation could occur when a higher quality part is overstressed or otherwise misapplied in the design. It cannot be concluded that quality has an inverse effect on reliability. In this situation, the data collected was either not adequate to accurately identify the difference or there were too many uncontrolled and unidentified variables inherent in the data.

Table 1-2: Component Growth Rate Factors

Part Type	B
Electrolytic Capacitors	0.229
Non-Electrolytic Capacitors	0.00824
Resistors	0.00
Rectifier Diodes	0.297
Zener Diodes	0.150
Other Diodes	0.223
Bipolar Transistors	0.281
FET Transistors	0.397
Darlington Transistors	0.269
Bipolar Digital Microcircuits (Plastic Encapsulated)	0.552
Bipolar Linear Microcircuits (Plastic Encapsulated)	0.197
MOS Digital Microcircuits (Plastic Encapsulated)	0.475
MOS Digital Microprocessors (Plastic Encapsulated)	0.526

In virtually all field failure data collected by the RAC, time to failure was not available. Few DoD or commercial data tracking systems report elapsed time indicator (ETI) readings to allow time-to-failure computations. Those that do report ETI readings lose accuracy following removal and replacement of failed items. To accurately monitor these times, each replaceable item would require its own individual time recording device. The RAC's data collection efforts typically track only the total number of item failures, part populations, and the number of system operating hours. This means that the assumed underlying time-to-failure distribution for all failure rates presented in this document is the exponential.

1.4 Document Overview

This document has been organized into the following sections:

Section 1: Introduction
Section 2: Part Summaries
Section 3: Part Details
Section 4: Data Sources
Section 5: Part Number/Mil Number Index
Section 6: National Stock Number Index with Federal Stock Class Prefix
Section 7: National Stock Number Index without Federal Stock Class Prefix
Section 8: Part Description Index

Sections 2 through 8 are described in detail in the following pages.

1.4.1 Section 2 "Part Summaries" Overview

The summary section of this document contains combined failure rate data in order of Part Description, Quality Level, Application Environment, and Data Source. The Part Description itself is presented in a hierarchical classification. The known technical characteristics, in addition to the classification, are contained in Section 3, “Part Details”. All data records were combined by totaling the failures and operating hours from each unique data source. In some cases, only failure rates were reported to RAC. These data points do not include specific operating hours and failures, and have dashes in the Total Failed and Operating Hours/Miles fields. Table 1-3 describes each field presented in the summary section.

Table 1-3: Field Descriptions

Field#	Field Name	Field Description
1	Part Description	Description of part including the major family of parts and specific part type breakdown within the part family. The Part Description used in this document is presented in levels of classification. The first level is used to describe the generic function/description of the part and the remaining levels are used as more detailed descriptions of the part. Table 1-4 summarizes the descriptions for each level associated with each component type. In some cases, only generic part descriptions were supplied to the RAC. For these, detailed part descriptions are not known.
2	Quality Level	The Quality Level of the part as indicated by: Commercial - Commercial quality parts Military - Parts procured in accordance with MIL specifications Unknown - Data resulting from a device of unknown quality level
3	App. Env.	The Application Environment describes the conditions of field operation. See Table 1-5 for a detailed list of application environments and descriptions. These environments are consistent with MIL-HDBK-217. In some cases, environments more generic than those used in MIL-HDBK-217 are used. For example: "A" indicates the part was used in an Airborne environment, but the precise location and aircraft type was not known. Additionally, some are more specific than the current version of MIL-HDBK-217 since the current version has merged many of the environments and the data was originally categorized into the more specific environment. Environments preceded by the term "No" are indicative of components used in a non-operating system in the specified environment.
4	Data Source	Source of data comprising this entry. The source number may be used as a reference to Section 4 to review individual data source descriptions.
5	Failure Rate Fails / (E6)	The failure rate presented for each part type, environment, quality, and source. It is the total number of failures divided by the total number of life units. No letter suffix indicates the failure rate is in failures per million hours. An "M" suffix indicates the unit is failures per million miles. For roll-up data entries (i.e., those without sources listed), the failure rate is derived using the data merge algorithm described in this section. A failure rate preceded by a "<" is representative of entries with no failures. The failure rate listed was calculated by using a single failure divided by the given number of operating hours. The resulting number is a worst case failure rate and the real failure rate is less than this value. All failure rates are presented in a fixed format of four decimal places after the decimal point. The user is cautioned that the presented data has inherently high variability and that four decimal places does not imply any level of precision or accuracy.
6	Total Failed	The total number of failures observed in the merged data records.
7	Op. Hours/ Miles (E6)	The total number of operating life unit (in millions) observed in merged data records. Absence of a suffix indicates hours is the life unit and "M" indicates that miles is the life unit.
8	Detail Page	The page number containing the detail data which comprise the summary record.

Table 1-4: Part Descriptions

Component Type	Device Type Descriptors
Capacitor	Fixed or Variable, Dielectric Type, Further Description
Diode	Function or Type, Further Description
Integrated Circuit *	Package Material, Function, Process Technology
Optoelectronic Device	Device Type, Further Description
Resistor	Fixed, Variable, or Network, Resistive Material, Further Description
Thyristor	SCR or Triac, Further Description
Transformer	Further Description
Transistor	Type or Technology, Further Description

* Note: For IC's, the second level is always the Package Material and the last level is always the Technology Type. The term "Unknown" is either of these fields indicates insufficient data to accurately describe the field.

Table 1-5: Application Environments

Env	Description
A	Airborne - The most generalized aircraft operation and testing conditions.
AI	Airborne Inhabited - General conditions in inhabited areas without environmental extremes.
AIA	Airborne Inhabited Attack - Typical conditions in cargo compartments occupied by aircrew without environment extremes of pressure, temperature, shock and vibration and installed on high performance aircraft such as used for ground support.
AIB	Airborne Inhabited Bomber -Typical conditions in bomber compartments occupied by aircrew without environment extremes of pressure, temperature, shock and vibration and installed on long mission bomber aircraft.
AIC	Airborne Inhabited Cargo - Typical conditions in cargo compartments occupied by aircrew without environment extremes of pressure, temperature, shock and vibration and installed on long mission transport aircraft .
AIF	Airborne Inhabited Fighter - Typical conditions in cargo compartments occupied by aircrew without environment extremes of pressure, temperature, shock and vibration and installed on high performance aircraft such as fighters and interceptors.
AIT	Airborne Inhabited Transport - Typical conditions in cargo compartments occupied by aircrew without environment extremes of pressure, temperature, shock and vibration and installed on high performance aircraft such as trainer aircraft.
ARW	Airborne Rotary Wing - Equipment installed on helicopters; includes laser designators and fire control systems.
AU	Airborne Uninhabited - General conditions of such areas as cargo storage areas, wing and tail installations where extreme pressure, temperature, and vibration cycling exist.
AUA	Airborne Uninhabited Attack - Bomb bay, equipment bay, tail, or where extreme pressure, vibration, and temperature cycling may be aggravated by contamination from oil, hydraulic fluid and engine exhaust. Installed on high performance aircraft such as used for ground support.
AUB	Airborne Uninhabited Bomber - Bomb bay, equipment bay, tail, or where extreme pressure, vibration, and temperature cycling may be aggravated by contamination from oil, hydraulic fluid and engine exhaust. Installed on long mission bomber aircraft.
AUF	Airborne Uninhabited Fighter - Bomb bay, equipment bay, tail, or where extreme pressure, vibration, and temperature cycling may be aggravated by contamination from oil, hydraulic fluid and engine exhaust. Installed on high performance aircraft such as fighters and interceptors.
AUT	Airborne Uninhabited Transport - Bomb bay, equipment bay, tail, or where extreme pressure, vibration, and temperature cycling may be aggravated by contamination from oil, hydraulic fluid and engine exhaust. Installed on high performance aircraft such as used for trainer aircraft.
DOR	Dormant - Component or equipment is connected to a system in the normal operational configuration and experiences non-operational and/or periodic operational stresses and environmental stresses. The system may be in a dormant state for prolonged periods before being used in a mission.
G	Ground - The most generalized ground operation and test conditions.
GB & GBC	Ground Benign - Non-mobile, laboratory environment readily accessible to maintenance; includes laboratory instruments and test equipment, medical electronic equipment, business and scientific computer complexes. GBC refers to a commercial application of a commercial part.
GF	Ground Fixed - Conditions less than ideal such as installation in permanent racks with adequate cooling air and possible installation in unheated buildings; includes permanent installation of air traffic control, radar and communications facilities.
GM	Ground Mobile - Equipment installed on wheeled or tracked vehicles; includes tactical missile ground support equipment, mobile communication equipment, tactical fire direction systems.
ML	Missile Launch - Severe conditions related to missile launch (air and ground), and space vehicle boost into orbit, vehicle re-entry and landing by parachute. Conditions may also apply to rocket propulsion powered flight.
MP	Manpack - Portable electronic equipment being manually transported while in operation; includes portable field communications equipment and laser designations and rangefinders.
N	Naval - The most generalized normal fleet operation aboard a surface vessel.
NH	Naval Hydrofoil - Equipment installed in a hydrofoil vessel.
NS	Naval Sheltered - Sheltered or below deck conditions, protected from weather; include surface ships communication, computer, and sonar equipment.
NSB	Naval Submarine - Equipment installed in submarines; includes navigation and launch control systems.
NU	Naval Unsheltered - Nonprotected surface shipborne equipment exposed to weather conditions; includes most mounted equipment and missile/projectile fire control equipment.
N/R	Not Reported - Data source did not report application environment.
SF	Spaceflight - Earth orbital. Approaches benign ground conditions. Vehicle neither under powered flight nor in atmosphere re-entry; includes satellites and shuttles.

Data records are also merged and presented at each level of part description (from most generic to most specific). The data entries with no source listed represent these merged records. Merging data becomes a particular problem due to the wide dispersion in failure rates, and because many data points consist of only survival data in which no failures occurred, thus making it impossible to derive a failure rate. Several approaches were considered in defining an optimum data merge routine. These options are summarized as follows:

1) Summing all failures and dividing by the sum of all hours. The advantages of this methodology are its simplicity and the fact that all observed operating hours are accounted for. The primary disadvantage is that it does not weigh outlier data points less than those clustering about a mean value. This can cause a single failure rate to dominate the resulting value.

2) Using statistical methods to identify and exclude outliers prior to summing hours and failures. This methodology would be very advantageous in the event there are enough failure rate data points to properly apply the statistical methods. The data being combined in this document often consists of a very few number of data points, thus negating the validity of such methods.

3) Deriving the arithmetic mean of all observed failure rates which are from data records with failures and modifying this value in accordance with the percentage of operating hours associated with zero failure records. Advantages of this method are that modifying the mean in accordance with the percentage of operating hours from survival data will ensure that all observed part hours are accounted for, regardless whether they have experienced failures. Disadvantages are that the arithmetic mean does not apply less weight to those data points substantially beyond the mean and, therefore, a single data point could dominate the calculated failure rate.

4) Using a mean failure rate by taking the lower 60% confidence level (Chi-Square) for zero failure data records and combining these with failure rates from failure records. The disadvantages of this methodology are that the 60% lower confidence limit can be a pessimistic approximation of the failure rate, especially in the case where there are few observed part hours of operation. An arithmetic mean failure rate of these values combined with the failure rates from failure records could yield a failure rate which is dominated by a single failure rate, which itself may be based on a zero failure data point. The use of a geometric mean would alleviate some of this effect, however, the problem with the pessimistic nature of using the confidence level will remain.

5) Deriving the geometric mean of all the failure rates associated with records having failures and multiplying the derived failure rates by the proportion: [observed hours with failures/total observed hours]. For example, if 70 percent of the total part hours correspond to records with failures, the geometric mean of failure rates from the data records with failures would be multiplied by 0.7. This option is appealing, since the geometric mean will inherently apply less weight to failure rates that are significantly greater than the others for the same part type. The merged failure rate should be representative of the population of parts since it takes into consideration all observed operating hours, regardless of whether or not there were observed failures or not.

Option 5 was selected since it is the only one that (1) accounts for all operating hours and (2) applied less weighting to the outliers. The resulting algorithm used to merge data is:

$$\lambda_{merged} = \left(\prod_{i=1}^{n'} \lambda i \right)^{\frac{1}{n'}} \bullet \left(\frac{\sum_{i=1}^{n'} h'}{\sum_{i=1}^{n} h} \right)$$

where,

$\prod_{i=1}^{n'} \lambda i$ = The product of failure rates from Section 2 records with failures*

$\sum_{i=1}^{n'} h'$ = The sum of hours from Section 2 records with failures*

$\sum_{i=1}^{n} h$ = The sum of hours from Section 2 records

n = The total number of Section 2 data records
n’ = The total number of Section 2 data records with failures*
h = The number of hours associated with all Section 2 data records
h’ = The number of hours associated with all Section 2 data records with failures*

* Note: Or having a second source failure rate.

Data entries with "(Summary)" following the part description are comprised of a merge of all data related to the generic part type listed. As an example, consider the entry for "Capacitor, Fixed, Electrolytic (Summary)" in Figure 1-1. The bottom entry of 0.0957 represents a roll-up of all failure rate data sources for electrolytic capacitors of a Ground Fixed (G_F) application environment. The failure rate of 0.3410 (entry opposite the Military Quality Level) represents the roll-up of all data sources and all environments for military quality capacitors. The failure rate of 0.1745 (entry opposite the "Summary" heading) represents the rolled-up failure rate for all electrolytic capacitors for all quality levels, environments and data sources. In this example, the summary data represents a roll-up of all data contained following having part descriptions beginning with "Capacitor, Fixed, Electrolytic".

Data entries associated with part descriptions are displayed in three levels, Summarized, Roll-Up, and Summary. Summarized entries represent the actual data from each data source and are identified by having an entry in the Data Source column for the line of data. These records are a combination of the detailed records in Section 3. Roll-Up entries represent roll-ups of

Summarized entries at the Quality and/or Application Environment levels. Roll-Up entries are identified by having no entry in the Data Source column for the line of data. Summary entries are roll-ups of an entire higher level Part Descriptor and are identified by having the term "(Summary)" immediately following the Part Description.

Part Description	Quality Level	App Env	Data Source	Fail. Rate Fails/(E6)	Total Failed	Op. Hours/ Miles (E6)
Capacitor, Fixed, Electrolytic (Summary)				0.1745		
	Commercial	GBC		0.0070		
	Military			0.3410		
		AIA		<0.1669		
		AIC		0.1847		
		AU		0.2149		
		AUA		2.3770		
		AUF		5.3966		
		G		0.7143		
		GF		0.0957		
Capacitor, Fixed, Electrolytic				1.1228		
	Military			1.1228		
		AIA	23035-000	<0.1728	0	5.7865
		AIC	17189-000	<0.3166	0	3.1584
		AU	13655-000	0.2200	85	386.3482
		AUA	23035-000	2.4194	28	11.5731
		AUF	23035-000	5.4930	36	6.5538
		GF	14851-000	0.5899	17	28.8183
Capacitor, Fixed, Electrolytic, Al				0.0455		
	Commercial	GBC	13567-021	0.0099	236	23852.2128
	Military			0.0859		
		AU	13655-000	<0.1091	0	9.1624
		AUA	23035-000	<4.8388	0	0.2067
		AUF	23035-000	<8.5447	0	0.1170
		GF		0.0976		
			14851-000	0.2082	10	48.0305
			23039-000	0.0458	1	21.8542
Capacitor, Fixed, Electrolytic, Ta				0.0094		
	Commercial	GBC	13567-021	0.0049	224	45341.4884
	Military	GF	14851-000	0.0189	3	166.5056
Capacitor, Fixed, Electrolytic, Ta Foil				0.7143		
	Military	G	23040-000	0.7143	5	7.0000
Capacitor, Fixed, Electrolytic, Ta Solid				0.0655		
	Military			0.0655		
		AIA	23035-000	<4.8388	0	2.2067
		AIC	17189-000	0.4433	1	2.2560
		GF	14851-000	<0.0781	0	12.8081

Figure 1-1: Example of Part Summary Entries

As an example, consider the Military failure rate entry of 1.1228 under "Capacitor, Fixed, Electrolytic". As previously stated, this represents a roll-up of six individual data entries, of which four have failures. These six represent all the combinations of environments and data source for the available data. The previously described algorithm was used, and is illustrated as follows:

$$\lambda_{\text{merged}} = \left[(.2200 \bullet 2.4194 \bullet 5.4930 \bullet .5899)^{\frac{1}{4}} \bullet \frac{386.3482 + 11.5731 + 6.5538 + 28.8183}{386.3482 + 11.5731 + 6.5538 + 28.8183 + 5.7865 + 3.1584} \right]$$

$$= 1.1228(\text{F}/10^{6})$$

In this particular case, the roll-up for "Capacitor, Fixed, Electrolytic" is also 1.1228 because there was no data for commercial quality parts.

In the previous example, the summary entry is distinguished from the non-summary entry because the summary entry represents a roll-up of all electrolytic capacitors and the non-summary entry represents electrolytic capacitors for which the specific type was unknown.

Roll-ups are performed at every combination of part description, quality level, and application environment. The data points being merged in the summary section include only those records for which a data source is listed. These individual data points were already combined by summing part hours and failures (associated with the detailed records) for each unique data source. Roll-ups performed on only zero failure data records are accomplished simply by summing the total operating hours, calculating a failure rate by assuming one failure, and denoting the resulting worst case failure rate with a "<" sign.

The roll-ups were performed in this manner to give the user maximum flexibility in choosing data on the most specific part type possible. For example, if the user needs data on a part type which is not specified in detail or for conditions for which data does not exist in this document, the user can choose data on a more generic part type or summary condition for which there is data.

1.4.2 Section 3 "Part Details" Overview

The detailed part data in Section 3 can be used to:

- Determine if there is data on a specific part number, manufacturer or device with similar physical characteristics to the one of interest.
- View the detailed data that was used to generate the summarized data section, so that a qualitative assessment of the data can be made.

The user is cautioned that individual data points from the detailed section may be of limited value relative to the merged summary data in Section 2 which combines records from several sources and typically results in many more part hours. In no case should the detailed data or summary data be used to pick the most desirable failure rate for a particular part or assembly.

Section 3 contains a listing of all field experience records contained in the RAC electronic part databases. The detailed data section presents individual data records representative of specific part types used in a particular application from a single data source. For example, if 20 relays of the same type were used in a specific military system, for which there were 300 systems in service, each with 1300 hours of operation over the time in which the data was collected, the part population is 20 X 300 = 6000, and the total part operating hours are: 6000 x 1300 = 7,800,000 hours. If the same part is used in another system, or the system is used in different operating environments, or if the information came from a different source, separate data records are generated. If known, the population size is given for each data record.

To reduce the size of descriptions used in the detailed section, terms were often abbreviated. Common abbreviations used are given in Table 1-6.

Table 1-6: Common Abbreviations

Abbr.	Description
#	Number of
Act	Character
Cont	Contact
Cur	Current
Deg	Degrees
Elm	Element
Encl	Enclosure
Freq	Frequency
Herm	Hermetic Hermeticity
Imp Imped	Impedance
Ja	Junction to Ambient
Jc	Junction to Case
Junc	Junction
Mat	Material
Mfr	Manufacturer
N	Nano
NSN	National Stock Number
Op	Operating
P	pico
P#	Part Number
Pkg	Package
Pop	Population
Pos	Position
Pwr	Power
Qty	Quantity
Res	Resistance
Semi	Semiconductor
Term	Terminal
Tol	Tolerance
u	Micro
UP#	User Part Number
v	Volt
w	Watt

1.4.3 Section 4 "Data Sources" Overview

This section describes each of the data sources from which data were extracted for this publication. Title, author(s), publication dates, report numbers, and a brief abstract are presented. In a number of cases, information regarding the source had to be kept proprietary. In these cases, "Source Proprietary" is stated.

1.4.4 Section 5 "Part Number/MIL Number" Index

This section provides an index, ordered by generic part type, of those Section 3 data entries that contain a part number or MIL-Spec number. The Section 3 page which contains the specific entry for the part or MIL number of interest is given. Note that not all data entries contain a part or MIL number since these numbers are not applicable or were not known for all entries.

1.4.5 Section 6 “National Stock Number Index with Federal Stock Class”

This section provides an index of those Section 3 data entries that contain a National Stock Number (NSN), including the four digit Federal Stock Class (FSC) prefix. This index contains all parts for which the NSN was known.

1.4.6 Section 7 "National Stock Number Index without Federal Stock Class Prefix"

This section provides an index similar to the Section 6 index, with the exception that the first four digit FSC is omitted.

1.4.7 Section 8 "Part Description Index"

The Part Description Index provides a comprehensive cross-reference to both the Summary (Section 2) and Detail (Section 3) data sections. Each part category has been indexed on all pertinent words contained in the part description. The Section 2 and Section 3 page numbers which contain the specific entry of interest are listed.