1.0 INTRODUCTION

The purpose of this document is to present failure rate data on a wide variety of electrical, electromechanical, and mechanical parts/assemblies. This document contains data on more part types than contained in its predecessor, NPRD-91. Highlights of the improvements made in this document since NPRD-91 are:

1) New data sources have been added: These sources represent a 56% increase in the quantity of data. Descriptions of the primary new sources can be found in Section 5 listed under the following data source numbers: 23045, 23046, 23047 and 23048

2) Mile Data Has Been Added: Since several of the above data sources were from ground vehicles that use miles as their life unit, data has been added that are in units of failures per million miles instead of the standard failures per million hours. This data is indicated with an "M" (for miles) next to the failure rate in Section 2 and next to the failures/hours in Section 3.

3) Part Number Indexes Have Been Added: In addition to the part type index that was contained in NPRD-91, a part number index has been added which indexes both the part number and the MIL-SPEC number. Two additional indexes have been provided for national stock number (NSN), one with the four digit Federal Stock Class (FSC) prefix and one without.

1.1 Background

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. While there are well accepted reliability prediction methodologies for standard electronic components such as MIL-HDBK-217, "Reliability Prediction of Electronic Equipment," there are few such sources of failure rate data for other component types.

A potential use for this document is to complement existing reliability prediction methodologies by providing failure rate data in a consistent format on various electrical, electromechanical, and mechanical parts and assemblies. All part types and assemblies for which RAC has data are included in this publication with the exception of selected electronic components. Although the data contained in this publication were collected from a wide variety of sources, RAC has done everything possible to screen 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 part types 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 insured.

The intent of this introductory section is to provide the user with information to adequately interpret and use the data contained. Since the primary purpose of this document is to provide data 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 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 electronic components. Therefore, NPRD-95 serves a variety of needs;

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

2) To provide failure rates on assemblies (ex. disk drives) in cases where piece part level analyses are not feasible or required.

1.2 Data Collection

The failure rate data contained in this document represent a cumulative compilation of data collected from the early 1970's through May 1994. However, it should be noted that data is periodically purged from the database in the event that newer data of higher quality is obtained or if data is on obsolete part types. 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 for which there is a lack of field experience.

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.

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 Organizations, Military or Commercial, That Maintain Failure Databases

Section 5 briefly describes the specific reports and sources utilized in this document. Each summary 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) • Insure Correct Version of System Consistent with Maintenance Data • Identify Characteristics of Components (Part Numbers, FSN, 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
(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 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. Data from these maintenance systems are used in RAC's data collection efforts for piece parts 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 RAC. Section 5 of this document contains a brief description of each data source used in this publication. These descriptions are given since RAC believes it is important for the user of this document to understand the types of data that were used in deriving the failure rates.

RAC has done everything possible to insure 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, and characterization of operational histories are all used to determine adequacy of data. In many cases, data submitted to RAC is discarded since a reasonable degree of credibility does not exist in the data. Although this is often a qualitative judgment, it is readily apparent when a data set is questionable and must be discarded.

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

- There are many more factors affecting reliability than can be identified.
- There is a certain degree of uncertainty in any failure rate data collection effort, due to:
  - Uncertainty 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 were identified by maintenance technicians performing a repair action. This indicates 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 such sources are given in the source description section of this document.

1.3 Data Interpretation

Data contained in this document reflect 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 exponentially distributed failure lifetime components and systems 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.

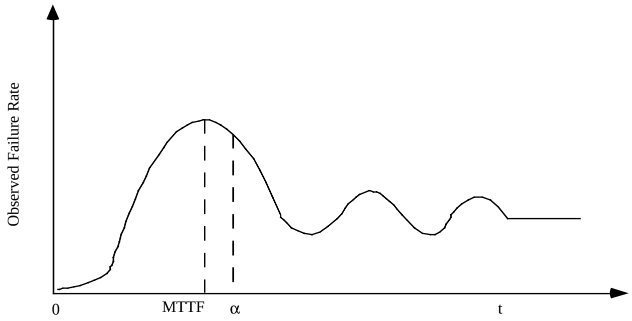
To give NPRD-91 users a better understanding of the confidence they can place in the presented estimated failure rates, an analysis was performed on the variation in observed failure rates. It was concluded that, for a given generic part type, the natural logarithm of the observed failure rate is normally distributed with a sigma of 1.5. This indicates that 68 percent of actual failure rates will be between .22 and 4.5 times the mean value. Similarly, 90% of actual failure rates will be between .08 and 11.9 times the presented value.

This type of precision is typical of probabilistic reliability prediction models and point estimated failure rates such as those contained herein. It should be noted that these precisions are 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.

It should be stressed that NPRD-95 data should not be used to form general conclusions or to guide policy decisions. For example, data in the summary section for a particular device 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.

In virtually all field failure data collected by RAC, time to failure was not available. Few DoD or commercial data tracking systems report elapsed time indicator (ETI) meter readings to allow time-to-failure compilations. 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. 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 NPRD-95 is the exponential distribution. Unfortunately, many part types for which data are presented typically do not follow the exponential failure law, but rather exhibit wearout characteristics, or an increasing failure rate in time.

While the actual time to failure distribution may be Weibull or lognormal, it may appear to be exponentially distributed if a long enough time has elapsed. This is true only under the condition that components are replaced upon failure, which is true for the vast majority of data contained in this document. To illustrate this, refer to Figure 1-1 which depicts the apparent failure rate for a population of components that are replaced upon failure, each of which follow the Weibull time to failure distribution.



MTTF = Mean-Time-to-Failure, α = Weibull Characteristic Life

FIGURE 1-1: APPARENT FAILURE RATE FOR REPLACEMENT UPON

At t=0, the population of parts has not experienced operation. As operating time increases, parts in the original population are replaced and the failure rate increases. The failure rate then decreases as the majority of parts have been replaced with new parts. The population of replaced parts undergo the same process with the exception that the deviation of the second distribution is greater due to the fact that the "time zeros" of the replaced parts themselves are spread over time. This process continues until the "time zeros" of the parts have become sufficiently randomized to result in an apparent exponentially distributed population. The approximate time at which this asymptotic value is reached as a function of β is given in Table 1-2. The asymptotic value of failure rate is $\frac{1}{\alpha}$, regardless of β.

TABLE 1-2: TIME AT WHICH ASYMPTOTIC VALUE IS REACHED

β	Asymptote
2	1.0α
4	2.4α
6	4.2α
8	7.0α

Additionally, since mean-time-to-failure (MTTF) is often used instead of characteristic life, their relationship should be understood. The ratio of α/MTTF is a function of β and is given in Table 1-3.

TABLE 1-3: $\frac{\alpha}{\text{MTTF}}$ RATIO AS A FUNCTION OF β

β	α/MTTF
1	1.00
2	1.15
2.5	1.12
3.0	1.10
4.0	1.06

Based on the previous discussion, it is apparent that the time period over which data is collected is very important. For example, if the data is collected from time zero to a time which is a fraction of α, the failure rate will be increasing over that period and the average failure rate will be much less than the asymptotic value. If however the data is collected during a time period after which the failure rate has reached its asymptote, the apparent failure rate will be constant and will have the value $1/\alpha$.

The detailed data section presents part populations which provide the user the ability to further analyze the time logged to an individual part or assembly and to estimate characteristic life. For example, the detailed section presents the population and the total number of operating hours for each data record. Dividing the part operating hours by the population yields the average number of operating hours for the system/equipment in which the part/assembly was operating. For example, an entry for a commercial quality mercury battery in a GF environment indicates that a population of 328 batteries had experienced a total of .8528 million part-hours of operation. This indicates that each battery had experienced an average of .0026 million hours of operation in the time period over which the data was collected. If a shape parameter, β, of the Weibull distribution is known for a particular part/assembly, the user can use this data to extrapolate the average failure rate presented herein to a Weibull characteristic life (α). If the percent failure rate is relatively low, the methodology is of limited value. If a significant percent of the population has failed, the methodology will yield results for which the user should have a higher degree of confidence. The methodology to be presented is useful only in cases where time to failure characteristics are needed. In many instances, knowledge of a parts characteristic life is of limited value if the logistics demand is the concern. This data can however be used to estimate characteristic life in support of preventive maintenance efforts. The assumptions in the use of this methodology are:

1) Data in this publication were collected from "time zero" of the part/assembly field usage.
2) The Weibull distribution is valid and β is known.

Table 1-4 contains cumulative percent failure as a function of Weibull β and the time/characteristic life ratio (t/α). The percent failure from the detailed data section can be converted to a (t/α) ratio using the data in Table 1-4. Once this ratio is determined, an α can be determined by dividing the average operating hours per part (part hours/population) by the (t/α) ratio.

It should be noted here that the percentage failures in the table can be greater than 100 since parts are replaced upon failure and for any given part, there can be any number of replacements.

TABLE 1-4: PERCENT FAILURE FOR WEIBULL DISTRIBUTION

(t/α)	β					
	1	2	3	4	5	6
.1	10	4.1	1.3	.2	0	0
.2	20	8.6	3.0	1.0	.2	0
.3	30	15	6.8	3.1	1.0	.7
.4	40	23	13	8.1	3.7	1.7
.5	50	31	20	13	8.3	5.0
.6	60	41	31	21	15	12
.7	70	52	42	32	27	26
.8	80	62	55	47	29	42
.9	90	75	68	64	47	64
1.0	100	88	82	80	65	85
1.1	110	99	96	93	79	98
1.2	120	109	107	105	87	103
1.3	130	121	117	111	92	106
1.4	140	133	128	119	97	111
1.5	150	145	139	126	105	119
1.6	160	155	149	136	116	129
1.7	170	169	160	148	130	144
1.8	180	180	171	161	145	161
1.9	190	190	192	175	159	176
2.0	200	202	195	189	171	191
> 2.0	for (t/α) > 2, % failure = 100(t/α)					

As an example, consider the detailed data entry on page 3-275 for Electrical Motors, Sensor, Mil, AU, 16953-000, No Details, Pop:960. For this data entry, there were 359 failures in .7890 million part-operating hours. This data may be converted to a characteristic life in the following manner;

1) Determine Percent Failure:

$$\% \text{ Failure} = \frac{359}{960} = 37.4\%$$

2) Determine a typical Weibull shape parameter (β); For motors β typically is 3 (Ref. RADC-TR-77-408).

3) Convert Percent Failure to t/α ratio using Table 1-4 (for % fail = 37.4 and $\beta = 3$)

$$\frac{t}{\alpha} \cong .65 \qquad \text{(Extrapolating between 31 and 42)}$$

4) Calculate average operating hours per part;

$$\frac{\text{part hours}}{\text{population}} = \frac{.7890}{960} = .00082 \text{ million hours}$$

5) Calculate α

$$\alpha = \frac{\left(\dfrac{\text{part hours}}{\text{population}}\right)}{\left(\dfrac{t}{\alpha}\right)} = \frac{.00082}{.65} = .00126 \text{ million hours}$$

Based on this data, an approximate Weibull characteristic life is 1260 hours.

The user of this methodology is cautioned that this is a very approximate method of determining an items characteristic life (α) when time to failure data is not available. It should also be noted that for small time (i.e.; $t < .1\ \alpha$), random failures can predominate, effectively masking wearout characteristics and rendering the methodology inaccurate. Additionally, for small operating times relative to α, the results are dependent on the extreme tail of the distribution, thus significantly decreasing the confidence in the α derived.

For part types exhibiting wearout characteristics, the failure rate presented represents an average failure rate over the time period in which the data was collected. It should also be noted that for complex nonelectronic devices or assemblies, the exponential distribution is a reasonable assumption. The user of this data should also be aware of how data on cyclic devices such as circuit breakers is presented. Ideally, these devices should have failure rate presented in terms of failures per operating cycles. Unfortunately, from the field data collected, the number of actuations is rarely known, and therefore failure rates listed are presented in terms of failures per operating hour for the equipment in which the part is used.

1.4 Document Overview

This document has been organized into the following sections to provide information in the most convenient and logical manner possible.

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 sorted by Part Description, Quality Level, Application Environment, and Data Source. The Part Description itself is presented in up to four levels of classification. The first level describes the primary function of the part and successive levels further describes its functionality or application. In cases where not all four levels are used, details were not known. The known technical characteristics in addition to the (up to) four level description is contained in the 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 generic 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 fields. Table 1-5 describes each field presented in the summary section.

Data records are also merged and presented at each level of part description (from most generic to most specific). Merging data becomes a particular problem due to the wide dispersion in failure rates and because many data points consist of only zero failure survival data, thus making it impossible to derive a failure rate. Several approaches were considered in defining an optimum data merge routine.

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 datapoints 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 datapoints to properly apply the statistical methods. The data being combined in this document often consists of a very few number of datapoints, 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 insure 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 datapoints substantially beyond the mean and therefore a single datapoint 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 maybe based on a zero failure datapoint. The use of a geometric mean would alleviate some of this effect, however, the problem with the pessimistic nature of taking 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 .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 there were observed failures or not.

TABLE 1-5: 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. In this document, RAC does not distinguish parts from assemblies. Information is presented on parts/assemblies at the indenture level which it was available. The description of each item for which data exists is made as clear as possible so that the user can choose a failure rate on the most similar part or assembly. The parts/assemblies for which data is presented can be comprised of several part types or can be a constituent part of a larger assembly. In general, however, data on the part type listed first in the data table is representative of the part type listed and not of the higher level of assembly. For example, a listing for Stator, Motor represents failure experience on the stator portion of the motor and not the entire motor assembly. Added descriptors to the right, separated by commas, provide further details on the part type listed first. Additional detailed part/assembly characteristics can be found, if available, in the Part Details section.
2	Qual Lev	The Quality Level of the part as indicated by: Mil - Parts procured in accordance with MIL specifications. Com - Commercial quality parts. Unk (Unknown) - Data resulting from a device of unknown quality level
3	App Env	The Application Environment describes the conditions of field operation. See Table 1-6 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 non-operating systems in the specified environment.
4	Data Source	Source of data comprising this entry. The source number may be used as a reference to Section 5 to review individual data source descriptions.
5	Failure Rate	For individual data entries, (same part type, environment, quality, and source) this 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 whereas an "m" suffix indicates the unit is failures per million miles. For roll-up data entries (i.e., those without sources listed) 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 data presented 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	Operating Hours (E6)	The total number of operating life unit (in millions) observed in merged data records. No letter suffix indicates hours is the life unit and the suffix "m" indicates that miles is the life wait.
8	Detail Page	The NPRD-95 page number containing the detail data which comprise the summary record.

TABLE 1-6: 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 intercepters.
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 intercepters.
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	Ground Benign - Non-mobile, laboratory environment readily accessible to maintenance; includes laboratory instruments and test equipment, medical electronic equipment, business and scientific computer complexes.
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.

Option 5 was selected since it is the only one that both (1) accounts for all operating hours and (2) weighs failure rates less that are significantly greater than the norm.

The resulting algorithm used to merge data is:

λ_{merged} = a summary failure rate derived from several constituent data sources.

$$\lambda_{merged} = \left(\prod_{i=1}^{n} \lambda_i\right)^{\frac{1}{n}} \bullet (\%)$$

where:

n = number of records having either failures or a second source failure rate (a second source failure rate is from failure rate data supplied to RAC without hours and failures)

λ_i = failure rate from each individual source having failures or a second source failure rate

% = Percentage of total hours associated with records having failures. Used to reduce the overall summary failure rate to account for survival data

In Section 2, part descriptions with "(Summary)" following the part name comprise a merge of all data related to the generic part listed. An example of the summary section is given in Figure 1-2. The failure rate of 35.4090 is a roll-up of Linear Mechanical Actuators of commercial quality in an A_{uc} environment. This failure rate is a merge, using the previously described algorithm, of two individual data entries (sources NPRD-090 and 098).

```
Part                                  Qual      App       Data           Fail Per       Total     Operating           Detail
Description                           Lev       Env       Source         E6 Hours       Failed    Hours (E6)          Page

Actuator,Mechanical (Summary)                                               25.8092
                                      Com       AUC                         35.4090
                                      Mil       AIF                      <   2.8699
                                      Unk                                   21.5140
                                                A                           57.9558
                                                AUT                          5.1100
                                                GM                           3.6241

Actuator,Mechanical                             Mil                          5.5413
                                                AIF                      <   2.8699
                                                          18138-000      <  12.0499         0         0.0830            3-3
                                                          18139-000      <   3.7671         0         0.2655            3-3
                                                Unk                         13.1079
                                                AUT       18459-000          5.1100         1         0.1957            3-3
                                                GM        18459-000         33.6241         2         0.0595            3-3

Actuator,Mechanical,Linear                                                  41.7293
                                      Com       AUC                         35.4090
                                                          NPRD-090         227.8282      1061         4.6570            3-3
                                                          PRD-098            5.5032        83        15.0820            3-3
                                      Unk       A         14182-001         57.9558         -       --------            3-3
```

FIGURE 1-2: EXAMPLE OF PART SUMMARIES ENTRY

To illustrate how the data was rolled up, consider the entries for linear mechanical actuators. The failure rate of 41.7293 listed for "Actuator, Mechanical, Linear" is a roll-up of three individual data entries for which there are sources listed (two for commercial quality, A_{UC} environment and one for unknown quality in an airborne environment). The listing of 5.5413 for "Actuator, Mechanical" is a roll-up of four individual data entries (two for Mil / A_{IF} , one for Unk / A_{UT} , and one for Unk / G_M). Using the algorithm described previously, the roll-up was calculated as follows:

$$\lambda_{\text{summary}} = [(5.110)(33.6241)]^{\frac{1}{2}} \left[\frac{.1957 + .0595}{.1957 + .0595 + .0830 + .2655}\right] = 5.5413$$

Now consider the entry for "Actuator, Mechanical (Summary)". This listing is a roll-up of all "Actuator, Mechanical" data (in this case Actuator, Mechanical and Actuator, Mechanical, Linear) using the algorithm described previously. In other words, the failure rate of 25.8092 is a summary of failure data from 7 individual data sources. For these "(Summary)" data entries, sources are not listed since they represent a merge of one or more data sources which are presented below the summary level. Roll-up values are presented for each specific quality level and application environment for all components having multiple part type entries at the same indenture level.

If there is no summary record listed for a particular part type, the part description listed represents the lowest level of indenture available. For example, the listing for "Actuator, Mechanical," although being identical to the generic level for which the summary data is presented, was the most detailed description available for the particular data entry.

More detailed part level information may be available in Section 3. Each failure rate record listed in the summary section is a merge of all detailed data from Section 3 for a specific part type, quality, environment and unique data source. Each of these failure rate records refers to a Section 3 page which contains all detailed records including part details, if known.

Roll-ups are performed at every combination of Part Description (up to 4 Levels), 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 for each unique data source. For the purposes of merging data, those data entries with only failure rates presented (no failures and hours reported) were assumed to have one million operating hours. 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 upper bound failure rate with a "<" sign.

These 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 which data does not exist in this document, the user can then choose data on a more generic part type for which data exists.

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 a device with similar physical characteristics to the one being analyzed.
- Present to the user the detailed data that was used to generate the summarized data section, so that a qualitative assessment of the data quality 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 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 of this document contains a listing of all field experience records contained in the RAC nonelectronic 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 in service, each with 1300 hours of operation over the time in which the data was collected, the part population is 20 X 300 = 600, and the total part operating hours are: 600 x 1300 = 78,000 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 as the last entry. An example of the section is as follows:

Part Desc.	Qual Level	App Env	Data Source	Part Characteristics	Fail/Hours (E6)
Actuator,Mechanical					
	Mil	AIF	18138-000	-P#:169252-1,Pop:348,	0/0.0830
	Mil	AIF	18139-000	-P#:169252-1,,op:1014,	0/0.2655
	Unk	AUT	18459-000	-No Details,Pop:464	1/0.1957
	Unk	GM	18459-000	-No Details,Pop:25	2/0.0595
Actuator,Mechanical,Linear					
	Com	AUC	NPRD-090	-No Details,	1061/4.6570
	Com	AUC	NPRD-098	-No Details,Pop:42	83/15.0820
	Unk	A	14182-001	-No Details,	FR: 57.9560

FIGURE 1-3: EXAMPLE OF PART DETAILS ENTRY

To reduce the size of descriptions used in the detailed section, descriptive terms were often abbreviated. Common abbreviations used in describing device part characteristics are described below:

Abbr.	Description	Abbr.	Description	Abbr.	Description
#	Number of	Int	Internal	Pwr	Power
Act	Actuation	Lgth	Length	Qty	Quantity
Brd	Board	Lub	Lubrication	Res	Resistance
Condu	Conductor	Mat	Material	Semi	Semiconductor
Conn	Connection(s)	Mnt	Mount	Term	Terminal
Cont	Contact	Mntg	Mounting	Tol	Tolerance
Cur	Current	Op	Operating	Ty	Type
Deg	Degrees	P#	Part Number	Volt	Voltage
Encl	Enclosure	Pkg	Package	Watt	Wattage
Freq	Frequency	Pop	Population	Wdg	Winding
Herm	Hermeticity	Pos	Position	X-Sec	Cross Section
Imp	Impedance				

1.4.3 Section 4 "Data Sources" Overview

This section describes each of the data sources from which data were extracted for this publication. Where possible, title, authors, 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, the words "Source Proprietary" are specifically stated.

1.4.4 Section 5 "Part Number / MIL Number" Index

This section provides an index of those Section 3 data entries that contain a part number or MIL-Spec number. The section 3 page is given which can be scanned to identify the specific entry for the number of interest. Note that not all data entries contain a part or MIL number.

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 is the same as the Section 6 index with the exception that the first four digit FSC is omitted.

1.4.7 Section 8 "Part Description Index" Overview

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. For example: The word "Solenoid" is indexed regardless of where the word occurred in the part type description as shown in Figure 1-4.

Solenoid
- Accumulator, Hydraulic, Pressure Solenoid (2-2, 3-1)
- Bracket, Solenoid (2-23, 3-27)
- Electrical Motor, Rotary Solenoid (2-85, 3-275)
- Inductive Device, Inductor, Solenoid (2-122, 3-330)
- Relay, Contact, Heavy Duty Solenoid (2-167, 3-423)
- Relay, Contact, Solenoid Motor Drive (2-168, 3-423)
- Relay, Solenoid (2-171, 3-437)
- Relay, Solenoid, Solenoid-Driven (2-172, 3-437)
- Solenoid (2-190, 3-476)
- Solenoid, Assembly (2-190, 3-477)
- Solenoid, Coil (2-190, 3-477)
- Solenoid, Electrical (2-190, 3-477)
- Solenoid, Linear (2-190, 3-477)
- Solenoid, Rotary (2-190, 3-477)
- Switch, Contact, Solenoid (2-198, 3-485)
- Valve, Fuel, Solenoid (2-226, 3-548)
- Valve, Hydraulic, Solenoid (2-231, 3-552)
- Valve, Solenoid, Solenoid, Angle (2-231, 3-552)
- Valve, Pneumatic, Solenoid (2-235, 3-554)
- Valve, Solenoid, 3-Way (2-236, 3-555)
- Valve, Solenoid, 4-Way (2-236, 3-555)
- Valve, Solenoid (2-236, 3-555)
- Valve, Solenoid Operator (2-237, 3-556)

FIGURE 1-4: EXAMPLE OF PART INDEX ENTRY

Page references are listed in parenthesis and separated by commas. For example, in the entry "Electrical Motor, Rotary Solenoid (2-85,3-275)" shown above, "2-85" refers to Section 2, page 85 and "3-275" refers to Section 3, page 275.