NPRD 2016

NONELECTRONIC PARTS RELIABILITY DATA

RELIABILITY DATABOOK SERIES

failure data for a wide variety of component types

QUANTERION SOLUTIONS INCORPORATED

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Nonelectronic Parts Reliability Data

2016

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Preface

This Databook contains field failure rate data on a variety of electrical, mechanical, electromechanical, and microwave parts and assemblies. The data can be used as a surrogate source of reliability failure rate data in the absence of other data to assist in performance of reliability analyses and assessments.

The data contained in NPRD-2016 represents an increase of 400% over its NPRD-2011 predecessor. The CD-ROM version of NPRD-2016 incorporates a user interface with search capabilities that assist in rapid data retrieval. Data searches can be conducted on all pertinent parameters, including part type, quality, environment and data source.

For the hardcopy format of the publication, comprehensive part number indexes are provided to assist the user in identifying and locating specific parts of interest.

Data was collected for this product from a wide variety of commercial and military sources.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The purpose of this document is to present failure rate data on a wide variety of electrical assemblies and electromechanical/mechanical parts and assemblies. Compared to the NPRD-2011 publication, NPRD-2016 adds 138,000 new parts and over 370 billion part hours, representing approximately a 400% increase in the data contained over its predecessor. The expanded part types and data in NPRD-2016 cover ground, airborne and naval environments.

1.1 Background

Accurate and timely reliability predictions are an important part of a well-structured reliability program. When properly performed, they can provide valuable 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" and the 217Plus™ System Reliability Assessment methodology (currently at 217Plus:2015), 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 assemblies and electromechanical/mechanical parts and assemblies. Although the data contained in this publication were collected from a wide variety of sources, Quanterion 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 NPRD-2016 user should note that the use of reliability prediction techniques, or the use of the data contained in this book, should complement (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 for which their own data does not already exist. Sound reliability engineering practices must include knowledge of the failure physics of all components, modules and interconnection assemblies in a system. 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 contained in the book. Since the primary purpose of this document is to provide data to augment reliability prediction methodologies, a brief description of how the data in this document can be used to augment a reliability prediction method is presented.

It is not feasible for reliability prediction methodologies of any kind to contain failure rate models on every conceivable type of component and assembly. Traditionally, reliability prediction models have been applicable only for generic electronic components. Therefore, NPRD-2016 serves a variety of needs:

1) To provide surrogate failure rate data sources when an organization does not have failure rate experience data from its own products/systems
2) To provide failure rates on assemblies (e.g., disk drives) in cases where piece-part level analyses are not feasible or required (e.g., Commercial Off-the-Shelf and other "black box" items)
3) To complement reliability 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 of data collected from the early 1970's through late-2014. However, it should be noted that some data may be periodically purged from the database in the event that newer data of higher quality is obtained, or if data is on obsolete part types. Quanterion is continuously soliciting new field failure rate data sources/platforms in an effort to keep the databases current. The goals of these data collection efforts are as follows:

1) To obtain field data on new part types and assemblies
2) To collect as much new data from as many different data sources, application environments and quality levels as possible
3) To identify as many key characteristics of the data as possible, including both part and application parameters

Quanterion utilized the following generic sources of data for NPRD-2016, as applicable:

- 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 from military or commercial organizations that maintain failure databases

Section 5 of this databook briefly describes the specific reports and sources utilized in NPRD-2016. Each summary failure rate can be mapped to one of these data sources. An example of the process by which Quanterion identifies candidate systems and extracts failure rate 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/Miles, Part Hours/Miles • Application Environment
(5)	Transform Data to Common RIAC 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 REMIS system or the Navy's OARS (formerly 3M) and DECKPlate (formerly Avionics 3M) systems, typically will not provide accurate data at the piece-part level. They can, however, provide acceptable field 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 Quanterion's data analyses 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 Quanterion. Section 4 of this document contains a brief description of each data source used in NPRD-2016 because Quanterion believes it is important for the user to understand the types of data that were used in deriving these failure rates.

Quanterion 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 is discarded since an acceptable level 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 NPRD-2011 were 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 sources is given in Section 4 of the databook.

1.3 Data Interpretation

Data contained in NPRD-2016 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.

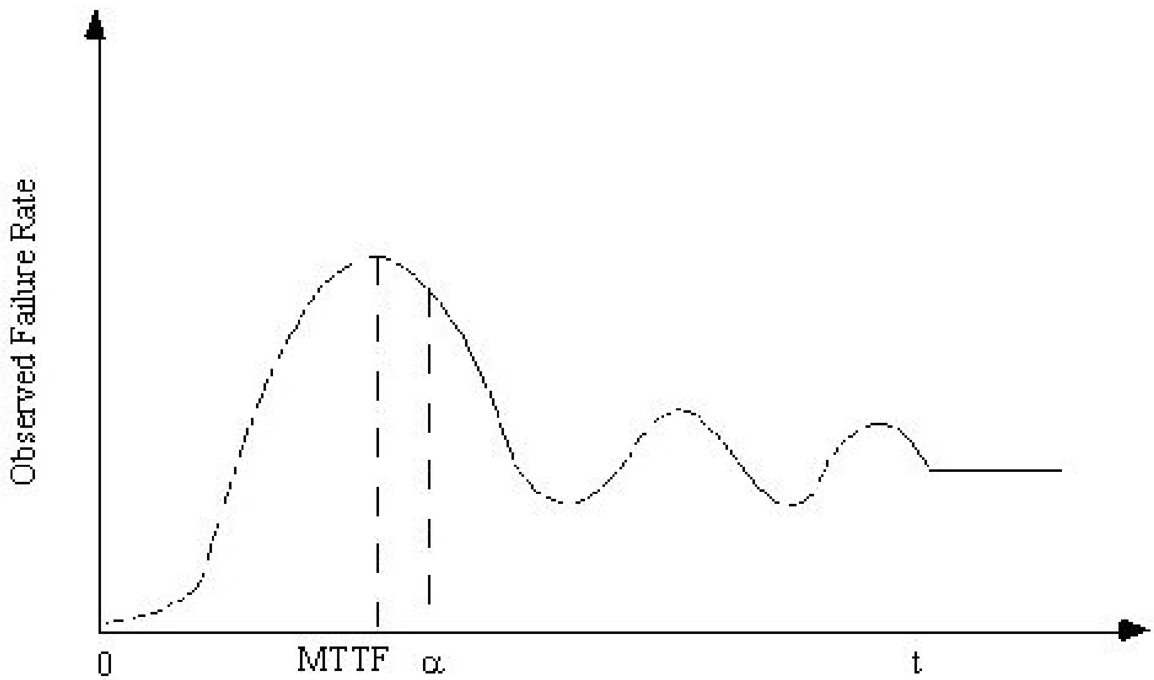
Data in the summary section of NPRD-2016 represent an "estimate" of the expected failure rate and the "true" value will lie in some confidence interval about that estimate. The traditional method of identifying confidence limits for components with exponentially distributed lifetimes has been the use 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 NPRD-2016 a better understanding of the confidence they can place in the presented failure rates, an analysis of data in the past 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. As a general rule-of-thumb, 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 this precision 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.

It should be stressed that NPRD-2016 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 of the field failure data collected, time-to-failure (TTF) was not available. Few DoD or commercial data tracking systems report elapsed time indicator (ETI) meter readings to allow TTF compilations. Those that do 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. Quanterion'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 TTF distribution for all failure rates presented in NPRD-2016 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 TTF distribution may be Weibull or lognormal, it may appear to be exponentially distributed if 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 NPRD-2016. 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 FAILURE

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 beta is given in Table 1-2. The asymptotic value of failure rate is 1/alpha, regardless of beta.

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

β	Asymptote
2	1.0
4	2.4
6	4.2
8	7.0

Additionally, since Mean Time to Failure (MTTF) is often used instead of characteristic life, their relationship should be understood. The ratio of alpha/MTTF is a function of beta and is given in Table 1-3.

TABLE 1-3: α/MTTF RATIO AS A FUNCTION OF β

β	Asymptote
1.0	1.00
2.0	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 alpha, 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 (Section 3) 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 0.8528 million part-hours of operation. This indicates that each battery had experienced an average of 0.0026 million hours of operation in the time period over which the data was collected. If a shape parameter, beta, 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 (alpha). 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 TTF characteristics are needed. In many instances, knowledge of a part's 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 NPRD-2016 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 Section 3 can be converted to a (t/alpha) 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

	beta					
(t/alpha)	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/a) > 2, % failure = 100(t/alpha)						

As an example, consider the detailed data for "Electrical Motors, Sensor", Military quality grade, Airborne, Uninhabited (AU) environment, and the Population size is 960 units. Assume for this data entry that there were 359 failures in 0.7890 million part-operating hours. The data may be converted to a characteristic life in the following manner:

1) Determine the Percent Failure:

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

2) Determine a typical Weibull shape parameter (β). For motors, a typical beta value is 3.0 (Reference RADC-TR-77-408, "Electric Motor Reliability Model")

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

$$\frac{t}{\alpha} \cong 0.65 \quad \text{(extrapolating between 31 and 42)}$$

4) Calculate average operating hours per part:

$$\frac{\text{Part Hours}}{\text{Population Count}} = \frac{0.7890}{960} = 0.00082 \text{ million hours}$$

5) Calculate α:

$$\alpha = \frac{\left(\frac{\text{Part Hours}}{\text{Population Count}}\right)}{\left(\frac{t}{\alpha}\right)} = \frac{0.00082}{0.65} = 0.00126 \text{ million hours}$$

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

The user of this approach is cautioned that this is a very approximate method for determining an item's characteristic life (alpha) when TTF data is not available. It should also be noted that for small times (i.e., t < 0.1alpha), 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 derived value of alpha.

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 rates presented in terms of failures per operating cycles. Unfortunately, from the field data collected, the number of actuations is rarely known. When the number of cycles is unknown, the 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:

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 NPRD-2016 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 RIAC. These data points do not include specific operating hours and failures, and have dashes in the Total Failed and Operating Hours/Miles fields. Table 1-5 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). 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 statistical methods. The data being combined in NPRD-2016 often consists of a very small 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.

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, Quanterion does not distinguish parts from assemblies. Information is presented on parts/assemblies at the indenture level at 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	Quality Level	The Quality Level of the part as indicated by: Commercial - Commercial/industrial 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 1-6 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 (F, Notice 2) 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. The absence of a letter suffix indicates the failure rate is in failures per million operating hours. An "M" suffix indicates the unit is failures per million miles. A “C” suffix indicates the unit is failures per million cycles. 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 "<" (less-than symbol) is representative of entries with no failures. The failure rate listed is 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/Cycles (E6)	The total number of operating life units (in millions) observed in the merged data records. Absence of a suffix indicates hours is the life unit, "M" indicates that miles is the life unit, and "C" indicates that cycles is the life unit.
8	Detail Page	The 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.
AA	Airborne Attack – General conditions for equipment installed on high performance aircraft such as used for ground support.
AF	Airborne Fighter – General conditions used for equipment installed in high performance aircraft such as fighters or interceptors.
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.
AT	Airborne Trainer – General conditions for equipment installed on high performance aircraft such as trainer aircraft.
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.
AUC	Airborne Uninhabited Cargo – 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 transport 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.
GMW	Ground Mobile Wheeled – Equipment installed on wheeled vehicles; includes tactical missile ground support, mobile communications equipment, and tactical fire detection 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.

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 life units with failures/total observed life units]. For example, if 70 percent of the total part life hours (life units) corresponds 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 units, regardless of whether or not there were observed failures.

Option 5 was used by Quanterion since it is the only one that (1) accounts for all operating hours and (2) applies less weighting to the outliers. The resulting algorithm used to merge data in NPRD-2016 is:

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

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.

In Section 2, part descriptions with "(Summary)" following the part name comprise a merge of all data related to the generic part listed. A hypothetical example of the summary section is given in Figure 1-2. The failure rate of 35.409040 is a roll-up of Linear Mechanical Actuators of commercial quality in an Airborne Uninhabited Cargo (AUC) environment. This failure rate is a merge of two individual data entries using the previously described algorithm.

Part Description	Quality Level	App Env	Data Source	Fail Per E6 Hours	Total Failed	Operating Hours (E6)	Detail Page
Actuator,Mechanical (Summary)				25.970684			
	Commercial	AUC		35.409040			
	Military	ARW		< 4.289581			
	Unknown			21.514077			
		A		57.956000			
		AUT		5.109966			
		GM		33.624183			
Actuator,Mechanical				6.849986			
	Military	ARW		< 4.289581			
			221006-000	< 37.782899	0	0.026467	3-18
			221007-000	< 37.194079	0	0.026886	3-18
			221008-000	< 37.170576	0	0.026903	3-18
			221009-000	< 39.215686	0	0.025500	3-18
			221010-000	< 36.919442	0	0.027086	3-18
			221011-000	< 35.527765	0	0.028147	3-18
			221012-000	< 37.770056	0	0.026476	3-18
			221013-000	< 40.701697	0	0.024569	3-18
			221014-000	< 47.418085	0	0.021089	3-18
	Unknown			13.107953			
		AUT	18459-000	5.109966	1	0.195696	3-18
		GM	18459-000	33.624183	2	0.059481	3-18
Actuator,Mechanical,Linear				41.729409			
	Commercial	AUC		35.409040			
			NPRD-090	227.829075	1061	4.657000	3-18
			NPRD-098	5.503249	83	15.082000	3-18
	Unknown	A	14182-001	57.956000	-	--------	3-18

FIGURE 1-2: EXAMPLE OF PART SUMMARY ENTRIES

To illustrate how the data was rolled up, consider the entries for linear mechanical actuators. The failure rate listing of 6.849986 for "Actuator, Mechanical" is a roll-up of eleven individual data entries (nine for Mil/ARW, one for Unk/AUT , and one for Unk/GM). The failure rate of 41.7293409 failure rate for "Actuator, Mechanical, Linear" is a roll-up of the three individual data entries for which there are sources listed (two for commercial quality, AUC environment and one for unknown quality in an airborne environment). Using the algorithm described previously, the roll-up was calculated as follows:

$$\lambda_{summary} = [(5.109966)(33.624183)]^{0.5} \left[\frac{0.195696 + 0.059481}{\begin{array}{l} 0.19696 + 0.059481 + 0.026467 + 0.026886 + 0.026903 + 0.025500 + \\ 0.027086 + 0.028147 + 0.026476 + 0.024569 + 0.021089 \end{array}} \right] = 6.849986$$

Now consider the entry for "Actuator, Mechanical (Summary)". This listing is a roll-up of all "Actuator, Mechanical" data (" Actuator, Mechanical" and "Actuator, Mechanical, Linear") using the algorithm described previously. In other words, the failure rate of 25.970684 is a summary of failure data from 14 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 Section 2 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 (down 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 (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 for 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 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 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 as the last entry. An example of the section is as follows:

Part Description	Quality Level	App Env	Data Source	Part Characteristics	Fail Per E6 Hours
Actuator,Mechanical					
	Mil	ARW	221006-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.026467
	Mil	ARW	221007-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.026886
	Mil	ARW	221008-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.026903
	Mil	ARW	221009-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.025500
	Mil	ARW	221010-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.027086
	Mil	ARW	221011-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.028147
	Mil	ARW	221012-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.026476
	Mil	ARW	221013-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.024569
	Mil	ARW	221014-000	-P#:12120-8; NSN:1680-01-496-5131; Mfr:AMI Industries Inc.; Pop:105	0/0.021089
	Unk	AUT	18459-000	-Pop:464	1/0.195696
	Unk	GM	18459-000	-Pop:25	2/0.059481
Actuator,Mechanical,Linear					
	Com	AUC	NPRD-090	-No Details	1061/4.657000
	Com	AUC	NPRD-098	-Pop:42	83/15.082000
	Unk	A	14182-001	-No Details	FR:57.956000

FIGURE 1-3: EXAMPLE OF PART DETAIL ENTRIES

To reduce the size of descriptions used in the detailed section, terms were often abbreviated. Common abbreviations used are given in Table 1-7.

TABLE 1-7: COMMON ABBREVIATIONS

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 NPRD-2016. 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 four-digit FSC prefix 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. For a hypothetical example, the word "Solenoid" is indexed regardless of where the word occurred in the part type description as shown below:

Solenoid

Bracket,**Solenoid** (2-106;3-483)
Inductive Device,Inductor,**Solenoid** (2-484;3-1974)
Plunger,**Solenoid** (2-660;3-2929)
Relay,Contact,Heavy Duty **Solenoid** (2-714;3-3058)
Relay,**Solenoid** (2-719;3-3079)
Solenoid (2-832,833;3-3662,3663)
Solenoid Assembly (2-833,834;3-3665)
Solenoid Assembly,Gun (2-834;3-3665)
Solenoid,Electric (2-833;3-3663)
Solenoid,Electrical (2-833;3-3663,3664)
Solenoid,Linear (2-833;3-3664,3665)
Solenoid,Pressure (2-833;3-3665)
Solenoid,Rotary (2-833;3-3665)
Valve with Actuator,**Solenoid** Control (2-1003;3-4280)
Valve with Actuator,**Solenoid** Control,3-Way (2-1003;3-4280)
Valve with Actuator,**Solenoid** Control,4-Way (2-1003;3-4280)
Valve with Actuator,**Solenoid** Control,Hydraulic (2-1003;3-4280)
Valve with Actuator,**Solenoid** Control,Hydraulic,Fuel (2-1003;3-4280)
Valve with Actuator,**Solenoid** Control,Pneumatic (2-1003;3-4280)
Valve,Hydraulic,**Solenoid** (2-985,986;3-4238)
Valve,**Solenoid** (2-997,998;3-4265,4266,4267,4268,4269,4270,4271,4272)
Valve,**Solenoid**,3/8-In (2-998;3-4272)
Valve,**Solenoid**,Fuel (2-998;3-4272,4273)
Valve,**Solenoid**,Hydraulic (2-998;3-4273)
Valve,**Solenoid**,Start Control (2-998;3-4273)

Page references are listed in parenthesis and separated by commas. For example, in the entry "Relay,Contact,Heavy Duty **Solenoid** (2-714, 3-3058)" shown above, "2-714" refers to Section 2, page 714 and "3-3058" refers to Section 3, page 3058.

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