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Final Technical Report
December 1977

DEVELOPMENT OF NONELECTRONIC PART CYCLIC FAILURE RATES

George F. Guth

Martin Marietta Corporation

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

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APPROVED: Lester J. Gubbins
LESTER J. GUBBINS
Project Engineer

APPROVED: Joseph J Naresky
JOSEPH J. NARESKY
Chief, Reliability & Compatibility Division

FOR THE COMMANDER: John P. Huss
JOHN P. HUSS
Acting Chief, Plans Office

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Martin Marietta Corporation conducted a 12-month program to develop base failure rates and failure rate mathematical models for relays, switches, and connectors. These models are provided in the format of MIL-HDBK-217B and include the model and instructions for its use. More than 10 billion part-hours of operating field data were collected from industrial and Government data sources. Data was analyzed manually and sorted by computer.

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Conclusions are summarized in the revised base failure rates and mathematical models described. Failure rates for connectors and switches show a significant decrease from present rates and, for relays, show a marginal decrease. A mating factor, π_K, has been developed for the connector model, and a stress factor has been added to the switch model.

pi sub K

EVALUATION

This contractual effort is part of the broad RADC Reliability Program intended to provide reliability prediction procedures for military electronic equipment and systems. These prediction procedures are contained in MIL-HDBK-217B for which RADC is the preparing activity. The failure rate models developed in this study will replace the models for switches, relays, and connectors that are presently in MIL-HDBK-217B.

Lester J. Gubbins

LESTER J. GUBBINS
R&M Engineering Techniques Section
Reliability Branch

SUMMARY

The reliability of relays, switches, and connectors, as described in Sections 2.9, 2.10, and 2.11 of MIL-HDBK-217B, was studied from September 1976 to September 1977. Major objectives of this study were to develop base failure rates and failure rate mathematical models using rates in terms of cycles of actuation for relays and switches and in terms of cycles of engagement for connectors. The models can be used in conjunction with base failure rates to apply appropriate environmental, circuit use, application, and packaging factors for estimating device failure rates.

The study was initiated by mailing a survey questionnaire to industrial and Government facilities, followed by telephone contact with survey respondents and personal visits to facilities having the most favorable data response. Simultaneously, in-house equipment data and library data were reviewed. All data collected were programmed into a computer for sorting and analyzed by hand.

Collected data on relays, switches, and connectors were grouped, analyzed, and tested for homogeneity before combination. A 60 percent confidence limit was calculated for all data under evaluation. A complete component type listing was developed for data used to generate operating failure rates for MIL-HDBK-217B.

More than 10 billion part hours of operating data were collected in this study. These data cover relays, switches, and connectors in ground fixed, ground mobile, naval sheltered, airborne inhabited, airborne uninhabited, and space flight environments. Failure rate mathematical models and revised base failure rates were also developed for the relays, switches, and connectors.

PREFACE

Under Contract F30602-76-C-0437, this final technical report for Development of Nonelectronic Part Failure Rates was prepared by the Product Support Engineering Laboratory of Martin Marietta Corporation, Orlando, Florida, for the Rome Air Development Center, Griffiss Air Force Base, New York. Major objectives of this study were to develop base failure rates and failure rate mathematical models for relays and switches in terms of cycles of actuation, and to develop base failure rates and failure rate mathematical models for connectors in terms of cycles of engagement. The relays, switches, and connectors studied are identified in Section 2.9, 2.10, and 2.11 of MIL-HDBK-217B, Reliability Prediction of Electronic Equipment.

The contract was issued in September, 1976, by Rome Air Development Center. Mr. Les Gubbins (RBRT) was the RADC Project Engineer. The period of contract performance was September 1976 to September 1977.

Technical consultation and assistance in acquisition of data was provided by Messrs. Edwin Kimball, Donald Cottrell, William Maynard, Thomas Kirejczyk, Thomas Gagnier, Edward French, and Bradley Olson. In addition, other Martin Marietta study team members were Messrs. Aaron Penkacik, Robert Whalen, Thomas Young, and Mmes. Lynn Westling, Lynn Mercer, and Betty Jean Thomas.

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TABLE OF CONTENTS

Section Page

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SECTION I

INTRODUCTION

MIL-HDBK-217B, "Reliability Prediction of Electronic Equipment", is the current source of reliability prediction models for estimating reliability of proposed equipment designs. However, models in this handbook to predict relay, switch, and connector failure rates have fallen behind current trends and technology.

The purpose of the contract was to revise and update models for predicting failure rates of relays, switches, and connectors. These models have been constructed and validated. They facilitate reliability assessment based on device type, complexity, application, stresses, operational environment, and other significant influence factors. Results of the contractual effort include a complete listing of data collected by component type, methodology for data analysis and modeling, and assumptions and procedures followed for constructing reliability prediction models and failure rate data for incorporation in to Section 2.9 of MIL-HDBK-217B for relays, Section 2.10 for switches, and Section 2.11 for connectors.

SECTION II

DATA COLLECTION

2.1 Literature Review

Data for operating failure rates of relays, switches, and connectors have been collected from contractors, institutions, and Government agencies. A comprehensive literature review was also made to obtain information and pertinent data on the components. Martin Marietta's Technical Information Center (TIC) was researched for up-to-date information. A bibliography, constructed using key words, was formulated and reviewed for applicability. Data sources used in this computer search included Martin Marietta in-house documents and documents listed by other documentation centers, such as the Defense Documentation Center (DDC), NASA Scientific and Aerospace Reports (STAR), and National Technical Information Services (NTIS).

2.2 Data Source Contacts

Upon contract initiation, a list of potential data were generated from sources used in previous study contracts and from Government-Industry Data Exchange Program (GIDEP) memberships. Other suggested sources resulted from consultation with RADC. A total of 560 companies and agencies were on the mailing list for the data survey letter. Of these, answers were received from about 260 companies. Every survey sheet returned was reviewed carefully to determine whether the data would be useful in this study. Each respondent to the survey was contacted by telephone to further detail the amount and type of reliability information available. Where possible, the data were mailed directly to Martin Marietta. In areas where significant data retrieval was possible, visits by Martin Marietta personnel were arranged. During these visits, operational data was reviewed, reduced as necessary, and returned to Martin Marietta for further analysis. A total of 47 data sources were visited, with trips completed to the Northeast, the Midwest, Los Angeles, San Francisco, the Southwest. These trips resulted in the accumulation of the majority of data.

A summary of data sources contributing to this study program is shown in Appendix A.

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SECTION III

FAILURE MODE MECHANISM DATA AND RELIABILITY DESIGN NOTES

Failure mode and mechanism data and design note information were obtained from telephone conversations and visits to major component and system manufacturers, as well as from a broad cross-section of users. The objective of this comprehensive industry survey was to identify problem areas. Failure mode data were collected for various categories of relays, switches, and connectors.

3.1 Relays

3.1.1 General Purpose Relays

The commonly recognized general purpose relay usually has a clapper type armature, leaf springs, and button contacts,with the core pulling directly on the clapper armature and movable contacts attached to the armature (Figure 1). These relays are rated as light duty (up to 2 amperes), medium duty (2 to 10 amperes), and power type (contacts rated for more than 15 amperes). The general purpose relays are relatively low cost components and are generally available from open stock. They have the disadvantages of general design, position sensitivity, and little shock or vibration resistance.

The major failure modes associated with general purpose relays are contamination problems which occur between contacts or between pole pieces and the armature, resulting in failure to make a good connection.

3.1.2 Dry-Reed Relay

In the dry-reed relay, an electromagnet generates flux that acts directly on the contacts with no mechanical linkages. Two elements, in a sealed glass envelope, are attracted to each other due to the flux generated in the coil, and they complete an electrical circuit. This relay is shown in Figure 2.

This relay switch is inherently a low-current, low-voltage device. Because of low contact pressures and a small gap between contacts, the dry-reed relay has limited use in vibration and shock environments.

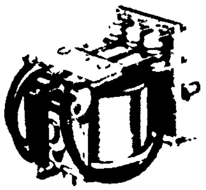

Figure 1. General Purpose Relay

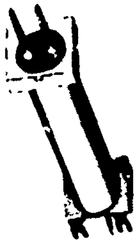

Figure 2. Dry-Reed Relay

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Failures most frequently result from contamination problems affecting contact performance and hampering the reed action. Random contact sticking is caused by tiny magnetic wear fragments at the contact gap. Arcing across the contacts causes metal transfer, resulting in spike and crater formation that produce sticking contacts.

Dry-reed relays require careful handling. Switch contact members extend beyond each end of the glass capsule and are used as switch terminals. Bending, cutting, or heating the leads can change the sensitivity of the switch. They are also affected by other magnetic fields. Stray magnetic fields in the order of 5 to 10 gauss can cause reed relays to malfunction. The operation of one dry-reed relay adjacent to another can change its sensitivity.

3.1.3 Mercury Wetted Contact Relays

In this type of switching relay, electrical contacting is accomplished by mercury-to-mercury contact. The contacting faces are renewed by capillary action, which draws a film of mercury over the surfaces of the contact switching members when the movable contact member is moved from one transfer position to the other (Figure 3). No solid metal to solid metal contacting takes place, and the contacts are actually renewed for each operation.

These relays are position sensitive and must be used in the upright position with less than a 30 degree tilt from the vertical. Another disadvantage is that it is temperature sensitive at low temperatures. Mercury becomes solid at -37.8°F, and failure occurs in this range of temperature.

3.1.4 Mercury Wetted Reed Relays

Mercury wetted reed relays are basically similar to dry-reed relays, except that mercury has been added to the reed capsule during manufacture. Contacting takes place from mercury film to mercury film (Figure 4). Characteristics of this type relay are similar to those in mercury wetted contact relays, with vertical positioning and low temperature sensitivity being the major disadvantages.

3.1.5 Magnetic-Latching Relays

Magnetic-latching relays are armature type electromagnetic relays in which latching is accomplished by utilizing permanent magnets in conjunction with the normal soft-iron circuit. The permanent magnet flux holds the armature in the operated condition after electromagnetic coil energy has been removed (Figure 5). They are all dc relays that must either be polarized or require reverse polarity for operation. They can be in open or sealed versions, but sealed versions are recommended to prevent the permanent magnet from picking up iron particles that might interfere with operation. Relays of this type are generally applicable to memory applications, overload response, and as an aid in resistance to vibration and shock.

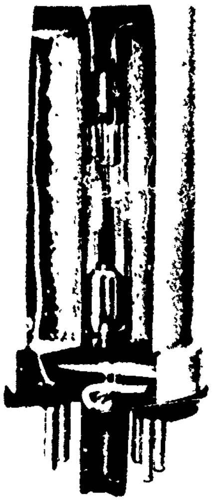

Figure 3. Mercury Wetted Contact Relay

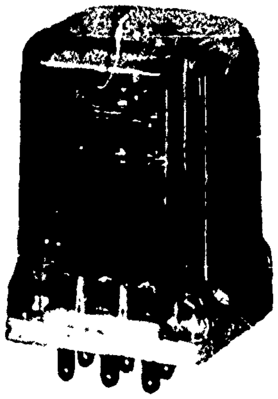

Figure 5. Magnetic Latching Relay

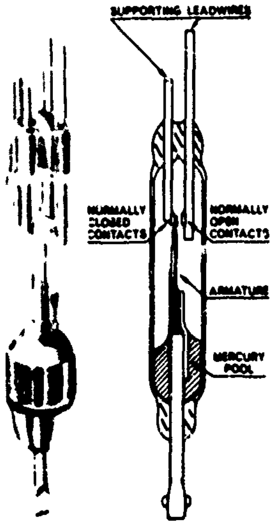

Figure 4. Mercury Wetted Reed Relay

3.1.6 Solenoid-Actuated Relays

Solenoid actuation of relay contacts is generally used where relatively large movement of the contacts is desirable, or where a large amount of contact pressure is required. Solenoid relays are usually considered as on-off devices and are not generally used in applications where precise pick-up voltage or sensitive operation is required (Figure 6).

Solenoid relays can be operated with ac or dc voltage. In ac operation, the change in impedance of the solenoid due to the closing of the armature produces an in-rush surge current much larger than rated current for a short duration. The dc operation allows the current to build up to rated value during energization with no overshoot. Protective devices, such as resistance/capacitance (RC) networks, diodes, or short-circuited secondary windings, are required to absorb energy when the solenoid is disconnected to prevent high voltage transients from discharging through the disconnecting gap or bleed off through the insulation.

3.1.7 Thermal Time Delay Relays

Thermal relays have a heating element to provide a temperature differential for thermal expansion and consequent movement to actuate the contacts (Figure 7). Time is required for the element to heat and attain desired temperature, so these relays can be used for time-delay functions. Thermal relays are voltage-sensitive devices that operate equally well on ac or dc voltage.

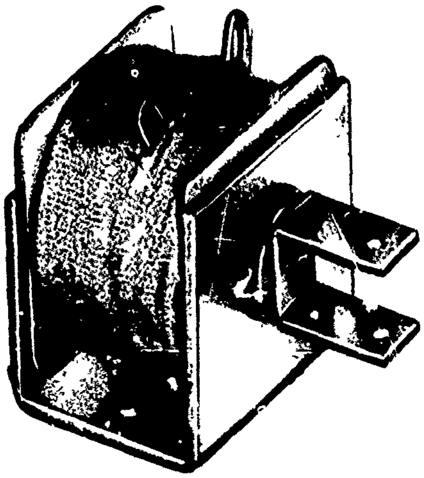

Figure 6. Solenoid-Actuated Relays

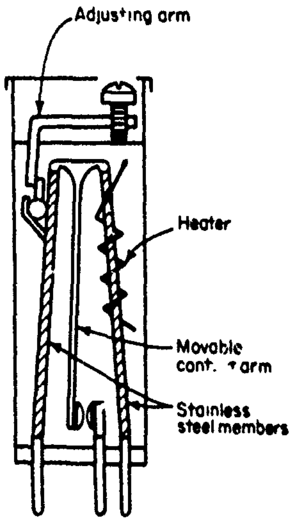

Figure 7. Thermal Time Delay Relay

3.1.8 Power Type Relays

Power relays resemble the general purpose relay, except they are larger (Figure 8). The insulation is thicker, and the terminals are larger. Contacts in power relays are capable of handling heavy current and highly inductive loads. The most widely used contact materials are silver-cadmium oxide and tungsten. These materials are well suited for heavy motor loads in which the inrush current may be five to six times the steady state current. This type of contact material is well suited for power applications, but it should be avoided for low energy applications.

3.2 Switches

3.2.1 Snap Action (Toggle or Push Button)

A snap action switch has a specially formed and prestressed main spring or blade (Figure 9). By prestressing, the center section of the bipositional blade is compressed, but the two outside sections are in tension, causing it to remain in an unoperated or normal position. Depressing the center section by means of a plunger rapidly changes the blade to operated position. This action provides good contact pressure, allowing heavier load currents through the switch. Advantages of this type switch are:

- High contact pressure
- Fast transfer times
- Variety of operating forces
- Good repeatibility, due to only one moving part
- No wear points and long life in the one-piece blade.

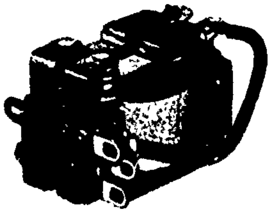

Figure 8. Power Relay

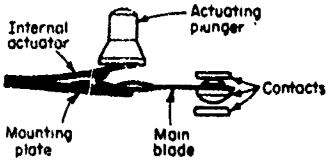

Figure 9. Snap Action Switch

The major contributor to switch failures is the presence of contamination, either as particulate matter or as corrosion. Particulate matter can be solder balls, metal flushings, etc., which can result in wedging or jamming of the operating parts of the switch. Nonconductive material can also be present within the switch, such as flashings from case material. Corrosion is usually the result of sulfides or halides that occur on contact surfaces. These materials are caused by reaction with the sulfur compounds in industrial locations.

3.2.2 Push Button (nonsnap action)

Push button switches are available with the contacts that remain operated after the button has been depressed and with nonmaintained operation after finger removal (nonlatching), as shown in Figure 10. In most cases, visual observation is required to determine whether the switch is in the operated state. Indicating lamps are used with push button switches, either separate or self-contained. Contact ratings and switch life vary between switch types and vendors so that it is difficult to generalize push button switch data.

3.2.3 Rotary Selector Switches

The rotary switch is a manually operated multideck switch offering a varying number of contacts per deck (Figure 11). Contacts of the rotary switch are formed into double finger grips that provide good contact pressure and wiping action that provides low and constant contact resistance. Characteristics of the switch are determined by the shape of the rotor, which rotates with the shaft, to switch from one contact to another. The rotor may contain single or multiple notches, tabs, or combinations of both. The tab is a radial projection of metal designed to touch the short terminal contacts. The notch is a cutout designed to avoid contact with the short terminals but to make

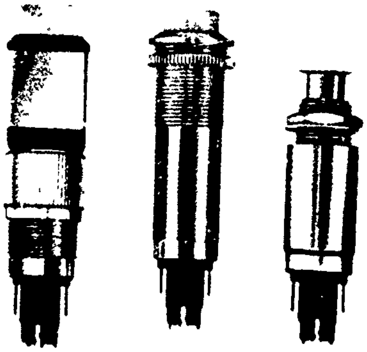

Figure 10. Push Button Switch

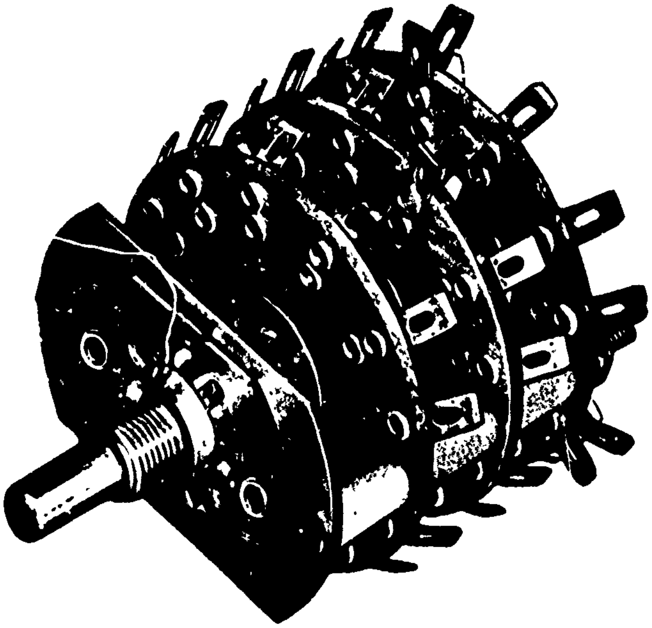

Figure 11. Rotary Switch

contact with the long terminals. Tab and notch widths are designed so that adjacent contact terminals are either momentarily bridged or so that a complete circuit break is made as the switch is moved from one position to the next. Bridging circuits are usually referred to as shorting, and non-bridging circuits as non-shorting. Many switching combinations are available with the number of poles, throws, and decks utilized in each switch. Common failure modes of rotary switches are jammed shafts, cracked wafers, and contact contamination.

3.3 Connectors

3.3.1 Rectangular Connectors

Rectangular connectors generally fall into two generic types: rack and panel, and plug and receptacle. A wide variety of rectangular connectors are available, from rugged heavy-duty types to very-high-density, light-duty types. Contact ratings depend on contact size.

One type of connector is the heavy-duty connector, which is suitable for heavy sliding drawer applications. This connector is available with solder, taper pins, and crimp/removable contacts (Figure 12). The miniature rectangular connector is used very widely. It is available as a plain rack and panel connector with polarizing guide pins (Figure 13). Another variation of the miniature rectangular connector utilizes a center jackscrew to provide positive connection (Figure 14). The general purpose rectangular connector is available with 12 gage, 16 gage, and 20 gage contacts, making it useful for a combination of power and signal connections in the same connector. Contact types can be molded in with solder terminations, or removable with crimp terminations. The D subminiature series connector is another type of rectangular connector in common usage (Figure 15). Pin arrangements are available from 9 to 50 contacts in size 20. Other types of rectangular connectors available are Jones connectors, micro ribbon connectors, and miniature rectangular connectors with floating molded inserts.

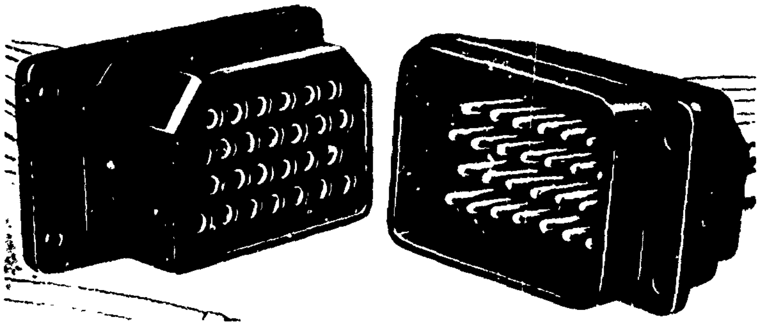

Figure 12. Heavy-duty Connector

Figure 13. Miniature Rectangular Connector

Figure 14. Center Jackscrew Miniature Rectangular Connector

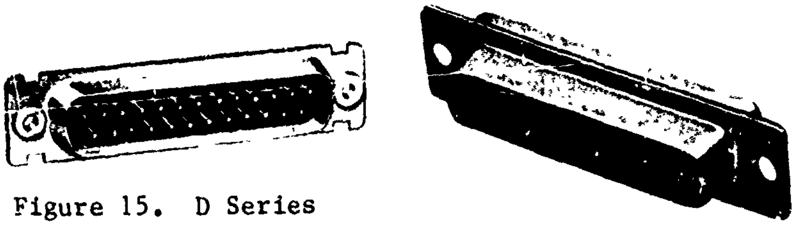

Figure 15. D Series Subminiature Connector

Rectangular rack and panel connectors with removable contacts have the capability to intermix various sizes of pin and socket contacts, as well as miniature and subminiature coaxial contacts, within the same connector. Another advantage is the ability to change from single wire leads to twisted pairs if there is a noise problem in the circuit.

Three military specifications cover the rectangular connectors most commonly used:

- MIL-C-28748 "Connectors, Electrical, Rectangular, Rack and Panel, Solder Type and Crimp Type Contacts"
- MIL-C-83733, "Connectors, Electrical, Miniature, Rectangular Type, Rack to Panel, Environmental Resisting, 200°C Total Continuous Operating Temperature"
- MIL-C-24308, "Connectors, Electrical, Rectangular, Miniature, Polarized Shell, Rack and Panel".

3.3.2 Circular Connectors

Circular connectors consist of two parts, a plug assembly and a receptacle assembly mated with a coupling device that is part of the plug assembly. Coupling methods include a threaded coupling ring, a bayonet lock, or push-pull coupling. The plug is usually movable, while the receptacle remains fixed. Connector contacts are held in place by a dielectric insert which insulates each contact from another.

A common connector is one covered by MIL-C-5015 (Figure 16). This connector is the standard AN type connector and is available in six types of connector (wall-mounting receptacles, cable receptacles, box-mounting receptacles, quick-disconnect plugs, straight plugs, and angle plugs). The connector contacts may be either solder or removable crimp types. The connectors are rated for operation from -55 to 125, 175 or 200°C, depending on class. These connectors are for use in electronic, electrical power, and control circuits.

Miniature circular connectors are included under MIL-C-26482 (Figure 17). This specification covers the general requirements for two series of environment-resisting, quick-disconnect, miniature circular electrical connectors. Each series contains hermetic receptacles. Series 1 is a connector which is bayonet-coupled, with solder or front release [illegible] connections. It is temperature rated at 125°C. Series 2 is also a bayonet-coupled connector, with rear release crimp removable contacts. It is temperature rated at 200°C.

Another type of circular connector covered under a military specification is MIL-C-38999 (Figure 18). This specification includes two series of miniature, high density, quick-disconnect, bayonet-coupled connectors. They are capable of operation within a temperature range of -65 to 200°C. Both series employ rear release removable pin and socket contacts with crimp termination. Series I provides electrical continuity between mated shells prior to contact engagement and has the contacts located for protection from handling damage and inadvertent electrical contact. Series II provides low silhouette for minimum size and weight and includes connectors that provides shell-to-shell electrical continuity when mated. Restrictions on the use of the connectors are:

- Series I - Army: Limited to environmentally protected applications on ground equipment

  Navy: Not for shipboard-jacketed cable applications.

Air Force: No restrictions except for Class P, which is inactive for new design.

- Series II -Army: Not for use.

Navy: Not for use.

Air Force: No restrictions except for Class P, which is inactive for new design.

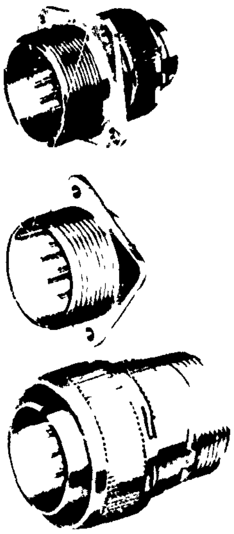

Figure 16. MIL-C-5015 Connectors

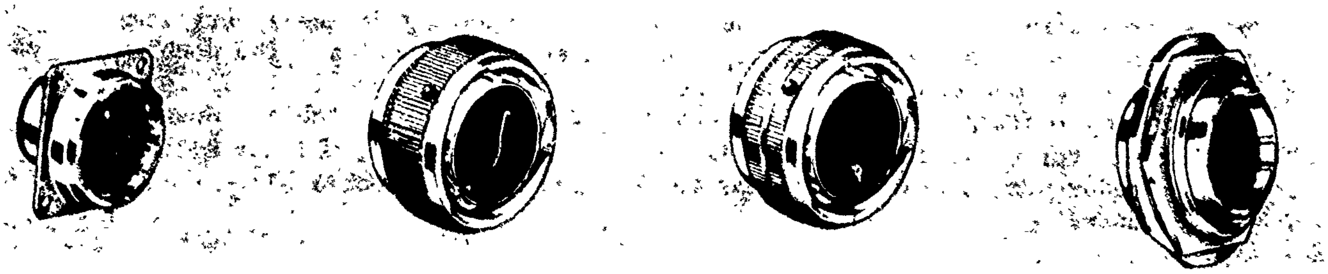

Figure 17. MIL-C-26482 Connectors

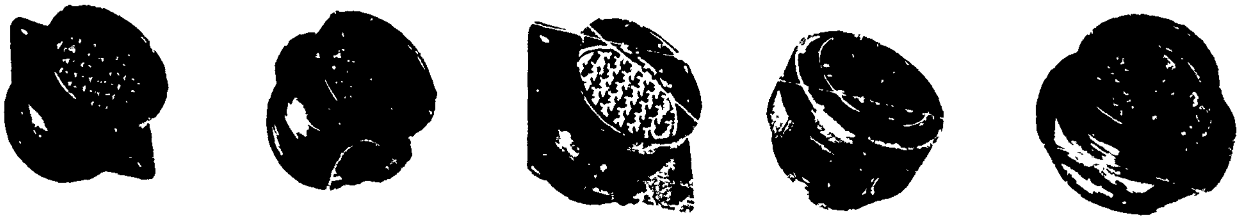

Figure 18. MIL-C-38999 Connectors

MIL-C-81511 (Figure 19) covers a miniature, high contact density cylindrical connector. It provides environmental resistance and prevents contact damage by recessing contacts beyond the outer shell and providing closed entry hard inserts for socket contacts.

One predominant failure mode associated with circular connectors is cocked, bent, or broken pins or contacts within the connector. This condition can be reduced with use of connectors that require all connections to be made simultaneously using special "scoop proof" connectors. These connectors align the mating shells prior to making contact with the pins and sockets within the connector. Contamination may also appear from conditions in which the pin fails to seat correctly in the socket. Contamination may result in a open or high resistance electrical circuit.

3.3.3 RF Coaxial Connectors

Radio frequency (RF) connectors normally consist of only one pin and socket connector coaxially mounted within a shell. Physical features are similar to the cylindrical connector except for construction of the female contact and rigidity of the insert material.

Three basic areas in a coaxial connector design are important in achieving stable performance in the frequency ranges required and under the environmental conditions observed. These are dielectric insert material, coupling mechanism, and assembly procedure.

Coupling of RF coaxial connectors may be accomplished by screw-thread, bayonet-coupling, and push-on connections. The coupling device is critical to stable electrical performance and environmental protection. The double-lead coarse thread design provides the best features of coupling. It is rugged, non-fouling, vibration resistant, and electrically stable. Assembly techniques for coaxial cable utilize the crimp extensively, which simplifies the procedure for assembly and improves mechanical and electrical performance.

RF connectors vary in size and are classified into four types·

- Miniature connectors
- Small connectors
- Medium connectors
- Large connectors.

Small connectors are used with flexible coaxial cables in protected and exposed environments. Some types of small connectors are the MHV (Figure 20), the BNC (Figure 21), and TPS (Figure 22). These connectors are bayonet-coupled. The TNC type is similar to the BNC, but is a thread-coupled connector. Small connectors are not especially rugged and should be used with care.

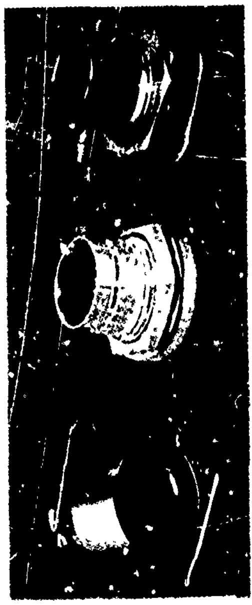

Figure 19. MIL-C-81511 Connectors

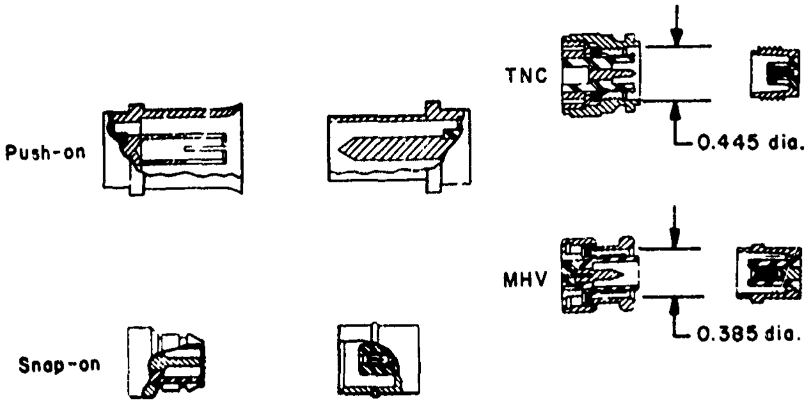

Figure 20. MHV-Type Connector

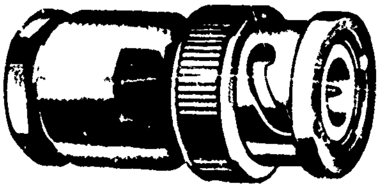

Figure 21. BNC-Type Connector

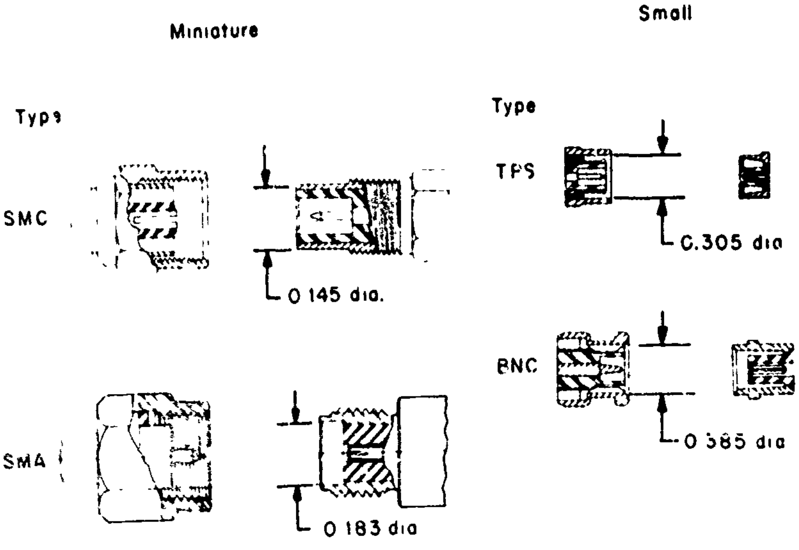

Figure 22. TPS-Type Connector

Medium connectors are used for flexible and semi-rigid cable. They are generally used as interconnections between an antenna and receiver or transmitter. The C type connector (Figure 23) is a two-point bayonet connector, while the N (Figure 24) and SC (Figure 25) types are fine-thread coupling. These connectors are not exceptionally rugged but perform well where environmental hazards are not overly severe.

While there is a great variety of large connectors, many are special types or for special applications. Some generally used connectors are the LC (Figure 26), QM, and QL (Figure 27). The QM and QL are rugged connectors and utilize a course double lead-thread coupling. Other large connectors utilized in RF applications are the BN, HN, LN, QDC, SKL, and UHF types. These are available from manufacturers, but are generally decreasing in usage.

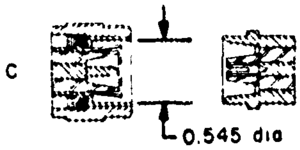

Figure 23. C-Type Connector

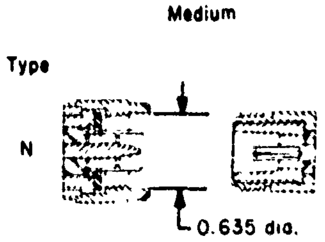

Figure 24. N-Type Connector

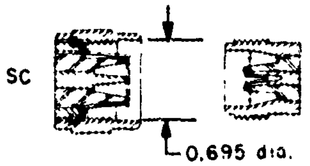

Figure 25. SC-Type Connector

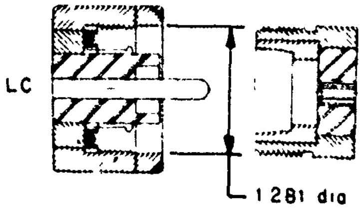

Figure 26. LC-Type Connector

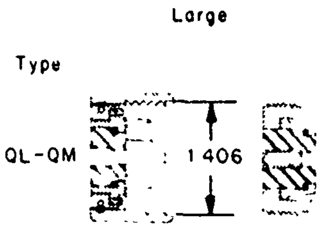

Figure 27. QL and QM-Type Connectors

Military RF connectors are specified basically in MIL-C-39012, "Military Specification, Coaxial Radiofrequency Connectors." Connector types included in MIL-C-39012 are:

- QNC
- SMA
- SMB
- QSC
- QM
- QL
- SC
- N
- C
- BNC
- TNC
- OSC
- SMC

MIL-C-3643 covers the series HN type connector. The series LC connector is covered under MIL-C-3650. Other MIL Specs for RF coaxial connectors are:

- MIL-C-3607, "General Specification for Series Pulse Radiofrequency Coaxial Connectors"
- MIL-C-3655, "General Specification for Series Twin Radiofrequency Coaxial Connectors"
- MIL-C-25516, "General Specification for Miniature Coaxial Electrical Connectors, Environmental Resistant Type."

SECTION IV

DATA ANALYSIS

4.1 Statistical Analysis

As part of this study, data were collected on relays, switches, and connectors. The data were analyzed and summarized in the form of failure rates for individual components. Basic ground rules and assumptions were established for these analyses, along with defining statistical tests for combining the data. Numerical examples are given for the statistical tests and the calculation of failure rates.

4.2 Calculation of Failure Rates

All failure rates were calculated at the upper single-sided 60 percent confidence level. Before calculating failure rates, component data were identified as time- or failure-truncated. As far as could be determined, no failure-truncated data were received. All data were assumed to be time-truncated. The upper confidence level failure rate was calculated by using the component part-hours and the 40 percent chi-square value at 2r+2 degrees of freedom. If the data had been failure-truncated, the value would be obtained at 2r degrees of freedom. The general equation used for calculating the failure rate was obtained from Reference 1 and is:

$$\frac{\chi^2(\alpha, 2r+2)}{2T} = \text{Upper single-sided confidence level}$$

Where:

r = The number of failures and determines the degree of freedom coordinate used in determining χ^2 (chi-squared)

$2r+2$ = Total number of degrees of freedom

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

$1-\alpha$ = Confidence level (60 percent in this study)

T = Total number of component part-hours.

As an example, three failures occurred during 133.679×10^6 part hours of ground fixed operation were used to calculate the failure rate at the upper single-sided 60 percent confidence level on connectors conforming to MIL-C-5015. A table from Reference 1 was used as the source of the chi-squared value:

$$\text{Failure Rate (60 percent confidence)} = \frac{\chi^2(0.40, 8)}{2T} = \frac{8.35}{267.358 \times 10^6}$$

$$\text{Failure Rate (60 percent confidence)} = 0.031 \text{ failures}/10^6 \text{ hours.}$$

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Since the reference statistical tables are limited to chi-squared values up to 100 degrees of freedom, it was necessary to calculate an estimate of the chi-squared percentile points whenever more than 49 failures were observed in the data. In accordance with Reference 1, χ^2 confidence level values are approximated by:

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

Where:

χ^2_p = Approximated Chi-Squared value

f = Total number of degrees of freedom

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

Using actual data from "D" type insert connectors in the airborne uninhabited environment, which had 363 failures in 1,160.87 million part-hours of operation, the failure rate is calculated as:

$$\text{Failure Rate (60 percent confidence)} = \frac{1/2(0.25335 + \sqrt{2 \times 728-1})^2}{2\ (1{,}160.87 \times 10^6)}$$

$$\text{Failure Rate (60 percent confidence)} = 0.318 \times 10^{-6} \text{ failures/hou}$$

4.3 Part Classes and Failure Rates

To update Sections 2.9, 2.10, and 2.11 of MIL-HDBK-217B, failure rate mathematical models and base failure rates were revised for relays, switches, and connectors utilized in military equipment. Field operational data and information on these components were collected, studied, analyzed, and categorized by specific component type and environmental application. Results are presented in Tables 1-3. No component testing was performed to obtain data, but an extensive data survey and collection effort was undertaken to locate and obtain necessary data. Components studied were typical of those used in military ground, airborne, satellite, ground mobile, and shipboard applications.

The data listed are in the form of failures per million hours and are calculated at the point estimate where failures occurred, and also at the 60 percent upper confidence level for all categories. Failure rates were not calculated when less than 1.0 million part-hours of data were collected. The environmental abbreviations are the same as MIL-HDBK-217B, except for airborne values, where an additional letter designation was added. The subscript T on airborne abbreviations designates data generated in subsonic type aircraft, such as transport and cargo planes, while the subscript F has been reserved to designate supersonic aircraft, such as fighters and interceptors.

TABLE 1

Summary of Operating Data Collected on Connectors by Type and Environment

Insert Type	Environment	Failures	Part Hours (x 10^6)	Failure Rate Point Estimate (x 10^{-6})	 60 Confidence (x 10^{-6})
B	Ground fixed	26	5123.56	0.005	0.0054
C	Ground fixed	4	187.7	0.021	0.0278
D	Ground fixed	38	153.17	0.248	0.263
B	Naval sheltered	0	31.99	-	0.029
D	Naval sheltered	1	7.42	0.135	0.272
B	Airborne uninhabited	0	4.792	-	0.19
C	Airborne uninhabited	6	49.531	0.121	0.148
D	Airborne uninhabited	363	1160.87	0.312	0.318
B	Ground mobile	0	0.035	-	-
D	Ground mobile	0	0.028	-	-
B	Airborne inhabited	0	2.48	-	0.369
A	Airborne inhabited	0	0.116	-	-
C	Airborne inhabited	0	0.015	-	-
D	Airborne inhabited	0	0.10	-	-
B	Space flight	0	63.859	-	0.014
C	Space flight	1	12.584	0.08	0.16
D	Space flight	0	25.478	-	0.035

TABLE 2

Summary of Operating Data Collected on Relays by Type and Environment

Part Type	Environment	Failures	Part-Hours (x 10^6)	Failure Rate Point Estimate (x 10^{-6})	 60. Confidence (x 10^{-6})
General purpose	Ground fixed	54	242.86	0.22	0.23
High voltage	Ground fixed	0	4.617	-	0.198
Reed	Ground fixed	15	3.974	3.77	4.2
Thermal	Ground fixed	2	4.596	0.435	0.676
Armature (lower quality)	Ground mobile	0	4.767	-	0.19
Armature (lower quality)	Ground benign	113	19.25	5.07	6.04
General purpose	Ground benign	0	3.77	-	0.243
Reed (lower quality)	Ground benign	45	28.0	1.6	1.69
MIL-R-6016	Naval sheltered	1	2.571	0.388	0.786
General purpose	Naval sheltered	5	15.5	0.323	0.406
Thermal	Naval sheltered	611	1765.17	0.346	0.351
MIL-R-39016	Airborne inhabited	21	392.04	0.054	0.058
MIL-R-6016	Airborne inhabited	1	23.41	0.043	0.086
Latching relay	Space flight	0	5.133	-	0.178

TABLE 3

Summary of Operating Data Collected on Switches by Type and Environment

Part Type	Environment	Failures	Part-Hours (x 10^6)	Failure Rate Point Estimate (x 10^{-6})	 60% Confidence (x 10^{-6})
Push button	Airborne inhabited	1	9.921	0.10	0.203
Rotary	Airborne inhabited	0	4.47	-	.204
Thermostat	Airborne inhabited	7	1.163	6.02	7.22
Toggle	Ground fixed	0	4.329	-	0.211
Rotary	Ground fixed	3	26.61	0.112	0.157
Push button	Ground fixed	3	23.84	0.125	0.175
Rotary (lower)	Ground fixed	6	26.68	0.224	0.275
Sensitive	Ground fixed	0	2.99	-	0.306
Thermostat	Ground fixed	0	38.45	-	.024
Reed (lower)	Ground mobile	2	16.252	0.123	0.19
Toggle	Naval sheltered	0	1.934	-	0.473
Toggle (lower)	Naval sheltered	4	367.3	0.01	0.014
Thermostatic	Naval sheltered	0	4.137	-	0.22
Sensitive	Space flight	0	5.48	-	0.157

Component failure is defined as the inability of the part to properly perform its intended function, resulting in its repair or replacement. When detailed failure information was available, all secondary failures, premature removals, and procedural and personnel errors were censored.

Since most of the data obtained listed only the quantity of failures and experience with no elaboration of failure modes and mechanisms, much of the data are dependent on the source's ability to properly categorize their equipment failures. As a result of direct contact with most of the sources, the majority of data contributed to this study were felt to have been properly screened by contributors.

SECTION V

FAILURE RATE MODELS

Failure rate models for connectors, relays, and switches described in Sections 2.9, 2.10, and 2.11 of MIL-HDBK-217B were reviewed with respect to the operating failure rates derived from field data collected during the study. Many variations were found to exist between failure rates derived from MIL-HDBK-217B and those derived from field data. In most cases, operating failure rates were lower than those in MIL-HDBK-217B.

5.1 Connector Failure Rate Prediction Models

5.1.1 Connector Base Failure Rate (λ_b) Evaluation

Failure rates were calculated for connectors in each environment for which sufficient data had been collected. Each set of connectors was categorized within environment by type of insert material used. Operating failure rates for each set of data were calculated at point estimate (where failures had occurred) and at the upper 60 percent confidence level in every case. Results of these calculations are summarized in Table 4. The failure rates calculated at the 60 percent confidence level are used for comparisons and further computations presented in this report.

TABLE 4

Observed Failure Rate
(Failures/Million Hours)

Environment	Insert Type			
	A	B	C	D
Ground fixed	-	0.0054	0.0278	0.263
Naval sheltered	-	0.029	-	0.272
Airborne uninhabited	-	0.19	0.148	0.318
Airborne inhabited	-	0.369	-	-
Space flight	-	0.014	0.16	0.035

The present mathematical model used to determine the predicted failure rate of a connector as shown in Section 2.11 of MIL-HDBK-217B is:

$$\lambda_p = \lambda_b (\pi_E \times \pi_P) + N \lambda cyc$$

where:

λ_b = base failure rate

π_E = environmental factor

π_p = pin density factor

N = number of active pins

λcyc = cycling rate factor.

Using this equation and substituting parameters from operating field data, a typical failure rate is calculated for a connector ground fixed enviroument having a "B" type insert material, and 50 active pins. The ambient temperature is 25°C, and the current through the 20 gage contact is 2.5 amperes. Cycling rate is less than 40 cycles/1000 hours.

Constants are derived from MIL-HDBK-217B are:

π_E = 4.0 (for ground fixed environment)

π_p = 9.5 (for 50 active pins)

$\lambda_b = 0.009 \times 10^{-6}$ (for "B" material at 30°C)

$\lambda cyc = 0$ (for cycling rate < 40 cycles/1000 hours).

N = 50

Substituting these constants into the failure rate model results in:

$$\lambda_p = 0.009 \times 10^{-6} (4 \times 9.5) + 0 (50)$$

$$\lambda_p = 0.342 \times 10^{-6} \text{ failures/hour.}$$

This value is the predicted failure rate for the given connector.

Failure rates were calculated in the same manner for each of the categories of connectors listed in Table 4. Predicted failure rates for these connectors are shown in Table 5.

TABLE 5

Predicted Failure Rates From MIL-HDBK-217B
(Failures/Million Hours)

Enviornment	Insert Type			
	A	B	C	D
Ground fixed	-	0.342	0.32	3.16
Naval sheltered	-	0.404	-	3.78
Airborne uninhabited	-	3.39	0.467	6.03
Airborne inhabited	-	0.608	-	-
Space flight	-	0.076	0.16	0.655

Comparing predicted failure rate to observed failure rate shows that the observed field failure rate was less than the predicted failure rate from MIL-HDBK-217B in each case except one. These comparisons are shown in Table 6 and indicate improvement ranging from 1.0 to 63.3. The demonstrated improvement in the reliability of each set of connectors implies that the base failure rate has been improved. Using the ground fixed environment as a normalizing value, the improvement factor is 16.0. Thus, the scaling factor A in the base failure rate equation ($\lambda_b = Ae^x$) is reduced from 0.324 to 0.02 for "A" type insert material, from 6.9 to 0.431 for "B" type insert material, from 3.06 to 0.19 for "C" type insert material, and from 12.3 to 0.77 for "D" type insert material.

TABLE 6

Ratio of Predicted Failure Rates
to Observed Failure Rates

Environment	Insert Type			
	A	B	C	D
Ground fixed	-	63.3	15.20	12.74
Naval sheltered	-	13.9	-	28.00
Airborne uninhabited	-	21.0	3.15	18.97
Space flight	-	5.43	1.0	18.7

5.1.2 Connector Cycling Factor (π_K) Evaluation

Connectors are subjected to stress and wear with each mating or unmating of the connector. These conditions relate directly to failure rate of the connector.

In the present mathematical model for connectors in Section 2.11 of MIL-HDBK-217B, failure rate due to mating and unmating of connectors is added to the connector failure rate and depends on the cycling rate and number of active pins in the connector. The cycling failure rate is described as:

$$\lambda cyc = 0.001\ e^{(f/100)}$$

where f is the cycling rate in cycles/1000 hours (Table 7).

This factor is ignored for connectors experiencing cycling rates $\leq$ 40 cycles/ 1000 hours.

Evaluation of cycling data (Reference 2) on all types of connectors showed a definite relationship between mating/unmating cycles and environmental usage of the connector. In the space flight environment, one connection was assumed, and a multiplying factor for the cycling of connectors was developed. This factor was labeled π_K. The base factor π_K for space flight was set to 1.0. Table 8 indicates the frequency of mating/

TABLE 7

Cycling Failure Rate Versus Cycling Rate from Existing MIL-HDBK-217E

f	λ_c	f	λ_c
10	0.0011	260	0.0135
20	0.0012	270	0.0149
30	0.0013	280	0.0164
40	0.0015	290	0.0182
50	0.0016	300	0.0201
60	0.0018	310	0.0222
70	0.0020	320	0.0245
80	0.0022	330	0.0271
90	0.0025	340	0.0300
100	0.0027	350	0.0331
110	0.0030	360	0.0366
120	0.0033	370	0.0404
130	0.0037	380	0.0447
140	0.0041	390	0.0494
150	0.0045	400	0.0546
160	0.0050	410	0.0603
170	0.0055	420	0.0667
180	0.0060	430	0.0737
190	0.0067	440	0.0815
200	0.0074	450	0.0900
210	0.0082	460	0.0995
220	0.0090	470	0.1099
230	0.0100	480	0.1215
240	0.0110	490	0.1343
250	0.0122	500	0.1484

Note: $\lambda_c = 0.001\, e^{(f/100)}$
where λ_c is failures/ million hours and f is cycling rate in cycles/ 1000 hours.

TABLE 8

Frequency of Mating/ Connecting Cycles

Environment	Operating Hours Between Mating
Space flight	>2000
Naval	2000
Ground	200
Airborne	20

unmating cycles determined from the evaluation of cycling data. The frequency of cycling connectors is set at 0 for space flight and increases to once every 20 operating hours for airborne equipment. Evaluation of predicted failure rates (reduced by a factor of 16) indicates a range of from 1.0 to 4.0 for π_K. This range was determined from observation of the cycling rate of the connectors and the effects of the cycling rate on the predicted failure rates. Table 9 lists the π_K factors derived in terms of mating cycles/1000 hours. The new factor includes all cycling rates. From 0 to 1 cycle every 20,000 operating hours, the factor π_K is 1.0, not affecting the base failure rate. Between 1.0 cycle every 20,000 hours and 1 cycle every 2000 hours, π_K becomes 1.5. Between 1 cycle every 2000 hours and 1 cycle every 200 hours, π_K is 2.0. From 1 cycle every 200 hours to 1 cycle every 20 hours, π_K is 3.0. For cycling rates above 50 cycles/1000 hours, the π_K is 4.0.

TABLE 9

Coupling Factors π_K

Cycles/1000 Hours	π_K
0 - 0.05	1.0
0.05 - 0.5	1.5
0.5 - 5.0	2.0
5.0 - 50.0	3.0
>50	4.0

5.1.3 Connector Pin Density Factor (π_p) Evaluation

π_p, as determined in MIL-HDBK-217B, is a factor which increases exponentially as the number of active pins in the connector increase. π_p modifies the base failure rate. The equation used to determine π_p is:

$$\pi_p = e\left(\frac{N-1}{N_o}\right)^q$$

where:

N_o = 10

q = 0.51064

N = number of active pins.

π_p was evaluated for its contribution to the total failure rate prediction and was found to be not substantially changed. The unchanged value of π_p in the base model is therefore valid.

5.1.4 Connector Failure Rate Model

With development of the π_K factor as a multiplicative modifying factor, a new failure rate model was developed:

$$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K)$$

where:

λ_p = predicted failure rate

λ_b = base failure rate

π_E = environmental factor

π_P = pin density factor

π_K = cycling rate factor.

Using the developed failure rate model, failure rates were calculated in the same environmental categories as listed in Table 1. Table 10 lists calculated failure rates and compares them to the observed failure rates from field data.

TABLE 10

Observed Failure Rates versus Predicted Failure

Insert Type	Environment	Failure Rate Observed ($\times 10^{-6}$)	 Predicted ($\times 10^{-6}$)
B	Ground fixed	0.0054	0.043
C	Ground fixed	0.0278	0.044
D	Ground fixed	0.263	0.35
B	Naval sheltered	0.029	0.037
D	Naval sheltered	0.272	0.383
B	Airborne uninhabited	0.19	0.635
C	Airborne uninhabited	0.148	0.296
D	Airborne uninhabited	0.318	0.968
B	Airborne inhabited	0.369	0.109
B	Space flight	0.014	0.0[illegible]
C	Space flight	0.16	0.0055
D	Space flight	0.035	0.02

A typical calculation is performed for the "D" type insert connector in the ground fixed environment. Ambient temperature is 30°C, and current stress through the contacts is assumed to be 50 percent. Active pin density is 30 pins, and the cycling rate is one mating/unmating cycle every 200 operating hours. These constants apply:

$\pi_E = 4.0$

$\pi_p = 5.6$

$\pi_K = 2.0$

$\lambda_b = 0.0078 \times 10^{-6}$ failures/hour.

Substituting the constants into the mathematical model equation results in:

$$\lambda_p = 0.0078 \times 10^{-6} (4.0 \times 5.6 \times 2.0)$$

$$\lambda_p = 0.35 \times 10^{-6} \text{ failures/hour}$$

5.1.5 Connector Environmental Factor (π_E)

Examination of failure rates determined using the new mathematical model showed that the environmental factors required further adjustment. Comparison of the failure rates in the ground fixed environment indicated a reduction of the π_E factor should be from 4.0 to 2.0. The naval sheltered environmental factor was found to drop from 4.0 to 3.0. Airborne uninhabited values showed a decrease in π_E from 10.0 to 5.0. Airborne inhabited values showed an increase of 4.0 to 5.0. Space flight values indicated a decreasing π_E factor; however, a review of collected data from the space flight environment showed a minimum amount of data has been collected in this area. Since space flight is a benign environment and there is a minimum of connector mating and unmating, more collected data was expected to show an improved failure rate. Thus, the environmental factor for space flight should remain at 1.0.

The present table in MIL-HDBK-217B lists an environmental factor for lower quality connectors in comparison to military-type connectors. Present values show a quality factor of 1/10 in the ground benign environment, reducing to a factor of 1/2 for the most severe environment (missile launch).

Environmental factors for ground benign environments have little effect on connectors, while factors associated with missile launch greatly affect lower quality connectors. Therefore, the π_E factors for lower quality connectors were revised for each environment to reflect more accurately the severity of the environment with regard to the connector.

The airborne environment was expanded to four categories to separate supersonic aircraft from subsonic aircraft. It is generally accepted that supersonic aircraft are exposed to higher levels of shock, vibration, and acoustic noise, and to a more severe operating temperature range than equipment on other aircraft. Mission duration is usually much shorter for supersonic aircraft.

In this study, only data from the subsonic aircraft equipment were collected. From other studies (References 3 and 4), analyses of data have been made and a factor of 2:1 for supersonic versus subsonic environmental stress was developed. This value was determined to be a good general factor to differentiate between subsonic and supersonic aircraft. The term supersonic aircraft includes fighters and interceptors, while the subsonic category encompasses transport, heavy bomber, cargo, and patrol aircraft. The revised environmental factors are shown in Table 11.

TABLE 11

Revised Environmental Factors (π_E)

Environment	π_E	
	MIL-SPEC	Lower Quality
Ground benign	1.0	1.5
Space flight	1.0	1.5
Ground fixed	2.0	4.0
Naval sheltered	3.0	6.0
Airborne inhabited $_T$	5.0	15.0
Airborne uninhabited $_T$	5.0	15.0
Ground mobile	5.0	15.0
Naval unsheltered	9.0	19.0
Airborne inhabited $_F$	10.0	30.0
Airborne uninhabited $_F$	10.0	30.0
Missile launch	15.0	30.0

5.1.6 Temperature Rise in RF Connectors

Table 2.11-4 of MIL-HDBK-217B presently derives the insert temperature rise for connectors by determining current in the contacts and temperature rise based on contact size and current. This approach is not applicable to RF connectors. RF connectors do not have a significant heat rise due to current flow. Therefore, a standard temperature rise of 5°C was added to the ambient temperature for RF connectors to determine λ_b (base failure rate).

5.1.7 Validation of Revised Failure Rates for Connectors

Failure rates for each category of connectors shown in Table 1 were calculated using the new mathematical model and modified factors:

1 Ground fixed, insert type B

$$\lambda_p = \lambda_b (\pi_E \times \pi_p \times \pi_k)$$

λ_b = 0.00056 (for B material at 30°C)

π_E = 2.0 (ground fixed)

$\pi_P = 9.5$ (for 50 pins)

$\pi_K = 2.0$ (for 5 cycles/1000 hours)

$\lambda_p = 0.0056\ (2.0 \times 9.5 \times 2.0) = 0.021 \times 10^{-6}$ failures/hour

2 Ground fixed, insert type C

$\lambda_p = \lambda_b\ (\pi_E \times \pi_P \times \pi_K)$

$\lambda_b = 0.0041$ (for C material at 30°C)

$\pi_E = 2.0$ (ground fixed)

$\pi_P = 1.36$ (for 2 pins)

$\pi_K = 2.0$ (for 5 cycles/1000 hours)

$\lambda_p = 0.0041\ (2.0 \times 1.36 \times 2.0) = 0.022 \times 10^{-6}$ failures/hour

3 Ground fixed, insert type D

$\lambda_p = \lambda_b\ (\pi_E \times \pi_P \times \pi_K)$

$\lambda_b = 0.0078$ (for D material at 30°C)

$\pi_E = 2.0$ (ground fixed)

$\pi_P = 5.6$ (for 30 pins)

$\pi_K = 2.0$ (5 cycles/1000 hours)

$\lambda_p = 0.0078\ (2.0 \times 5.6 \times 2.0) = 0.175 \times 10^{-6}$ failures/hour

4 Naval sheltered, insert type B

$\lambda_p = \lambda_b\ (\pi_E \times \pi_P \times \pi_K)$

$\lambda_b = 0.00075$ (for B type material at 40°C)

$\pi_E = 3.0$ (Naval sheltered)

$\pi_P = 8.42$ (for 45 pins)

$\pi_K = 1.5$ (for 0.5 cycles/1000 hours)

$\lambda_p = 0.00075\ (3.0 \times 8.42 \times 1.5) = 0.028 \times 10^{-6}$ failures/hour

5 Naval sheltered, insert type D

$\lambda_p = \lambda_b\ (\pi_E \times \pi_P \times \pi_K)$

λ_b = 0.0099 (for D type material at 40°C)

π_E = 3.0 (naval sheltered)

π_P = 6.46 (for 35 pins)

π_K = 1.5 (for 0.5 cycles/1000 hours)

$\lambda_p = 0.0099\ (3.0 \times 6.46 \times 1.5) = 0.288 \times 10^{-6}$ failures/hour

6 Airborne uninhabited, transport, insert type B

$\lambda_p = \lambda_b\ (\pi_E \times \pi_P \times \pi_K)$

λ_b = 0.00075 (for B type material at 40°C)

π_E = 5.0 (airborne uninhabited, transport)

π_P = 21.19 (for 90 pins)

π_K = 4.0 (for >50 cycles/1000 hours)

$\lambda_p = 0.00075\ (5.0 \times 21.19 \times 4.0) = 0.318 \times 10^{-6}$ failures/hour

7 Airborne uninhabited, transport, insert material C

$\lambda_p = \lambda_b\ (\pi_E \times \pi_P \times \pi_K)$

λ_b = 0.0054 (C type material at 45°C)

π_E = 5.0 (airborne uninhabited, transport)

π_P = 1.36 (for 2 pins)

π_K = 4.0 (for cycling 750/1000 hours)

$\lambda_p = 0.0054\ (5.0 \times 1.36 \times 4.0) = 0.147 \times 10^{-6}$ failures/hour

8 Airborne uninhabited, transport insert material D

$\lambda_p = \lambda_b\ (\pi_E \times \pi_P \times \pi_K)$

λ = 0.0112 (for D type material at 45°C)

π_E = 5.0 (airborne uninhabited transport)

π_P = 2.16 (for 7 pins)

π_K = 4.0 (for cycling >50/1000 hours)

$\lambda_p = 0.0112\ (5.0 \times 2.16 \times 4.0) = 0.484 \times 10^{-6}$ failures/hour

9 Airborne inhabited, transport, insert material B

$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K)$

λ_b = 0.00106 (for B type material at 55°C)

π_E = 5.0 (for airborne inhabited, transport)

π_P = 6.46 (for 35 pins)

π_K = 4.0 (for cycling >50/1000 hours)

$\lambda_p = 0.00106 (5.0 \times 6.46 \times 4.0) = 0.137 \times 10^{-6}$ failures/hour

10 Space flight, insert material B

$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K)$

λ_b = 0.00056 (for B type material at 30°C)

π_E = 1.0 (for space flight)

π_P = 8.42 (for 45 pins)

π_K = 1.0 (for 1 cycle/1000 hours)

$\lambda_p = 0.00056 (1.0 \times 8.42 \times 1.0) = 0.0047 \times 10^{-6}$ failures/hour

11 Space flight, insert material C

$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K)$

λ_b = 0.0041 (for C type material at 30°C)

π_E = 1.0 (for space flight)

π_P = 1.36 (for 2 pins)

π_K = 1.0 (for 1 cycle/1000 hours)

$\lambda_p = 0.0041 (1.0 \times 1.36 \times 1.0) = 0.0054 \times 10^{-6}$ failures/hour

12 Space flight, insert material D

$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K)$

λ_b = 0.0078 (for D type material at 30°C)

π_E = 1.0 (for space flight)

π_P = 2.58 (for 10 pins)

π_K = 1.0 (for 1 cycle/1000 hours)

$$\lambda_p = 0.0078\ (1.0 \times 2.58 \times 1.0) = 0.02 \times 10^{-6} \text{ failures/hour}$$

These values are summarized and compared to the observed failure rates in Table 12.

TABLE 12

Observed Failure Rates versus Predicted Failure Rates
Using New Model and New Environmental Factors

Insert Type	Environment	Failure Rate	
		Observed $(\times 10^{-6})$	Predicted $(\times 10^{-6})$
B	Ground fixed	0.0054	0.021
C	Ground fixed	0.0278	0.022
D	Ground fixed	0.263	0.175
B	Naval sheltered	0.029	0.028
D	Naval sheltered	0.272	0.287
B	Airborne uninhabited	0.19	0.317
C	Airborne uninhabited	0.148	0.146
D	Airborne uninhabited	0.318	0.418
B	Airborne inhabited	0.369	0.137
B	Space flight	0.014	0.0047
C	Space flight	0.16	0.0055
D	Space flight	0.035	0.02

5.2 Relay Failure Rate Prediction Models

5.2.1 Relay Base Failure Rate (λ_b) Evaluation

For relays in each environment, failure rates were calculated by categories where sufficient data had been collected. Each group of relays is categorized either by MIL-SPEC classification or part type, as applicable. Operating failure rates for each set of data were calculated at point estimates (where failures had occurred) and at the upper 60 percent confidence level in every case. Results of these calculations appear in Table 13. Failure rates calculated at the upper 60 percent confidence level were used for comparisons and further computations.

The present mathematical model to predict failure rate of a relay appears in Section 2.9 of MIL-HDBK-217B:

$$\lambda_p = \lambda_b\ (\pi_E \times \pi_C \times \pi_{cyc} \times \pi_F)$$

TABLE 13

Observed Failure Rates for Relays
(Failures/Million Hours)

Environment	Relay Type	Failure Rate (x 10^{-6} hours)
Ground fixed	General purpose	0.23
Ground fixed	High voltage	0.198
Ground fixed	Reed	1.19
Ground fixed	Thermal	0.676
Ground mobile	Armature (lower quality)	0.425
Ground benign	General purpose	0.243
Naval sheltered	MIL-R-6016	0.786
Naval sheltered	General purpose	0.406
Naval sheltered	Thermal	0.351
Airborne inhabited	MIL-R-39016	0.058
Airborne inhabited	MIL-R-6016	0.086
Space flight	Latching relay	0.09

where:

λ_p = predicted failure rate

λ_b = base failure rate

π_E = environmental factor

π_c = contact form and quantity factor

π_{cyc} = cycling rate factor

π_F = relay application and construction type factor.

Using this equation and substituting parameters from operating field data, a typical failure rate is calculated for the relay (MIL-C-39016) in an airborne inhabited environment. The relay is rated at 125°C, and is a double-pole double-throw configuration. Seven constants apply:

π_c = 3.0 (for double-pole, double-throw)

π_E = 8.0 (for airborne inhabited)

π_F = 5.0 (for balanced armature)

π_{cyc} = 0.1 (less than 1 cycle/hour)

λ_t = 0.0065 x 10^{-6} (125°C rating and 45°C ambient temperature)

π_L = 1.48 (50 percent stress)

$\lambda_b = (\lambda_T \times \pi_L)$

$\lambda_b = 0.0101 \times 10^{-6}$ failures/hour

$\lambda_p = 0.0101 \times 10^{-6} (8.0 \times 3.0 \times 0.1 \times 5.0) = 0.121 \times 10^{-6}$ failures/hour.

This value is the predicted failure rate for the relay given. In the same manner, failure rates were calculated for each relay type and environment listed in Table 13. Predicted failure rates are shown in Table 14.

TABLE 14

Predicted Failure Rates from MIL-HDBK-217B
(Failures/Million Hours)

Environment	Relay Type	Predicted Failure Rate ($\times 10^{-6}$ hours)
Ground fixed	General purpose	0.27
Ground fixed	High voltage	0.216
Ground fixed	Reed	0.216
Ground fixed	Thermal	2.7
Ground mobile	Armature (lower quality)	8.125
Ground benign	General purpose	0.372
Naval sheltered	MIL-R-6016	1.25
Naval sheltered	General purpose	1.26
Naval sheltered	Thermal	12.59
Airborne inhabited	MIL-R-39016	0.121
Airborne inhabited	MIL-R-6016	0.22
Space flight	Latching relay	0.131

Predicted failure rates were compared with observed failure rates, and these ratios are shown in Table 15. Examination of the data does not show a clear cut trend of improvement or degradation of the failure rate. Consequently, the base failure rate, λ_b, has not been changed in MIL-HDBK-217B.

5.2.2 Environmental Factor (π_E) Evaluation

Data were collected for the relay study using six environments:

- Ground fixed
- Ground mobile
- Ground benign
- Naval sheltered

- Airborne inhabited
- Space flight

One type of relay, general purpose, exhibited data in three environments that could be used for evaluation of environmental factors. In the ground fixed environment, the predicted failure rate for general purpose relays was 1.17 times the observed value, and in the ground benign environment, the predicted failure rate was 1.5 times the observed failure rate. In naval sheltered environment, the predicted failure rate was 3.1 times the observed value, indicating a reduction of π_E for naval sheltered. The environmental factor for the naval sheltered environment has been 9.0 and is reduced to 5.0.

TABLE 15

Ratio of Predicted Failure Rates to Observed Failure Rates

Environment	Relay Type	Ratio of Predicted to Observed Failure Rates
Ground fixed	General purpose	1.17
Ground fixed	High voltage	1.09
Ground fixed	Reed	0.18
Ground fixed	Thermal	4.0
Ground mobile	Armature (lower quality)	19.11
Ground benign	General purpose	1.5
Naval sheltered	MIL-R-6016	1.4
Naval sheltered	General purpose	3.1
Naval sheltered	Thermal	35.9
Airborne inhabited	MIL-R-39016	2.08
Airborne inhabited	MIL-R-6016	2.56
Space flight	Latching relay	1.46

Data for relays specified by MIL-R-6016 are shown in two environments, naval sheltered and airborne inhabited. Since the naval sheltered environment values were reduced by 1.8, the ratio of predicted to observed failure rates for MIL-R-6016 relays in the naval sheltered environment is reduced from 1.6 to 0.9. The ratio of predicted to observed failure rates for the airborne inhabited environment is 2.56, indicating that π_E (which is 8.0) must be reduced by factor of 2 to 4.0.

One set of data exists for the lower quality armature type relay in the ground mobile environment. Based on a ratio of predicted to observed failure rate of 19, the factor π_E must be reduced by the same factor as naval sheltered and airborne inhabited. This adjustment reduces the π_E factor for ground mobile to 5.0.

The aircraft environment was expanded to four categories to separate supersonic aircraft from other types. It is generally accepted that equipment on supersonic aircraft are exposed to higher levels of shock, vibration, and acoustic noise, and to a more severe operating temperature range than equipment on other aircraft. Mission duration is usually much shorter for supersonic aircraft. In this study, only data from the subsonic aircraft equipment were collected. From other studies, (References 3 and 4) analyses of data have been made, and a factor of 2:1 for supersonic versus subsonic environmental stress was developed. This value was determined to be a good general factor to differentiate between subsonic and supersonic aircraft. The term subsonic aircraft includes fighters and interceptors, while the subsonic category encompasses transport, heavy bomber, cargo, and patrol aircraft.

No other data justify further changes in environmental factors. These factors are summarized in Table 16.

TABLE 16

Environmental Factors π_E for Relays

Environment	π_E	
	MIL SPEC	Lower Quality
Ground benign	1.0	2.0
Space flight	1.0	2.0
Ground fixed	2.0	4.0
Airborne inhabited$_T$	4.0	8.0
Naval sheltered	5.0	15.0
Ground mobile	5.0	15.0
Airborne inhabited$_F$	8.0	16.0
Naval unsheltered	11.0	30.0
Airborne uninhabited$_T$	12.0	30.0
Airborne uninhabited$_F$	24.0	60.0
Missile launch	100.0	300.0

5.2.3 Failure Rate Factor (π_F) Evaluation for Relay Application and Construction Type

Environmental factor reductions were calculated into predicted failure rates for relays, and predicted rates were compared to observed failure rates using the new π_E factors. These values are summarized in Table 17. Four categories of latching relays (armature, lower quality, thermal, and general purpose) exhibited failure rate ratios with predicted higher than observed. One category (reed switch) exhibited a predicted failure rate lower than observed. The factor for relay application and construction type required modification in each of these categories. Five changes were made in the π_F factor:

TABLE 17

Ratio of Predicted to Observed Failure Rates
Using Modified π_E Factors

Environment	Relay Type	Ratio of Predicted to Observed Failure Rates
Ground fixed	General purpose	1.17
Ground fixed	High voltage	1.09
Ground fixed	Reed	0.18
Ground fixed	Thermal	4.0
Ground mobile	Armature (lower quality)	9.5
Ground benign	General purpose	1.5
Naval sheltered	MIL-R-6016	0.89
Naval sheltered	General purpose	2.6
Naval sheltered	Thermal	17.9
Airborne inhabited	MIL-R-39016	1.04
Airborne inhabited	MIL-R-6016	1.78
Space flight	Latching relay	1.46

- Decrease the factor for high voltage (ceramic) from 10 to 5
- Decrease the factor for thermal time delay relays from 50 to 10
- Decrease the factor for armature relay (lower quality) by a factor of 1.5
- Decrease the factor for latching relays from 6 to 4
- Increase the factor for reed relays from 2 to 6.

Table 18 summarizes the π_F factors as modified.

5.2.4 Evaluation of Quality Factor (π_Q) for Established Reliability Relays

Relays specified by MIL-R-39016B, Established Reliability Electromagnetic Relays, are designated in four categories for failure rate level designation (levels L, M, P, R). The designations are included as a suffix on the part numbers, i.e., MIL-R-39016/10-001M. The four levels of failure rate designation require a factor (π_Q) to be added to the failure rate model for relays to modify failure rates of established reliability (ER) relays, based on their failure rate level. The only data collected on ER relays in this study was at the M level. The failure rate calculations were made on this level relay, thus the π_Q factor for level M ER relays should be equal to 1.0. Other MIL-SPEC relays should be set equal to 1.0 also, based on the failure rate calculations made in the previous sections. No other data on other levels of ER relays were collected, therefore the levels set in other portions of MIL-HDBK-217B apply. The factor of improvement between levels for ER devices in both the resistor and capacitor sections is 3, and π_Q values for relays are set accordingly. Values of π_Q are shown in Table 19.

TABLE 18

Failure Rate Factor π_F for Relay Application and Construction Type

Contact Rating	Application Type	Construction Type	π_F	
			MIL SPEC	Lower Quality
Signal current (low mv and ma)	Dry circuit	Armature (long)	4	8
		Dry reed	6	18
		Mercury wetted	1	3
		Magnetic latching	4	8
		Balanced armature	7	14
		Solenoid	7	14
0-5 Amp	General purpose	Armature (long and short)	3	6
		Balanced armature	5	10
		Solenoid	6	12
	Sensitive (0-100 mw)	Armature (long and short)	5	10
		Mercury wetted	2	6
		Magnetic latching	6	12
		Meter movement	100	100
		Balanced armature	10	20
	Polarized	Armature (short)	10	20
		Meter movement	100	100
	Vibrating reed	Dry reed	6	12
		Mercury wetted	1	3
	High speed	Armature (balanced and short)	25	NA
		Dry reed	6	NA
	Thermal time delay	Bimetal	10	20
	Electronic time delay (non-thermal)		9	12
	Latching (magnetic)	Dry reed	10	20
		Mercury wetted	5	10
		Balanced armature	5	10
5-20 Amp	High voltage	Vacuum (glass)	20	40
		Vacuum (ceramic)	5	10
	Medium power	Armature (long and short)	3	6
		Mercury wetted	1	3
		Magnetic latching	2	6
		Mechanical latching	3	9
		Balanced armature	2	6
		Solenoid	2	6
25-600 Amp	Contactors (high current)	Armature (short)	7	14
		Mechanical latching	12	24
		Balanced armature	10	20
		Solenoid	5	10

TABLE 19

Quality Factor π_Q for Established Reliability Relays

Failure Rate Level	π_Q
L	1.5
M	1.0
P	0.3
R	0.1

5.2.5 Validation of Revised Factors for Relays

Failure rates for each of the categories of relays shown in Table 2 were calculated using the modified π_E and π_F factors. Sample calculations, compared in Table 20 to observed values, show the methodology employed:

1 Ground fixed, general purpose relay

$T = 30°C$

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \pi_L$

$\lambda_T = 0.0061 \times 10^{-6}$ (based on 30°C)

$\pi_L = 1.48$ (based on 50 percent stress)

$\lambda_b = 0.009 \times 10^{-6}$ failures/hour

$\pi_E = 2.0$ (ground fixed)

$\pi_c = 3.0$ (double-pole, double-throw)

$\pi_Q = 1.0$ (quality factor)

$\pi_F = 5.0$ (general purpose, balanced armature)

$\pi_{cyc} = 1.0$ (10 cycles/hour)

$\lambda_p = 0.27 \times 10^{-6}$ failures/hour

2 Ground fixed, high voltage relay (lower quality)

$T = 30°C$

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \pi_L$

$\lambda_T = 0.0061 \times 10^{-6}$ (based on 30°C)

$\pi_L = 1.48$ (based on 50 percent stress)

$\lambda_b = 0.009 \times 10^{-6}$ failures/hour

$\pi_E = 4.0$ (ground fixed)

$\pi_c = 3.0$ (double-pole, double-throw)

$\pi_F = 2.0$ (high voltage, ceramic, lower quality)

$\pi_{cyc} = 0.1$ (less than 1 cycle per hour)

$\pi_Q = 1.0$ (quality factor)

$\lambda_p = 0.216 \times 10^{-6}$ failures/hour

3 Ground fixed, reed relay, lower quality

$T = 30°C$

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \pi_L$

$\lambda_T = 0.0061 \times 10^{-6}$ (based on 30°C)

$\pi_L = 1.48$ (based on 50 percent stress)

$\lambda_b = 0.009 \times 10^{-6}$ failures/hour

$\pi_E = 4.0$ (ground fixed)

$\pi_c = 1.0$ (based on single-pole, single-throw)

$\pi_F = 12$ (reed relay, lower quality)

$\pi_{cyc} = 1.0$ (based on 10 cycles/hour)

$\pi_Q = 1.0$ (for quality factor)

$\lambda_p = 0.432 \times 10^{-6}$ failures/hour

4 Ground fixed, thermal, MIL-SPEC

$T = 30°C$

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \pi_L$

λ_T = 0.0061 x 10^{-6} (based on 30°C)

π_L = 1.48 (based on 50 percent stress)

λ_b = 0.009 x 10^{-6} failures/hour

π_E = 2.0 (ground fixed)

π_c = 3.0 (double-pole, double-throw)

π_F = 10.0 (thermal relay, MIL-SPEC)

π_{cyc} = 1.0 (based on 10 cycles/hour)

π_Q = 1.0 (for quality factor)

λ_p = 0.54 x 10^{-6} failures/hour

5 Ground mobile, armature (lower quality)

T = 30°C

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \pi_L$

λ_T = 0.0061 x 10^{-6} (based on 30°C)

π_L = 1.48 (based on 50 percent stress)

λ_b = 0.009 x 10^{-6} failures/hour

π_E = 15 (ground mobile, lower quality)

π_c = 3.0 (double-pole, double-throw)

π_F = 8.0 (armature, lower quality)

π_{cyc} = 0.1 (based on 1 cycle/hour)

π_Q = 1.0 (for quality factor)

λ_p = 0.324 x 10^{-6} failures/hour

6 Ground benign, general purpose

T = 35°C

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \pi_L$

λ_T = 0.0063×10^{-6} (based on 35°C)

π_L = 1.48 (based on 50 percent stress)

λ_b = 0.0093×10^{-6} failures/hour

π_E = 1.0 (based on ground benign environment)

π_c = 8.0 (based on six-pole, double-throw)

π_F = 5.0 (based on general purpose, balanced armature)

π_{cyc} = 1.0 (based on 10 cycles per hour)

π_Q = 1.0 (for quality factor)

λ_p = 0.372×10^{-6} failures/hour

<u>7</u> Naval sheltered, MIL-R-6016

T = 40°

$\lambda_p = \lambda_b \, (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \, \pi_L$

λ_T = 0.0063×10^{-6} (based on 40°C)

π_L = 1.48 (based on 50 percent stress)

π_b = 0.0093×10^{-6} failures/hour

π_E = 5.0 (based on naval sheltered)

π_c = 3.0 (double-pole, double-throw)

π_F = 5.0 (based on balanced armature)

π_{cyc} = 1.0 (based on 10 cycles/hour)

π_Q = 1.0 (for quality factor)

λ_p = 0.699×10^{-6} failures/hour

<u>8</u> Naval sheltered, general purpose

T = 40°C

$\lambda_p = \lambda_b \, (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \, \pi_L$

λ_T = 0.0063×10^{-6} (based on naval sheltered)

π_L = 1.48 (based on 50 percent stress)

λ_b = 0.0093×10^{-6} failures/hour

π_E = 5.0 (based on naval sheltered)

π_c = 3.0 (double-pole, double-throw)

π_F = 5.0 (based on balanced armature)

π_{cyc} = 1.0 (based on 10 cycles/hour)

π_Q = 1.0 (quality factor)

λ_p = 0.699×10^{-6} failures/hour

9 Naval sheltered, thermal

T = 40°C

$\lambda_p = \lambda_b \, (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \, \pi_L$

λ_T = 0.0063×10^{-6} (based on 40°C)

π_L = 1.48 (based on 50 percent stress)

λ_b = 0.0093×10^{-6} failures/hour)

π_E = 5.0 (naval sheltered)

π_c = 3.0 (double-pole, double-throw)

π_F = 10 (thermal travel delay)

π_{cyc} = 1.0 (based on 10 cycles/hour)

π_Q = 1.0 (quality factor)

λ_p = 1.398×10^{-6} failures/hour

10 Airborne inhabited MIL-R-39016

T = 55°C

$\lambda_p = \lambda_b \, (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \, \pi_L$

λ_T = 0.00685×10^{-6} (based on 55°C)

π_L = 1.48 (based on 50 percent stress)

λ_b = 0.0101×10^{-6} failures/hour

π_E = 5.0 (based on airborne inhabited)

π_c = 3.0 (double-pole, double-throw)

π_F = 5.0 (balanced armature)

π_{cyc} = 0.1 (based on 1 cycle per hour

π_Q = 1.0 (quality factor)

λ_p = 0.076×10^{-6} failures/hour

<u>11</u> Airborne inhabited, MIL-R-6016

T = 55°C

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \pi_L$

λ_T = 0.00685×10^{-6} (based on 55°C)

π_L = 1.48 (based on 50 percent stress)

λ_b = 0.0101×10^{-6} failures/hour

π_E = 5.0 (airborne inhabited, transport)

π_c = 5.5 (four pole, double-throw)

π_F = 5.0 (balanced armature)

π_{cyc} = 0.1 (based on 1 cycle/hour)

π_Q = 1.0 (quality factor)

λ_p = 0.139×10^{-6} failures/hour

<u>12</u> Space flight, [illegible]

T = 25°C

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$

$\lambda_b = \lambda_T \pi_L$

λ_T = 0.0059 x 10^{-6} (based on 25°C)

π_L = 1.48 (based on 50 percent stress)

λ_b = 0.0087 x 10^{-6} failures/hour

π_E = 1.0 (for space flight)

π_c = 3.0 (double-pole, double-throw)

π_F = 4.0 (magnetic latching)

π_{cyc} = 1.0 (based on 10 cycles/hour)

π_Q = 1.0 (quality factor)

λ_p = 0.104 x 10^{-6} failures/hour

Complete revision of Section 2.9 of MIL-HDBK-217B is in Appendix C.

TABLE 20

Validation of Predicted Failure Rates Using Modified Factors

Environment	Relay Type	Failure Rate (x 10^{-6} hours)	
		Observed	Predicted
Ground fixed	General purpose	0.23	0.27
Ground fixed	High voltage	0.198	0.216
Ground fixed	Reed	1.19	0.432
Ground fixed	Thermal	0.676	0.54
Ground mobile	Armature (lower quality)	0.425	0.324
Ground benign	General purpose	0.243	0.372
Naval sheltered	MIL-R-6016	0.786	0.699
Naval sheltered	General purpose	0.406	0.699
Naval sheltered	Thermal	0.351	1.398
Airborne inhabited	MIL-R-39016	0.058	0.076
Airborne inhabited	MIL-R-6016	0.086	0.139
Space flight	Latching relay	0.899	0.104

5.3 Switch Failure Rate Prediction Models

5.3.1 Switch Base Failure Rate (λ_b) Evaluation

Failure rates were calculated by categories for switches in each environment in which sufficient data had been collected. Each group of switches was categorized by MIL-SPEC classification or part type, where applicable. Operating failure rates for each set of data were calculated at point estimate (where failures had occurred) and at the upper 60 percent confidence level in every case. Results of these calculations appear in Table 21. Failure rates calculated at the upper 60 percent confidence level were used for comparisons and further computations.

TABLE 21

Observed Failure Rates for Switches
(Failures/Million Hours)

Environment	Switch Type	Failure Rate ($x 10^{-6}$ hours)
Airborne inhabited	Pushbutton	0.203
Airborne inhabited	Rotary	0.204
Ground fixed	Toggle	0.005
Ground fixed	Rotary	0.157
Ground fixed	Pushbutton (lower)	0.175
Ground fixed	Rotary (lower)	4.54
Ground fixed	Sensitive	0.306
Ground mobile	Reed (lower)	0.19
Naval sheltered	Toggle	0.473
Naval sheltered	Toggle (lower)	0.014
Space flight	Sensitive	0.167

The present mathematical model used to determine the predicted failure rate of a toggle or pushbutton which appears in Section 2.10 of MIL-HDBK-217B:

$$\lambda p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc}) \text{ failure [illegible]}$$

where:

λ_p = part failure rate

λ_b = base failure rate

π_E = environmental factor

π_c = contact form factor

π_{cyc} = cycling rate factor

Using this equation and substituting parameters from the operating field data, a typical failure rate was calculated for a lower quality non-snap action push button switch, as used in the ground fixed environment. The switch is operated in an ambient temperature of 30°C and is a single-pole, single-throw switch. It is operated at a rate of one cycle per hour. Applicable constants are:

$\lambda_b = 0.6 \times 10^{-6}$ failures/hour

$\pi_E = 1.0$

$\pi_C = 1.0$

$\pi_{cyc} = 1.0$

$\lambda_p = 0.6 \times 10^{-6}$ failures/hour.

This value is the predicted failure rate for the given switch. In the same manner, failure rates were calculated for each of the switch types and environments listed in Table 21. Predicted failure rates are shown in Table 22.

TABLE 22

Predicted Failure Rates from MIL-HDBK-217b
(Failures/Million Hours)

Environment	Switch Type	Predicted Failure Rate (failures/10^6 hours)
Airborne inhabited	Pushbutton	4.8
Airborne Inhabited	Rotary	24.7
Ground fixed	Toggle	0.025
Ground fixed	Rotary	2.06
Ground fixed	Pushbutton	0.6
Ground fixed	Rotary (lower)	4.4
Ground fixed	Sensitive	0.4035
Ground mobile	Reed (lower)	0.6
Naval sheltered	Toggle	0.012
Naval sheltered	Toggle (lower)	0.9
Space flight	Sensitive	0.121

Predicted failure rates were compared with observed failure rates, resulting in ratios shown in Table 23. These data indicate that the predicted failure rates exceed the observed failure rates in all cases except one. The toggle switch in the naval sheltered environment has a high failure rate, based on a minimum amount of data (no failures in 1.9 x 10^6 hours). The toggle switch in the ground fixed environment has a lower observed than predicted failure rate (based on 0 failures in 180 x 10^6 hours). Therefore, as the toggle switch in the naval sheltered environment accumulates more operating hours, the failure rate should decrease accordingly and would be less than predicted.

TABLE 23

Ratio of Predicted Failure Rates to Observed Failure Rates

Environment	Switch Type	Ratio of Predicted to Observed Failure Rates
Airborne inhabited	Pushbutton	23.64
Airborne inhabited	Rotary	121.0
Ground fixed	Toggle	5.0
Ground fixed	Rotary	13.1
Ground fixed	Pushbutton	3.43
Ground fixed	Rotary (lower)	0.969
Ground fixed	Sensitive	1.32
Ground mobile	Reed (lower)	3.15
Naval sheltered	Toggle	0.025
Naval sheltered	Toggle (lower)	64.3
Space flight	Sensitive	0.724

5.3.2 Normalization of Environmental Factor (π_E)

Table 2.10-4 of section 2.10 in MIL-HDBK-217B lists environmental factors presently applied to switches (Table 24). The lowest factor is 0.3 for both ground benign and space flight environments. To normalize this value to 1.0, each factor must be multiplied by 3.33. Normalized values of π_E appear in Table 25.

TABLE 24

π_E Based on Environmental Service Condition for Switches

Environment	Symbol	π_E
Ground benign	G_B	0.3
Space flight	S_F	0.3
Ground fixed	G_F	1.0
Airborne inhabited	A_I	12.0
Naval sheltered	N_S	1.2
Ground mobile	G_M	5.0
Naval unsheltered	N_U	7.0
Airborne uninhabited	A_U	15.0
Missile launch	M_L	200.0

TABLE 25

π_E Normalized Based on
Environmental Service Condition for Switches

Environment	π_E
Ground benign	1.0
Space flight	1.0
Ground fixed	3.33
Airborne inhabited	40.0
Naval sheltered	4.0
Ground mobile	17.0
Naval unsheltered	23.3
Airborne uninhabited	50.0
Missile launch	666.0

5.3.3 Development of Stress Factor (π_L)

Processes operative at switch contacts are identical to those in relay contacts. In the relay failure rate model, π_L relates the effect of the stress to the part failure rate. Electrical stress is defined as the operating load current divided by the rated resistive load current. It is specified for resistive loads, inductive loads, and lamp loads.

For higher current density in the contacts, heat is generated faster than it can be carried away. When contacts are operated close to the high end of their rated load range, the contacts soften and melt upon closure. Some junction points may weld, breaking apart when the switch reopens. Under these conditions, the switch exhibits its rated initial contact resistance over the initial portion of its operating life. Later, this resistance rises due to contact wear, pitting, and surface contamination.

Based on the fact that current stress decreases the life of a switch contact and that relay and switch contacts are identical in operation, π_L in the relay failure rate model is also applied to the switch failure rate model. Table 26 defines stress factors for switch contacts.

5.3.4 Base Failure Rate Evaluation for Toggle and Pushbutton Switches

Normalization of the environmental factor π_E and addition of the multiplicative factor π_L require revision of the base failure rate to compensate for the increase in predicted failure rate. Failure rates were calculated for switch categories of Table 21, using revised π_E factors and assuming the multiplicative factor π_L to be 1.48, based on 50 percent stress. These failure rates are shown in Table 27.

TABLE 26

π_L Stress Factor for Switch Contacts

Stress	Load Type		
	Resistive	Inductive	Lamp
0.05	1.00	1.02	1.06
0.1	1.02	1.07	1.28
0.2	1.06	1.28	2.72
0.3	1.15	1.76	9.49
0.4	1.28	2.72	54.60
0.5	1.48	4.77	
0.6	1.76	9.49	
0.7	2.15	21.40	
0.8	2.72		
0.9	3.55		
1.0	4.77		

TABLE 27

Predicted Failure Rates with π_L and π_E Modified

Environment	Switch Type	Failure Rate (10^{-6} hours)
Airborne inhabited	Pushbutton	23.68
Airborne inhabited	Rotary	121.95
Ground fixed	Toggle	0.111
Ground fixed	Rotary	9.14
Ground fixed	Pushbutton (lower)	2.66
Ground fixed	Rotary (lower)	19.53
Ground fixed	Sensitive	1.79
Ground mobile	Reed (lower)	15.09
Naval sheltered	Toggle	0.059
Naval sheltered	Toggle (lower)	4.44
Space flight	Sensitive	0.597

The data indicate that the predicted failure rate is higher than the observed for all cases but one. Ratios of predicted to observed failure rate are summarized in Table 28.

TABLE 28

Ratio of Revised Failure Rates to
Observed Failure Rates

Environment	Switch Type	Ratio of Predicted to Observed Failure Rates
Airborne inhabited	Pushbutton	116.65
Airborne inhabited	Rotary	597.8
Ground fixed	Toggle	22.2
Ground fixed	Rotary	58.21
Ground fixed	Pushbutton (lower)	15.2
Ground fixed	Rotary (lower)	4.3
Ground fixed	Sensitive	5.85
Ground mobile	Reed (lower)	79.42
Naval sheltered	Toggle	0.12
Naval sheltered	Toggle (lower)	317.14
Space flight	Sensitive	3.57

Snap action toggle and pushbutton switches are listed in three environments. For the reasons of section 5.3.1, the naval sheltered toggle switch data has been censored. The data indicate an improvement ratio of between 15.2 and 317.14 in failure rates. Using these ratios, λ_b in the fixed ground environment for the non-snap action pushbutton switch in the lower quality grade category should decrease by a factor of 15. The toggle switch in the same environment shows a decrease of 22. Modified base failure rates for these switches are shown in Table 29.

TABLE 29

Base Failure Rate (λ_b) for Snap Action
Toggle and Pushbutton Switches
(Failures/Million Hours)

Description	λ_b			
	MIL-HDBK-217B	New	MIL-HDBK-217B	New
	MIL-SPEC		Lower Quality	
Snap action	0.01	0.00045	0.75	0.034
Non-snap action	0.04	0.0027	0.60	0.04

5.3.5 Base Failure Rate Evaluation for Sensitive Switches

Failure rate data for sensitive switches were collected in two environments, space flight and ground fixed. Both categories of switches have predicted failure rates higher than observed failure rates, indicating the base failure rates for sensitive switches should be reduced by a factor of four. Revised failure rates for sensitive switches are shown in Table 30.

TABLE 30

Base Failure Rate (λ_b) for Sensitive Switches
(Failures/Million Hours)

Description	λ_b			
	MIL-HDBK-217B	New	MIL-HDBK-217B	New
	MIL-SPEC		Lower Quality	
Actuation Differential >0.002 in. λ_{bc}	0.0035	0.0009	1.8	0.45
Actuation Differential <0.002 in. λ_{bd}	0.007	0.0018	4.9	1.25
Actuation Assembly λ_{bE}	0.4	0.1	0.4	0.1

5.3.6 Base Failure Rate Evaluation for Rotary Switches

Failure rate data for rotary switches were collected in two environments in three sets of data. One set of data collected in the ground fixed environment consists of lower quality switches, while the other two sets are MIL-SPEC switches in ground fixed and airborne inhabited environments. Lower quality switches indicate an improvement of 4.1 for the observed data over the predicted failure rate data. Data collected on MIL-SPEC switches indicate an improvement of from 58 to 597 in the ground fixed and airborne inhabited environments, indicating a reduction of 60 is required in the MIL-SPEC switch category. Revised base failure rates for rotary switches are shown in Table 31.

TABLE 31

Base Failure Rate (λ_b) for Rotary Switches
(Failures/Million Hours)

Description	MIL-SPEC		Lower Quality	
	MIL-HDBK-217B	New	MIL-HDBK-217B	New
Actuator assembly	0.4	0.0067	0.4	0.1
Ceramic RF wafers	0.002	0.00003	0.08	0.02
Medium power wafers	0.002	0.00003	0.24	0.06

5.3.7 Evaluation of Environmental Factor (π_E)

As discussed in section 5.3.2, π_E was normalized, but the relationship between environments remained the same. Base failure rates were revised and the factor π_L was added to the base failure rate model. Using the revised mathematical model, failure rates can be calculated to determine the impact of the environmental factor. Table 32 lists failure rates calculated from the new model and compares them to the observed field failure rates. All failure rates correlated well, with the exception of data in the airborne inhabited environment. Data from pushbutton switches and rotary switches indicate a ratio of 8 to 10 higher for predicted failure rates. The value of π_E is 40.0 for the airborne inhabited environment. This factor has reduced by a factor of 8 to equal 5.0. Evaluation of failure rates using the value of $\pi_E = 5.0$ in the mathematical model shows correlation between the observed and predicted failure rates (Table 33).

TABLE 32

Failure Rates Derived from New Model Compared to Observed Failure Rates

Environment	Switch Type	Observed Failure Rate (x 10^{-6} hours)	New Predicted Failure Rate (x 10^{-6} hours)
Airborne inhabited	Pushbutton	0.203	1.6
Airborne inhabited	Rotary	0.204	2.04
Ground fixed	Toggle	0.005	0.0046
Ground fixed	Rotary	0.157	0.153
Ground fixed	Pushbutton	0.175	0.178
Ground fixed	Rotary (lower)	4.54	4.88
Ground fixed	Sensitive	0.306	0.44
Naval sheltered	Toggle	0.473	.0027
Naval sheltered	Toggle (lower)	0.014	0.201
Space flight	Sensitive	0.167	0.161

TABLE 33

Comparison of Failure Rates for Airborne Inhabited Environment after π_E Modification

Environment	Switch Type	Observed Failure Rate (x 10^{-6} hours)	Predicted Failure Rate (x 10^{-6} hours)
Airborne inhabited	Pushbutton	0.203	0.20
Airborne inhabited	Rotary	0.204	0.255

The aircraft environment was expanded to four categories to separate supersonic aircraft from other types. It is generally accepted that equipment on supersonic aircraft are exposed to higher levels of shock, vibration, and to a more severe operating temperature range than equipment on other aircraft. Mission duration is usually much shorter for supersonic aircraft. In this study, only data from the subsonic aircraft equipment were collected. From other studies (References 3 and 4), analyses of data have been made, and a factor of 2:1 for supersonic versus subsonic envirionmental stress was developed. This value was determined to be a good general factor to differentiate between subsonic and supersonic aircraft. The term supersonic aircraft includes fighters and interceptors, while the subsonic category encompasses transport, heavy bomber, cargo, and patrol aircraft. The revised values of the π_E factors are shown in Table 2.10-4 of Appendix D.

5.3.8 Evaluation of New Mathematical Model with Modified Factors

Each category of switches was evaluated using these assumptions and equations:

1 Airborne inhabited, pushbutton switch

$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_L)$

$\lambda_b = 0.0027$ failure/10^6 hours (base failure rate)

$\pi_E = 5.0$ (revised for airborne inhabited)

$\pi_c = 1.0$ (single-pole, single-throw)

$\pi_{cyc} = 10.0$ (10 cycles/hour)

$\pi_L = 1.48$ (50 percent stress)

$\lambda_p = 0.0027 (5 \times 1.0 \times 10.0 \times 1.48) = 0.2$ failures/10^6 hours

2 Airborne inhabited, rotary switch

λ_p = λ_b (π_E x π_{cyc} x π_L)

λ_b = λ_{bE} x $n\lambda_{bG}$

λ_{bE} = 0.0067 failures/10^6 hours

$n\lambda_{bG}$ = [illegible] x 0.00003 = 0.00018 failures/10^6 hours

λ_b = 0.00688 failures/10^6 hours

π_E = 5.0 (revised for airborne inhabited)

π_c = 5.0 (5 cycles/hours)

π_L = 1.48 (50 percent stress)

λ_p = 0.00688 (5.0 x 5.0 x 1.48) = 0.255 failures/10^6 hours

3 Ground fixed, toggle switch

λ_p = λ_b (π_E x π_c x π_{cyc} x π_L)

λ_b = 0.00045 failures/10^6 hours

π_E = 3.0 (for ground fixed)

π_c = 2.5 (four-pole, single-throw)

π_{cyc} = 1.0 (1 cycle/hour)

π_L = 1.48 (50 percent stress)

λ_p = 0.00045 (3.0 x 2.5 x 1.0 x 1.48) = 0.005 failures/10^6 hours

4 Ground fixed, rotary switch

λ_p = λ_b (π_E x π_{cyc} x π_L)

λ_b = λ_{bE} + $n\lambda_{bG}$

λ_{bE} = 0.0067 failures/10^6 hours

$n\lambda_{bG}$ = 6 x 0.00003 = 0.00018 failures/10^6 hours

λ_b = 0.00688 failures/10^6 hours

π_E = 3.0 (for ground fixed)

π_{cyc} = 5.0 (for 5 cycles/hour)

π_L = 1.48 (for 50 percent stress)

λ_p = 0.00688 (3.0 x 5.0 x 1.48) = 0.153 failures/10^6 hours

5 Ground fixed, pushbutton switch (lower)

$\lambda_p = \lambda_b\,(\pi_E \times \pi_C \times \pi_{cyc} \times \pi_L)$

λ_b = 0.04 failures/10^6 hours

π_E = 3.0 (for ground fixed environment)

π_C = 1.0 (for single-pole, single-throw)

π_{cyc} = 1.0 (for 1 cycle/hour)

π_L = 1.48 (for 50 percent stress)

λ_p = 0.04 (3.0 x 1.0 x 1.0 x 1.48) = 0.178 failures/10^6 hours

6 Ground fixed (rotary switch, lower)

$\lambda_p = \lambda_b\,(\pi_E \times \pi_{cyc} \times \pi_L)$

$\lambda_b = \lambda_{bE} + n\,\lambda_{bG}$

λ_{bE} = 0.1 failures/10^6 hours

$n\lambda_{bG}$ = 6 x 0.02 = 0.12 failures/10^6 hours

λ_b = 0.22 failures/10^6 hours

π_E = 3.0 (for ground fixed)

π_{cyc} = 5.0 (for 5 cycles/hour)

π_L = 1.48 (for 50 percent stress)

λ_p = 0.22 (3.0 x 5.0 x 1.48) = 4.88 failures/10^6 hours

7 Ground fixed, sensitive switch

$\lambda_p = \lambda_b\,(\pi_E \times \pi_{cyc} \times \pi_L)$

$\lambda_b = \lambda_{bE} + n\,\lambda_b$

λ_{bE} = 0.1 failures/10^6 hours

$n\,\lambda_{bG}$ = 1 x 0.0009 = 0.0009 failures/10^6 hours

λ_b = 0.10009 failures/10^6 hours

π_E = 3.0 (for ground fixed)

π_{cyc} = 1.0 (for 1 cycle/hour)

π_L = 1.48 (for 50 percent stress)

λ_p = 0.10009 (3.0 x 1.0 x 1.48) = 0.44 failures/10^6 hours

8 Naval sheltered, toggle switch

λ_p = λ_b (π_E x π_c x π_{cyc} x π_L)

λ_b = 0.00045 failures/10^6 hours

π_E = 4.0 (for naval sheltered)

π_c = 1.0 (for single-pole, single-throw)

π_{cyc} = 1.0 (for 1 cycle/hour)

π_L = 1.48 (for 50 percent stress)

λ_p = 0.0045 (4.0 x 1.0 x 1.0 x 1.48) = 0.0027 failure/10^6 hours

9 Naval sheltered, toggle switch (lower)

λ_p = λ_b (π_E x π_c x π_{cyc} x π_L)

λ_b = 0.034 failures/10^6 hours

π_E = 4.0 (for naval sheltered)

π_c = 1.0 (for single-pole, single-throw)

π_{cyc} = 1.0 (for 1 cycle per hour)

π_L = 1.48 (for 50 percent stress)

λ_p = 0.034 (4.0 x 1.0 x 1.0 x 1.48) = 0.2 failures/10^6 hours

10 Space flight, sensitive switch

λ_p = λ_b (π_E x π_{cyc} x π_L)

λ_b = λ_{bE} + n λ_b

λ_{bE} = 0.1 failures/10^6 hours

$n\ \lambda_{bG}$ = 1 x 0.0009 failures/10^6 hours

λ_b = 0.1009 failures/10^6 hours

π_E = 1.0 (for space flight)

π_c = 1.0 (for single-pole, single throw)

π_L = 1.48 (for 50 percent stress)

λ_p = 0.1009 (1.0 x 1.0 x 1.48) = 0.149 failures/10^6 hours

Complete revision of Section 2.10 of MIL-HDBK-217B is included in Appendix D.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Under the Development of Nonelectronic Part Cyclic Failure Rates program, Contract F30602-76-C-0437, more than 10 billion part hours have been collected from all sources. This data base was used to prepare an update of Sections 2.9, 2.10, and 2.11 of MIL-HDBK-217B.

Many categories of part classification were not well defined. Data contributors are generally reluctant to incur large expenditures to further refine data and information they provide without charge. They are also hesitant to allow visitors unrestricted access to their detailed records. Some data categories were consequently modified by similarity to other categories in which valid data were achieved.

All types of connectors (rack and panel, circular, coaxial, power) were included in this study. Printed circuit board connectors studied under a separate contract (F30602-76-C-0439) were included in a new subsection of MIL-HDBK-217B (Section 2.11.1). The failure rate model for connectors was modified to include a multiplicative cycling factor (π_K) in place of an additive cycling factor (λ_{cyc}). Base failure rates (λ_b) were lowered in all categories, and environmental factors (π_E) were modified. The field failure rates collected in this study were compared with failure rates derived from Section 2.11 of MIL-HDBK-217B and showed significant improvement in reliability of all connectors. These data indicate that reliability growth has been taking place and the state-of-the-art is still improving.

Relay failure rate prediction models were examined, and failure rate data from field observation were compared to predicted failure rates from Section 2.9 of MIL-HDBK-217B. No significant changes were found in the base failure rate. Some modifications in the relationship of environmental stress (π_E) were made in the airborne inhabited enviroments. These data indicate that relays have maintained their previous level of reliability, but have not improved significantly.

Switch failure rate prediction models were modified to include a contact stress factor (π_L), based on a similar factor used in the relay model. Base failure rates were reduced for all categories of switches. The environmental factor (π_E) was normalized with the lowest factor, space flight, set to a value of 1.0 and all other values adjusted accordingly. The environmental factor for airborne inhabited was reduced from 40.0 to 5.0, indicating improvement in the design of switches for airborne applications. Failure rates, from field data collected in this study were compared with failure rates from Section 2.10 of MIL-HDBK-217B and showed significant improvement in the reliability of switches. These data indicate that reliability growth has been taking place and the state-of-the-art is still improving.

In all three sections of MIL-HDBK-217B, the environmental factor table was expanded to include environments relating to transport and fighter aircraft. Both airborne uninhabited and airborne inhabited environments are delineated for transport and fighter aircraft.

6.2 Recommendations

Three recommendations are submitted for consideration and possible implementation:

1. Sections 2.9, 2.10, and 2.11 should be updated and revised every three years. This revision would promote retention and analysis of field data on a current basis. Also, a large amount of data over three years old are either lost or thrown away, and data of this vintage which can be obtained are sometimes difficult to trace. In addition, changes in the state-of-the-art would be reflected on a timely basis.

2. The benefits of a low key effort to collect reliability data on connectors, relays and switches should be investigated. In this study, a growing tendency was noted that major military systems contractors are increasingly reluctant to furnish uncontracted data free of charge. This reluctance seems due to material and manpower costs incurred in reconstructing past or present applicable data without economic compensation. This reluctance is further heightened by cutbacks in military defense spending, which directly results in more austere methods on the part of private contractors.

3. A separate effort should be initiated to update the impact of environmental factors on the base failure rate to be incorporated in MIL-HDBK-217B. This effort would include a specialized data collection program, data analysis, and mathematical model.

REFERENCES

1. Hald, A., "Statistical Tables and Formulas," John Wiley and Sons, Inc., New York, 1952.

2. Plein, K. M., Funk, J. R., and James, L. E., "Reliability Study Circular Electrical Connectors," Hughes Aircraft Company, RADC-TR-73-171, June 1973, AD765609.
3. Kern, G. A., and Drnas, I. M., "Operational Influences on Reliability," Hughes Aircraft Company, RADC-TR-76-366, December 1976, page 5-4, ADA035016.

4. Pearce, M. B., and Rice, G. D., "Technique for Developing Equipment Failure Rate K factors," Boeing Aerospace Company, December 1973, page 13.

BIBLIOGRAPHY

1. Abbot, W. H., "State-Of-The-Art Survey on Materials for Electrical Contact and Connector Applications," Harry Diamond Laboratories, Washington, D.C, AD 918 659L

2. Adams, A. O., "Reliability Goes in Long Before the Wrapper Goes On," Leach Relay Division, Los Angeles, California, April 1968

3. "Advances in Connector Technology Deliver Longer Life, Better Performance," Product Engineering, July 1977.

4. Atkinson, J. E. "Established Reliability for Electrical Connectors," Amphenol Connector Division, Chicago, Illinois

5. Ball, M., Harde, F. H., and Struckus, E. J., "Increase Connector Contact Reliability," Electronic Engineer, March 1968

6. Bock, E. M., and Whitley, J. H., "Fretting Corrosion in Electric Contacts," Amp Incorporated, Harrisburg, Pennsylvania, October 1974

7. Boylan, A. P., "Contact Capsules - Aid to Relay Reliability," U.S. Signal Research and Development Lab, Fort Monmouth, New Jersey

8. Bryezenski, C. J., "Reliability Provisions in Specifications for Relays"

9. Buszkrewicz, B., "Circular Connector Current/Thermal Rating Method," Amphenol Connector Division, Broadview, Illinois

10. Carr, L. D., "Relay Contact Failures," Sperry Gyroscope Company, Great Neck, New York

11. Curry, J., "Reed Switch Engineering Theory and Practice," Electronic Engineering, August 1977

12. Cuthrell, R. E., "A Review of Electrical Switch Design Factors for High Reliability Space and Weapons Applications," Sandia Laboratories, Albuquerque, NM, March 1975

13. De Lalio, L. D., and Nunn, C. P., "The DC Inductive Loading of Contacts," Filtors, Inc., Port Washington, NY

14. Diamond, E. H., "Field Report and Specification Improvement Program for Relays," Arinc Research Corporation, September 1964

15. "Exploiting the Lowly Solenoid is an Art as Much as a Science," Product Engineering, July 1976

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16. "Focus on Multipin Cable/Panel Connectors," Electronic Design, June 1977

17. Fontana, W. J., "Life Expectancy of a Form C Dry Reed Switch as a Function of Its Operating Environment," U. S. Army Electronics Command, Fort Monmouth, New Jersey, April 1966

18. Fontana, W. J., "Life Expectancy of a New Miniature Power Relay," U. S. Army Electronics Command, Fort Monmouth, New Jersey, March 1966

19. Freudinger, E., "Contamination on Electrical Contacts," Texas Instruments, Attleboro, Mass.

20. Gebauer, B. G., "Prerequisite of Relay Reliability," Automatic Electric Labs, Northlake, Illinois

21. Ginsberg, G., "Connectors and Interconnections Handbook," Electronic Connector Study Group, Camden, NJ

22. Gwyn, C., "Let's Take Some of the Mystery Elements Out of Electrical Contacts," Gibson Electric Company, Delmont, PA

23. Hall, R. C., and Penkacik, J., "Reliable Connectors for Tactical Electronic Equipment," Martin Marietta Corporation, Orlando, Florida, Technical Report, Number TR-ECOM-0458-F, November 1970

24. Harper, C. A., "Handbook of Components for Electronics," McGraw Hill, New York, 1977

25. Harwood, R., "Connectors - Bridging the Speed Gap," Amp. Incorporated, Harrisburg, PA

26. Howell, D., "The SMA Connection," Electronic Products Magazine, September 1977

27. Juris, M. A., "High Density Environmental Circular Connectors Conforming to MIL-C-81511," Amphenol Corporation

28. Lannan, P., "Circular/Plastic - A New Generation of Connectors," Amp Incorporated, Harrisburg, PA

29. Lannan, P., and Rundle, D., "MIL-C-81659/Arinc 404A, Common Denominator for Military and Commercial Applications," Amp Incorporated, Harrisburg, PA, 1974

30. Lightner, L S., "A Modular Zero Insertion Force Cable Connector," Amp Incorporated, Harrisburg, PA

31. Lombard, J. J., "Relay Failure Analysis Techniques," Grumman Aircraft Corp., Bethpage, New York

32. National Association of Relay Manufacturers, "Engineer's Relay Handbook," Hayden Book Company, Inc., New York, 1966

33. Maeding, C. E., "Spacecraft Electrical Connector Quality Criteria," Hughes Aircraft Company, El Segundo, CA

34. Mahler, P., "The Effects of Contamination on Relay Performance," Picatinny Arsenal, Dover, NJ

35. Morgan, R. W., "Selection and Application of MIL-C-39012B RF Coaxial Connectors," Boeing Company, Wichita, Kansas, October 1971

36. "Analysis of Failure Rate Data for Electronic Components," 4th R&M Symposium, April 1974

37. Russakoff, R., and Snowball, R., "Measurement of Contact Resistance," Review of Scientific Instruments, March 1967

38. Sauter, H. D., "The Engineering Approach to Failure Analysis of Switching Devices," Potter and Brumfield, Princeton, Indiana, April 1969

39. Schilling, W. A., "The User-Oriented Connector," Microwave Journal, October 1976

40. Schneider, C., "Military Relay Reliability," Bell Telephone Laboratories, New York, April 1966

41. Schmidts, J., and Sliwinski, E. T., "The Status of Relay Reliability," Guardian Electric Manufacturing Company, Chicago, Illinois

42. Schumaker, W. L., "Precision Coaxial RF Interface," Amp Corporation, Harrisburg, PA

43. Smith, G., "Allocating and Predicting Cabling/Connector Failure Rates For a Complex System," Boeing Aerospace Company, Seattle, Washington

44. Snowball, R. F., Williamison, J. B. P., and Hack, R. C., "Ingress - Limited Corrosion of Contact Surfaces," IEEE Transactions on Parts, Materials and Packaging, Vol PMP-3, No. 3, September 1967

45. Spergel, J., and Godwin, E. F., "Reliable Interconnections for Army Avionics," U. S. Army Electronics Command, Fort Monmouth, New Jersey

46. Steinberg, G., "High Reliability Connective Devices," U. S. Army Electronics Laboratories, Fort Monmouth, New Jersey, AD 462503

47. Wagar, H. N., "Impact of the Contact on Electrical Systems," 1976

48. Wendling, L. W., and Thomas, E. U., "Guidelines for Reliable Relay Application and Selection," 17th Annual National Relay Conference, 1969

49. Whitley, J. H., "How to Choose the Right Electrical Connection," Amp Incorporated, Harrisburg, PA

50. Whitley, J. H., "A Measurement of Constriction Resistance Based on Its Non-Linearity," Amp Incorporated, Harrisburg, PA, June 1966

51. Whitley, J. H., "Rational Section of Alternate Materials for Electrical Connector Contacts," Amp Incorporated, Harrisburg, PA, May 1974

52. Whitley, J. H., "Connector Requirements and Technology," Amp Incorporated, Harrisburg, PA, October 1974

APPENDIX A

DATA SOURCES

APPENDIX A

DATA SOURCES

Aerojet Corporation
Azusa, California

Autonetics
Anaheim, California

Collins Radio Group
Cedar Rapids, Iowa

Electronic Communications, Inc.
St. Petersburg, Florida

E-Systems
Falls Church, Virginia

General Electric Corporation
Syracuse, New York

GIDEP
Corona, CA

Harris Corporation
Melbourne, Florida

Lear Siegler Corporation
Grand Rapids, Michigan

Litton Industries
Van Nuys, California

Magnavox Corporation
Fort Wayne, Indiana

Martin Marietta Corporation
Orlando, Florida

Philco-Ford Corporation
Palo Alto, California

Raytheon Corporation
Wayland, Massachussetts

Reliability Analysis Center
Rome, New York

Sperry Univac
St. Paul, Minnesota

Sperry Systems Management
Great Neck, New York

APPENDIX B

SECTION 2.11, MIL-HDBK-217B

Table 2.11-1. Prediction Procedure for Connectors

PART SPECIFICATIONS COVERED (Table 2.11-2 shows connector configurations)

Type	MIL-C-SPEC	Type	MIL-C-SPEC
Rack and panel	24308 28748 83733	Coaxial, RF	3607 3643 3650 3655 25516 39012
Circular	5015 26482 38999 81511 83723	Power	3767

Part Failure Rate Model (λ_p)

The failure rate model (λ_p) is for a mated pair of connectors:

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

where:

π_E - Table 2.11-6

π_p - Table 2.11-7

π_K - Table 2.11-8

Table 2.11-1. Prediction Procedure for Connectors (Cont)

Base Failure Rate Model (λ_b)

$$\lambda_b = Ae^x$$

$$\text{where } x = \frac{N_T}{T+273} + \left(\frac{T+273}{T_o}\right)^P$$

$e = 2.718$, natural logarithm base

T = operating temperature (°C)

T = ambient + temperature rise (Table 2.11-4)

Constants	Insert Material			
	A	B	C	D
A	0.02	0.431	0.19	0.77
T_o	473	423	373	358
N_T	-1592	-2073.6	-1298	-1528.8
P	5.36	4.66	4.25	4.72

Calculated values of λ_b for selected operating temperatures are shown in Table 2.11-5.

Table 2.11-2. Configuration, Applicable Specification, and Insert Material for Connectors

Configuration	Specification	Insert Material (Table 2.11-3)			
		A	B	C	D
Rack and panel	MIL-C-28748		X		
	MIL-C-83733		X		
	MIL-C-24308	X	X		
Circular	MIL-C-5015		X		X
	MIL-C-26482	X	X		X
	MIL-C-38999	X	X		
	MIL-C-81511		X		
	MIL-C-83723		X		
Power	MIL-C-3767				X
Coaxial	MIL-C-3607			X	
	MIL-C-3643			X	
	MIL-C-3650			X	
	MIL-C-3655			X	
	MIL-C-25516			X	
	MIL-C-39012			X	

Table 2.11-3. Temperature Ranges of Insert Materials

Type	Common Insert Materials	Temperature Range (°C)*
A	Vitreous glass, alumina ceramic, polyimide	-55 to 250
B	Diallyl phthalate, melamine, fluorosilicone, silicone rubber, polysulfone, epoxy resin	-55 to 200
C	Polytetrafluoroethylene (teflon) chlorotrifluoroethylene (kel-f)	-55 to 125
D	Polyamide (nylon), polychloroprene (neoprene), polyethylene	-55 to 125

*These temperature ranges indicate maximum capability of the insert material only. Connectors using these materials generally have a reduced temperature range caused by other considerations of connector design. Applicable connector specifications contain connector operating temperature.

Table 2.11-4. Insert Temperature Rise (°C) versus Contact Current

Amperes Per Contact	Contact Size			
	22 GA	20 GA	16 GA	12 GA
2	3.7	2.4	1.0	0.4
3	7.7	5.0	2.2	0.8
4	13.0	8.5	3.7	1.4
5	20.0	13.0	5.5	2.0
6	27.0	18.0	7.7	2.8
7	36.0	24.0	10.0	3.7
8	46.0	30.0	13.0	4.8
9	58.0	37.0	16.0	5.9
10	70.0	45.0	20.0	7.2
15		95.0	41.0	15.0
20			70.0	25.0
25			105.0	38.0
30				53.0
35				71.0
40				91.0

$\Delta T = 0.989\,(i)^{1.85}$ for 22 gauge contacts

$\Delta T = 0.64\,(i)^{1.85}$ for 20 gauge contacts

$\Delta T = 0.274\,(i)^{1.85}$ for 16 gauge contacts

$\Delta T = 0.1\,(i)^{1.85}$ for 12 gauge contacts

ΔT = °C insert temperature rise

i = amperes per contact

NOTE: Operating temperature of the connector is usually assumed to be the sum of the ambient temperature surrounding the connector plus the temperature rise generated in the contact. If the connector is mounted on a suitable heat sink, the heat sink temperature is usually taken as ambient. For those circuit design conditions which generate a contact hot spot, this hot spot temperature rise is added to the ambient to obtain the operating temperature.

For RF coaxial connectors, assume $\Delta T = 5°C$.

Table 2.11-5. Operating Temperature versus Base Failure Rate (λ_b) (Failures/10^6 Hours)

Temperature (°C)	Insert Material*			
	A	B	C	D
0	0.00006	0.00025	0.0020	0.0038
10	0.00008	0.00031	0.0027	0.0048
20	0.00009	0.00044	0.0033	0.0061
30	0.00012	0.00056	0.0041	0.0078
40	0.00014	0.00075	0.0049	0.0099
50	0.00017	0.00094	0.0059	0.0125
60	0.00020	0.0012	0.0073	0.0159
70	0.00023	0.0015	0.0087	0.0202
80	0.00028	0.00188	0.0106	0.0258
90	0.00032	0.00231	0.0131	0.033
100	0.00038	0.00288	0.0161	0.043
110	0.00044	0.00362	0.0197	
120	0.00051	0.00450	0.0246	
130	0.00059	0.00556		
140	0.00069	0.00694		
150	0.00081	0.00869		
160	0.00096	0.01093		
170	0.00110	0.01381		
180	0.00133	0.01756		
190	0.00159	0.02243		
200	0.00290	0.02894		
210	0.00229			
220	0.00279			
230	0.00343			
240	0.00426			
250	0.00536			

*If a mating pair of connectors uses two types of insert materials, use the average of the base failure rates for the two insert types.

Table 2.11-6. π_E Based on Environmental Service Condition

Environment	π_E	
	MIL-SPEC	Lower Quality
G_B	1.0	1.5
S_F	1.0	1.5
G_F	2.0	4.0
N_S	6.0*	3.0*
A_{IT}	5.0*	15.0*
A_{UT}	5.0	15.0
G_M	5.0	15.0
N_U	9.0	19.0
A_{IF}	10.0*	30.0*
A_{UF}	10.0	30.0
M_L	15.0	30.0

*For coaxial connectors in A_{IT}, π_E (MIL-SPEC) = 6.0, π_E (lower quality) = 24.0.

In N_S, π_E (MIL-SPEC) = 6.0, π_E (lower quality) = 36.0

In A_{IF}, π_E (MIL-SPEC) = 12.0, π_E (lower quality) = 48.0.

Table 2.11-7. Values of Failure Rate Multiplier, π_P, for Number of Active Contacts (Pins) in a Connector

Number Of Active Contacts	π_P	Number Of Active Contacts	π_P
1	1.00	65	13.20
2	1.36	70	14.60
3	1.55	75	16.10
4	1.72	80	17.69
5	1.87	85	19.39
6	2.02	90	21.19
7	2.16	95	23.10
8	2.30	100	25.13
9	2.44	105	27.28
10	2.58	110	29.56
11	2.72	115	31.98
12	2.86	120	34.53
13	3.00	125	37.22
14	3.14	130	40.02
15	3.28	135	43.08
16	3.42	140	46.25
17	3.57	145	49.60
18	3.71	150	53.12
19	3.86	155	56.83
20	4.00	160	60.74
25	4.78	165	64.85
30	5.60	170	69.17
35	6.46	175	73.70
40	7.42	180	78.47
45	8.42	185	83.47
50	9.50	190	88.72
55	10.65	195	94.23
60	11.89	200	100.00

For coaxial and triaxial connectors, the shield contact is counted as an active pin.

π_P is a function of the number of active pins:

$$\pi_P = e^{\left(\frac{N-1}{N_o}\right)^q}$$

where N_o = 10

q = 0.51064

N = number of active pins

Table 2.11-8. π_K Mating/Unmating Factor

Mating/Unmating Cycles (per 1000 hours)	π_K
0-0.05	1.0
>0.05-0.5	1.5
>0.5-5	2.0
>5-50	3.0
>50	4.0

One cycle includes both connect and disconnect.

Connector

EXAMPLE

Connector not experiencing a high cycling rate

Given: A MIL-SPEC connector, with with 20 GA pins, uses insert material, type B. The connector has 20 active pins and is installed in a ground fixed environment with an ambient temperature of 25°C. The load current is expected to be 5 amperes, and the connector is expected to be connected and disconnected once every 200 operating hours.

Find: The failure rate of the connector.

Step 1. The insert temperature rise is determined to be 13°C, derived from Table 2.11-4 for size 20 GA pins at 5 amperes.

The operating temperature is determined from:

Operating temperature = ambient temperature + insert temperature rise.
Operating temperature = 25°C + 13°C = 38°C

Step 2. The insert material is type B. Utilizing Table 2.11-5, the base failure rate for type B insert material at 38°C is 0.00073 failures/10^6 hours.

Step 3. The environmental factor for ground fixed (π_E) is 2.0, as shown in Table 2.11-6. The pin density factor (π_P) is 4.0, as shown in Table 2.11-7 for 20 active pins. The π_K factor is 2.0, as determined from Table 2.11-8, for mating/unmating cycles of 5/1000 hours.

Step 4. The failure rate of the connector is found by substituting the values of λ_b, π_E, π_P, and π_K into the part failure rate model:

$$\lambda_p = \lambda_b (\pi_E \times \pi_P \times \pi_K)$$

$$\lambda_p = 0.00073 (2.0 \times 4.0 \times 2.0)$$

$$\lambda_p = 0.0117 \text{ failures}/10^6 \text{ hours.}$$

Connector

EXAMPLE

Connector experiencing a high cycling rate

Given: A lower quality connector, with 16 GA pins, uses insert material, type D. The connector has 10 active pins and is installed in an airborne inhabited, transport environment with an ambient temperature of 40°C. The load current is expected to be 5.0 amperes, and the connector is expected to be connected and disconnected once every 20 hours.

Find: The failure rate of the connector.

Step 1. The insert temperature rise is determined to be 5.5°C, derived from Table 2.11-4, for size 16 GA pins at 5.0 amperes.

The operating temperature is determined from:

Operating temperature = ambient temperature + insert temperature rise.
Operating temperature = 40°C + 5.5°C = 45.5°C.

Step 2. The insert material is type D. Utilizing Table 2.11-5, the base failure rate for type D insert material at 45.5°C is 0.0113 failures/10^6 hours.

Step 3. The environmental factor for airborne inhabited, transport, lower quality is 15.0, as shown in Table 2.11-6. The pin density factor (π_P) is 2.58, as shown in Table 2.11-7, for 10 active pins. The π_K factor is 4.0, as determined from Table 2.11-8 for 50 mating/unmating cycles per 1000 hours.

Step 4. The failure rate of the connector is determined by substituting the values of λ_b, π_F, π_P, and π_K into the part failure rate model:

$$\lambda_p = \lambda_b \, (\pi_E \times \pi_p \times \pi_K)$$

$$\lambda_p = 0.0113 \, (15.0 \times 2.58 \times 4.0)$$

$$\lambda_p = 1.75 \text{ failures}/10^6 \text{ hours.}$$

APPENDIX C

SECTION 2.9, MIL-HDBK-217B

Table 2.9-1. Prediction Procedure for Relays

Part Specifications Covered

Military Specifications

1. MIL-R-5757	3. MIL-R-19523	5. MIL-R-19648
2. MIL-R-6016	4. MIL-R-39016	6. MIL-R-83725
		7. MIL-R-83726

Part failure rate model (λ_p)

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

where the factors are shown in these tables:

π_E - Table 2.9-4
π_C - Table 2.9-5
π_F - Table 2.9-7
π_{cyc} - Table 2.9-6

π_Q - Table 2.9-8

Note - Values of π_{cyc} for cycling rates beyond the basic design limitations of the relay are not valid. Design Specifications should be consulted prior to evaluation of π_{cyc}.

Table 2.9-1. Prediction Procedure for Relays (Continued)

Base failure rate model (λ_b)

$$\lambda_b = \lambda_T \pi_L$$

where $\lambda_T = A e^x$

$$\pi_L = e^y$$

$$y = \left(\frac{S}{N_S}\right)^H$$

$$x = \left(\frac{T + 273}{N_T}\right)^G$$

T = Ambient operating temperature in °C

S = Operating load current/rated resistive load current

e = 2.718, natural logarithm base.

Constants	λ_T (85°C)	λ_T (125°C)	π_L (Lamp)	π_L (Inductive)	π_L (Resistive)
A	5.55×10^{-3}	5.4×10^{-3}	-	-	-
N_T	352.0	377.0	-	-	-
N_S	-	-	0.2	0.4	0.8
G	15.7	10.4	-	-	-
H	-	-	2.0	2.0	2.0

Note - Table 2.9-2 contains λ_T

Table 2.9-3 contains π_L

Table 2.9-2. Relay Failure Rate (λ_T) vs Ambient Temperature

T (°C)	Relay Temperature Rating	
	85°C	125°C
25	0.0060	0.0059
30	0.0061	0.0060
40	0.0065	0.0063
50	0.0072	0.0066
60	0.0085	0.0071
70	0.0110	0.0079
75	0.0130	0.0084
80	0.0160	0.0090
85	0.0210	0.0097
90		0.0110
95		0.0120
100		0.0130
105		0.0150
110		0.0180
115		0.0210
120		0.0250
125		0.0310

Table 2.9-3. π_L - Stress Factor vs Load Type

S	Load Type		
	Resistive	Inductive	Lamp
0.05	1.00	1.02	1.06
0.10	1.02	1.07	1.28
0.20	1.06	1.28	2.72
0.30	1.15	1.76	9.49
0.40	1.28	2.72	54.60
0.50	1.48	4.77	
0.60	1.76	9.49	
0.70	2.15	21.40	
0.80	2.72		
0.90	3.55		
1.00	4.77		

$$S = \frac{\text{Operating Load Current}}{\text{Rated Resistive Load Current}}$$

Table 2.9-4. π_E Based on Environmental Service Condition

Environment	π_E	
	MIL-SPEC	Lower Quality
G_B	1.0	2.0
S_F	1.0	2.0
G_F	2.0	4.0
A_{IT}	4.0	8.0
N_S	5.0	15.0
A_{IF}	8.0	16.0
G_M	5.0	15.0
N_U	11.0	30.0
A_{UT}	12.0	30.0
A_{UF}	24.0	60.0
M_L	100.0	300.0

Table 2.9-5. π_C Factor For Contact Form

Contact Form	π_C
SPST	1.00
DPST	1.50
SPDT	1.75
3PST	2.00
4PST	2.50
DPDT	3.00
3PDT	4.25
4PDT	5.50
6PDT	8.00

This table applies to active conducting contacts.

Table 2.9-6. π_{cyc} Factor
For Cycling Rates

Cycle Rate (Cycles per Hour)	π_{cyc} (MIL-SPEC)
≥ 1.0	$\frac{\text{Cycles per Hour}}{10}$
< 1.0	0.1

Cycle Rate (Cycles per Hour)	π_{cyc} (Lower Quality)
> 1000	$\left(\frac{\text{Cycles per Hour}}{100}\right)^2$
10-1000	$\frac{\text{Cycles per Hour}}{10}$
< 10	1.0

Table 2.9-7. Failure Rate Factor (π_F) For Relay Application and Construction Type

Contact Rating	Application Type	Construction Type	π_F	
			MIL-SPEC	Lower Quality
Signal current (low mv and ma)	Dry circuit	Armature (long)	4	8
		Dry reed	6	18
		Mercury wetted	1	3
		Magnetic latching	4	8
		Balanced armature	7	14
		Solenoid	7	14
0-5 amp	General purpose	Armature (long)	3	6
		Balanced armature	5	10
		Solenoid	6	12
	Sensitive (0-100 mw)	Armature (long and short)	5	10
		Mercury wetted	2	6
		Magnetic latching	6	12
		Meter movement	100	100
		Balanced armature	10	20
	Polarized	Armature (short)	10	20
		Meter movement	100	100
	Vibrating reed	Dry reed	6	12
		Mercury wetted	1	3
	High speed	Armature (balanced and short)	25	NA
		Dry reed	6	NA
	Thermal time delay	Bimetal	10	20
	Electronic time delay, non-thermal		9	12
	Latching, magnetic	Dry reed	10	20
		Mercury wetted	5	10
		Balanced armature	5	10
5-20 amp	High voltage	Vacuum (glass)	20	40
		Vacuum (ceramic)	5	10
	Medium power	Armature (long and short)	3	6
		Mercury wetted	1	3
		Magnetic latching	2	6
		Balanced armature	2	6
		Solenoid	2	6
25-600 amp	Contactors (high current)	Armature (short)	7	14
		Mechanical latching	12	24
		Balanced armature	10	20
		Solenoid	5	10

Table 2.9-8. Quality Factor (π_Q) For Relay Application

Failure Rate Level	π_Q
L	1.5
M	1.0
P	0.3
R	0.1

For relays other than ER (MIL-R-39016), use $\pi_Q = 1.0$

EXAMPLE

Given: A relay rated at 125°C is operated in a ground fixed environment with an ambient temperature of 30°C. The relay is double-pole, double-throw with a resistive load of 50 percent of rated load. The relay is expected to be cycled at an average of 5 cycles per hour. The relay is a balanced armature, general purpose relay.

Find: The failure rate of the relay.

Step 1. From Table 2.9-2, λ_T is 0.006 failures/10^6 hours, based on the ambient temperature of 30°C for 125°C rated relay.

Step 2. From Table 2.9-3, $\pi_L = 1.48$ for a resistive load at 50 percent rating.

Step 3. From Table 2.9-4, π_E is 2.0 for ground fixed environment.

Step 4. From Table 2.9-5, π_c is 3.0 for double-pole, double-throw contacts.

Step 5. From Table 2.9-6, π_{cyc} is 0.5 for 5 cycles $\left(\frac{\text{5 cycles per hour}}{10}\right)$.

Step 6. From Table 2.9-7, π_F is a 5 for a balanced armature, general purpose relay.

Step 7. From Table 2.9-8, π_Q is 1.0.

Step 8. The failure rate is determined by substituting the factors into the failure rate mathematical model:

$$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q)$$

$$\lambda_b = \lambda_T \pi_c = 0.006 \times 1.48 = 0.0089 \text{ failures}/10^6 \text{ hours}$$

$$\lambda_p = 0.0089 (2.0 \times 3.0 \times 0.5 \times 5.0 \times 1.0) = 0.133 \text{ failures}/10^6 \text{ hours.}$$

APPENDIX D

SECTION 2.10, MIL-HDBK-217B

Switches

Toggle or pushbutton (single body)

TABLE 2.10-1

Prediction Procedures for Toggle or Pushbutton Switches

Part specifications covered	Description
1. MIL-S-3950	
2. MIL-S-8805	Snap-action toggle or pushbutton

Part failure rate model (λ_p)

$$\lambda_p = \lambda_b (\pi_E \times \pi_C \times \pi_{cyc} \times \pi_L) \text{ failures}/10^6 \text{ hours}$$

where factors are shown in:

π_E - Table 2.10-4

π_C - Table 2.10-5

π_{cyc} - Table 2.10-6

π_L - Table 2.10-7

Base failure rate model (λ_b)

Description	λ_b	
	MIL-SPEC	Lower Quality
Snap-action	0.00045	0.034
Non-snap action	0.0027	0.04

Switches

Basic sensitive

Table 2.10-2. Prediction Procedure for Basic Sensitive Switch

Part specifications covered	Description
MIL-S-8805	Basic sensitive

Part failure rate model (λ_p)

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

where factors are shown in:

π_E - Table 2.10-4

π_{cyc} - Table 2.10-6

π_L - Table 2.10-7

Base failure rate model (λ_b)

$\lambda_b = \lambda_{bE} + n\,\lambda_{bC}$ (if actuation differential is >0.002 inches)

$\lambda_b = \lambda_{bE} + n\,\lambda_{bD}$ (if actuation differential is <0.002 inches)

where n = number of contacts or active poles

Description	MIL-SPEC	Lower Quality
λ_{bE}	0.1	0.1
λ_{bC}	0.0009	0.45
λ_{bD}	0.0018	1.25

Switches

Rotary (wafer)

Table 2.10-3. Prediction Procedure for Rotary Switches

Part specification covered	Description
MIL-S-3786	Rotary, ceramic or glass wafer, silver alloy contacts

Part failure rate model (λ_p)

$$\lambda_p = \lambda_b \, (\pi_E \times \pi_{cyc} \times \pi_L) \text{ failures}/10^6 \text{ hours}$$

where factors are shown in:

π_E - Table 2.10-4

π_{cyc} - Table 2.10-6

π_L - Table 2.10-7

Base failure rate model (λ_b)

$\lambda_b = \lambda_{bE} + n \, \lambda_{bF}$ (for ceramic RF wafers)

$\lambda_b = \lambda_{bE} + n \, \lambda_{bG}$ (for rotary switch medium power wafers)

where n is the number of active contacts

Description	MIL-SPEC	Lower Quality
λ_{bE}	0.0067	0.1
λ_{bF}	0.00003	0.02
λ_{bG}	0.00003	0.06

Table 2.10-4. π_E - Environmental Factors Based on Service Condition for Switches

Environment	π_E
G_B	1.0
S_F	1.0
G_F	3.0
N_S	4.0
A_{IT}	5.0
A_{IF}	10.0
G_M	17.0
N_J	23.0
A_{UT}	50.0
A_{UF}	100.0
M_L	667.0

Table 2.10-5. π_C Factor for Contact Form and Quantity

Contact Form	π_C
SPST	1.0
DPST	1.5
SPDT	1.75
3PST	2.0
4PST	2.5
DPDT	3.0
3PDT	4.25
4PDT	5.5
6PDT	8.0

Table 2.10-6. π_{cyc} Factor for Cycling Rates

Switching Cycles per Hour	π_{cyc}
$\leq$ 1 cycle/hour	1.0
> 1 cycle/hour	number of cycles/hour

Table 2.10-7. π_L Stress Factor for Switch Contacts

Stress	Load Type		
	Resistive	Inductive	Lamp
0.05	1.00	1.02	1.06
0.1	1.02	1.07	1.28
0.2	1.06	1.28	2.72
0.3	1.15	1.76	9.49
0.4	1.28	2.72	54.60
0.5	1.48	4.77	
0.6	1.78	9.49	
0.7	2.15	21.40	
0.8	2.72		
0.9	3.55		
1.0	4.77		

where $S = \frac{\text{operating load current}}{\text{rated resistive load}}$

Switches

Example

Given: A MIL-SPEC toggle switch is used in a ground fixed environment. The switch is a snap-action switch and is single-pole, double-throw. It is operated on the average of one cycle per hour, and load current is 50 percent of rated and is resistive.

Find: The failure rate of the switch.

Step 1. The base failure rate λ_b is found in Table 2.10-1 and is determined to be 0.00045 failures/10^6 hours.

Step 2. The environmental factor π_E for ground fixed environment is determined from Table 2.10-4 to be 3.0.

Step 3. The contact form factor π_C is determined from Table 2.10-5. For a single-pole, double-throw switch, π_C is 1.75.

Step 4. The cycling factor π_{cyc} is determined from Table 2.10-6 to be equal to 1.0.

Step 5. The stress factor π_L from Table 2.10-7 for 50 percent stress factor and a resistive load is determined to be 1.48.

Step 6. The failure rate mathematical model for toggle switches is:

$$\lambda_p = \lambda_b (\pi_E \times \pi_C \times \pi_{cyc} \times \pi_L)$$

Substituting for these factors:

$$\lambda_p = 0.00045 (3 0 \times 1.75 \times 1.0 \times 1.48)$$

$$\lambda_p = 0.0035 \text{ failures}/10^6 \text{ hours.}$$

Switches

Example

Given: A MIL-SPEC rotary switch is installed in an airborne inhabited, transport environment. It has a medium power wafer, one deck, and six contacts. The switch is cycled at average of 5 cycles per hour, and the load current is 50 percent of rated current and is resistive.

Find: The failure rate of the switch.

Step 1. The base failure rate λ_b is determined from Table 2.10-3.

$$\lambda_b = \lambda_{bE} + n\ \lambda_{bG}$$

Substituting the values from Table 2.10-3:

$$\lambda_b = 0.0067 + 6\ (0.00003)$$

$$\lambda_b = 0.00688 \text{ failures}/10^6 \text{ hours.}$$

Step 2. The environmental factor for airborne inhabited, transport (π_E) is determined from Table 2.10-4 to be 5.0.

Step 3. The cycling factor π_{cyc} is determined from Table 2.10-6 to be 5.0.

Step 4. The stress factor π_{cyc} is determined from Table 2.10-7 to be 1.48.

Step 5. The failure rate mathematical model for rotary switches is:

$$\lambda_p = \lambda_b\ (\pi_E \times \pi_{cyc} \times \pi_L)$$

Substituting values determined in the formula:

$$\lambda_p = 0.00688\ (5.0 \times 5.0 \times 1.48)$$

$$\lambda_p = 0.255 \text{ failures}/10^6 \text{ hours.}$$

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