

AD A050678

RADC-TR-77-417
Final Technical Report
December 1977



DEVELOPMENT OF NONELECTRONIC PART CYCLIC
FAILURE RATES

George F. Guth

Martin Marietta Corporation

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| 19 REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|--|-----------------------|---|
| 1. REPORT NUMBER RADC TR-77-417 ✓ | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle) DEVELOPMENT OF NONELECTRONIC PART CYCLIC FAILURE RATES | | 5. TYPE OF REPORT & PERIOD COVERED Final Technical Report September 1976 — September 1977 |
| 7. AUTHOR(s) George F./Guth | | 6. PERFORMING ORG. REPORT NUMBER OR-148841 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Martin Marietta Corporation/Orlando Division P. O. Box 5837 Orlando FL 32855 | | 8. CONTRACT OR GRANT NUMBER(s) F30602-76-C-0437 now |
| 11. CONTROLLING OFFICE NAME AND ADDRESS Rome Air Development Center (RBRT) Griffiss AFB NY 13441 | | 10. PROGRAM ELEMENT, PROJECT, TASK, AREA & WORK UNIT NUMBERS 62702F 23380208 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Same | | 12. REPORT DATE December 1977 |
| 16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. | | UNCLASSIFIED 15. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Same | | |
| 18. SUPPLEMENTARY NOTES RADC Project Engineer: Lester J. Gubbins (RBRT) | | |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Connectors Connectors, Failure Rates Connectors, Reliability Models Connectors, Reliability Prediction Relays Relays, Failure Rates Relays, Reliability Prediction Reliability Information Switches Switches, Failure Rates (Cont'd on back) | | |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) 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. (Cont'd on back) | | |

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19. (Continued)

Switches, Reliability Models
Switches, Reliability Prediction

20. (Continued)

→ 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_q , has been developed for the connector model, and a stress factor has been added to the switch model.

p_i sub k

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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-217C.



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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 Mes. Lynn Westling, Lynn Mercer, and Betty Jean Thomas.

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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.

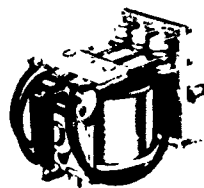


Figure 1. General Purpose Relay



Figure 2. Dry-Reed Relay

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.

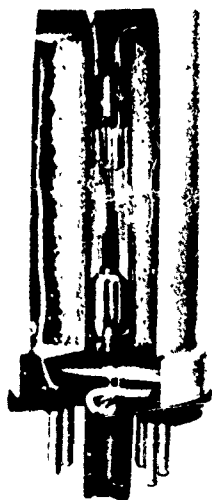


Figure 3. Mercury Wetted Contact Relay

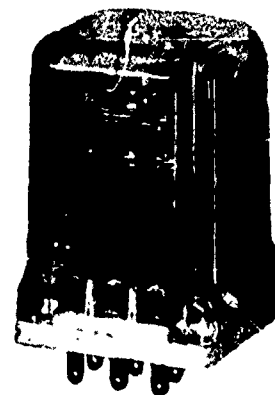


Figure 5. Magnetic Latching Relay

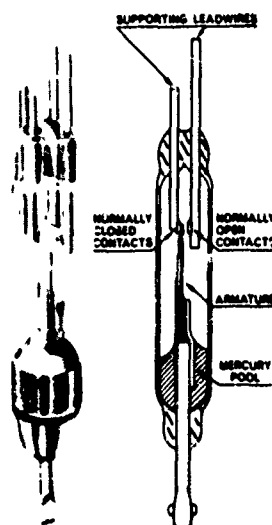


Figure 4. Mercury Wetted Reed Relay

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.

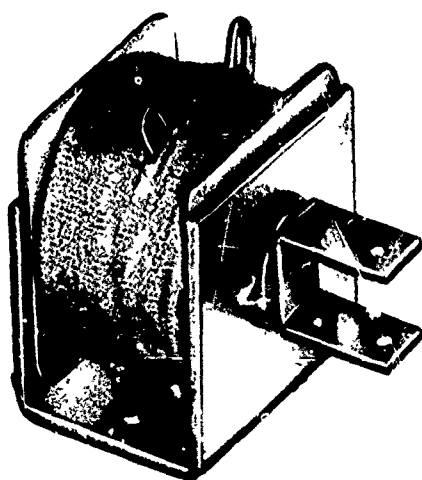


Figure 6. Solenoid-Actuated Relays

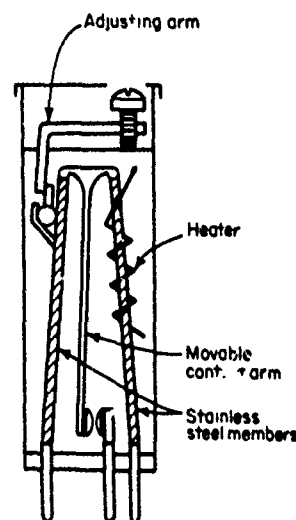


Figure 7. Thermal Time Delay Relay

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 repeatability, due to only one moving part
- No wear points and long life in the one-piece blade.

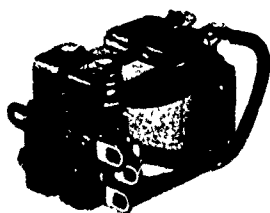


Figure 8. Power Relay

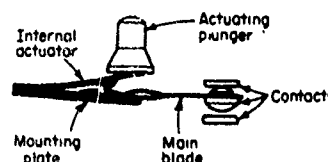


Figure 9. Snap Action Switch

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

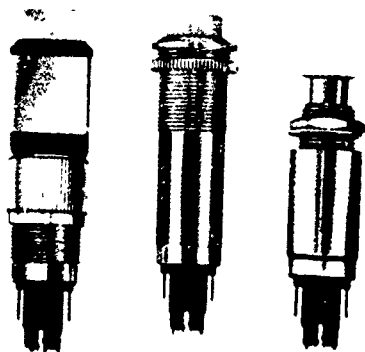


Figure 10. Push
Button Switch

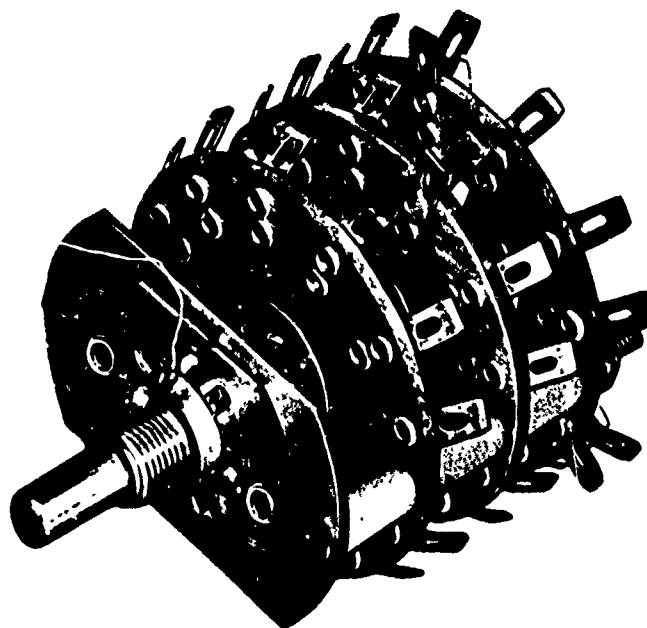


Figure 11. Rotary
Switch

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.

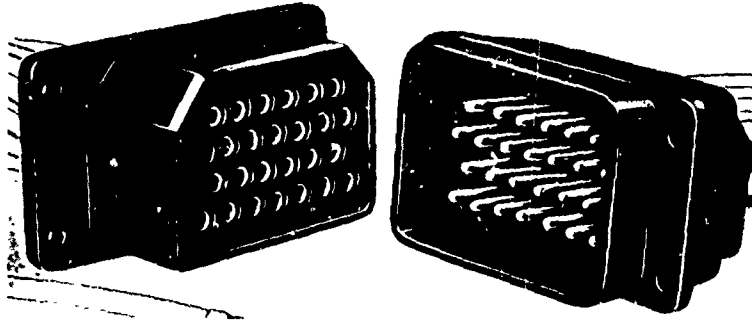


Figure 12. Heavy-duty Connector



Figure 13. Miniature Rectangular Connector

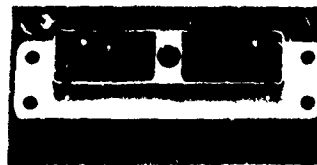


Figure 14. Center Jackscrew Miniature Rectangular Connector

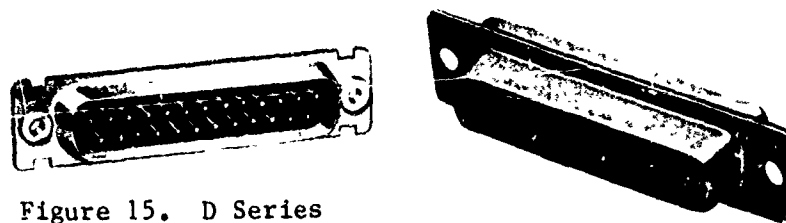


Figure 15. D Series Subminiature Connector

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 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.

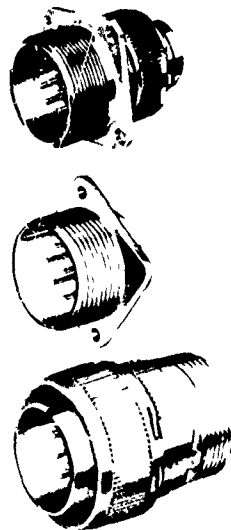


Figure 16. MIL-C-5015
Connectors



Figure 17. MIL-C-26482 Connectors



Figure 18. MTL-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 an 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

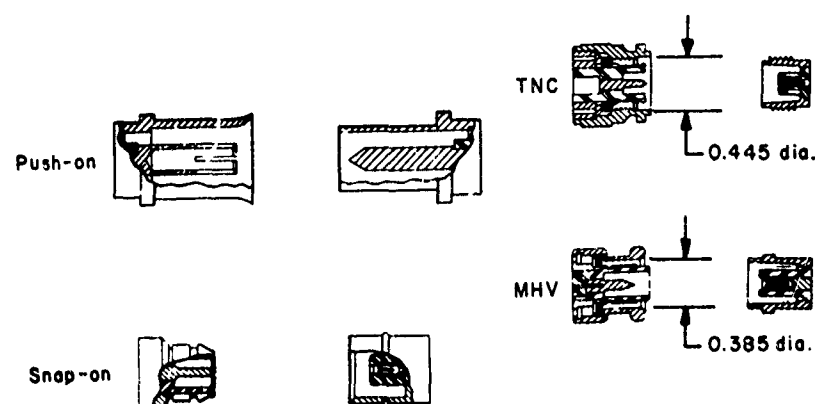


Figure 20. MHV-Type Connector

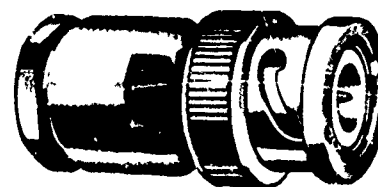


Figure 21. BNC-Type Connector

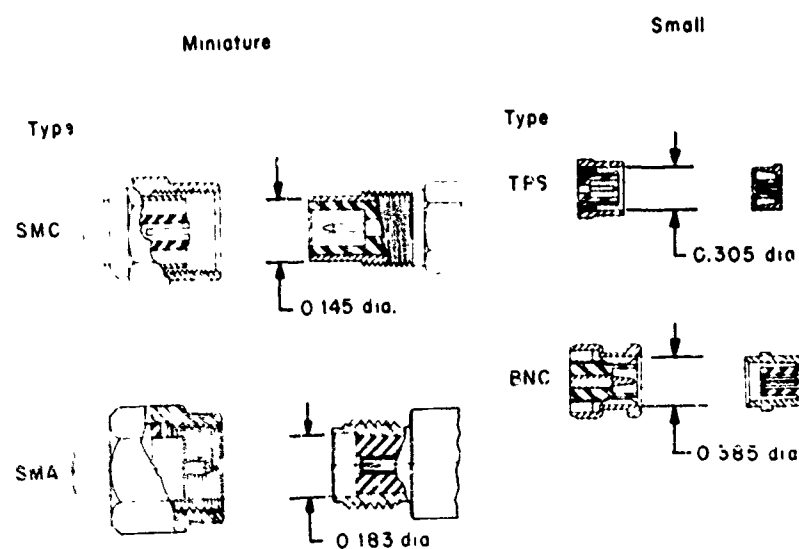


Figure 22. TPS-Type Connector

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 coarse 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.

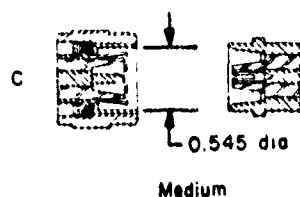


Figure 23. C-Type Connector

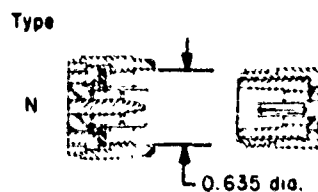


Figure 24. N-Type Connector

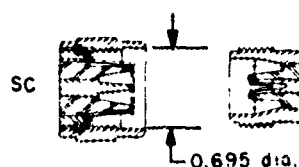


Figure 25. SC-Type Connector

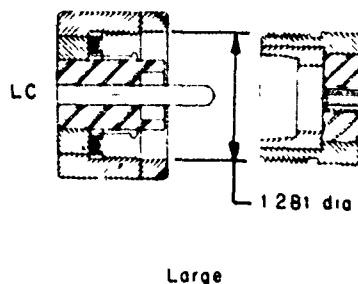


Figure 26. LC-Type Connector

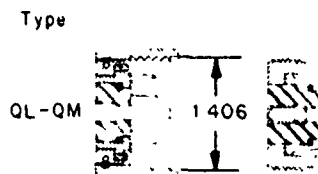


Figure 27. QL and QM-Type Connectors

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

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

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:

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

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

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 ship-board 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 | 0.055 | - | - |
| 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 | 4.379 | - | 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

λ_{cyc} = cycling rate factor.

Using this equation and substituting parameters from operating field data, a typical failure rate is calculated for a connector ground fixed environment 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)

λ_b = 0.009×10^{-6} (for "B" material at 30°C)

λ_{cyc} = 0 (for cycling rate < 40 cycles/1000 hours).

N = 50

Substituting these constants into the failure rate model results in:

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

$\lambda_p = 0.342 \times 10^{-6}$ 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)

| Environment | Insert Type | | | |
|----------------------|-------------|-------|-------|-------|
| | A | B | C | D |
| Ground fixed | - | 0.342 | 0.32 | 3.16 |
| Naval sheltered | - | 0.404 | - | 3.78 |
| Airborne uninhabited | - | 3.99 | 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 ≤ 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:

$$\pi_p = e^{\left(\frac{N-1}{N_0}\right)^q}$$

where:

$$N_0 = 10$$

$$q = 0.51064$$

$$N = \text{number of active pins.}$$

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 (x 10 ⁻⁶) | Predicted (x 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 | 0.0055 |
| 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:

$$\begin{aligned}\pi_E &= 4.0 \\ \pi_P &= 5.6 \\ \pi_K &= 2.0 \\ \lambda_b &= 0.0078 \times 10^{-6} \text{ failures/hour.}\end{aligned}$$

Substituting the constants into the mathematical model equation results in:

$$\begin{aligned}\lambda_P &= 0.0078 \times 10^{-6} (4.0 \times 5.6 \times 2.0) \\ \lambda_P &= 0.35 \times 10^{-6} \text{ failures/hour}\end{aligned}$$

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

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

$$\lambda_b = 0.00056 \text{ (for B material at } 30^\circ\text{C)}$$

$$\pi_E = 2.0 \text{ (ground fixed)}$$

$$\pi_p = 9.5 \text{ (for 50 pins)}$$

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

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

2 Ground fixed, insert type C

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

$$\lambda_b = 0.0041 \text{ (for C material at } 30^\circ\text{C)}$$

$$\pi_E = 2.0 \text{ (ground fixed)}$$

$$\pi_p = 1.36 \text{ (for 2 pins)}$$

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

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

3 Ground fixed, insert type D

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

$$\lambda_b = 0.0078 \text{ (for D material at } 30^\circ\text{C)}$$

$$\pi_E = 2.0 \text{ (ground fixed)}$$

$$\pi_p = 5.6 \text{ (for 30 pins)}$$

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

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

4 Naval sheltered, insert type B

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

$$\lambda_b = 0.00075 \text{ (for B type material at } 40^\circ\text{C)}$$

$$\pi_E = 3.0 \text{ (Naval sheltered)}$$

$$\pi_p = 8.42 \text{ (for 45 pins)}$$

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

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

5 Naval sheltered, insert type D

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

$$\lambda_b = 0.0099 \text{ (for D type material at } 40^\circ\text{C)}$$

$$\pi_E = 3.0 \text{ (naval sheltered)}$$

$$\pi_P = 6.46 \text{ (for 35 pins)}$$

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

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

6 Airborne uninhabited, transport, insert type B

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

$$\lambda_b = 0.00075 \text{ (for B type material at } 40^\circ\text{C)}$$

$$\pi_E = 5.0 \text{ (airborne uninhabited, transport)}$$

$$\pi_P = 21.19 \text{ (for 90 pins)}$$

$$\pi_K = 4.0 \text{ (for } >50 \text{ cycles/1000 hours)}$$

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

7 Airborne uninhabited, transport, insert material C

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

$$\lambda_b = 0.0054 \text{ (C type material at } 45^\circ\text{C)}$$

$$\pi_E = 5.0 \text{ (airborne uninhabited, transport)}$$

$$\pi_P = 1.36 \text{ (for 2 pins)}$$

$$\pi_K = 4.0 \text{ (for cycling 750/1000 hours)}$$

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

8 Airborne uninhabited, transport insert material D

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

$$\lambda_b = 0.0112 \text{ (for D type material at } 45^\circ\text{C)}$$

$$\pi_E = 5.0 \text{ (airborne uninhabited transport)}$$

$$\pi_P = 2.16 \text{ (for 7 pins)}$$

$$\pi_K = 4.0 \text{ (for cycling } >50/1000 \text{ hours)}$$

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

9 Airborne inhabited, transport, insert material B

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

$$\lambda_b = 0.00106 \text{ (for B type material at } 55^\circ\text{C)}$$

$$\pi_E = 5.0 \text{ (for airborne inhabited, transport)}$$

$$\pi_P = 6.46 \text{ (for 35 pins)}$$

$$\pi_K = 4.0 \text{ (for cycling } >50/1000 \text{ hours)}$$

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

10 Space flight, insert material B

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

$$\lambda_b = 0.00056 \text{ (for B type material at } 30^\circ\text{C)}$$

$$\pi_E = 1.0 \text{ (for space flight)}$$

$$\pi_P = 8.42 \text{ (for 45 pins)}$$

$$\pi_K = 1.0 \text{ (for 1 cycle/1000 hours)}$$

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

11 Space flight, insert material C

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

$$\lambda_b = 0.0041 \text{ (for C type material at } 30^\circ\text{C)}$$

$$\pi_E = 1.0 \text{ (for space flight)}$$

$$\pi_P = 1.36 \text{ (for 2 pins)}$$

$$\pi_K = 1.0 \text{ (for 1 cycle/1000 hours)}$$

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

12 Space flight, insert material D

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

$$\lambda_b = 0.0078 \text{ (for D type material at } 30^\circ\text{C)}$$

$$\pi_E = 1.0 \text{ (for space flight)}$$

$$\pi_P = 2.58 \text{ (for 10 pins)}$$

$$\pi_K = 1.0 \text{ (for 1 cycle/1000 hours)}$$

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

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

$$\pi_L = 1.48 \text{ (50 percent stress)}$$

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

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

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

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 (x 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_P 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 |
| 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

$$T = 30^\circ\text{C}$$

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

$$\lambda_b = \lambda_T \pi_L$$

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

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

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

$$\pi_E = 2.0 \text{ (ground fixed)}$$

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

$$\pi_Q = 1.0 \text{ (quality factor)}$$

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

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

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

2 Ground fixed, high voltage relay (lower quality)

$$T = 30^\circ\text{C}$$

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

$$\begin{aligned}
\lambda_b &= \lambda_T \pi_L \\
\lambda_T &= 0.0061 \times 10^{-6} \text{ (based on } 30^\circ\text{C)} \\
\pi_L &= 1.48 \text{ (based on 50 percent stress)} \\
\lambda_b &= 0.009 \times 10^{-6} \text{ failures/hour} \\
\pi_E &= 4.0 \text{ (ground fixed)} \\
\pi_c &= 3.0 \text{ (double-pole, double-throw)} \\
\pi_F &= 2.0 \text{ (high voltage, ceramic, lower quality)} \\
\pi_{cyc} &= 0.1 \text{ (less than 1 cycle per hour)} \\
\pi_Q &= 1.0 \text{ (quality factor)} \\
\lambda_p &= 0.216 \times 10^{-6} \text{ failures/hour}
\end{aligned}$$

3 Ground fixed, reed relay, lower quality

$$\begin{aligned}
T &= 30^\circ\text{C} \\
\lambda_p &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q) \\
\lambda_b &= \lambda_T \pi_L \\
\lambda_T &= 0.0061 \times 10^{-6} \text{ (based on } 30^\circ\text{C)} \\
\pi_L &= 1.48 \text{ (based on 50 percent stress)} \\
\lambda_b &= 0.009 \times 10^{-6} \text{ failures/hour} \\
\pi_E &= 4.0 \text{ (ground fixed)} \\
\pi_c &= 1.0 \text{ (based on single-pole, single-throw)} \\
\pi_F &= 12 \text{ (reed relay, lower quality)} \\
\pi_{cyc} &= 1.0 \text{ (based on 10 cycles/hour)} \\
\pi_Q &= 1.0 \text{ (for quality factor)} \\
\lambda_p &= 0.432 \times 10^{-6} \text{ failures/hour}
\end{aligned}$$

4 Ground fixed, thermal, MIL-SPEC

$$\begin{aligned}
T &= 30^\circ\text{C} \\
\lambda_p &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q) \\
\lambda_b &= \lambda_T \pi_L
\end{aligned}$$

$$\begin{aligned}\lambda_T &= 0.0061 \times 10^{-6} \text{ (based on } 30^\circ\text{C)} \\ \pi_L &= 1.48 \text{ (based on 50 percent stress)} \\ \lambda_b &= 0.009 \times 10^{-6} \text{ failures/hour} \\ \pi_E &= 2.0 \text{ (ground fixed)} \\ \pi_c &= 3.0 \text{ (double-pole, double-throw)} \\ \pi_F &= 10.0 \text{ (thermal relay, MIL-SPEC)} \\ \pi_{cyc} &= 1.0 \text{ (based on 10 cycles/hour)} \\ \pi_Q &= 1.0 \text{ (for quality factor)} \\ \lambda_p &= 0.54 \times 10^{-6} \text{ failures/hour} \\ \underline{5} \text{ Ground mobile, armature (lower quality)}\end{aligned}$$

$$\begin{aligned}T &= 30^\circ\text{C} \\ \lambda_p &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q) \\ \lambda_b &= \lambda_T \pi_L \\ \lambda_T &= 0.0061 \times 10^{-6} \text{ (based on } 30^\circ\text{C)} \\ \pi_L &= 1.48 \text{ (based on 50 percent stress)} \\ \lambda_b &= 0.009 \times 10^{-6} \text{ failures/hour} \\ \pi_E &= 15 \text{ (ground mobile, lower quality)} \\ \pi_c &= 3.0 \text{ (double-pole, double-throw)} \\ \pi_F &= 8.0 \text{ (armature, lower quality)} \\ \pi_{cyc} &= 0.1 \text{ (based on 1 cycle/hour)} \\ \pi_Q &= 1.0 \text{ (for quality factor)} \\ \lambda_p &= 0.324 \times 10^{-6} \text{ failures/hour}\end{aligned}$$

6 Ground benign, general purpose

$$\begin{aligned}T &= 35^\circ\text{C} \\ \lambda_p &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q) \\ \lambda_b &= \lambda_T \pi_L\end{aligned}$$

$$\begin{aligned}
\lambda_T &= 0.0063 \times 10^{-6} \text{ (based on } 35^\circ\text{C)} \\
\pi_L &= 1.48 \text{ (based on 50 percent stress)} \\
\lambda_b &= 0.0093 \times 10^{-6} \text{ failures/hour} \\
\pi_E &= 1.0 \text{ (based on ground benign environment)} \\
\pi_c &= 8.0 \text{ (based on six-pole, double-throw)} \\
\pi_F &= 5.0 \text{ (based on general purpose, balanced armature)} \\
\pi_{cyc} &= 1.0 \text{ (based on 10 cycles per hour)} \\
\pi_Q &= 1.0 \text{ (for quality factor)} \\
\lambda_p &= 0.372 \times 10^{-6} \text{ failures/hour}
\end{aligned}$$

7 Naval sheltered, MIL-R-6016

$$\begin{aligned}
T &= 40^\circ \\
\lambda_p &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q) \\
\lambda_b &= \lambda_T \pi_L \\
\lambda_T &= 0.0063 \times 10^{-6} \text{ (based on } 40^\circ\text{C)} \\
\pi_L &= 1.48 \text{ (based on 50 percent stress)} \\
\pi_b &= 0.0093 \times 10^{-6} \text{ failures/hour} \\
\pi_E &= 5.0 \text{ (based on naval sheltered)} \\
\pi_c &= 3.0 \text{ (double-pole, double-throw)} \\
\pi_F &= 5.0 \text{ (based on balanced armature)} \\
\pi_{cyc} &= 1.0 \text{ (based on 10 cycles/hour)} \\
\pi_Q &= 1.0 \text{ (for quality factor)} \\
\lambda_p &= 0.699 \times 10^{-6} \text{ failures/hour}
\end{aligned}$$

8 Naval sheltered, general purpose

$$\begin{aligned}
T &= 40^\circ\text{C} \\
\lambda_p &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q) \\
\lambda_b &= \lambda_T \pi_L
\end{aligned}$$

$$\lambda_T = 0.0063 \times 10^{-6} \text{ (based on naval sheltered)}$$

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

$$\lambda_b = 0.0093 \times 10^{-6} \text{ failures/hour}$$

$$\pi_E = 5.0 \text{ (based on naval sheltered)}$$

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

$$\pi_F = 5.0 \text{ (based on balanced armature)}$$

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

$$\pi_Q = 1.0 \text{ (quality factor)}$$

$$\lambda_p = 0.699 \times 10^{-6} \text{ failures/hour}$$

9 Naval sheltered, thermal

$$T = 40^\circ\text{C}$$

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

$$\lambda_b = \lambda_T \pi_L$$

$$\lambda_T = 0.0063 \times 10^{-6} \text{ (based on } 40^\circ\text{C)}$$

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

$$\lambda_b = 0.0093 \times 10^{-6} \text{ failures/hour}$$

$$\pi_E = 5.0 \text{ (naval sheltered)}$$

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

$$\pi_F = 10 \text{ (thermal travel delay)}$$

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

$$\pi_Q = 1.0 \text{ (quality factor)}$$

$$\lambda_p = 1.398 \times 10^{-6} \text{ failures/hour}$$

10 Airborne inhabited MIL-R-39016

$$T = 55^\circ\text{C}$$

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

$$\lambda_b = \lambda_T \pi_L$$

$$\begin{aligned}\lambda_T &= 0.00685 \times 10^{-6} \text{ (based on } 55^\circ\text{C)} \\ \pi_L &= 1.48 \text{ (based on 50 percent stress)} \\ \lambda_b &= 0.0101 \times 10^{-6} \text{ failures/hour} \\ \pi_E &= 5.0 \text{ (based on airborne inhabited)} \\ \pi_c &= 3.0 \text{ (double-pole, double-throw)} \\ \pi_F &= 5.0 \text{ (balanced armature)} \\ \pi_{cyc} &= 0.1 \text{ (based on 1 cycle per hour)} \\ \pi_Q &= 1.0 \text{ (quality factor)} \\ \lambda_p &= 0.076 \times 10^{-6} \text{ failures/hour}\end{aligned}$$

11 Airborne inhabited, MIL-R-6016

$$\begin{aligned}T &= 55^\circ\text{C} \\ \lambda_p &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q) \\ \lambda_b &= \lambda_T \pi_L \\ \lambda_T &= 0.00685 \times 10^{-6} \text{ (based on } 55^\circ\text{C)} \\ \pi_L &= 1.48 \text{ (based on 50 percent stress)} \\ \lambda_b &= 0.0101 \times 10^{-6} \text{ failures/hour} \\ \pi_E &= 5.0 \text{ (airborne inhabited, transport)} \\ \pi_c &= 5.5 \text{ (four pole, double-throw)} \\ \pi_F &= 5.0 \text{ (balanced armature)} \\ \pi_{cyc} &= 0.1 \text{ (based on 1 cycle/hour)} \\ \pi_Q &= 1.0 \text{ (quality factor)} \\ \lambda_p &= 0.139 \times 10^{-6} \text{ failures/hour}\end{aligned}$$

12 Space flight, MIL-R-6016

$$\begin{aligned}T &= 25^\circ\text{C} \\ \lambda_p &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_F \times \pi_Q) \\ \lambda_b &= \lambda_T \pi_L\end{aligned}$$

$$\begin{aligned}\lambda_T &= 0.0059 \times 10^{-6} \text{ (based on } 25^\circ\text{C)} \\ \pi_L &= 1.48 \text{ (based on 50 percent stress)} \\ \lambda_b &= 0.0087 \times 10^{-6} \text{ failures/hour} \\ \pi_E &= 1.0 \text{ (for space flight)} \\ \pi_c &= 3.0 \text{ (double-pole, double-throw)} \\ \pi_F &= 4.0 \text{ (magnetic latching)} \\ \pi_{cyc} &= 1.0 \text{ (based on 10 cycles/hour)} \\ \pi_Q &= 1.0 \text{ (quality factor)} \\ \lambda_p &= 0.104 \times 10^{-6} \text{ failures/hour}\end{aligned}$$

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 ($\times 10^{-6}$ 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 for each 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 switch appears in Section 2.10 of MIL-HDBK-217B:

$$\lambda_p = \lambda_b (\pi_E \times \pi_c \times \pi_{cyc}) \text{ failure rate}$$

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:

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

$$\pi_E = 1.0$$

$$\pi_C = 1.0$$

$$\pi_{cyc} = 1.0$$

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

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 1.9×10^9 hours). The toggle switch in the ground fixed environment has a lower observed than predicted failure rate (based on 0 failures in 180×10^6 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 | 1.23 |
| 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 rates 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 } λ_{bc} >0.002 in. | | 0.0035 | 0.0009 | 1.8 | 0.45 |
| Actuation Differential } λ_{bd} <0.002 in. | | 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 ($\times 10^{-6}$ hours) | New Predicted Failure Rate ($\times 10^{-6}$ 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 | 0.305 | 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 ($\times 10^{-6}$ hours) | Predicted Failure Rate ($\times 10^{-6}$ 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 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 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

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

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

$$\pi_E = 5.0 \text{ (revised for airborne inhabited)}$$

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

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

$$\pi_L = 1.48 \text{ (50 percent stress)}$$

$$\lambda_P = 0.0027 (5 \times 1.0 \times 10.0 \times 1.48) = 0.2 \text{ failures}/10^6 \text{ hours}$$

2 Airborne inhabited, rotary switch

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

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

$$\lambda_{bE} = 0.0067 \text{ failures}/10^6 \text{ hours}$$

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

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

$$\pi_E = 5.0 \text{ (revised for airborne inhabited)}$$

$$\pi_c = 5.0 \text{ (5 cycles/hours)}$$

$$\pi_L = 1.48 \text{ (50 percent stress)}$$

$$\lambda_p = 0.00688 (5.0 \times 5.0 \times 1.48) = 0.255 \text{ failures}/10^6 \text{ hours}$$

3 Ground fixed, toggle switch

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

$$\lambda_b = 0.00045 \text{ failures}/10^6 \text{ hours}$$

$$\pi_E = 3.0 \text{ (for ground fixed)}$$

$$\pi_c = 2.5 \text{ (four-pole, single-throw)}$$

$$\pi_{cyc} = 1.0 \text{ (1 cycle/hour)}$$

$$\pi_L = 1.48 \text{ (50 percent stress)}$$

$$\lambda_p = 0.00045 (3.0 \times 2.5 \times 1.0 \times 1.48) = 0.005 \text{ failures}/10^6 \text{ hours}$$

4 Ground fixed, rotary switch

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

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

$$\lambda_{bE} = 0.0067 \text{ failures}/10^6 \text{ hours}$$

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

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

$$\pi_E = 3.0 \text{ (for ground fixed)}$$

$$\pi_{cyc} = 5.0 \text{ (for 5 cycles/hour)}$$

$$\pi_L = 1.48 \text{ (for 50 percent stress)}$$

$$\lambda_P = 0.00688 \text{ (3.0 x 5.0 x 1.48) = 0.153 failures/10}^6 \text{ hours}$$

5 Ground fixed, pushbutton switch (lower)

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

$$\lambda_b = 0.04 \text{ failures/10}^6 \text{ hours}$$

$$\pi_E = 3.0 \text{ (for ground fixed environment)}$$

$$\pi_c = 1.0 \text{ (for single-pole, single-throw)}$$

$$\pi_{cyc} = 1.0 \text{ (for 1 cycle/hour)}$$

$$\pi_L = 1.48 \text{ (for 50 percent stress)}$$

$$\lambda_P = 0.04 \text{ (3.0 x 1.0 x 1.0 x 1.48) = 0.178 failures/10}^6 \text{ hours}$$

6 Ground fixed (rotary switch, lower)

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

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

$$\lambda_{bE} = 0.1 \text{ failures/10}^6 \text{ hours}$$

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

$$\lambda_b = 0.22 \text{ failures/10}^6 \text{ hours}$$

$$\pi_E = 3.0 \text{ (for ground fixed)}$$

$$\pi_{cyc} = 5.0 \text{ (for 5 cycles/hour)}$$

$$\pi_L = 1.48 \text{ (for 50 percent stress)}$$

$$\lambda_P = 0.22 \text{ (3.0 x 5.0 x 1.48) = 4.88 failures/10}^6 \text{ hours}$$

7 Ground fixed, sensitive switch

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

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

$$\lambda_{bE} = 0.1 \text{ failures/10}^6 \text{ hours}$$

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

$$\lambda_b = 0.10009 \text{ failures/10}^6 \text{ hours}$$

$$\begin{aligned}\pi_E &= 3.0 \text{ (for ground fixed)} \\ \pi_{cyc} &= 1.0 \text{ (for 1 cycle/hour)} \\ \pi_L &= 1.48 \text{ (for 50 percent stress)} \\ \lambda_P &= 0.10009 \text{ (3.0 x 1.0 x 1.48) = 0.14 failures/10}^6 \text{ hours}\end{aligned}$$

8 Naval sheltered, toggle switch

$$\begin{aligned}\lambda_P &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_L) \\ \lambda_b &= 0.00045 \text{ failures/10}^6 \text{ hours} \\ \pi_E &= 4.0 \text{ (for naval sheltered)} \\ \pi_c &= 1.0 \text{ (for single-pole, single-throw)} \\ \pi_{cyc} &= 1.0 \text{ (for 1 cycle/hour)} \\ \pi_L &= 1.48 \text{ (for 50 percent stress)} \\ \lambda_P &= 0.0045 \text{ (4.0 x 1.0 x 1.0 x 1.48) = 0.0027 failure/10}^6 \text{ hours}\end{aligned}$$

9 Naval sheltered, toggle switch (lower)

$$\begin{aligned}\lambda_P &= \lambda_b (\pi_E \times \pi_c \times \pi_{cyc} \times \pi_L) \\ \lambda_b &= 0.034 \text{ failures/10}^6 \text{ hours} \\ \pi_E &= 4.0 \text{ (for naval sheltered)} \\ \pi_c &= 1.0 \text{ (for single-pole, single-throw)} \\ \pi_{cyc} &= 1.0 \text{ (for 1 cycle per hour)} \\ \pi_L &= 1.48 \text{ (for 50 percent stress)} \\ \lambda_P &= 0.034 \text{ (4.0 x 1.0 x 1.0 x 1.48) = 0.2 failures/10}^6 \text{ hours}\end{aligned}$$

10 Space flight, sensitive switch

$$\begin{aligned}\lambda_P &= \lambda_b (\pi_E \times \pi_{cyc} \times \pi_L) \\ \lambda_b &= \lambda_{bE} + n \lambda_b \\ \lambda_{bE} &= 0.1 \text{ failures/10}^6 \text{ hours}\end{aligned}$$

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

$$\lambda_b = 0.1009 \text{ failures}/10^6 \text{ hours}$$

$$\pi_E = 1.0 \text{ (for space flight)}$$

$$\pi_C = 1.0 \text{ (for single-pole, single throw)}$$

$$\pi_L = 1.48 \text{ (for 50 percent stress)}$$

$$\lambda_P = 0.1009 (1.0 \times 1.0 \times 1.48) = 0.149 \text{ failures}/10^6 \text{ hours}$$

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 environments. 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.

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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, Massachusetts

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

Connector

Table 2.11-1. Prediction Procedure for Connectors

| <u>PART SPECIFICATIONS COVERED (Table 2.11-2 shows connector configurations)</u> | | | |
|--|-------------------|----------------|-------------------|
| <u>Type</u> | <u>MIL-C-SPEC</u> | <u>Type</u> | <u>MIL-C-SPEC</u> |
| Rack and panel | 24308 | Coaxial, RF | 3607 |
| | 28748 | | 3643 |
| | 83733 | | 3650 |
| | | | 3655 |
| | | | 25516 |
| | | | 39012 |
| Circular | 5015 | Power | |
| | 26482 | | 3767 |
| | 38999 | | |
| | 81511 | | |
| | 83723 | | |

| | |
|---|--|
| <u>Part Failure Rate Model (λ_p)</u> | |
| 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 | |

Connector

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

| Base Failure Rate Model (λ_b) | | | | |
|---|-----------------|---------|-------|---------|
| $\lambda_b = Ae^x$ | | | | |
| where $x = \frac{N_T}{T+273} + \left(\frac{T+273}{T_0}\right)^p$ | | | | |
| 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_0 | 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. | | | | |

Connector

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 | |

Connector

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.

Connector

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 |

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

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

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

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

$$\Delta T = \text{°C insert temperature rise}$$

$$i = \text{amperes per contact}$$

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 $\Delta T = 5^{\circ}\text{C}$.

Connector

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.

Connector

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_{IJ} | 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.

Connector

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:

$$\pi_p = e^{\left(\frac{N-1}{N_0}\right)^q}$$

where $N_0 = 10$

$q = 0.51064$

$N =$ number of active pins

Connector

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/10⁶ 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:

$$\begin{aligned}\lambda_p &= \lambda_b (\pi_E \times \pi_p \times \pi_K) \\ \lambda_p &= 0.00073 (2.0 \times 4.0 \times 2.0) \\ \lambda_p &= 0.0117 \text{ failures}/10^6 \text{ hours.}\end{aligned}$$

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/10⁶ 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_E , π_p , and π_K into the part failure rate model:

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

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

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

APPENDIX C

SECTION 2.9, MIL-HDBK-217B

Relays

Table 2.9-1. Prediction Procedure for Relays

Part Specifications CoveredMilitary 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)

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

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} .

Relays

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

| Base failure rate model (λ_b) | | | | | |
|---|-----------------------|----------------------|----------------|---------------------|---------------------|
| $\lambda_b = \lambda_T \pi_L$ <p>where $\lambda_T = A e^x$ $\pi_L = e^y$ $y = \left(\frac{S}{N_S} \right)^H$ $x = \left(\frac{T + 273}{N_T} \right)^G$</p> <p>T = Ambient operating temperature in °C S = Operating load current/rated resistive load current e = 2.718, natural logarithm base.</p> | | | | | |
| 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 |
| <p>Note - Table 2.9-2 contains λ_T</p> <p>Table 2.9-3 contains π_L</p> | | | | | |

Relays

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. η_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 = $\frac{\text{Operating Load Current}}{\text{Rated Resistive Load Current}}$ | | | |

Relays

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.

Relays

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 |

Relays

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 |

Relays

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 $\pi_Q = 1.0$

Relays

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 $\left(\frac{5 \text{ cycles per hour}}{10}\right)$.

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 Procedure for Toggle or Pushbutton Switches

| <u>Part specifications covered</u> | <u>Description</u> |
|---|----------------------------------|
| 1. MIL-S-3950 | Snap-action toggle or pushbutton |
| 2. MIL-S-8805 | |
| <u>Part failure rate model (λ_p)</u> | |
| $\lambda_p = \lambda_b (\pi_E \times \pi_C \times \pi_{cyc} \times \pi_L)$ failures/ 10^6 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

| <u>Part specifications covered</u> | <u>Description</u> |
|--|--------------------|
| 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)

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

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

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

| <u>Part specification covered</u> | <u>Description</u> |
|--|---|
| MIL-S-3786 | Rotary, ceramic or glass wafer, silver alloy contacts |
| <u>Part failure rate model (λ_p)</u> $\lambda_p = \lambda_b (\pi_E \times \pi_{cyc} \times \pi_L) \text{ failures}/10^6 \text{ hours}$ 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)

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

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

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 |

Switches

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 |

Switches

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} |
|---------------------------|-----------------------|
| ≤ 1 cycle/hour | 1.0 |
| > 1 cycle/hour | number of cycles/hour |

Switches

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 | 21.60 | |
| 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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