RADC RELIABILITY ENGINEER'S TOOLKIT

An application oriented guide for the practicing reliability engineer

Systems Reliability and Engineering Division
Rome Air Development Center

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Systems Reliability and Engineering Division
Rome Air Development Center
Air Force Systems Command (AFSC)
Griffiss Air Force Base, NY 13441-5700

Quick Reference Application Index

How Do I . . . ?

For More Help Appendices

How Do I . . . ?

Preface

This document was written by the Systems Reliability and Engineering Division of Rome Air Development Center as an "in-house" project. It represents the collective thoughts and experience of the organization's over 30 years in developing and applying reliability and maintainability principles. The following individuals were the primary technical contributors to the completion of the project:

Seymour F. Morris
Preston R. MacDiarmid
Anthony J. Feduccia
Bruce W. Dudley
Jerome Klion
David Garafalo

Nancy Phalen was responsible for the typing of the document.

Comments and/or questions relative to the information in this document can be addressed to:

Systems Reliability & Engineering Division
RADC/RBE
Griffiss AFB NY 13441-5700

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Introduction

Purpose

This TOOLKIT is intended for use by a practicing reliability and maintainability (R&M) engineer. Emphasis is placed on his role in the various R&M activities of an electronic systems development program. The TOOLKIT is not intended to be a complete tutorial or technical treatment of the R&M discipline but rather a compendium of useful R&M reference information to be used in everyday practice.

Format

The format of the TOOLKIT has been designed for easy reference. Five main sections are laid out to follow the normal time sequence of a military development program. Each section contains a summary cover sheet which defines the process which is the subject of the section and describes the R&M engineer's role in the key activities of that process. Because the processes (sections) are interrelated, coverage of certain steps in a particular process may be by reference to a different section.

Descriptions of the "how to" of the R&M engineer's activities have been designed to take the form of figures, tables, and step-by-step procedures as opposed to paragraphs of text. Appendices are included to give a greater depth of technical coverage to some of the topics as well as to present additional useful reference information.

The TOOLKIT also includes a "Quick Reference Application Index" which can be used to quickly refer the R&M engineer to the portion of a section that answers his specific questions. A quick reference "For More Help Appendices" index is also included for the more in-depth topics of the appendices.

Terminology

The term "Reliability" used in the title of this document is used in the broad sense to include the field of maintainability. The content of the report addresses reliability and maintainability (R&M) because they are usually the responsibility of one government individual in a military electronics development program. In this context, testability is considered as a part of maintainability and is, therefore, inherently part of the "M" of "R&M." Where testability issues, such as development of quantitative requirements, are appropriate for separation from "M" discussion, they are and have been labeled accordingly.

Underlying Philosophy

The development and application of a successful reliability program requires a number of tasks and coordination steps. Key ingredients include:

- Aggressive Program Manager Support
- Firm and Realistic Requirements
- Effective Built-in-Test
- Thorough Technical Reviews
- Complete Verification

This document was developed to support this RADC philosophy on reliability and maintainability.

R&M 2000

Air Force leadership is committed to increasing combat capability through improved reliability and maintainability (R&M). In September 1984, the Secretary and Chief of Staff of the Air Force stated as policy that R&M would be equal with cost, schedule and (other) performance in weapon system acquisition. In February 1985, the Secretary and Chief of Staff promulgated the "R&M 2000 Action Plan" to guide the Air Force and industry institutionalization process. The "R&M 2000 Process" contains three major segments: **Goals** which establish the basic purpose and direction for the Air Force R&M Program; **Principles** which provide a coherent, logical framework for many actions and players in the process; and **Building Blocks** which are activities that will result in a successful R&M program. The goals can be achieved by application of the building blocks within the framework of the principles.

The R&M 2000 Goals are:

1. Increase Combat Capability
2. Decrease the Vulnerability of the Combat Support Structure
3. Decrease Mobility Requirements per Unit
4. Decrease Manpower Requirements per Unit of Output
5. Decrease Costs

The R&M 2000 process's five Principles are:

1. Management Involvement
2. Motivation of Industry
3. Clearly Communicated Requirements
4. Designing for R&M and Growth to Inherent R&M
5. Preservation of Inherent R&M

The R&M 2000 process includes 21 Building Blocks as follows:

Management Involvement

- Source Selection
- Performance Based Progress
- Incentives and Warranties

Requirements

- Clear Requirements
- Technician Transparency
- Simplification
- Modularity
- R&M Plans
- Company Policies and Practices

Design and Growth

- Systems Engineering Process
- Allocation and Prediction
- Analysis
- Growth Management
- Parts Selection
- Derating
- Computer Aided Tools
- Test-Analyze-and-Fix

Preservation

- Variability Reduction Program
- Environmental Stress Screening
- System Testing
- Feedback

These building blocks are derived from examining successful programs; they consist of time-tested techniques that work.

This TOOLKIT, although not structured to address the R&M 2000 building blocks per se, addresses the practical application of proven reliability and maintainability techniques that results in meeting the R&M 2000 objectives.

Section R

Requirements

How do I develop and specify the right RELIABILITY & MAINTAINABILITY requirements?

R&M Engineer's Role:

Insight

Requirement development is critical to program success. MIL-STDs cannot be blindly applied. Requirements must be tailored to the individual program situation considering the following:

- **Mission Criticality**
- **Operation Environment**
- **Phase of Development**
- **Other Contract Provisions (incentives, warranties, etc.)**
- **Off-The-Shelf Versus Newly Designed Hardware**

For More Information

MIL-STD-470	"Maintainability Program for Systems and Equipment"
MIL-STD-721	"Definition of Terms for Reliability and Maintainability"
MIL-STD-785	"Reliability Program for Systems and Equipment Development and Production"
MIL-STD-2165	"Testability Programs for Electronic Systems and Equipment"
DOD 5010.12-L	"Acquisition Management Systems and Data Requirements Control List" (complete Data Item Description listing)
AFR 800-2	"Acquisition Program Management"
AFR 800-18	"Air Force Reliability and Maintainability Program"
RADC-TR-87-50	"R&M Program Cost Drivers"
	"RADC Program Managers Guide to Reliability and Maintainability" Slide Rule (order directly from RADC/RBE, Griffiss AFB NY 13441-5700)

Topic R1: Quantitative Reliability Requirements

Scope of Requirements:

Reliability parameters expressed by operational users and ones specified in contractual documents take many forms. Tables R1-1 and R1-2 identify the characteristics of reliability parameters.

Table R1-1: Logistics (Basic) and Mission Reliability Characteristics

Logistics (Basic) Reliability	Mission Reliability
• Measure of system's ability to operate without logistics support. • Recognize effects of all occurrences that demand support without regard to effect on mission. • Degraded by redundancy. • Usually equal to or lower than mission reliability.	• Measure of system's ability to complete mission. • Consider only failures that cause mission abort. • Improved by redundancy. • Usually higher than logistics reliability.

Table R1-2: Operational and Contractual Reliability Characteristics

Contractual Reliability	Operational Reliability
• Used to define, measure and evaluate contractor's program. • Derived from operational needs. • Selected such that achieving them allows projected satisfaction of operational reliability. • Expressed in inherent values. • Account only for failure events subject to contractor control. • Include only design and manufacturing characteristics.	• Used to describe reliability performance when operated in planned environment. • Not used for contract reliability requirements (requires translation). • Used to describe needed level of reliability performance. • Include combined effects of item design, quality, installation environment, maintenance policy, repair, etc.

Table R1-2 (continued)

Contractual Reliability	Operational Reliability
• Typical terms: • MTBF (mean-time-between-failures) • Mission MTBF (sometimes also called MTBCF)	• Typical terms: • MTBM (mean-time-between-maintenance) • MTBD (mean-time-between-demand) • MTBR (mean-time-between-removal) • MTBCF (mean-time-between-critical-failure)

Operational Constraints:

- Mission Criticality
- Availability Constraints
- Self-Sufficiency Constraints
- Attended/Unattended Operation
- Operational Environment
- Use of Off-the-shelf or Newly Designed Equipment

How to Develop Requirements:

Figure R1-1 defines the general reliability requirement development process. Key points to recognize from this process are:

1. User requirements can be expressed in a variety of forms that include combinations of mission and logistics reliability, or they may combine reliability with maintainability in the form of availability. Conversion to commonly used operational terms such as mean-time-between-maintenance (MTBM) and mean-time-between-critical-failure (MTBCF) must be made from terms such as operational availability (A_0), and break-rate, etc., to enable translation to parameters which can be specified in contracts.

   An example is:

   $$A_0 = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}}$$

   (Solve for MTBM using mean downtime (MDT) which includes the actual repair time plus logistics delay time.)

2. Since operational reliability measures take into account factors beyond the control of development contractors, they must be translated to contractual reliability terms for which contractors can be held accountable. (Appendix 1 provides one means of accomplishing this translation.)

3. The process cannot end with the translation to a contractual value. Evaluation of the realism of the translated requirements is a necessary step. Questions that have to be answered are: are the requirements compatible with the available technology and do the requirements unnecessarily drive the design (conflict with system constraints such as weight and power). Addressing these issues requires reviewing previous studies and data for similar systems. Adjustment factors may be appropriate for improvement of technology and for different operating environments, duty cycles, etc. See Topic A11 for Reliability Adjustment Factors.

4. Systems with mission critical requirements expressed by the user present difficulties in the requirement development process. Translation models don't account for the nonexponential situations that exist with redundant systems. Because the reliabilities of redundant paths are high compared to serial ones, an approximation can be made that these paths have an equivalent failure rate of zero so that only the remaining serial elements need to be translated.

5. The requirement process involves allocation of values to lower levels. In some cases, this is an iterative process requiring several tries to satisfy all requirements. For other cases, the requirements can't be satisfied and dialogue and tradeoffs with the user are required.

6. For cases where user needs are not specified it still makes sense to invoke at least a logistics (basic) reliability requirement. In so doing, the contractor has a degree of accountability and is likely to put more effort into designing a reliable system.

7. Table R1-3 indicates typical ranges of reliability for different types of electronic systems:

Table R1-3: Typical Reliability Values

Radar Systems	MTBF (Hours)
Ground Rotating Search Radar	75–175
Large Fixed Phase Array Radar	3–6
Tactical Ground Mobile Radar	25–75
Airborne Fighter Fire Control Radar	50–200
Airborne Search Radar	300–500
Airborne Identification Radar	200–2,000
Airborne Navigation Radar	300–4,500
Communications Equipment	**MTBF (Hours)**
Ground Radio	5,000–20,000
Portable Ground Radio	1,000–3,000
Airborne Radio	500–10,000
Ground Jammer	500–2,000
Computer Equipment	**MTBF (Hours)**
Ground Computer	1,000–5,000
Ground Monochrome Display	15,000–25,000
Ground Color Display	2,500–7,500
Ground Hard Disk Drive	5,000–20,000
Ground Tape Storage Unit	2,500–5,000
Ground Printer	2,000–8,000
Ground Modem	20,000–50,000
Miscellaneous Equipment	**MTBF (Hours)**
Airborne Countermeasures System	50–300
Airborne Power Supply	2,000–20,000
Ground Power Supply	10,000–50,000

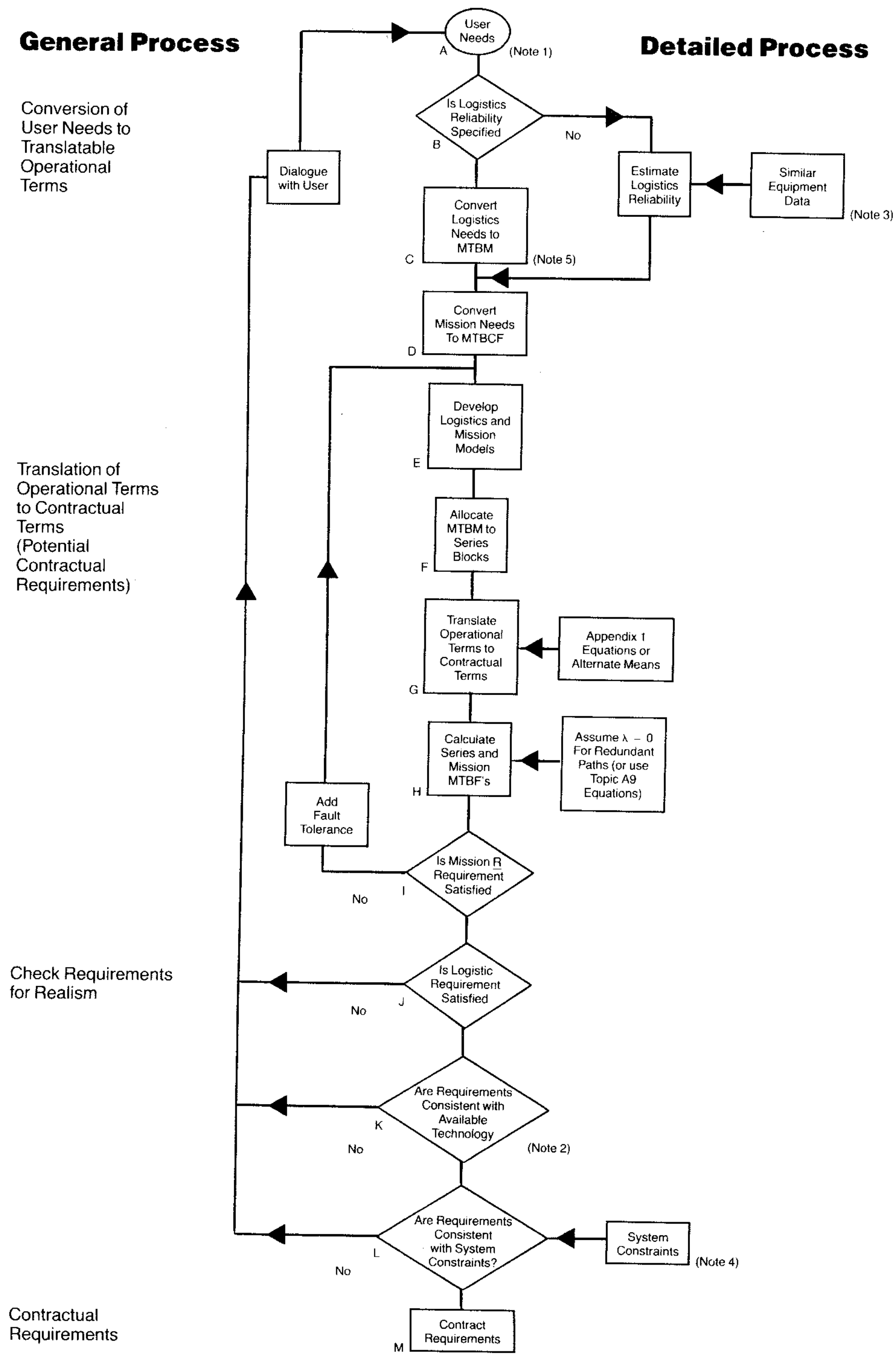


Figure R1-1: Quantitative Reliability Requirement Development Process

Figure R1-1 Notes:

1. User Needs Cases

Case	Logistics Reliability	Mission Reliability	Comments
1	Specified	Specified	
2	Specified	Not specified	Delete steps D, H, I
3	Not specified	Specified	
4	Not specified	Not specified	Delete steps D, H, I

2. A 10–20% reliability improvement factor is reasonable for advancement of technology.
3. Adjustment of data to use environment may be required (see Topic A11). See Appendix 8 for R&M data sources.
4. Reliability requirements necessitating redundancy add weight, cost and power.
5. Alternate forms of user requirements should be converted to MTBM's to enable translation.

Topic R2: Quantitative Maintainability Requirements

Scope of Requirements:

Unique maintainability parameters need to be specified for three basic levels of repair:

- **Organizational Level**—Repair at the system location. Usually involves replacing plug-in modules and other items with relatively short isolation and replacement times.
- **Intermediate Level**—Repair at an intermediate shop facility which has more extensive capabilities to repair lower hardware indenture levels.
- **Depot Level**—Highly specialized repair facility capable of making repairs at all hardware indenture levels. Sometimes the original equipment manufacturer.

Recent Air Force policy has promoted the concept of two level maintenance in place of the traditional three level system. Under this concept the classification is:

- **On-equipment**—Maintenance actions accomplished on complete end items.
- **Off-equipment**—In-shop maintenance actions performed on removed components.

Parameters which need to be specified vary with the level of repair being considered. Key maintainability parameters include:

- **Mean time to repair (MTTR)**—Average time required to bring system from a failed state to an operational state. Strictly design dependent. Assumes maintenance personnel and spares are on hand (i.e., does not include logistics delay time). MTTR is used interchangeably with mean corrective maintenance time (Mct).
- **Mean maintenance manhours (M-MMH)**—Total manpower per year (expressed in manhours) required to keep the system operating (not including logistics delay time).
- **Mean time to restore system (MTTRS)**—The average time it takes to restore a system from a failed state to an operable state, including logistics delay time (MTTRS = logistics delay time + MTTR). Logistics delay time includes all time to obtain spares and personnel to start the repair.
- **Preventive maintenance (PM)**—Preventive maintenance. Time associated with the performance of all required preventive maintenance. Usually expressed in terms of hours per year.

Operational Constraints:

Basic maintainability requirements are determined through an analysis of user operational constraints. Operational constraints include:

- Operating hours per unit calendar time and/or per mission.
- Downtime, maintenance time, or availability constraints.

- Mobility requirements.
- Attended/unattended operation.
- Self-sufficiency constraints.
- Reaction time.
- Operational environment.
- Skill levels of maintenance personnel.
- Manning.
- Types of diagnostics and maintenance support equipment which can be made available or implemented (Built-in-test, manual test equipment, external automatic test equipment, etc.).
- Levels at which repair takes place.
- Use of off-the-shelf equipment versus newly designed equipment.

How to Develop Requirements:

The best guidance available is to provide a range of typical values usually applied for each parameter:

Table R2-1: Typical Maintainability Values

	Organizational	Intermediate	Depot
MTTR	.5–1.5 hr	.5–3 hr	1–4 hr
M-MMH	Note 1	Note 1	Note 1
MTTRS	1–8 hrs (Note 2)	NA	NA
PM	2–15 hr/yr	NA	NA

Notes:

1. M-MMH depends on the number of repair visits to be made, the MTTR for each repair visit and the number of maintenance personnel required for each visit. Typical calculations of the mean maintenance manhours per year include:

   a. Immediate maintenance of a continuously operated system: M-MMH = (8760 hr/yr)/(MTBF) × (MTTR) × (maintenance personnel per repair) + (PM hours per year) (Maintenance personnel).

   b. Delayed maintenance of a fault tolerant system: M-MMH = (number of expected repair visits) × (time for each visit) × (maintenance personnel per visit) + (PM hours per year) (maintenance personnel).

   c. Maintenance of a continuously operated redundant system allowed to operate until failure. M-MMH = (8760 hr/yr)/(MTBCF) × (time for each visit) × (maintenance personnel per visit) + (PM hours per year) (Maintenance personnel).

   Time for each visit is the number of repairs to be made times the MTTR for each repair if repairs are made in series.

2. For unique systems that are highly redundant, MTTRS may be specified as the switch time.

Topic R3: Quantitative Testability Requirements

Scope of Requirements:

Parameters that need to be specified for each repair level:

- **Fault Detection**—A process which discovers the existence of faults.
- **Fault Isolation**—Where a fault is known to exist, a process which identifies the location of that fault.
- **False Alarms**—An indication of a fault where no fault exists such as operator error, transient condition, BIT design deficiency.

Parameters are sometimes expressed in the form of rates or fractions such as:

- **Fraction of Faults Detected (FFD)**—The quantity of faults detected by on-board test divided by the quantity of all faults detected by other means (including manual).
- **Fraction of Faults Isolated (FFI)**—The fraction of on-board test detected faults correctly isolated to the *replacable* unit.
- **False Alarm Rate (FAR)**—The frequency of occurrence of false alarms.

Scope of Diagnostics:

- **Integrated**—Use of built-in-test (BIT) which operates on demand or automatically.
- **External**—Special purpose test equipment that must be connected by a maintenance technician.
- **Manual**—Testing that requires the use of technical manuals, troubleshooting procedures and general purpose test equipment (e.g., voltmeter) by a maintenance technician.

How to Develop Requirements:

The best guidance available is to provide a range of typical values usually applied for each parameter.

Table R3-1: Typical Testability Values

	% Capability	Repair Level
Fault Detection (all means)	90–100	Organizational
	100	Intermediate
	100	Depot
Fault Detection (BIT)	90–98	Organizational
	95–98	Intermediate
	95–100	Depot
Fault Isolation		
Eight or less modules	95–100	All
Three or less modules	90–95	All
One module	80–90	All
False Alarms	1000–5000 hours between alarm	

Note: Information and guidance concerning testability/diagnostics specification, design, assessment, and evaluation is currently being developed and organized under RADC contract F30602-87-C-0099. The documentation forthcoming is in the form of a Government Program Managers Guide, Contractor Program Managers Guide, and a Testability Design Encyclopedia. Release of the documents is expected by January 1989. Information about obtaining these documents can be obtained from RADC/RBET at (315) 330-4726.

Topic R4: Program Phase Terminology

The R&M tasks required on a program are based on the program's development phase and intended application (ground, airborne, space, etc.).

Table R4-1: Acquisition Phase Purposes and Corresponding Scope of R&M Requirements

Acquisition Phase	Phase Purpose	Scope of the R&M Requirements
1. Research	• Expansion of knowledge in a scientific area. • Paper study. • Usually no hardware developed.	• No structured R&M tasks.
2. Exploratory Development	• Study and analysis of a specific military problem. • Consideration of alternative solutions.	• Usually no structured R&M tasks. R&M tradeoff studies may be considered.
3. Advanced Development* (Demonstration and Validation)	• Develop hardware to solve a specific military problem.	
Laboratory Test Vehicle	• Development of a system/equipment which is not intended for operational use.	• Only minimum R&M requirements are needed (e.g., data collection).
Field Use (Limited Quantity)	• Development of very small quantities (1 or 2) of specialized equipment/systems.	• Moderate R&M requirements are usually specified to provide reasonable reliability and minimum logistics costs.
High Potential for Further Development	• This is the category of true advanced development with the purpose of building and testing hardware for proving concepts. The hardware is not intended for operational use.	• Moderate R&M requirements are needed (e.g., R&M prediction, part derating, FRACAS, limited parts control).
Likely to Go Directly to Production	• Advanced development hardware is being developed for production prototype purposes.	• Significant R&M requirements are necessary (e.g., R&M prediction, part derating, parts control, FRACAS).

4. Full Scale Development	• Develop and test a prototype model for production purposes.	• Extensive R&M requirements are considered necessary (e.g., all the above plus testing).
5. Production	• To build, test and accept operational units without degrading the capabilities previously designed into the hardware.	• Emphasis is on quality assurance and ESS tasks.

*RADC experience has shown that Advanced Development programs have a range of purposes varied enough to warrant different R&M Requirements.

For the purpose of the remaining discussions on R&M task priorities (Topic R5), the four most common cases in the three most common environments (Ground, Airborne & Space) are addressed:

Advanced Development (or Demonstration and Validation): This category is the "normal" advanced development model situation above designated as "High Potential for Further Development."

Full Scale Development: As described above.

Production: As described above.

Off-Shelf Buys: This category can be either an advanced development model or full scale development when the equipment being acquired is already designed, or modified only slightly.

Topic R5: Reliability and Maintainability Task Application/Priorities

	Adv Dev Model (New Design)			Full Scale Development (New Design)			Production			Off-Shelf Hdwre Buys			Recommended Data Items
	Grnd	Abrne	Space	Grnd	Abrne	Space	Grnd	Abrne	Space	Grnd	Abrne	Space	(See Notes Below)
R&M Program Tasks													
Program Surveillance and Control Tasks													
• R&M&T Design Reviews	R	R	R	R	R	R				R	R	R	• DI-R-7080 & 7104
• Failure Reporting & Corrective Action System (FRACAS)	E4	E5	E6	E3	E4	E5	E1	E1	E2	E1	E1	E1	• DI-R-7041
• Failure Review Board							O	O	O				• Incl in DI-R-7080
• Subcontractor Control				R	R	R	R	R	R	E3	E3	E3	• Incl in DI-R-7080
Design & Analysis Tasks													
• Part Selection and Control	E1	E1	E1	E1	E1	E1							• DI MISC 80071
• Part Derating	E2	E2	E2	E2	E2	E2							• See AFSCP 800-27 (Derating Pamphlet)
• Failure Modes, Effects & Criticality Analysis (FMECA)		O	E4	O	R	E4							• DI-R-7085
• R&M&T Prediction & Allocation	E3	E4	E5	E5	E7	E6				E5	E5	E5	• DI-R-7094, 7095 & 7108
• Sneak Circuit Analysis			O		O	R			O				• DI-R-7083
• Critical Items		O	R	O	O	E8	O	O	O				• DI-R-35011
• Thermal Management & Analysis	O	E3	E3	R	E3	E3				E2	E2	E2	• Incl in DI-R-7095
• Effects of Storage, Handling, etc.				R	R	R	O	O	O				• Incl in DI-R-7095

Test & Evaluation Tasks											
• Reliability Qualification Test		E4	E6					O	O		• DI-RELI-80250, 80251, 80252
• Maintainability Demo Test		E6	E8					O	O		• DI-R-7112 & 7113
• Testability Demonstration		O	O					O	O		• DI-R-7112
• Environmental Stress Screening (ESS)		P	P	P	E2	E2	E1	E4	E4	E4	• Incl in DI-R-7041
• Production Reliability Acceptance Tests					E3	E3					• DI-R-7034, 7035
• Reliability Growth Testing	O	O	E5	E7				O	O		• Incl in DI-R-7080

Key

E = Essential (1-Highest Priority)
R = Recommended
P = Plan For
O = Optional

Notes:

1. See Topic R6 for a complete list of data items and delivery dates.
2. See Appendix 2 for sample statement of work and specification paragraphs.

Topic R6: Contract Data Requirements

In order for the government to receive outputs from the required contractor performed tasks, the appropriate deliverables must be specified in the Contract Data Requirements List (CDRL). The content of these CDRL items is specified by reference to standard Data Item Descriptions. The timing and frequency of the required reports must be specified in the CDRL.

Table R6-1: Data Items & Delivery Dates

	Title	Recommended Delivery Date
Reliability		
DI-R-7040	Burn-in Test Report	60 days after end of testing
DI-R-7041	Failure Summary & Analysis Report	Start of testing, monthly
DI-R-7079	Reliability Program Plan	90 days prior to PDR
DI-R-7080	Reliability Status Report	90 days prior to PDR & bimonthly
DI-R-7083	Sneak Circuit Analysis Report	30 days prior to PDR & CDR
DI-R-7085	FMECA Report	30 days prior to CDR
DI-R-7086	FMECA Plan	90 days prior to PDR
DI-R-7094	Reliability Block Diagram & Math Model Report (Note 4)	30 days prior to PDR & CDR
DI-R-7095	Rel Pred & Documentation of Supporting Data (Note 3)	30 days prior to PDR & CDR
DI-R-7100	Rel Report for Exploratory Development Models	30 days prior to end of contract
DI-R-35011	Critical Item Control Plan	30 days prior to PDR
DI-MISC-80071	Part Approval Request (Note 2)	As Required
DI-RELI-80247	Thermal Survey Report	30 days prior to PDR & after testing
DI-RELI-80248	Vibration Survey Report	30 days prior to PDR & after testing
DI-RELI-80250	Reliability Test Plan	90 days prior to start of testing
DI-RELI-80251	Reliability Test Procedures	30 days prior to start of testing
DI-RELI-80252	Reliability Test & Demo Report	60 days after end of testing
DI-RELI-80253	Failed Item Analysis	As Required
DI-RELI-80254	Corrective Action Plan	30 days after end of testing

	Title	Recommended Delivery Date
Maintainability		
DI-R-7103	Maintainability Program Plan	90 days prior to PDR
DI-R-7104	Maintainability Status Report	90 days prior to PDR & Bimonthly
DI-R-7105	Data Collection, Analysis & Corrective Action Rpt	As Required
DI-R-7106	Maintainability Modeling Report	30 days prior to PDR & CDR
DI-R-7107	Maintainability Allocations Report	30 days prior to PDR & CDR
DI-R-7108	Maintainability Predictions Report	30 days prior to PDR & CDR
DI-R-7109	Maintainability Analysis Report	30 days prior to PDR & CDR
DI-R-7110	Maintainability Design Criteria Plan	90 days prior to PDR
DI-R-7111	Inputs to the Detailed Maintenance Plan & Logistics Support	
DI-R-7112	Maintainability Demo Test	90 days prior to start of testing
DI-R-7113	Maintainability Demo Report	90 days prior to start of testing
Testability		
DI-R-7080 & 7105	(See Reliability Data Item List)	
DI-R-7112 & 7113	(See Maintainability Data Item List)	
DI-T-7198	Testability Program Plan	90 days prior to PDR
DI-T-7199	Testability Analysis Report	30 days prior to PDR & CDR

Notes:

1. Combine R&M data items into a single submission whenever possible.
2. DESC must be included on the distribution list of this CDRL Data Item. The government lead system engineer must establish contact and agreement for review with DESC and DISC. Contacts are: (1) Electronics, DESC: DESC/EPA, AV: 986-5431 or (513)296-5431; and (2) Mechanical Parts, DISC: DISC/ESM, Autovon: 442-4395 or (215) 697-4395.
3. Add the following to the data item if a thermal analysis will be required: "The junction and hot-spot temperatures listed in the Reliability Predictions Report shall be obtained from a detailed thermal analysis, conducted down to the part level. The report shall include: (1) a description of the equipment analyzed, (2) sources of estimates of part dissipations, (3) thermal resistances (values used, assumptions, coolant flow rates), (4) sources of estimates of sink temperatures, and (5) analysis method."
4. Add to the data item: Reliability allocations shall be performed for both mission and series reliability and documented to the circuit card level.

Topic R7: R&M Information for Proposals

Proposal preparation guidance should be provided in the request for proposal (RFP) package to guide the contractor in providing the information most needed to properly evaluate the R&M area during source selection. This is part of the requirements definition process.

Depending on the scope of the R&M requirements specified, information such as the following should be requested for inclusion in the proposal:

- Preliminary R&M analysis/models and estimates of values to be achieved (to at least the line replaceable unit (LRU) level).
- Design approach (including thermal design, parts derating, and parts control).
- R&M organization and its role in the overall program.
- Key R&M personnel experience.
- Schedules for all R&M tasks.
- Description of R&M design guidelines/criteria to be used and trade studies and testing to be performed.

(**Note:** It is critical that qualified R&M personnel take part in the actual evaluation of technical proposals. The R&M engineer should make sure this happens by agreement with program management.)

Topic R8: Reliability Program Cost Estimation

Reliability Task	Independent Variable	Manhour Model	Independent Variable Range Min	Independent Variable Range Max
R&M Program Plan	Number of MIL-STD-785/470 tasks required (NOT)	$2.73\,(NOT)^2$	4	22
FRACAS	Duration of FRACAS implementation in months (DOI)	$8.25\,(DOI)^2$	2.5	38
Reliability Modeling/ Allocation	(1) Modeling and Allocation Complexity	$4.05\,(MAC)^2\,(NOU)$		
	MAC 1 Series System 2 Simple Redundancy 3 Very Complex Redundancy		1	3
	(2) Number of Items in Allocation Process (NOU)		7	445
Reliability Prediction	(1) Level of Detail	$4.54\,(LOD)^2\,(RF)^2\,(POC)$		
	LOD 1 Prediction Exists 2 Prediction made using similar system data 3 Full MIL-HDBK-217 Stress Prediction		1	3
	(2) Report Formality			
	RF 1 Internal Report 2 Formal Report Required		1	2
	(3) Percent Commercial Hardware Used			
	POC Percent 4 0–25 3 26–50 2 51–75 1 76–100		1	4
FMEA	Number of unique items requiring FMEA (NOI) NOI = Number of equipment for equipment level FMEA NOI = Number of circuit cards for piece part and circuit level FMEA's	$17.79\,(NOI)$	3	206

Reliability Task	Independent Variable	Manhour Model	Independent Variable Range Min	Independent Variable Range Max
Reliability Testing	Hardware Complexity	182.07 (HC)		
	HC Part Count		1	3
	1 <15000			
	2 15000–25000			
	3 >25000			
R&M Management	All of the above	16 percent of above subtotal		
Parts Program	Number of nonstandard parts	(No. of parts) (40 hr/part)		

Example: A program requires the following tasks. The manhour estimate is calculated as follows:

		Manhours
1. 36 month FRACAS program	$8.25(36)^2$	10,692
2. Reliability modeling (no redundancy) and allocation for 445 circuit cards	$4.05(1)^2(445)$	1,802
3. Stress type reliability prediction (formal report, 50% commercial hardware)	$4.54(3)^2(2)^2(3)$	490
4. Equipment level FMEA (3 major assemblies)	17.79(3)	53
		13,037
	R&M Management 16%	2,086
	Total Manhours	15,123

Note: For further detailed information on cost model development, see RADC-TR-87-50, R&M Program Cost Drivers, AD number A182773.

Section S
Source Selection

What's my role in the SOURCE SELECTION process and what criteria should be used to evaluate contractor proposals?

R&M Engineer's Role:

Insight

The criteria for evaluation of contractor proposals has to match the requirements specified in the Request for Proposal (RFP). Contractors must be scored by comparing their proposals to the criteria, not to each other. R&M are generally evaluated as parts of the technical area. The total source selection process includes other nontechnical areas. Recent AF policy has emphasized the importance of R&M in the source selection process.

For More Information

AFR 70-15 "Source Selection Policy and Procedures"

AFR 70-30 "Streamlined Source Selection Procedures"

Topic S1: Proposal Evaluation for Reliability and Maintainability

• Understanding

1. Does the contractor show understanding of the importance of designing in R&M&T in the effort?
2. Does the contractor show a firm understanding of R&M&T techniques, methodology, and concepts?
3. Does the contractor indicate understanding of the role of testability/ diagnostics on maintainability and maintenance?
4. Does the contractor understand integrated diagnostics design principles?
5. Does the contractor note similar successful R&M&T efforts?

• Approach

Management

1. Is an R&M&T manager identified, and are his/her experience and qualifications adequate in light of the scope of the overall program?
2. Are the number and experience of R&M&T personnel assigned to the program, and the number of manhours adequate, judged in accordance with the scope of the overall program?
3. Does the R&M&T group have adequate stature and authority in the organizational framework of the program (e.g., they should not fall under direct control of the design group)?
4. Does the R&M&T group have an effective means of crosstalk and feedback of information between design engineers and higher management?
5. Does the R&M&T manager have adequate control over R&M&T for subcontractors and vendors?
6. Is the testability diagnostics function integrated into the R&M program?

Design

1. Are design standards, guidelines and criteria such as part derating, thermal design, modular construction, ESS, and testability cited?
2. Is the contractor's failure reporting and corrective action system (FRACAS) a closed loop controlled process?
3. Is there a commitment to the required parts control program (e.g., MIL-M-38510, MIL-STD-883B, etc.)? Are approval procedures described/proposed for nonstandard parts?
4. Are system design reviews (internal and external) required regularly?

5. Are tradeoff studies proposed for critical design areas?
6. Is a time-phasing of R&M&T tasks provided along with key program milestones?
7. Are areas of R&M&T risk identified and discussed?
8. Does the contractor include consideration of software reliability?
9. Does the contractor describe his plan for testability/diagnostics design and the potential impacts on reliability and maintainability?
10. Does the contractor identify tools to be used to generate test vectors and other diagnostic procedures for BIT and ATE (automatic test equipment)?

Analysis/Test

1. Are methods of analysis and math models presented?
2. Are the R&M&T prediction and allocation procedures described?
3. Has the time phasing of the R&M&T testing been discussed, and is it consistent with the overall program schedule?
4. Is adequate time available for the test type required (such as maximum time for sequential test).
5. Is the ESS program consistent with the requirements in terms of methodology and scheduling?
6. Does the contractor make a commitment to predict the design requirement MTBF prior to the start of testing?
7. Are the resources (test chambers, special equipment, etc.) needed to perform all required testing identified and, is a commitment made to their availability?

• Compliance

Design

1. Does the contractor indicate compliance with all required military specifications for reliability, maintainability and testability?
2. Is adequate justification (models, preliminary estimates, data sources, etc.) provided to backup the claims of meeting R&M&T requirements?
3. Is there an explicit commitment to meet any ease of maintenance and preventive maintenance requirements?
4. Is there an explicit commitment to meet the built-in-test (BIT)/fault-isolation-test (FIT) requirements (FFD, FFI and FAR)?
5. Is each equipment environmental limitation specified and do these conditions satisfy the system requirements?
6. Are all removable modules keyed?

7. Will derating requirements be adhered to and are methods of verifying derating requirements discussed?

Analysis/Test

1. Is a commitment made to perform a detailed thermal analysis?
2. Will the contractor comply with all R&M&T required analyses?
3. Is there an explicit commitment to perform all required environmental stress screening?
4. Does the contractor comply with all system level R&M&T test requirements? Will the contractor demonstrate the R&M&T figures of merit (MTBF, MTTR, FFD, FFI and FAR) using the specified accept/reject criteria?
5. Does the contractor comply with the specification (or other commonly specified) failure definitions?
6. Does the contractor agree to perform thermal verification tests and derating verification tests?

Data

1. Is there an explicit commitment to deliver and comply with all of the required R&M&T data items?

CAUTION: Procuring activities have differing rules for the format of source selection criteria. The above issues should be addressed regardless of particular format.

Section D

Design

What is my role in developing design requirements and in the DESIGN PROCESS of a development program?

R&M Engineer's Role:

Select Design Requirements

Evaluate Design

Insight

Proven design approaches are critical to system R&M success. For many programs the government requires that certain approaches be used (such as a particular level of part stress derating). Other programs allow the contractor to develop and use his own design criteria as long as his end product design meets the government requirements or is subject to provisions of product performance agreements (guarantees, warranties, etc.). Regardless of the situation, the R&M engineer must actively evaluate the contractor design progress.

For More Information

MIL-STD-883	"Test Methods and Procedures for Microelectronics"
MIL-STD-965	"Parts Control Program"
MIL-STD-1521	"Technical Reviews and Audits for Systems, Equipments, and Computer Software"
MIL-HDBK-251	"Reliability/Design Thermal Applications"
MIL-HDBK-338	"Electronic Reliability Design Handbook"
MIL-M-38510	"Microcircuits, General Specification for"
MIL-S-19500	"Semiconductor Devices, General Specification for"
AFSC Pamphlet 800-27	"Parts Derating Guidelines"
RADC-TR-82-172	"RADC Thermal Guide for Reliability Engineers"

Topic D1: Part Stress Derating

The practice of limiting electrical, thermal and mechanical stresses on parts to levels below their specified ratings is called derating. If a system is expected to be reliable, one of the major contributing factors must be a conservative design approach incorporating realistic derating of parts. Table D1-1 defines the key factors for determining the appropriate level of derating for the given system constraints. Table D1-2 indicates the specific derating factors for each part type.

Table D1-1: Part Derating Level Determination

Factors		Score
Reliability Challenge	• For *proven design,* achievable with standard parts/circuits	1
	• For high reliability requirements, *special design features* needed	2
	• For new design challenging the state-of-the-art, *new concept*	3
System Repair	• For *easily accessible,* quickly and economically repaired systems	1
	• For high repair cost, limited access, *high skill levels required,* very low downtimes allowable	2
	• For *nonaccessible repair,* or economically unjustifiable repairs	3
Safety	• For *routine safety* program, no expected problems	1
	• For potential system or equipment *high cost damage*	2
	• For potential *jeopardization of life* of personnel	3
Size, Weight	• For no significant design limitation, *standard practices*	1
	• For *special design features* needed, difficult requirements	2
	• For new concepts needed, severe design limitations	3
Life Cycle	• For *economical repairs,* no unusual spare part costs expected	1
	• For potentially *high repair cost* or unique high cost spares	2
	• For systems that may require *complete substitution*	3

Instructions: Select score for each factor, sum and determine derating level or parameter.

Derating Level	Total Score
I	11–15
II	7–10
III	6 or less

Table D1-2: Part Derating Levels

Part Type	Derating Parameter	Derating Level I	II	III
Capacitors				
• Film • Mica • Glass • Ceramic	Voltage/Temp (°C)	50%/10	60%/10	60%/10
Capacitors				
• Electrolytic Aluminum	Voltage/Temp (°C)	NR	NR	80%/20
• Electrolytic Tantalum	Voltage/Temp (°C) (NR—Not recommended for use)	50%/20	60%/20	60%/20
Capacitors				
• Variable Piston	Voltage/Temp (°C)	40%/10	50%/10	50%/10
• Variable Ceramic	Voltage/Temp (°C)	30%/10	50%/10	50%/10
Connectors				
	Voltage	50%	70%	70%
	Current	50%	70%	70%
	Insert Temp (°C) (T from Max Limit)	50	25	25
Diodes				
• Signal/Switch (Axial Lead)	Forward Current	50%	65%	75%
	Reverse Voltage	70%	70%	70%
	Max Tj (°C)	95	105	125

Part Type	Derating Parameter	Derating Level I	II	III
Fiber Optics				
• ILD (Injection Laser)	Power Output	50%	60%	70%
	Max Tj (°C)	95	105	110
• APD (Avalanche Photo)	Reverse Voltage	70%	70%	70%
	Max Tj (°C)	95	105	125
Fiber Optics				
• Cable	Bend Radius (% of minimum)	200%	200%	200%
	Tension Cable (% Rated Tensile)	50%	50%	50%
	Tension Fiber (% Proof Test)	20%	20%	20%
Inductors				
• Pulse Transformers	Operating Current	60%	60%	60%
	Dielectric Voltage	50%	50%	50%
	Temp (°C) Hot Spot	40	25	15
Inductors				
• Coils	Operating Current	60%	60%	60%
	Dielectric Voltage	50%	50%	50%
	Temp (°C) Hot Spot	40	25	15
Lamps				
• Incandescent	Voltage	94%	94%	94%
• Neon	Current	94%	94%	94%

Diodes				
• Schottky/PIN (Axial Lead)	Power Dissipation	50%	60%	70%
	Reverse Voltage	70%	70%	70%
	Max Tj (°C)	95	105	125
Diodes				
• Power Rectifier	Forward Current	50%	65%	75%
	Reverse Voltage	70%	70%	70%
	Max Tj (°C)	95	105	125
Diodes				
• Voltage Regulator	Power Dissipation	50%	60%	70%
	Max Tj (°C)	95	105	125
• Voltage Reference	Current Izt	*	*	*
	Max Tj (°C)	95	105	125
	(P−% Rated)			
	*(Fixed Test Current, don't derate)			
Diodes				
• Suppressor Transient	Power Dissipation	50%	60%	70%
	Average Current	50%	65%	75%
	Max Tj (°C)	95	105	125
Diodes				
• Microwave	Power Dissipation	50%	60%	70%
	Reverse Voltage	70%	70%	70%
	Max Tj (°C)	95	105	125
Diodes				
• LED	Forward Current	50%	65%	75%
	Max Tj (°C)	95	105	110

Microcircuits				
• Linear	Supply Voltage	70%	80%	80%
	Input Voltage	60%	70%	70%
	Output Current	70%	75%	80%
	Max Tj (°C)	80	95	105
Microcircuits				
• Digital	Supply Voltage	+/−3%	+/−5%	+/−5%
	Frequency	80%	90%	95%
	Output Current	80%	85%	90%
	Max Tj (°C)	85	100	110
	(F−% Absolute Max)			
Microcircuits				
• Hybrid	Thick Film*	<50	<50	<50
	Thin Film*	<40	<40	<40
	Max Tj (°C)	85	100	110
	*(Pwr Density−W/in^2)			
Microcircuits				
• Complex (LSI, VLSI, VHSIC)	Supply Voltage	+/−3%	+/−5%	+/−5%
	Frequency	75%	80%	90%
	Output Current	70%	75%	80%
	Fan Out	70%	75%	80%
	Max Tj (°C)	85	100	125
	(F−% Absolute Max)			
Microcircuits				
• Memory	Supply Voltage	+/−3%	+/−5%	+/−5%
	Output Current	70%	75%	80%
	Max Tj (°C)	85	100	125

Table D1-2 (continued)

Part Type	Derating Parameter	Derating Level I	II	III
Miscellaneous				
• Circuit Breakers	Current	75%	80%	80%
• Fuses	Current	50%	50%	50%
Relays				
	Current (Res/Cap)	50%	75%	75%
	Current (Ind)	35%	40%	40%
	Contact Power	40%	50%	50%
	Temp (°C) (T from Max Limit)	20	20	20
Resistors				
• Composition	Power/Temp (°C)	50%/30	50%/30	50%/30
• Film	Power/Temp (°C)	50%/40	50%/40	50%/40
• Variable	Power/Temp (°C)	30%/45	50%/35	50%/35
• Thermistor	Power/Temp (°C) (T from Max Limit)	50%/20	50%/20	50%/20
Resistors				
• Wirewound Accurate	Power/Temp (°C)	50%/10	50%/10	50%/10
• Wirewound Power	Power/Temp (°C) (T from Max Limit)	50%/125	50%/125	50%/125
Transistors				
• Bipolar	Power Dissipation	50%	60%	70%
	Breakdown Voltage	60%	70%	70%
	Max Tj (°C)	95	105	125
Transistors				
• Field Effect	Power Dissipation	50%	60%	70%
	Breakdown Voltage	60%	70%	70%
	Max Tj (°C)	95	105	125
Transistors				
• Thyristors (SCR/TRIAC)	On-State Current	50%	70%	70%
	Off-State Voltage	70%	70%	70%
	Max Tj (°C) (It−% Rated) (VDM−% Rated)	95	105	125
Tubes				
	Power Output	80%	80%	80%
	Power Reflected	50%	50%	50%
	Duty Cycle	75%	75%	75%

Rotating				
	Bearing Load	75%	90%	90%
	Operating Temp (°C) (L–% Rated) (T from Max Limit)	40	25	15
Switches				
	Current (Res/Cap)	50%	75%	75%
	Current (Ind)	35%	40%	40%
	Contact Power	40%	50%	50%
SAW				
	Input Power (dB) (Freq > 500 MHz)	13	13	13
	Input Power (dB) (Freq < 500 MHz)	18	18	18
	Temp (°C) (T-Op Max)	125	125	125

Notes:

1. Voltage, current and power derating are percent of rated unless otherwise noted.
2. Temperature derating is from the maximum rated.
3. Quick reference designers derating slide rule available, without cost, from: RADC/RBER, Griffiss AFB NY 13441-5700.

Topic D2: Thermal Design Limitations

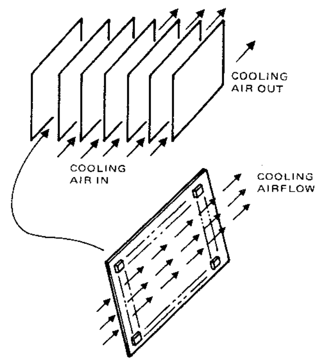
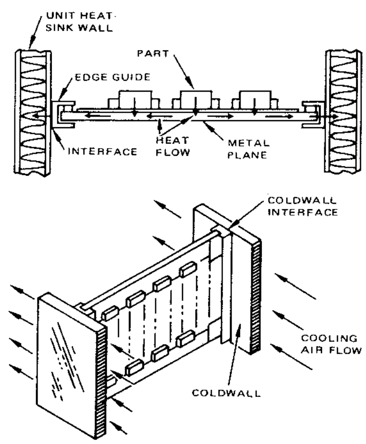
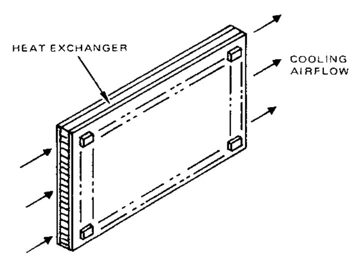
One of the important variables in system reliability is temperature. Therefore, the thermal design of a system must be planned and evaluated. Full discussion of this topic is beyond the scope of this document but it is important to point out to a reliability engineer what limitations there are for common thermal design approaches. Tables D2-1 and D2-2 summarize the most common cooling techniques for electronics and their limitations.

Table D2-1: Cooling Techniques Limitations (Per Unit Volume)

Dissipation Per Unit Volume (W/ft^3)	Sufficient Cooling Technique (Most Applications)
0–300*	Free convection to ambient air
300*–1000	Forced air convection
>1000	Custom design, thermal considerations should have top priority in physical design

*100W/ft^3 instead of 300W/ft^3 if box is poorly ventilated and thermally sensitive parts are mounted horizontally.

Table D2-2: Cooling Techniques Limitations (Per Unit Area)

Cooling Technique	Maximum Cooling Capacity W/M²	W/IN²	Description
Impingement			
—Free Convection	800	0.5	
—Forced Air	3000	2	
Coldwall	1500	1	
Flow-Through	3400	2	

Example: A 9″ × 5″ printed circuit board using free convection cooling would be limited to about 22.5 watts.

Topic D3: Parts Control

Managing a parts control program is a highly specialized activity and does not typically fall under the system's R&M engineer's responsibility. However, because of the interrelationship of parts control and good system reliability, it is important that R&M engineers and program managers have a general understanding of the parts control discipline. Parts control questions which are often asked include:

- Why do parts control?
- What are the various "tools" to accomplish parts control?
- What is a JAN part, a MIL-STD-883 part, a standard military drawing (SMD) part, and a vendor equivalent part?

Why do parts control? Since the invention of semiconductors, users could never be sure that a device purchased from one manufacturer would be an exact replacement for the same device obtained from another supplier. Major differences in device processing and electrical testing existed among suppliers. Because of the importance of semiconductors to military programs, the government introduced standard methods of testing and screening devices in 1968. Devices which were tested and screened to these methods were then placed on a government approval list called the qualified parts list (QPL). Through this screening and testing process, a part with known quality and performance characteristics is produced.

What are the various "tools" to accomplish parts control? The government has subdivided parts into three basic classifications: (1) microelectronics, (2) semiconductors (e.g., transistors, diodes, etc.), and (3) electrical parts (e.g., switches, connectors, capacitors, resistors, etc.). For each class, part specification and test method documents have been developed. Table D3-1 summarizes key documents and their content.

What is a JAN part, a MIL-STD-883 part, a standard military drawing (SMD) part, and a vendor equivalent part? The primary difference in these descriptions is that each of these part classes has undergone different levels of screening and certification. Certification involves specifying and documenting the part manufacturing process. It also involves government and manufacturer agreement on a detailed part specification. This ensures consistent part quality and known performance. Table D3-2 summarizes common classes of parts and what these classifications signify. Table D3-3 summarizes MIL-STD-883C screening procedures and is included to give the reader a feel for the wide range of tests required. Topic A11 shows the impact of the various part quality designations on system reliability.

Table D3-1: Key Parts Control Documents and Their Content

Document	Title	Content
MIL-M-38510	General Specification for Microcircuits	Provides detailed specification requirements in the form of "slash sheets" for several hundred of the most commonly used microcircuits. Covers screening requirements (referenced to MIL-STD-883), electrical testing, quality conformance, physical dimensions, configuration control for critical manufacturing processing steps and production line certification.
MIL-STD-883	Test Methods and Procedures for Microelectronics	Provides uniform methods and procedures for testing microelectronic devices. Structured into five classes of test methods: 1000 Class addresses environmental tests, 2000 Class addresses mechanical tests, 3000 Class addresses electrical tests for digital circuits, 4000 Class addresses electrical tests for linear circuits, and 5000 Class addresses test procedures. The tests covered include moisture resistance, seal test, neutron irradiation, shock and acceleration tests, dimensional tests, input/output current tests, and screening test procedures to name a few. Two test levels are described; Class B and Class S. Class S is geared toward space qualified parts and requires a host of tests not performed on Class B parts (e.g., wafer lot acceptance, bond pull, particle impact noise detection, serialization, etc.).
MIL-S-19500	General Specification for Semiconductors	Provides detailed specification sheets establishing general and specific requirements including electrical characteristics, mechanical characteristics, qualification requirements, inspection procedures and test methods.
MIL-STD-750	Test Methods for Semiconductor Devices	Provides uniform methods and procedures for testing semiconductors. Structured into five classes of test methods: 1000 Class addresses environmental tests, 2000 Class addresses mechanical characteristics, 3000 Class addresses electrical characteristics for transistors, 3100 Class addresses circuit performance and thermal resistance measurements, and the 3200 Class addresses low frequency tests.
MIL-STD-202	Test Methods for Electronic and Electrical Parts	Provides uniform methods for testing electronic and electrical parts. Structured into three classes of test methods: 100 Class addresses environmental tests, 200 Class addresses physical characteristic tests, and 300 Class addresses electrical characteristic tests. These tests are not tied to a single part specification document as with microelectronics and semiconductors, but rather, numerous specifications for various component types.
MIL-STD-965	Parts Control Program	Provides parts control procedures to be used in the design and development of military equipment, including the submission, review and approval of a Program Parts Selection List. Generally, an overall guide for the implementation and management of a parts control program. The document provides for two basic management procedures. Procedure I is applicable to a majority of programs and does not make use of a formal parts control board. Procedure II requires a formal parts control board and is recommended for consideration where there is an aggregation of contractor/subcontractors.

Table D3-2: Microelectronics Classifications and Descriptions

Part Classification	Part Classification Description
JAN or MIL-M-38510 Parts	These parts have a detailed specification (slash sheet) in MIL-M-38510 which controls all mechanical, electrical, and functional parameters of the part. Additionally, the manufacturing process flow is government certified, the devices are screened to MIL-STD-883 requirements, and the devices are subjected to rigorous quality conformance testing.
MIL-STD-883 or SMD (Standard Military Drawing) Parts	"SMD" and "883" are used interchangeably to describe part quality. A part which is marked "MIL-STD-883" indicates that the part has been tested to a host of MIL-STD-883 requirements. These include screening requirements, electrical tests over the military temperature range, packaging material requirements, lead material requirements, quality conformance inspection requirements, etc. The difference between a MIL-STD-883 part (or SMD part) and a JAN part is that a government approved specification is not listed in MIL-M-38510; therefore, manufacturing line certification has not been performed for the MIL-STD-883 part. The manufacturer is then free to vary the manufacturing process at any time. This could then change the mechanical or electrical characteristics of the part.
Vendor Equivalent Parts	Refers to parts which have been tested to a vendor's equivalent MIL-STD-883 test. The vendor may or may not modify the scope of the tests and a careful analysis is required to determine just how similar to MIL-STD-883 the tests are.

Table D3-3: MIL-STD-883 Screening Procedure Summary

Screen	Class S Method	Rqmt	Class B Method	Rqmt
Wafer lot acceptance	5007	All lots		—
Nondestructive bond pull	2023	100%		—
Internal visual	2010, test condition A	100%	2010, test condition B	100%
Stabilization bake no end point measurements required	1008 Condition C	100%	1008 Condition C	100%
Temperature cycling	1010, test condition C	100%	1010, test condition C	100%
Constant acceleration	2001, test condition E (min), Y_1 orientation only	100%	2001, test condition E (min), Y_1 orientation only	100%
Visual inspection		100%		100%
Particle impact noise detection (PIND)	2020, test condition A	100%		—
Serialization		100%		—
Pre-burn-in electrical parameters	Per applicable device specification	100%	Per applicable device specification	100%
Burn-in test	1015 240 hrs @ 125°C min	100%	1015 160 hrs @ 125°C min	100%
Interim (post-burn-in) electrical parameters	Per applicable device specification	100%		—
Reverse bias burn-in	1015; test condition A or C, 72 hrs @ 150°C min	100%		—
Interim (post-burn-in) electrical parameters	Per applicable device specification	100%	Per applicable device specification	100%
Percent defective allowable (PDA) calculation	5% 3%, functional parameters @ 25°C	All lots	5%,	All lots

Table D3-3 (continued)

Screen	Class S Method	Rqmt	Class B Method	Rqmt
Final electrical test	Per applicable device specification		Per applicable device specification	
(a) Static tests				
(1) 25°C (subgroup 1, table I, 5005)		100%		100%
(2) Maximum and minimum rated operating temp. (subgroups 2, 3, table I, 5005)		100%		100%
(b) Dynamic or functional tests				
(1) 25°C (subgroup 4 or 7, table I, 5005)		100%		100%
(2) Minimum and maximum rated operating temp (subgroups 5 and 6, or 8, table I 5005)		100%		100%
(c) Switching tests at 25°C (subgroup 9, table I 5005)		100%		100%
Seal (a) Fine (b) Gross	1014	100%	1014	100%
Radiographic	2012 two views	100%		—
Qualification or quality conformance inspection test sample selection	IAW MIL-M-38510		IAW MIL-M-38510	
External visual	2009	100%	2009	100%

Topic D4: Review Questions

Program and design reviews are key vehicles for measuring development progress and preventing costly redesigns. Participation by government individuals knowledgeable in R&M is critical to provoking discussions that bring out the issues important to R&M success. Of course, the questions to be posed to the development contractor depend on the timing of the review as indicated below. Action Items should be assigned at the reviews based on open R&M issues and the reliability engineer must follow-up to ensure that they're resolved satisfactorily.

Table D4-1: Major Program Reviews

Review	Purpose	R&M Engineers Role
System Requirements Review (SRR)	To ensure a complete understanding of system specification and statement of work requirements. This is usually done by means of a detailed expansion and review of the contractor's technical proposal.	Discuss the performance of all required R&M tasks and requirements with contractor R&M personnel. Topics such as the contractor's overall reliability program plan, data items and delivery schedule are usually discussed.
Preliminary Design Review (PDR)	To evaluate progress and technical adequacy of the selected design approach prior to the detailed design process.	Discuss and evaluate R&M tradeoffs and reasoning leading to the selected design approach. Review preliminary R&M modeling, allocations and predictions to ensure adequacy in meeting R&M requirements. Discuss status of other R&M tasks such as parts control, derating, thermal design and reliability critical items.
Critical Design Review (CDR)	To ensure that the detailed design satisfies the requirements of the system specification before freezing the design for production or field testing.	Review the final reliability analysis and modeling to ensure R&M requirements are met. Discuss parts control program status and military part procurement lead time requirements. Review adequacy of the final thermal analysis and derating. Discuss R&M testing.
Test Readiness Review (TRR)	To ensure that all CDR problems have been satisfactorily resolved and to determine if the design is mature enough to start formal testing.	Review R&M test plans and procedures to ensure acceptable ground rules and compliance with requirements.
Production Readiness Review (PRR)	To review test results and determine whether or not the design is satisfactory for production.	Discuss R&M testing results and ensure any design deficiencies found during testing have been corrected. Discuss production quality assurance measures and burn-in procedures to ensure adequacy.

Table D4-2: Design Review Checklist

Question	Review Where Usually Most Applicable SRR	PDR	CDR	TRR	PRR	Remarks
R&M Management						
What are the avenues of technical interchange between the R&M group and other engineering groups (e.g., Design, Systems Engineering, ILS, Procurement, and Test and Evaluation)?	X	X				R&M engineering should participate at all engineering group meetings where R&M is effected. Easy avenues of technical interchange between the electrical design group and other groups such as thermal engineering must exist.
Does the reliability group have membership and a voice in decisions of the Material Review Board, Failure Review Board, and Engineering Change Review Board?	X	X	X	X		Membership or an option to voice an opinion is essential if the failure tracking and corrective action loop is to be completed.
Is the contractor and subcontractor(s) a member of the Government Industry Data Exchange Program (GIDEP)? What is the procedure for comparing parts on the ALERT list to parts used in the system?	X	X	X			Incoming part types should be checked against the GIDEP ALERT data base and incoming ALERTS should be checked against the system parts list. (GIDEP ALERTS are notices of deficient parts, materials or processes.)
Are reliability critical items given special attention in the form of special analysis, testing or destructive laboratory evaluation?		X	X			Critical parts are usually defined by contract or by MIL-STD-785. Methods of tracking critical parts must be identified by the contractor. See Topic D5 for a critical items checklist.
Do the purchase orders require vendors to deliver specified levels of R&M&T based on allocation of higher level requirements?	X	X				Requirements should require verification by analysis or test.
Does the reliability group have access to component and failure analysis experts and how are they integrated into the program?	X	X	X			Failure analysis is essential to determine the cause and effect of failed components.
Is there adequate communication between testability design engineers and the electrical design group to ensure that testability considerations are worked into the upfront design?	X	X				
Are JAN microcircuits (MIL-M-38510) and semiconductors (MIL-S-19500) being used wherever possible and are procurement lead times for these devices adequate?		X	X			Part quality in order of preference: MIL-M-38510, Class B; MIL-STD-883, Class B; MIL-STD-883 vendor equivalent; commercial hermetically sealed. JAN parts usually require longer procurement times (3 to 6 months) which sometimes causes commercial parts to be forced into the design.

R&M Management Questions	Review Where Usually Most Applicable SRR	PDR	CDR	TRR	PRR	Remarks
Where nonstandard parts are used, are they procured via a specification control drawing (SCD) and do they have at least two suppliers? Are methods for nonstandard part approval clearly established and is there a clear understanding of what constitutes a standard and nonstandard part?	X	X	X			Specification control drawings should specify reliability, environment and testing requirements.
Has an up-to-date preferred parts selection list (PPSL) been established for use by designers?	X	X				DESC and DISC establish baseline PPSLs which should be the basis of the contractor's list. See Topic R6 Note 2 for points of contact.
R&M Design						
Do the R&M&T models accurately reflect the system configuration, its modes of operation, duty cycles, and implementation of fault tolerance?		X	X			
Do predictions meet numerical R&M specification requirements? Are prediction procedures in accordance with requirements?	X	X	X			If not, better cooling, part quality and/or redundancy should be considered.
Have R&M allocations been made to the LRU level or below? Do reliability predictions compare favorably to the allocation?	X	X				Weighted reliability allocations should be made to lower levels based on the upper test MTBF (θ_0), or similar measure.
Does the testability analysis show that numerical testability requirements will be met for the organizational, intermediate and depot repair levels?		X	X			If not, alternate design concepts must consider including more automated features.
Have tradeoff studies been performed in the areas of R&M&T?	X	X				Typical tradeoffs might include redundancy levels, weight, power, volume, complexity, acquisition cost, life cycle cost.
Has a thermal analysis been performed to ensure an adequate cooling technique is used and have the temperature results been factored into the reliability analysis?		X	X			Thermal analysis is essential to a complete program.
Has piece part placement been analyzed to ensure that high dissipating parts are placed away from heat sensitive parts?		X	X			For example, high power dissipation components such as large power resistors, diodes and transformers should be investigated.
Have methods been established to ensure that operating temperatures of off-the-shelf equipment will be within specified limits?	X	X				Reference environmental requirements in the system specification.

Table D4-2 (continued)

Questions	Review Where Usually Most Applicable SRR	PDR	CDR	TRR	PRR	Remarks
Do parts used in the design meet system environmental requirements?		X	X			Temperature range for most military parts is −55°C to +125°C. Temperature range for most commercial parts (plastic) is 0°C to 70°C.
Is there a clearly established derating criteria for all part types used in the design and is there a clear procedure for monitoring and enforcing this criteria?	X	X	X			The part derating levels are a function of program type but should be at least Level 3 of AFSC Pamphlet 800-27 "Part Derating Guidelines." See Topic D1.
Are temperature overheat sensors included in the system design?		X	X			
Is there a clear procedure for the identification of parts not meeting the derating criteria?	X	X	X			A tradeoff analysis should be performed on parts not meeting derating criteria to determine if a redesign to lower stress is appropriate.
Will part derating verification tests be performed?				X		Depending on system criticality, 3 to 7 percent of the system's parts should undergo stress verification. No more than 30 percent of the tested parts should be passive parts (resistors, capacitors, etc.).
Have limited life parts and preventive maintenance tasks been identified, and inspection and replacement requirements specified?		X	X			For example, inspection items may include waveguide couplers, rotary joints, switches, bearings, tubes and connectors. Typical PM items include air filters, lubrication, oil changes, batteries, belts, etc.
Have single points of failure been identified, and their effects determined?		X	X			Important for identifying areas where redundancy should be implemented and to assist in ranking the most serious failure modes for establishing a critical items list.
Have compensating features been identified for those single points of failure where complete elimination of the failure mode is impractical?		X	X			Compensating features could include increased part quality, increased testability, additional screening, fail safe design provisions, etc.
Have areas where fault ambiguity may exist been identified? Have alternative methods of isolation and checkout (e.g., semiautomatic, manual, repetitive replacement, etc.) been identified for these areas?		X	X			Additional test nodes must be considered to break ambiguity groups.

Questions	Review Where Usually Most Applicable SRR	PDR	CDR	TRR	PRR	Remarks
For each maintenance level, has a decision been made for each item on how built-in-test, automatic test equipment, and general purpose electronic test equipment will support fault detection and isolation?		X	X			
Are features being incorporated into the testability design to control false alarms?		X	X			Typical features might include definition of test tolerances, transient monitoring and control, multiple run decision logic, environmental effects filtering and identification, etc.
R&M Testing						
Is there a failure reporting and corrective action system (FRACAS) in place, and does it account for failures occurring during all phases of testing?			X	X	X	FRACAS should include data from incoming inspection, development testing, equipment integration testing and R&M testing. FRACAS should be "closed loop" emphasizing corrective action.
Is there a failure analysis capability and will failures be subjected to a detailed analysis?			X	X	X	Contractor should identify criteria used to determine which failures will be analyzed.
Are subcontractors subjected to the same FRACAS requirements, and will their failure analysis reports be included with the prime contractor's reports?		X		X	X	
Does the reliability demonstration test simulate the operating profile seen in the field and will all modes of equipment operation be tested over the required environmental extremes?			X	X		The test must simulate the operational profile and modes to have valid results.
Does the maintainability and testability demonstration test simulate realistic failures and is the candidate task list sufficient to reduce bias?			X	X		Candidate lists should be four to ten times the size of the test sample.
Are relevant and nonrelevant failure definitions clear and agreed upon?			X	X		See Topic T9 for failure definitions.
Are equipment performance checks to be performed during testing clearly defined and has the information to be recorded in the test log been clearly defined and agreed upon?				X		Items such as temperature variations, start/stop of vibration, event occurrence times and a detailed description of system recovery after failure should be included as a minimum.

Table D4-2 (continued)

R&M Design Questions	Review Where Usually Most Applicable SRR	PDR	CDR	TRR	PRR	Remarks
Do preliminary plans for ESS meet the required needs?				X	X	Temperature and random vibration are the most effective screens. At module level, perform 20 to 40 temperature cycles per module. At higher levels, perform 4 to 12 cycles. (See RADC-TR-82-87, Stress Screening of Electronic Hardware and DOD-HDBK-344, Environmental Stress Screening of Electronic Equipment and Topics T1–T3 for guidance.)

Note: For an exhaustive design checklist see MIL-HDBK-338, Chapter 7.

Topic D5: Critical Item Checklist

Major Concerns	Comments
• Has the contractor developed formal policies and procedures for identification and control?	• Policies should be distributed to design, manufacturing, inspection and test personnel.
• Are the procedures implemented at the initial design stage and do they continue through final acceptance period?	• The program has to start early so that safety related items can be minimized.
• Are periodic reviews planned to update the list and controls?	• Reviews at SRR, PDR, and CDR must be considered.
• Has an FMEA been performed on each critical item?	• Failure modes need to be identified so that control procedures can be developed.
• Are compensating features included in the design?	• Features such as safety margins, overstress testing, special checkouts should be considered.
• Does the contractor's control plan eliminate or minimize the reliability risk?	• Development of a list of critical items is only half the solution; controls such as stress tests, design margins, duty cycles, and others must be considered.
• As a minimum, are the following criticality factors considered: • Failures jeopardizing safety • Restrictions on limited useful life • Design exceeding derating limits • Single sources for parts • Historically failure prone items • Stringent tolerances for manufacturing or performance • Single failure points that disrupt mission performance	• A list of critical items, personnel responsible for monitoring and controlling, and review procedures must be established. Other application unique critical items should be identified by the procuring activity.

Section A
Analysis

What R&M ANALYSES should be required and how should they be evaluated?

R&M Engineer's Role

Insight

Reliability and maintainability analyses are a necessary part of most development programs. They provide a means of determining how well the design is progressing towards meeting the program's goals and requirements. They also provide means of evaluating the impact of important design decisions such as cooling approaches, classes of part quality being used, and areas of fault tolerance. In order for the government to receive the outputs of contractor performed analyses, appropriate contract deliverable data items must be required.

For More Information

MIL-STD-756	"Reliability Modeling and Prediction"
MIL-STD-1629	"Procedures for Performing a Failure Mode, Effects and Criticality Analysis"
MIL-HDBK-217	"Reliability Prediction of Electronic Equipment"
MIL-HDBK-472	"Maintainability Prediction"
RADC-TR-82-179	"Sneak Analysis Application Guidelines"
RADC-TR-87-55	"Predictors of Organizational-Level Testability Attributes"
RADC-TR-77-287	"A Redundancy Notebook"

Topic A1: Reliability and Maintainability Analyses

Table A1-1: R&M Analysis Types, Purpose and Application

Analysis Type	Purpose	Application
R&M Modeling, Allocations and Prediction	• To quantitatively evaluate the R&M of competing designs. • To direct R&M related design decisions.	• Perform early in the design phase. • More beneficial for newly designed hardware. • Applicable to all types of hardware. • Maintainability analyses usually applied to organizational level of repair.
• Modeling	• Identifies framework and integrates system interrelationships for analyses and assessment.	
• Allocations	• Distributes system quantitative requirements to lower levels of indenture using R&M models. Used as design goals.	
• Predictions	• Uses system models, failure rates and repair rates to estimate system R&M figures of merit. • Enables tradeoffs with respect to design approaches.	
Failure Modes, Effects and Criticality Analysis (FMECA)	• Bottom up approach to identify single failure points and their effects. • To assist in the efficient design of BIT and FIT. • To establish and rank critical failures. • To identify interface problems.	• Perform early in the design phase. • More beneficial if performed on newly designed equipment. • More applicable to equipment performing critical functions (e.g., control systems).

Table A1-1 (continued)

Analysis Type	Purpose	Application
Sneak Circuit Analysis (SCA)	• To identify system/equipment failures that are not caused by part failures. • To reveal unexpected logic flows that can produce undesired results. • To expose design oversights that create conditions of undesired operation.	• Perform prior to CDR to maximize cost effectiveness. • Mission and safety critical functions. • Hardware with numerous interfaces. • Systems with high testing complexities. • Use selectively due to cost of performing.
Worst Case Analysis (WCA)	• To evaluate circuits for tolerance to "drift." • To evaluate the simultaneous existence of all unfavorable tolerances.	• Not often applied. • Use selectively.
Fault Tree Analysis (FTA)	• Top down approach to identify effects of faults on system performance.	• Can be applied when FMECA considered too expensive. • Easier to apply and understand than FMECA.

Table A1-2: Summary of Failure Effects Analysis Characteristics

ANALYSIS TYPE	INDUCTIVE	DEDUCTIVE	SPECIALIZED APPLICATION	TIME DEPENDENCY	ADVANCED MATH	SINGLE FAILURES	MULTIPLE FAILURES	EXTERNAL INFLUENCES	ANY DESIGN STAGE	EARLY DESIGN STAGE	LATE DESIGN STAGE	LOGISTICS APPLICATION	TESTABILITY APPLICATION
FMEA	X					X			X	X			X
CRITICALITY						X			X	X		X	
SNEAK			X					X			X		
WORST CASE			X	X		X		X			X		X
FAULT TREE		X			X	X	X	X	X	X		X	X

Topic A2: Reliability Prediction Methods

Prediction Procedure	Application	Basic Parameters of Measure	Information Required
Parts Count Technique (MIL-HDBK-217 Para 5.2)*	• Gross prediction technique. • Early in design phase when detailed stress data not available.	Failure Rate	• System reliability model. • Number of parts as a function of general part types. • Quality levels of parts. • Operational environment. • Duty cycles.
Parts Stress Technique (MIL-HDBK-217 Para 5.1)	• More accurate prediction technique. • When stress levels can be estimated or measured.	Failure Rate	• System reliability models. • Number of parts as a function of specific part types. • Quality levels of parts. • Operational environment. • Duty cycles. • Stresses applied to parts.
Existing System/Equipment Data	• For off-the-shelf or modified designs. • When detailed part data not available.	Failure Rate	• Operating hours. • Number of failures. • Operational environment. • Duty cycle. • See Topic A6.

*MIL-HDBK-217 "Reliability Prediction of Electronic Equipment"

Topic A3: Maintainability Prediction Methods

Prediction* Procedure	Purpose	Application	Basic Parameters of Measure	Information Required
I	To predict flight line maintenance of airborne electronic and electromechanical systems involving modular replacement.	After establishment of the design concept provided that data as listed in the column entitled "Information Required" is available.	Distribution of downtimes for various elemental activities, maintenance categories, repair times, and system downtime.	(a) Location & failure rate of components (b) Number of: 1. Replaceable components 2. Spares 3. Test Points (c) Duration of average mission (d) Maintenance schedules, etc.
II	To predict the maintainability of shipboard and shore electronic equipment and systems. It can also be used to predict the maintainability of mechanical systems provided that required task times and functional levels can be established.	Applicable during the final design stage.	Part A procedure: Corrective maintenance expressed as an arithmetic or geometric mean time to repair in hours. Part B procedure: Active maintenance in terms of: (a) Mean corrective maintenance time in manhours. (b) Mean preventive maintenance time in manhours.	For corrective maintenance (Part A): (a) Packaging: to the extent that detailed hardware configurations can be established (b) Diagnostic procedure (c) Repair methods (d) Parts listing (e) Operating stresses (f) Mounting methods

Prediction* Procedure	Purpose	Application	Basic Parameters of Measure	Information Required
			(c) Mean active maintenance time in terms of mean manhours per maintenance action.	(g) Functional levels at which alignment and checkout occur. For active maintenance (Part B): The respective maintenance task times for corrective and preventive maintenance must have been determined.
III	To predict the mean and maximum active corrective maintenance downtime for Air Force ground electronic systems and equipment. It may also be used to predict preventive maintenance downtime.	Applied during the design development and control stages.	(a) Mean and maximum active corrective downtime (95th percentile). (b) Mean and maximum preventive downtime. (c) Mean downtime.	(a) Schematic diagrams (b) Physical layouts (c) Functional operation (d) Tools and test equipment (e) Maintenance aids (f) Operational and maintenance environment
IV	To predict the mean and/or total corrective and preventive maintenance downtime of systems and equipments.	Applicable throughout the design, development cycle with various degrees of detail.	(a) Mean system maintenance downtime. (b) Mean corrective maintenance downtime per operational period. (c) Total corrective maintenance downtime per operational period. (d) Total preventive maintenance downtime per operational period.	Complete system documentation portraying: (a) Functional diagrams (b) Physical layouts (c) Front panel layouts (d) End item listings with failure rates.

V	To predict maintainability parameters of avionics, ground and shipboard electronics at the organizational, intermediate and depot levels of maintenance.	Applied at any equipment or system level, at any level of maintenance pertinent to avionics, ground and shipboard electronics.	(a) Mean time to repair (MTTR). (b) Maximum corrective maintenance time (M_{max} (ϕ)). (c) Mean maintenance manhours per repair (MMH/repair). (d) Mean maintenance manhours per operating hour (MMH/OH). (e) Mean maintenance manhours per flight hour (MMH/FH).	Early Prediction (a) Primary replaceable items (b) Failure rates (c) Fault isolation strategy (d) Replacement concept (e) Packaging philosophy (f) Fault isolation resolution Detailed prediction (a) Replacement concept (b) Fault detection and isolation outputs (c) Failure rate (d) Maintenance procedure

*MIL-HDBK-472 "Maintainability Prediction"

Topic A4: Testability Analysis Methods

Procedure	Purpose	Application	Basic Parameters of Measure	Information Required
Prediction of Organizational Level Testability Attributes (RADC-TR-87-55)	To predict two basic testability attributes of the organizational level maintenance system; Cannot Duplicate (CND) Rate, Isolation Level (IL), and a combination of CND, IL and failure rate testability figure of merit.	This prediction technique can be applied before Full Scale Development. This will allow for appropriate design changes before full scale development begins.	(a) Cannot Duplicate Rate (CND) (b) Isolation Level (IL) (c) Testability Figure of Merit (TFOM)	(a) Functional Block Diagrams (b) Schematic Diagrams (c) Failure Rate Predictions (d) Illustrated Parts Breakdown
MIL-STD-2165* Testability Assessment	Provide requirements for the assessment of the inherent testability of a system or equipment design.	Applicable during the final design stage.	A weighting factor (WT) is assigned to each item based upon its relative importance in achieving a testable product. A score is determined for each item, representing the level of testability.	(a) Physical Layout of PC Boards (b) Illustrated Parts Breakdown (c) Schematic Diagrams

*Testability Program for Electronic Systems and Equipments.

Topic A5: Reliability Analysis Checklist

Major Concerns	Comments
Models	
Are all functional elements included in the reliability block diagrams/model?	System design drawings/diagrams must be reviewed to be sure that the reliability model/ diagram agrees with the hardware.
Are all modes of operation considered in the math model?	Duty cycles, alternate paths, degraded conditions and redundant units must be defined and modeled.
Do the math model results show that the design achieves the reliability requirement?	Unit failure rates and redundancy equations are used from the detailed part predictions in the system math model.
Allocation	
Are system reliability requirements allocated (subdivided) to useful levels?	Useful levels are defined as: equipment for subcontractors, assemblies for sub-subcontractors, circuit boards for designers.
Does the allocation process consider complexity, design flexibility, and safety margins?	Conservative values are needed to prevent reallocation at every design change.
Prediction	
Does the sum of the parts equal the value of the module or unit?	Many predictions conveniently neglect to include all the parts producing optimistic results (check for solders connections, connectors, circuit boards).
Are the environmental conditions and part quality representative of the requirements?	Optimistic quality levels and favorable environmental conditions are often assumed causing optimistic results.
Are the circuit and part temperatures defined and do they represent the design?	Temperature is the biggest driver of part failure rates; low temperature assumptions will cause optimistic results.
Are equipment, assembly, subassembly and part reliability drivers identified?	Identification is needed so that corrective actions for reliability improvement can be considered.
Are part failure rates from acceptable sources (i.e., MIL-HDBK-217)?	Use of generic failure rates require submission of backup data to provide credence in the values.
Is the level of detail for the part failure rate models sufficient to reconstruct the result?	Each component type should be sampled and failure rates completely reconstructed for accuracy.
Are critical components such as VHSIC, Monolithic Microwave Integrated Circuits (MMIC), Application Specific Integrated Circuits (ASIC) or Hybrids highlighted?	Prediction methods for advanced parts should be carefully evaluated for impact on the module and system.

Topic A6: Use of Existing Reliability Data

System development programs often make use of existing equipment (or assembly) designs, or designs adapted to a particular application. Sometimes, lack of detailed design information prevents direct prediction of the reliability of these items making use of available field and/or test failure data the only practical way to estimate their reliability. If this situation exists, the following table summarizes the information that is desired.

Table A6-1: Use of Existing Reliability Data

Information Required	Equipment Field Data	Equipment Test Data	Piece Part Data
Data collection time period	X	X	X
Number of operating hours per equipment	X	X	
Total number of part hours			X
Total number of observed maintenance actions	X		
Number of "no defect found" maintenance actions	X		
Number of induced maintenance actions	X		
Number of "hard failure" maintenance actions	X		
Number of observed failures		X	X
Number of relevant failures		X	X
Number of nonrelevant failures		X	X
Failure definition		X	X
Number of equipment or parts to which data pertains	X	X	X
Similarity of equipment of interest to equipment for which data is available	X	X	
Environmental stress associated with data	X	X	X
Type of testing		X	
Field data source	X		

Topic A7: Maintainability/Testability Analysis Checklist

Major Concerns	Comments
Are the maintainability/testability prediction techniques and data used clearly described?	
Is there a clear description of the maintenance concept and all ground rule assumptions?	Repair level, LRU/module definition, spares availability assumptions, test equipment availability assumptions, tools availability assumptions, personnel assumption, environmental conditions.
Are worksheets provided which show how LRU repair times were arrived at?	The breakout of repair time should include: fault isolation, disassembly, interchange, reassembly and checkout.
Are step-by-step repair descriptions provided to back up repair time estimates?	
Are fault isolation time estimates realistic?	Overestimating BIT/FIT capability is the primary cause of optimistic repair time estimates.
Are fault isolation ambiguity levels considered in the analysis?	
Can repair times be reconstructed from the worksheets and is addition, subtraction, multiplication and division correct?	Checking is mundane but often results in errors and inconsistencies being found.
Are preventive maintenance tasks described?	This includes frequency, maintenance time and detailed task description.
Is all the equipment included in the prediction?	
Has the best procedure been selected to provide estimates for the testability attributes?	Because of the number of variables which effect testability and the number of different procedures available to effect analyses, there must be rationale and logic provided to explain why the particular approach was taken.
Are the numerical values of the testability attributes within specified tolerances?	
Does the test equipment, both hardware and software, meet all design requirements?	All test points should be accessible.
Are the simulation and emulation procedures to be used to simulate/emulate units of the system, for diagnostics development, reasonable and practical?	

Topic A8: FMECA Analysis Checklist

Major Concerns	Comments
Is a system definition/description provided and is it compatible with the system specification?	
Are ground rules clearly stated?	These include approach, failure definition, acceptable degradation limits, level of analysis, etc.
Are block diagrams provided showing functional dependencies at all equipment indenture levels?	This diagram should graphically show what items (parts, circuit cards, subsystems, etc.) are required for the successful operation of the next higher assembly.
Does the failure effect analysis start at the lowest hardware level and systematically work to higher indenture levels?	The analysis should start at the lowest level specified in the SOW (e.g., part, circuit card, subsystem, etc.).
Are failure mode data sources fully described?	Consider use of MIL-HDBK-338 failure mode data.
Are detailed FMECA worksheets provided? Do the worksheets clearly track from lower to higher hardware levels? Do the worksheets clearly correspond to the block diagrams provided?	Worksheets should provide an item name, indenture code, item function, list of item failure modes, effect on next higher assembly and system for each failure mode, and a criticality ranking.
Are failure severity classes provided?	Typical classes are: 1. Catastrophic (life/death) 2. Critical (mission loss) 3. Marginal (mission degradation) 4. Minor (maintenance/repair)
Are results clearly summarized?	Actions for risk reduction of single point failures, critical items, areas needing BIT/FIT, etc.
Are results of FMECA being used to impact other program design decisions?	BIT design, critical parts, reliability prediction, derating, fault tolerance.

Topic A9: Redundancy Equations

Many military electronic systems readiness and availability requirements exceed the level of reliability to which a serial chain system can be practically designed. Use of high quality parts, a sound thermal design and extensive stress derating may not be enough. Fault tolerance, or the ability of a system design to tolerate a failure or degradation without system failure, is required. The most common form of fault tolerance is redundancy where additional, usually identical, units are added to a system in parallel with the other units. Because this situation is very common, the reliability equations for common redundancy situations are included below.

The following represents a sample list of specific redundancy relationships which define failure rate as a function of the specific type of redundancy employed. For a more comprehensive treatment of redundancy concepts and the reliability improvements achievable through their applications see RADC-TR-77-287, "A Redundancy Notebook."

Table A9-1: Redundancy Equation Approximations Summary

Redundancy Equations	
With Repair	**Without Repair**
All units are active on-line with equal unit failure rates. $(n-q)/n$ required for success.	
Equation 1 $$\lambda_{(n-q)/n} = \frac{n!\,(\lambda)^{q+1}}{(n-q-1)!\,(\mu)^q}$$	Equation 4 $$\lambda_{(n-q)/n} = \frac{\lambda}{\sum_{i=n-q}^{n} \frac{1}{i}}$$
Two active on-line units with different failure and repair rates. One of two required for success.	
Equation 2 $$\lambda_{1/2} = \frac{\lambda_A\lambda_B[(\mu_A+\mu_B)+(\lambda_A+\lambda_B)]}{(\mu_A)(\mu_B)+(\mu_A+\mu_B)(\lambda_A+\lambda_B)}$$	Equation 5 $$\lambda_{1/2} = \frac{\lambda_A^2\lambda_B+\lambda_A\lambda_B^2}{\lambda_A^2+\lambda_B^2+\lambda_A\lambda_B}$$
One standby off-line unit with n active on-line units required for success. Off-line spare assumed to have a failure rate of zero. On-line units have equal failure rates.	
Equation 3 $$\lambda_{n/n+1} = \frac{n[n\lambda+(1-P)\mu]\lambda}{\mu+n(P+1)\lambda}$$	Equation 6 $$\lambda_{n/n+1} = \frac{n\lambda}{P+1}$$

Key:

$\lambda_{x/y}$ is the effective failure rate of the redundant configuration where x of y units are required for success.

n = number of active on-line units. n! is n factorial (e.g., $5! = 5\times4\times3\times2\times1 = 120$, $1! = 1$, $0! = 1$)

λ = failure rate of an individual on-line unit (failures/hour).

q = number of on-line active units which are allowed to fail without system failure.

μ = repair rate ($\mu = 1/M_{ct}$, where M_{ct} is the mean corrective maintenance time in hours).

P = probability switching mechanism will operate properly when needed (P = 1 with perfect switching).

Notes:

1. Assumes all units are functional at the start.
2. The approximations represent time to first failure.
3. **CAUTION:** Redundancy equations for repairable systems should not be applied if delayed maintenance is used.

Example 1:

A system has five active units, each with a failure rate of 220 f/10^6 hours, and only three are required for successful operation. If one unit fails, it takes an average of three hours to repair it to an active state. What is the effective failure rate of this configuration?

Solution:

Substituting the following values into Equation 1:

$n = 5$

$q = 2$

$\mu = 1/3$

$\lambda_{(5-2)/5} = \lambda_{3/5}$

$$\lambda_{3/5} = \frac{5!\,(220 \times 10^{-6})^3}{(5-2-1)!(1/3)^2}$$

$\lambda_{3/5} = 5.75 \times 10^{-9}$ f/hour $= .00575$ f/10^6 hours

Example 2:

A ground radar system has a 2 level weather channel with a failure rate of 50 f/10^6 hours and a 6 level weather channel with a failure rate of 180 f/10^6 hours. Although the 6 level channel provides more comprehensive coverage, the operation of either channel will result in acceptable system operation. What is the effective failure rate of the two channels if one of two are required and the M_{ct} is 1 hour?

Solution:

Substituting the following values into Equation 2:

$\lambda_A = 50 \times 10^{-6}$

$\lambda_B = 180 \times 10^{-6}$

$\mu_A = \mu_B = 1/M_{ct} = 1$

$$\lambda_{1/2} = \frac{(50 \times 10^{-6})(180 \times 10^{-6})\,[(1+1) + (50 \times 10^{-6} + 180 \times 10^{-6})]}{(1)(1) + (1+1)(50 \times 10^{-6} + 180 \times 10^{-6})}$$

$\lambda_{1/2} = 1.8 \times 10^{-8}$ f/hour $= .018$ f/10^6 hours

Example 3:

Determine the effective failure rate for 8 of 10 identical units required with no repair. The failure rate of a single unit is 60 f/10^6 hours.

Solution:

Substituting the following values into Equation 4:

$$n = 10$$

$$q = 2$$

$$\lambda = 60 \times 10^{-6}$$

$$\lambda_{(10-2)/10} = \frac{60 \times 10^{-6}}{\sum_{i=10-2}^{10} \frac{1}{i}}$$

$$\lambda_{8/10} = \frac{60 \times 10^{-6}}{\frac{1}{8} + \frac{1}{9} + \frac{1}{10}}$$

$$\lambda_{8/10} = 1.79 \times 10^{-4} \text{ f/hour} = 179 \text{ f}/10^6 \text{ hours}$$

Having two redundant units improves the system failure rate from 480 f/10^6 hours (8 units required $\times$ 60 f/10^6 hours each) to 179 f/10^6 hours.

Topic A10: Parts Count Reliability Prediction

A standard technique for predicting reliability when detailed design data such as part stress levels is not yet available is the parts count reliability prediction technique. The technique has a "built-in" assumption of average stress levels which allows prediction in the conceptual stage or source selection stage by estimation of the part types and quantities. This section contains a summary of the MIL-HDBK-217 technique for four of the most common operational environments: space flight (S_F), ground fixed (G_F), Airborne Inhabited Cargo (A_{IC}) and Airborne Uninhabited Fighter (A_{UF}). *All failure rates in the following tables are in terms of failures per million hours.*

Assuming a series reliability model, the equipment failure rate can be expressed as:

$$\lambda_{EQUIP} = \sum_{i=1}^{n} N_i \lambda_{Gi} \pi_{Qi}$$

Where

λ_{EQUIP} = total equipment failure rate (failures/10^6 hrs)

λ_{Gi} = generic failure rate for the ith generic part type (failures/10^6 hrs)

π_{Qi} = quality factor for the ith generic part type

N_i = quantity of the ith generic part type

n = number of different generic part types

Table A10-1: Microcircuit Failure Rates (λ_G, π_Q, π_L)

Microcircuit λ_G

			Environment							
			S_F		G_F		A_{IC}		A_{UF}	
Part Type	Complexity	Technology	N	H	N	H	N	H	N	H
	No. of Gates									
Monolithic Bipolar & MOS Digital	1–100	Bipolar	0.0125	0.0114	0.0222	0.0211	0.0317	0.0280	******	0.1157
		MOS	0.0227	0.0125	0.0323	0.0222	0.0744	0.0317	******	0.1469
	>100–1000	Bipolar	0.0231	0.0208	0.0391	0.0368	0.0580	0.0506	******	0.2122
		MOS	0.0434	0.0231	0.0593	0.0391	0.1434	0.0580	******	0.2745
	>1000–3000	Bipolar	0.0451	0.0405	0.0750	0.0704	0.1129	0.0980	******	0.4132
		MOS	0.0856	0.0451	0.1155	0.0750	0.2836	0.1129	******	0.5378
	>3000–10000	Bipolar	0.1269	0.1177	0.2519	0.2427	0.3277	0.2979	******	1.1933
		MOS	0.2080	0.1269	0.3330	0.2519	0.6691	0.3277	******	1.4425
	>10000–30000	Bipolar	0.2201	0.2017	0.4103	0.3919	0.5618	0.5022	******	2.0496
		MOS	0.3822	0.2201	0.5724	0.4103	1.2445	0.5618	******	2.5481
Programmable Logic Arrays (PLA) & Programmable Array Logic (PAL)	1–100	Bipolar	0.0479	0.0410	0.0576	0.0507	0.1144	0.0920	******	0.4220
		MOS	0.1087	0.0479	0.1184	0.0576	0.3704	0.1144	******	0.6089
	>100–1000	Bipolar	0.0938	0.0800	0.1098	0.0960	0.2234	0.1787	******	0.8247
		MOS	0.2154	0.0938	0.2314	0.1098	0.7355	0.2234	******	1.1985
	>1000–5000	Bipolar	0.1865	0.1589	0.2164	0.1888	0.4437	0.3543	******	1.6381
		MOS	0.4297	0.1865	0.4596	0.2164	1.4678	0.4437	******	2.3858

	No. of Transistors									
Monolithic Bipolar & MOS Linear	1–100	Bipolar	0.0292	0.0147	0.0374	0.0229	0.1115	0.0404	******	0.2567
		MOS	0.0292	0.0147	0.0374	0.0229	0.1115	0.0404	******	0.2567
	>100–300	Bipolar	0.0554	0.0265	0.0666	0.0377	0.2148	0.0726	******	0.4839
		MOS	0.0554	0.0265	0.0666	0.0377	0.2148	0.0726	******	0.4839
	>300–1000	Bipolar	0.1072	0.0493	0.1231	0.0653	0.4195	0.1351	******	0.9315
		MOS	0.1072	0.0493	0.1231	0.0653	0.4195	0.1351	******	0.9315
	No. of Bits									
Monolithic Bipolar & MOS Digital Microprocessor Devices	8	Bipolar	0.0380	0.0346	0.0679	0.0645	0.1431	0.0852	******	0.3519
		MOS	0.0684	0.0380	0.0983	0.0679	0.2711	0.0963	******	0.4454
	16	Bipolar	0.0724	0.0655	0.1257	0.1188	0.2658	0.1602	******	0.6673
		MOS	0.1332	0.0724	0.1865	0.1257	0.5219	0.1825	******	0.8542
	32	Bipolar	0.1552	0.1414	0.2802	0.2664	0.5892	0.3492	******	1.4383
		MOS	0.2768	0.1552	0.4018	0.2802	1.1013	0.3938	******	1.8121
MOS Dynamic RAMS	≤16K	MOS	0.0485	0.0231	0.0581	0.0328	0.1632	0.0565	******	0.2855
	>16K–64K	MOS	0.0923	0.0417	0.1035	0.0529	0.3136	0.1002	******	0.5250
	>64K–256K	MOS	0.1783	0.0770	0.1895	0.0882	0.6096	0.1829	******	0.9870
	>256K–1M	MOS	0.3513	0.1486	0.3640	0.1613	1.2042	0.3507	******	1.9197
MOS Static RAMS	≤4K	MOS	0.0923	0.0417	0.1035	0.0529	0.3227	0.1093	******	0.5250
	>4K–16K	MOS	0.1792	0.0779	0.1920	0.0906	0.6224	0.1957	******	0.9957
	>16K–64K	MOS	0.3522	0.1495	0.3665	0.1638	1.2183	0.3648	******	1.9286
	>64K–256K	MOS	0.6972	0.2918	0.7131	0.3078	2.4064	0.6995	******	3.7857

Table A10-1 (continued)

Microcircuit λ_G

			Environment							
			S_F		G_F		A_{IC}		A_{UF}	
Part Type	Complexity	Technology	N	H	N	H	N	H	N	H
Bipolar Static RAMS	≤4K	Bipolar	0.0417	0.0359	0.0529	0.0471	0.1093	0.0907	******	0.3692
	>4K–16K	Bipolar	0.0788	0.0673	0.0931	0.0816	0.1994	0.1622	******	0.6931
MOS ROM Devices	≤16K	MOS	0.0692	0.0337	0.0851	0.0497	0.2322	0.0828	******	0.4131
	>16K–64K	MOS	0.1313	0.0603	0.1506	0.0796	0.4446	0.1459	******	0.7553
	>64K–256K	MOS	0.2517	0.1098	0.2710	0.1291	0.8591	0.2617	******	1.4020
	>256K–1M	MOS	0.4986	0.2148	0.5285	0.2447	1.7047	0.5098	******	2.7554
MOS PROM (UVEPROM, EEPROM, EAPROM)	≤16K	MOS	0.1122	0.0514	0.1282	0.0674	0.3802	0.1242	******	0.6441
	>16K–64K	MOS	0.2173	0.0957	0.2366	0.1150	0.7407	0.2286	******	1.2173
	>64K–256K	MOS	0.4238	0.1806	0.4430	0.1998	1.4512	0.4271	******	2.3260
	>256K–1M	MOS	0.8426	0.3562	0.8725	0.3861	2.8890	0.8406	******	4.6034
Bipolar ROM/PROM (Fusible Link & AIM)	≤16K	Bipolar	0.0513	0.0445	0.0672	0.0604	0.1237	0.1148	******	0.4572
	>16K–64K	Bipolar	0.0936	0.0800	0.1095	0.0960	0.2225	0.1917	******	0.8247
Monolithic Bipolar or MOS Analog Microprocessor Devices	1–100	Bipolar	0.0724	0.0655	0.1257	0.1188	0.1825	0.1602	******	0.5673
		MOS	0.1332	0.0724	0.1865	0.1257	0.4386	0.1825	******	0.8542

Notes:

1. ******Nonhermetic parts should not be used in these environments.
2. N = Nonhermetically sealed, H = Hermetically sealed

Microcircuit π_Q

Quality Level	S	S-1	B	B-1	B-2	D	D-1
π_Q	0.25	0.75	1	2	5	10	20

Microcircuit π_L

Maturity	π_L*
• New Device Initial Production • Major Changes in Design or Processes • Interruption in Production • New or Unproven Technology	10
All Others	1

*Multiply microcircuit λ_G by π_L

Table A10-2: Semiconductor Failure Rates (λ_G, π_Q)

Semiconductor λ_G

Type	Environment				Type	Environment			
	S_F	G_F	A_{IC}	A_{UF}		S_F	G_F	A_{IC}	A_{UF}
Transistors					Ge Microwave Det	.42	3.6	22.*	**
Si NPN	.0010	.016	.033	.29	Si Microwave Mix	.25	1.7	9.7	48.
Si PNP	.0015	.025	.052	.47	Ge Microwave Mix	.70	6.2	37.*	**
Ge NPN	.027	.53	1.6	12.*	Varactor, Step Recovery, Tunnel	.24	1.0	1.5	30.
Ge PNP	.010	.20	.61	4.4*					
Si FET	.029	.22	.50	5.7	Gunn & Impatt	.60	2.3	27.	42.
Unijunction	.16	.73	2.3	22.	PIN	.31	1.4	1.9	39.
					LED	.0065	.033	.098	1.1
Diodes									
Si Gen Purpose	.00066	.0031	.016	.075	Single Isolator	.055	.28	.83	9.3
Ge Gen Purpose	.0042	.025	.22	.77*	Bipolar Microwave Power Transistor	.79	1.9	2.9	14.
Zener & Avalanche	.0027	.012	.016	.31					
Thyristor	.033	.10	.35	3.4					
Si Microwave Det	.18	1.3	7.0	34.					

*This value is valid only for electrical stress less than or equal to .3 (S = operating stress/rated stress).

**Do not use in these environments since temperature normally encountered combined with normal power dissipation are above the device ratings.

	Semiconductor π_Q				
Part Types	JANTXV	JANTX	JAN	NON-MIL HERMETIC	PLASTIC
Microwave Diodes	0.3	0.6	1.0	1.4	—
Microwave Transistors	0.25	0.5	1.0	2.5	—
All Others	0.1	0.2	1.0	5.0	10.0

Table A10-3: Resistor and Capacitor Failure Rates (λ_G, π_Q)

Resistor λ_G								Capacitor λ_G						
			Environment											
Construction	Style	MIL-R-SPEC	S_F	G_F	A_{IC}	A_{UF}	Construction	Style	MIL-C-SPEC	S_F	G_F	A_{IC}	A_{UF}
Composition	RCR	39008	.0005	.0021	.0039	.036	Paper	CP	25	.011	.021	.040	.44
Composition	RC	11	.0025	.011	.019	.18	Paper	CA	12889	.012	.025	.061	1.2
Film	RLR	39017	.0005	.0033	.0039	.037	Paper/Plastic	CZR	11693	.0048	.012	.018	.20
Film	RL	22684	.0025	.016	.020	.18	Paper/Plastic	CPV	14157	.0021	.0050	.0055	.073
Film	RNR	55182	.0006	.0037	.0045	.043	Paper/Plastic	CQR	19978	.0021	.0050	.0055	.073
Film	RN	10509	.0028	.018	.022	.21	Paper/Plastic	CHR	39022	.0029	.0069	.0075	.10
Film, Power	RD	11804	.012	.030	.045	.34	Paper/Plastic	CH	18312	.020	.049	.053	.70
Film, Network	RZ	83401	.025	.087	.15	2.0							
							Plastic	CFR	55514	.0041	.0079	.015	.19

Table A10-3 (continued)

	Resistor λ_G								Capacitor λ_G					
			Environment											
Construction	Style	MIL-R-SPEC	S_F	G_F	A_{IC}	A_{UF}	Construction	Style	MIL-C-SPEC	S_F	G_F	A_{IC}	A_{UF}
Wirewound	RBR	39005	.013	.021	.087	.49	Plastic	CRH	83421	.0023	.0085	.0096	.080
Accurate	RB	93	.064	.11	.44	2.5							
Wirewound	RWR	39007	.0083	.023	.027	.44	Mica	CMR	39001	.0005	.0018	.0047	.10
Power	RW	26	.042	.12	.14	2.2	Mica	CM	5	.0030	.011	.028	.62
Wirewound	RER	39009	.0080	.022	.027	.27	Mica	CB	10950	.091	.23	.35	4.3
Chasis Mount	RE	18546	.040	.11	.14	1.3							
Variable							Glass	CYR	23269	.0003	.0007	.0031	.057
Wirewound	RTR	39015	.014	.037	.045	.44	Glass	CY	11272	.0010	.0020	.0093	.20
Trimmer	RT	27208	.070	.19	.23	2.2							
W.W., Precision	RR	12934	.820	2.2	7.1	28.	Ceramic	CKR	39014	.0029	.0059	.012	.060
W.W.	RA	19	.30	.85	3.1	*	Ceramic	CK	11015	.35	.089	.036	.18
W.W., Semiprecision	RK	39002	.30	.85	3.1	*	Ceramic	CCR	20	.030	.017	.0048	.15
W.W. Power	RP	22	.31	1.0	2.6	*							
							Ta, SOLID	CSR	39003	.0044	.014	.017	.027
Non-W.W.	RJR	39035	.020	.061	.070	.66	Ta, NON-SOLID	CLR	39006	.0001	.0092	.019	.39
Trimmer	RJ	22097	.099	.30	.35	3.3	Ta, NON-SOLID	CL	3965	.018	.028	.057	1.2
Composition	RV	94	.12	.25	5.3	22.							
Non-W.W., Precision	RQ	39023	.086	.29	.45	7.5	Al. Oxide	CU	39018	.073	.22	1.3	9.2
Film	RVC	23285	.095	.30	.42	5.9	Al. Dry	CE	62	.088	.29	2.1	19.

Variable						
Ceramic	CV	81	.26	1.2	1.6	51.
Piston	PC	14409	.098	.39	.63	14.
Air, Trimmer	CT	92	.40	1.8	3.0	100.
Vacuum	CG	23183	1.2	4.6	11.	390.

*Not normally used in these environments.

Resistor and Capacitor π_Q

Failure Rate Level	L	M	P	R	S	NONMIL
π_Q	1.5	1.0	0.3	0.1	0.03	3.0

Table A10-4: Inductor and Electromechanical Failure Rates Inductive and Electromechanical (λ_G, π_Q)

	λ_G				π_Q	
	Environment				Quality Level	
Part Type	S_F	G_F	A_{IC}	A_{UF}	MIL-SPEC	NON-MIL
Magnetrons					N/A	N/A
Continuous Wave	18.	36.	72.	540.		
Coaxial Pulsed	43.	86.	170.	1300.		
Conventional Pulsed	230.	470.	930.	7000.		

Table A10-4 (continued)

Part Type	λ_G Environment S_F	G_F	A_{IC}	A_{UF}	π_Q Quality Level MIL-SPEC	NON-MIL
Inductive					1	3
Low Power Pulse Xfmr	.0030	.019	.018	.051		
Audio Xfmr	.0060	.037	.035	.10		
High Power	.020	.13	.14	.47		
Pulse & Power Xfmr, Filter						
R.F. Xfmr	.024	.15	.14	.41		
R.F. Coils, Fix	.0017	.0066	.0087	.029		
R.F. Coils, Var	.0034	.013	.017	.057		
Motors	*	2.4	7.1	35.	1	6
Relays						
General Purp	.13	.32	.83	2.6	1	6
Contractor, HC	.43	1.0	2.7	8.5	1	6
Latching	.13	.32	.83	2.6	1	6
Reed	.11	.27	.75	3.0	1	6
Thermal Bi-met	.29	.69	1.8	5.7	1	6
Meter Movement	.89	2.1	5.6	18.	1	6
Solid State	.34	1.3	2.6	17.	1	3
Time Delay-Hybrid & Solid State	.63	3.7	6.7	47.	1	4

Switches						
Toggle & Push Button	.0010	.0029	.0080	.025	1	20
Sensitive	.15	.44	1.2	3.7	1	20
Thumbwheel	.56	1.6	4.5	14.	1	1.5
Other Rotary	.33	.95	2.6	8.2	1	50
Circuit Breakers					1	8.4
Thermal	.11	.26	.63	1.7		
Magnetic	.060	.14	.33	.90		
Connectors					1	3
Circular/Rack/Panel	.0055	.017	.059	.64		
Coaxial	.0060	.017	.058	.60		
PCBs	.0027	.024	.052	.32		
I.C. Sockets	.0019	.0060	.013	.039		
Interconnection Assemblies	.041	.094	.10	1.4	1	10

*Not normally used in these environments.

Table A10-5: Miscellaneous Part Failure Rates (λ_G, π_Q)

	λ_G				π_Q	
	Environment				Quality Level	
Part Type	S_F	G_F	A_{IC}	A_{UF}	MIL-SPEC	NON-MIL
SAWS	3.4	8.2	16.	42.	N/A	N/A
Quartz Crystals	.032	.083	.29	.90	1	2.1
Lamps, Incandescent					N/A	N/A
AC Applications	5.5	6.3	13.	23.		
DC Applications	18.	21.	41.	75.		
Electronic Filters					1	2.9
Ceramic-ferrite Construction	.037	.046	.12	.28		
Discrete LC Comp. Construction	.20	.25	.66	1.6		
Discrete LC & Crystal Comp. Construction	.45	.56	1.5	3.4		
Fuses	.018	.023	.068	.18	N/A	N/A

Topic A11: Reliability Adjustment Factors

An engineer is often faced with the situation where available reliability data is for a different environment, duty cycle, quality class, etc., than that for which it is desired. Many "what if" questions often arise regarding the impact of changing from one part quality, use environment or temperature to another. The tables below provide a means to make estimates of the effects of various changes.

Table A11-1: Part Quality Conversion Factors (Multiply MTBF by)

		From Quality Class			
	Quality Class	**Space**	**Typical Military**	**Vendor Equivalent**	**Commercial**
	Space	X	3	15	60
To Quality Class	Typical Military	.33	X	5	20
	Vendor Equivalent	.07	.20	X	4
	Commercial	.02	.05	.25	X
Part Qualities*	IC	Class S	Class B	Class B-2	Class D-1
	Semiconductors	JAN TXV	JAN TX	JAN	NONMIL
	Resistors/	ER(S)	ER(R)	ER(M)	NONMIL
	Capacitors	ER(S)	ER(R)	ER(M)	NONMIL
	Connectors	MIL	MIL	MIL	NONMIL

*Quality levels as defined in MIL-HDBK-217.

Caution: Do not apply to MTBCF.

Table A11-2: Environment Conversion Factors (Multiply MTBF by)

		From Environment					
	Environment*	**Space Flight (S_F)**	**Ground Benign (G_B)**	**Ground Fixed (G_F)**	**Ground Mobile (G_M)**	**Airborne Inhabited Cargo (A_{IC})**	**Airborne Uninhabited Fighter (A_{UF})**
To Environment	S_F	X	1	3	7	4	14
	G_B	1	X	3	7	4	14
	G_F	.33	.33	X	2	1	4
	G_M	.15	.15	.5	X	.5	2
	A_{IC}	.25	.25	1	2	X	4
	A_{UF}	.07	.07	.25	.5	.25	X

*Environmental factors as defined in MIL-HDBK-217.

Caution: Do not apply to MTBCF.

Temperature Conversion Factors

For each 10°C decrease in part ambient temperature multiply the system series MTBF by 1.25 and for each 10°C increase multiply by 0.8.

Adjustment Examples

Example 1 (Quality Adjustment):

An equipment has been designed using "typical military" part quality levels and has an MTBF of 400 hours. What would the expected reliability be if all "vendor equivalent" quality parts were substituted?

Solution: 400 hours $\times$ .2 = 80 hours.

Example 2 (Environmental Adjustment):

An equipment designed for use in a Ground Mobile environment has an MTBF of 100 hours. What would be the equipment's expected MTBF if operated in a Ground Benign environment?

Solution: 100 hours $\times$ 7 = 700 hours.

Example 3 (Temperature Adjustment):

An equipment has an MTBF of 60 hours with its current cooling supply. A potential reallotment of cooling air would decrease the equipment average part ambient temperature by 12°C. How would the equipment MTBF change?

Solution: 60 hours $\times$ 1.25 $\times$ 12°C/10°C = 90 hours.

Section T
Testing

What are the types of R&M TESTING and how do I structure an effective test program?

R&M Engineer's Role:

Develop a Tailored Test Program

Review Plans/Procedures

Insight

A well tailored reliability and maintainability program contains several forms of testing. Depending on the program constraints, a program should be invoked to mature the designed in reliability as well as to determine whether the contract quantitative reliability and maintainability requirements have been achieved prior to a commitment to production. All forms of testing (Environmental Stress Screening (ESS), Reliability Growth, Reliability Demonstration) must be tailored to fit specific program constraints. Test plans and procedures must be evaluated to ensure proper test implementation. Test participation depends on the program situation but test reports must be carefully evaluated by the government.

For More Information

MIL-STD-471	"Maintainability Verification/Demonstration/Evaluation"
MIL-STD-781	"Reliability Testing for Engineering Development, Qualification and Production"
MIL-HDBK-781	"Reliability Test Methods, Plans, and Environments for Engineering Development, Qualification, and Production"
DOD-HDBK-344	"Environmental Stress Screening of Electronic Equipment"
MIL-HDBK-189	"Reliability Growth Management"
RADC-TR-84-25	"Reliability/Maintainability Operational Parameter Translation" (Volumes I and II)
RADC-TR-86-241	"Built-In-Test Verification Techniques"

Topic T1: ESS Process

Environmental Stress Screening (ESS) has been the subject of many recent studies. RADC's position has been that no one set of generic screens is best for every situation. Determination of the optimum screens for a particular product, built by a particular manufacturer, at a given time is an iterative process. Procedures for planning for and controlling the screening process are contained in DOD-HDBK-344 (USAF) Environmental Stress Screening of Electronic Equipment. The process can be depicted as shown below:

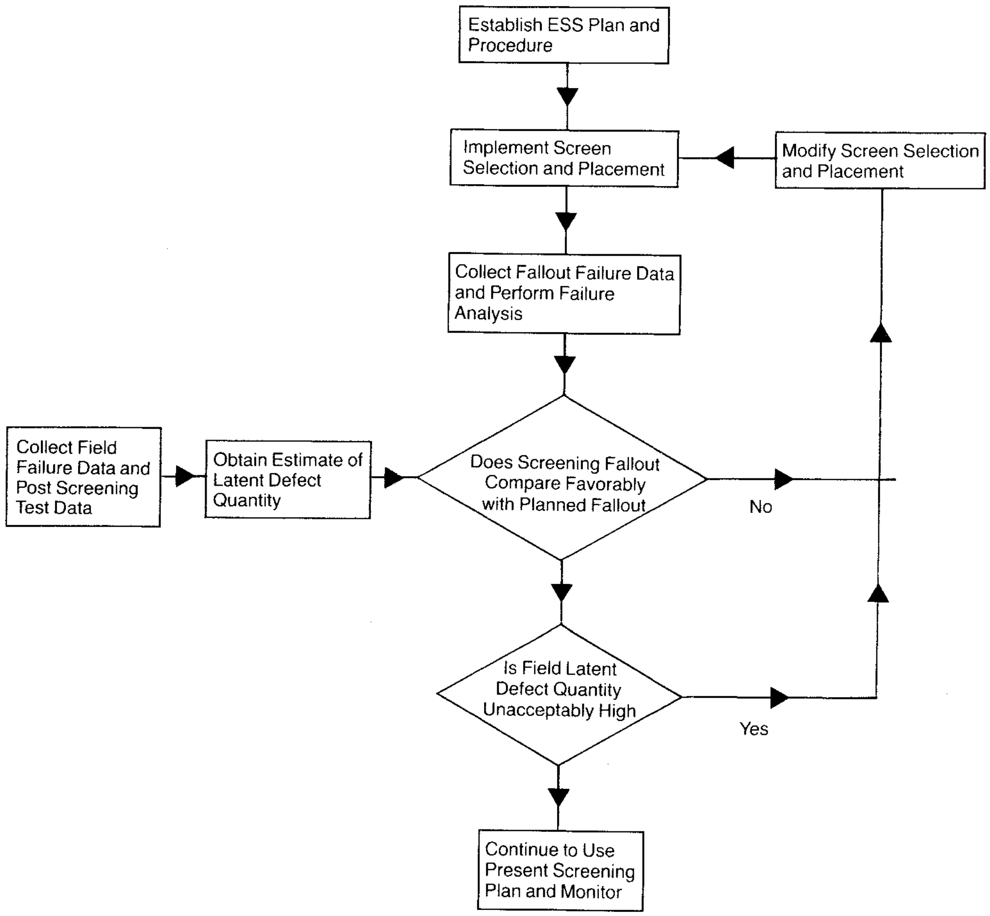


Figure T1-1: ESS Process

Topic T2: ESS Placement

Level of Assembly	Advantages	Disadvantages
Assembly	• Cost per flaw precipitated is lowest (unpowered screens). • Small size permits batch screening. • Low thermal mass allows high rates of temperature change. • Temperature range greater than operating range allowable.	• Test detection efficiency is relatively low. • Test equipment cost for screens is high.
Unit	• Relatively easy to power and monitor performance during screen. • Higher test detection efficiency than assembly level. • Assembly interconnections (e.g., wiring backplane) are screened.	• Thermal mass precludes high rates of change or requires costly facilities. • Cost per flaw significantly higher than assembly level. • Temperature range reduced from assembly level.
System	• All potential sources of flaws are screened. • Unit interoperability flaws detected. • High test detection efficiency.	• Difficult and costly to test at temperature extremes. • Mass precludes use of effective vibration screens or makes use costly. • Cost per flaw is highest.

Topic T3: "R&M 2000" ESS

Screen Type, Parameter and Conditions	Assemblies (Printed Wiring Assemblies) (SRU)*	Equipment or Unit (LRU/LRM)
Thermal Cycling Screen		
Temperature Range (Minimum) (See Note 1)	From −54°C to +85°C	From −54°C to +71°C
Temperature Rate of Change (Minimum) (See Note 2)	30°C/Minute (Chamber Air Temp)	5°C (Chamber Air Temp)
Temperature Dwell Duration (See Note 3)	Until Stabilization	Until Stabilization
Temperature Cycles (Minimum)	25	10
Power On/Equipment Operating	No	(See Note 5)
Equipment Monitoring	No	(See Note 6)
Electrical Testing After Screen	Yes (At Ambient Temperature)	Yes (At Ambient Temperature)
Random Vibration (See Note 7)		
Acceleration Level	(See Note 8)	6 G rms
Frequency Limits		50–1000 Hz
Axes Stimulated Serially or Concurrently		2 (minimum) (See Note 9)
Duration of Vibration (Minimum)		
• Axes stimulated serially		10 Minutes/Axis
• Axes stimulated concurrently		10 Minutes
Power On/Equipment		(See Note 5)
Equipment Monitoring		(See Note 6)

Piece Parts: Begin the manufacturing and repair process with 100 defects per million or less (see note 10).

* SRU—Shop Replaceable Unit LRM—Line Replaceable Module

LRU—Line Replaceable Unit

Notes:

1. Temperatures beyond stated values are acceptable.
2. Rapid transfers of the equipment between one chamber at maximum temperature and another chamber at minimum temperature are acceptable. SRU temperature rates of change may be reduced if equipment damage will occur at 30°C/minute.
3. The temperature has stabilized when the temperature of the part of the test item considered to have the longest thermal lag is changing no more than 2°C per hour.
4. A minimum of 5 thermal cycles must be completed after the random vibration screen. Random vibration frequently induces incipient failures.
5. Shall occur during the low to high temperature excursion of the chamber and during vibration. When operating, equipment shall be at maximum power loading. Power will be OFF on the high to low temperature excursion until stabilized at the low temperature. Power will be turned ON and OFF a minimum of three times at temperature extremes on each cycle.
6. Instantaneous go/no-go performance monitoring during the stress screen is essential to identify intermittent failures when power is on.
7. Specific level may be tailored to individual hardware specimen based on vibration response survey and operational requirements.
8. When random vibration is applied at the equipment level, random vibration is not required at the subassembly level. However, subassemblies purchased as spares are required to undergo the same random vibration required for the equipment level. An "LRU mock-up" or equivalent approach is acceptable.
9. One axis will be perpendicular to plane of the circuit board(s)/LRM(s).
10. The Air Force or its designated contractor MAY AUDIT part defective rates at its discretion. The test procedure will include thermal cycling as outlined below. Sample sizes and test requirements are included in the Stress Screening Military Handbook, DOD-HDBK-344(AF).

Minimum Temperature Range	From −54°C to +100°C
Minimum Temperature Rate of Change	The total transfer time from hot-to-cold or cold-to-hot shall not exceed one minute. The working zone recovery time shall be five minutes maximum after introduction of the load from either extreme in accordance with MIL-STD-883C.
Temperature Dwell	Until Stabilization (See Note 3)
Minimum Temperature Cycles	25
Power On/Equipment Monitoring	No
Electrical Testing After Screen	Yes (At high and low temperatures)

Topic T4: RGT and RQT Application

The Reliability Qualification Test (RQT) is an "accounting task" used to measure the reliability of a fixed design configuration. It has the benefit of holding the contractor accountable some day down the road from his initial design process. As such, he is encouraged to seriously carry out the other design related reliability tasks. The Reliability Growth Test (RGT) is an "engineering task" designed to improve the design reliability. It recognizes that the drawing board design of a complex system cannot be perfect from a reliability point of view and allocates the necessary time to fine tune the design by finding problems and designing them out. Monitoring, tracking and assessing the resulting data gives insight into the efficiency of the process and provides nonreliability persons with a tool for evaluating the development's reliability status and for reallocating resources when necessary. The forms of testing serve very different purposes and complement each other in development of systems and equipments. An RGT is not a substitute for an RQT, or other reliability design tasks.

Table T4-1: RGT and RQT Applicability as a Function of System/Program Constraints

	Reliability Growth Test			Reliability Qualification Test		
System/Program Parameter	**Apply**	**Consider**	**Don't Apply**	**Apply**	**Consider**	**Don't Apply**
Challenge to state-of-the-art	X			X		
Severe use environment	X			X		
One-of-a-kind system		X			X	
High quantities to be produced	X			X		
Benign use environment		X			X	
Critical mission	X			X		
Design flexibility exists	X			X		
No design flexibility			X		X	
Time limitations			X		X	
Funding limitations			X		X	
Very high MTBF system			X			X

Topic T5: Reliability Demonstration Plan Selection

	Program Constraints						
Test Characteristics	Previous Testing Performed	Calendar Time Required	Number of Equipments Available	Test Facility Limitations	Level of Required MTBF	Desired Confidence In Results	Notes
Test Type (Fixed length or sequential).		Time is known with fixed. Time is unknown with sequential.				Fixed gives demonstrated MTBF to desired confidence. Sequential is test of hypothesis.	• Sequential will accept/reject very high MTBFs and very low MTBFs more quickly. • Fixed are better for estimates of true MTBF. • Sequential tests have undetermined test lengths (maximum length must be planned for).
Test Plan Risks (Consumer & Producer) (1 – Consumer risk = confidence).	Lower confidence test acceptable.	High confidence makes test longer.	Multiple equipment requires less calendar time (Allows higher confidence test).	Can limit confidence by limiting number of equipments on test.	High MTBFs force higher risk tests. Some high MTBFs are impractical to demonstrate.	High confidence requires longer test time which can be limited by calendar time, number of equipments & facilities.	• The higher the desired confidence (lower risk) the longer the test. Usual range: 30% = high risk 10% = low risk • Consumer's risk = probability of accepting equipment with true MTBF = θ_1 (unacceptable). • Producer's risk = probability of rejecting equipment with true MTBF = θ_0 (acceptable).

Discrimination Ratio (D.R.) (θ_0/θ_1).	May justify using higher D.R.	Lower D.R. requires more test time.	More equipments will allow lower D.R.	Facilities may limit test to high D.R.	High MTBFs may force high D.R.		• The larger the θ_0/θ_1 ratio the shorter the test. • θ_0 (upper test MTBF)—MTBFs approaching θ_0 will be accepted with high probability. • θ_1 (lower test MTBF)—MTBFs approaching θ_1 will be rejected with high probability.
Notes	• Significant previous testing may allow lower confidence test to be chosen.	• Can be compensated for by more equipments (if facilities available).	• Limitations will require more calendar time.	• Real constraint if environment severe. • Can limit number of test articles (increase calendar time).	• Some high MTBFs are impractical to demo unless multiple equipments can be tested.	• Mission criticality is the driver. • Previous testing such as RGT may lower the confidence required by RQT.	

Note: See Appendix 5 for Summary of MIL-HDBK-781 Test Plans.

Topic T6: Maintainability Demonstration Plan Selection

	Program Constraints				
Test Characteristic	**Calendar Time Required**	**Number of Equipments Available**	**Test Facility Limitations**	**Level of Maintainability Required**	**Desired Confidence in Results**
Fixed sample size or sequential type tests.	Much less than that required for reliability demo. Time required is proportional to sample size number. Sample size may vary depending on program.	No effect on sample size number.		No effect on sample size number.	Fixed sample size test gives demonstrated maintainability to desired confidence. Sequential is test of hypothesis.
Test plan risks (consumer and producer) (1 − consumer risk = confidence) Risks can be tailored to program.	Low producer and consumer risks require larger sample sizes than higher risks.		Must have ability to simulate operational maintenance environment, scenario, skills, levels available.	No effect on sample size number.	Higher confidence levels require more samples than lower confidence levels.

Note: Demonstration facility must have capacity for insertion of simulated faults.

Topic T7: Testability Demonstration Plan Selection

	Program Constraints			
Test Characteristic	**Calendar Time Required**	**Number of Equipments Available**	**Test Facility Limitations**	**Desired Confidence in Results**
Fixed sample size type tests	Calendar time much less than that required for reliability demonstration. Time required is proportional to sample size. May vary depending on program.	No effect on sample size number.	Same as that required for maintainability demonstration.	Provides for producer's risks of 10%. Provides consumer assurance that designs with significant deviations from specified values will be rejected.
Preset Risks (consumer and producer). (1 − consumer risk = confidence).	Risks inversely proportional to sample size used.			

Notes:

1. Sample size dependent on total number of sample maintenance tasks selected as per paragraph A.10.4 of MIL-STD-471A.
2. Demonstration facility must have capability for insertion of simulated faults.

Topic T8: FRACAS (Failure Reporting And Corrective Action System)

Early elimination of failure trends is a major contributor to reliability growth and attaining the needed operational reliability. To be effective, a closed loop coordinated process must be implemented by the system/equipment contractor. A description of the major events and the participant's actions is shown below.

Event	Functions	Actions
Failure or Malfunction	Operators:	• Identify a problem, call for maintenance, annotate the incident.
	Maintenance:	• Corrects the problem, logs the failure.
	Quality:	• Inspects the correction.
Failure Report	Maintenance:	• Generates the failure report with supporting data (time, place, equipment, item, etc.)
	Quality:	• Insures completeness and assigns a travel tag for the failed item for audit control.
Data Logged	R&M:	• Log all the failure reports, validate the failures and forms, classify the failures (inherent, induced, false alarm).
Failure Review	R&M:	• Determine failure trends (i.e., several failures of the same or similar part).
	Design:	• Review operating procedures for error.
Failure Analysis	R&M:	• Decide which parts will be destructively analyzed.
	Physics of Failure:	• Perform failure analysis to determine the cause of failure (i.e., part or external).
	Quality:	• Inspect incoming test data for the part.
Failure Correction	Design:	• Redesign hardware, if necessary.
	Vendor:	• New part or new test procedure.
	Quality:	• Evaluate incoming test procedures, inspect redesigned hardware.
Post Data Review	R&M:	• Close the loop by collecting and evaluating post test data for reoccurrence of the failure.

Figure T8-1: Failure Reporting System Flow Diagram

Table T8-1: FRACAS Evaluation Checklist

Topic	Items to Be Addressed
General	• Closed loop (i.e., reported, analyzed, corrected and verified).
	• Responsibility assigned for each step.
	• Overall control by one group or function.
	• Audit trail capability.
	• Travel tags for all failed items.
	• Fast turn-around for analysis.
Failure Report	• Clear description of each event.
	• Surrounding conditions noted.
	• Operating time indicated.
	• Maintenance repair times calculated.
	• Built-in-test indications stated.
Failure Analysis	• Perform if three or more identical or similar parts fail.
	• Perform if unit reliability is less than half of predicted.
	• Results should indicate: overstress condition, manufacturing defect, adverse environmental condition, maintenance induced or wearout failure mode.
Failure Data	• Collated by week and month by unit.
	• Compared to allocated values.
	• Reliability growth tracked.
	• Problems indicated and tracked.
	• Correction data collected for verification.

Topic T9: Reliability Demonstration Test Plan Checklist*

Topic	Items to Be Addressed
Purpose and Scope	• Statement of overall test objectives. • General description of all tests to be performed.
Reference Documents	• List all applicable reference documents.
Test Facilities	• Description of test item configuration. • Sketches of system layout during testing. • Serial numbers of units to be tested. • General description of test facility. • Test safety features. • Identification of test location. • General description of failure analysis facility. • Security of test area. • Security of test equipment and records. • Test safety provisions.
Test Requirements	• Pre-reliability environmental stress screening (ESS). • Test length. • Number of units to be tested. • Number of allowable failures. • Description of MIL-HDBK-781 test plan showing accept, reject and continue test requirements. • List of government furnished equipment • List and schedule of test reports to be issued.
Test Schedule	• Start date (approximate). • Finish date (approximate). • Test program review schedule. • Number of test hours per day. • Number of test days per week.
Test Conditions	• Description of thermal cycle. • Description of thermal survey. • Description of vibration survey. • Description of unit under test mounting method. • Description of test chamber capabilities. • List of all limited life items and their expected life.

Topic	Items to Be Addressed
	• Description of all preventive maintenance tasks and their frequency. • Description of unit under test calibration requirements. • Description of unit under test duty cycle. • General description of unit under test operating modes and exercising method.
Test Monitoring	• Description of test software and software verification method. • List of all units under test functions to be monitored and monitoring method. • List of all test equipment parameters to be monitored and monitoring method. • Method and frequency of recording all monitored parameters.
Test Participation	• Description of all contractor functions. • Description of all contractor responsibilities. • Description of all government responsibilities. • Description of test management structure.
Failure Definitions	The following types of failures should be defined as *relevant* in the test plan: • Design defects. • Manufacturing defects. • Physical or functional degradation below specification limits. • Intermittent or transient failures. • Failures of limited life parts which occur before the specified life of the part. • Failures which cannot be attributed to a specific cause. • Failure of built-in-test (BIT). The following types of failures should be defined as *nonrelevant* in the test plan: • Failures resulting from improper installation or handling. • Failure of instrumentation or monitoring equipment which is external to equipment under test. • Failures resulting from overstress beyond specification limits due to a test facility fault. • Failures resulting from procedural error by technicians. • Failures induced by repair actions. • A secondary failure which is the *direct result* of a failure of another part within the system.

Topic	Items to Be Addressed
Test Ground Rules	The following test ground rules should be stated in the test plan: • *Transient Failures*—Each transient or intermittent failure is to be counted as relevant. If several intermittent or transient failures can be directly attributed to a single hardware or software malfunction which is corrected and verified during the test, then only a single failure will be counted as relevant. • *Classification of Failures*—All failures occurring during reliability testing, after contractor failure analysis, shall be classified as either relevant or nonrelevant. Based on the failure analysis, the contractor shall justify the failure as relevant or nonrelevant to the satisfaction of the procuring activity. • *Pattern Failure*—A pattern failure is defined as three or more relevant failures of the same part in identical or equivalent applications whose 95th percentile lower confidence limit failure rate exceeds that predicted. • *Malfunctions Observed During Test Set Up, Troubleshooting or Repair Verification*—Malfunctions occurring during test set up, troubleshooting or repair verification tests shall not be considered as reliability test failures; however, such malfunctions shall be recorded and analyzed by the contractor to determine the cause of malfunctions and to identify possible design or part deficiencies. • *Test Time Accumulation*—Only the time accumulated during the equipment power "on" portion of the test cycle shall be considered as test time, provided that all functions are operating as required. Operating time accumulated outside the operational cycles such as during tests performed to check out the setup or to verify repairs shall not be counted. Also, time accumulated during degraded modes of operation shall not be counted. • *Design Changes to the Equipment:* 1. *After test reject decision*—With procuring activity approval, the equipment may be redesigned and retested from time zero. 2. *Major design change prior to test reject*—The contractor may stop the test for purposes of correcting a major problem. The test will restart from time zero after the design change has been made. 3. *Minor design change prior to test reject*—With procuring activity approval, the test may be halted for the purpose of making a minor design change. Test time will resume from the point at which it was stopped and the design change shall have no effect on the classification of previous failures. Minor changes made as a result of other testing may be incorporated, with procuring activity approval, without declaring a failure of the equipment under test. • *Failure Categorization*—In order to clearly evaluate test results and identify problem areas, failure causes will be categorized as: (1) deficient system design, (2) deficient system quality control, and (3) deficient part design or quality.

Topic	Items to Be Addressed
Test Logs	The following types of test logs should be described in the test plan: • *Equipment Data Sheets* which will be used to record the exact values of all parameters measured during functional testing of the equipment. • *Test Log* which is a comprehensive narrative record of the required test events. All names and serial numbers of the equipments to be tested shall be listed before start of the test. An entry shall be made in the test log each time a check is made on the equipment under test, including data, time, elapsed time, and result (e.g., pass/ malfunction indication/failure or etc.). An entry shall be made in the log whenever a check is made of the test facilities or equipments (such as accelerometers, thermocouples, input power, self-test, etc.). In the event of a failure or malfunction indication, all pertinent data, such as test conditions, facility conditions, test parameters and failure indicators, will be recorded. The actions taken to isolate and correct the failure shall also be recorded. Whenever engineering changes, or equipment changes are implemented, an entry shall be made in the log. • *Failure Summary Record*—the failure summary record must chronologically list all failures that occur during the test. This record must contain all the information needed to reach an accept or reject decision for the test. Each failure must be described and all failure analysis data must be provided. • *Failure Report*—for each failure that occurs, a failure report must be initiated. The report should contain the unit that failed, serial number, time, data, symptoms of failure and part or parts that failed.

*Most of these contents also apply to reliability growth testing.

Topic T10: Reliability Test Procedure Checklist

Topic	Items to Be Addressed
Equipment Operation	A general description of the equipment under test and its operation must be provided.
On/Off Cycle	Specific on/off times for each subsystem must be described.
Operation Modes	Specific times of operation for each system/subsystem mode must be described.
Exercising Methods	Methods of exercising all system/subsystem operation modes must be described. (Note: The system should be exercised continuously, not just power on.)
Performance Verification Procedure	*Step by step* test procedures must be provided which fully describe how and when each performance parameter will be measured. Acceptable and unacceptable limits of each measured parameter should also be specified. All failure and out-of-tolerance indicators must be described and their location defined. Programmable alarm thresholds must be specified.
Failure Event Procedure	Step by step procedures must describe specific actions to be taken in the event of a trouble indication.
Adjustments and Preventive Maintenance	*Step by step* procedures must be provided which fully describe how and when all adjustments and preventive maintenance actions will be performed.

Topic T11: Maintainability Demonstration Plan and Procedure Checklist

Topic	Items to Be Addressed
Purpose and Scope	• Statement of general test objectives. • General description of test to be performed.
Reference Documents	• List of all applicable reference documents.
Test Facilities	• Description of test item configuration. • Sketches of system layout during testing. • Serial numbers of units to be tested. • General description of test facility. • Test safety features. • Identification of test location. • Description of all software to be used, both internal and external to the equipment under test. • Security of test area. • Security of test equipment and records. • Description of all test equipment to be used.
Test Requirements	• Description of MIL-STD-471 test plan requirements. • Method of generating candidate fault list. • Method of selecting and injecting faults from candidate list. • List of government furnished equipment. • List and schedule of test reports to be issued. • Levels of maintenance to be demonstrated. • Spares and other support material requirements.
Test Schedule	• Start date (approximate). • Finish date (approximate). • Test program review schedule.
Test Conditions	• Description of environmental conditions under which test will be performed. • Modes of equipment operation during testing.
Test Monitoring	• Method of monitoring and recording test results.
Test Participation	• Test team members and assignments. • Test decision making authority.

Topic	Items to Be Addressed
Test Ground Rules with Respect to	• Instrumentation failures. • Maintenance due to secondary failures. • Technical manual usage and adequacy. • Maintenance inspection. • GFE usage. • Maintenance time limits. • Skill level of maintenance technicians.
Testability Demonstration Considerations	• Repair levels for which requirements will be demonstrated. • Built-in-test requirements to be demonstrated. • External tester requirements to be demonstrated. • Evaluation method for making pass/fail decision. • Performance of FMEA prior to test start. • Method of selecting and simulating candidate faults. • Acceptable levels of ambiguity at each repair level.

Topic T12: Reliability and Maintainability Test Participation (Government)

Degree of Participation

Depends on:

- Availability of program resources to support on-site personnel.
- How important R&M are to program success.
- Availability and capability of other government on-site personnel (i.e., Defense Contract Administrative Service (DCAS), Air Force Plant Representative Office (AFPRO), Naval Plant Representative Office (NAVPRO), etc.).
- Confidence in and credibility of contractor.

Test Preliminaries

- All test plans and procedures must be approved.
- Agreements must be made among government personnel with respect to covering the test and incident reporting procedures.
- Units under test including serial numbers should be documented.
- Test equipment including serial numbers should be documented.
- Working fire alarms, heat sensors and overvoltage alarms should be used.
- Trial survey runs should be made per the approved test plan.

Test Conduct

- Approved test plans and procedures must be available and strictly adhered to.
- Equipment must not be tampered with.
- Test logs must be accurately and comprehensively maintained as in plan/procedures.
- Appropriate government personnel must be kept informed (per established agreements).
- Only authorized personnel should be allowed in area (a list should be posted).
- Test logs, data sheets, and failure reports should be readily available for government review.
- Units under test should be sealed to prevent tampering or unauthorized repair.
- A schedule of inspections and visits should be maintained.
- No repairs or replacements should be made without a government witness.
- Government representatives must take part in failure review process.
- Failed items should have "travel tags" on them.
- Technical orders should be used for repair if available.

Topic T13: Reliability and Maintainability Demonstration Reports Checklist

- **Identification and description of equipment/system tested**
- **Demonstration objectives and requirements**
  - Test Plans
  - Test Risks
  - Test Times
  - Test Conditions
  - Test Facilities
- **Data Analysis Techniques**
  - Statistical Equations
  - Accept/Reject Criteria
- **Test Results (Summarized)**

  Reliability
  - Test Hours
  - Number of Failures/Number of Incidents
  - Classification of Failures
  - Data Analysis Calculations
  - Application of Accept/Reject Criteria
  - Failure Trends/Design and Process Deficiencies
  - Status of Problem Corrections

  Maintainability
  - Maintenance Tasks Planned
  - Maintenance Tasks Selected
  - Selection Method
  - Personnel Qualifications Performing Tasks
  - Documentation Used During Maintenance
  - Measured Repair Times
  - Data Analysis Calculation
  - Application of Accept/Reject Criteria
  - Discussion of Deficiencies Identified

Testability

- Summary data for each item involved in testability demonstration including original plans, summarized results and any corrective action taken.
- Recommended action to be taken to remedy testability deficiencies or improve the level of testability achievable through prime equipment engineering changes, ATE improvements and/or test program set improvements.

- **Deviations from Test Plan/Procedures and Risk Assessment**
- **Data**
  - Test Logs
  - Failure Reports
  - Failure Analysis Results

Appendix 1

Operational Parameter Translation

Because field operation introduces factors which are uncontrollable by contractors (e.g., maintenance policy), "contract" reliability is not the same as "operational" reliability. For that reason, it is often necessary to convert, or translate, from "contract" to "operational" terms and vice versa. This appendix is based on RADC-TR-84-25, "Reliability/Maintainability Operational Parameter Translation." Table 1.1 defines the R&M parameters applicable to the translation models summarized in Tables 1.2 through 1.4 for three of the more common environments encountered: ground fixed (G_F), airborne inhabited transport (A_{IT}) and airborne uninhabited fighter (A_{UF}) (as defined in MIL-HDBK-217). RADC has a study underway to develop more refined models considering a wider range of operational and design influencing variables in addition to addressing a wider range of environments. Results are expected around September 1988.

Table 1.1: Operational Parameter Translation Definitions

$$\text{MTBM-TOTAL} = \frac{\text{Total Operating Hours}}{\text{Total Maintenance Events}}$$

$$\text{MTBM-INHERENT} = \frac{\text{Total Operating Hours}}{\text{Inherent Maintenance Events}}$$

$$\text{MTBM-NO DEFECT} = \frac{\text{Total Operating Hours}}{\text{Total Base Level No Defect Maintenance Events}}$$

$$\text{MMH/PH-INHERENT} = \frac{\text{Base Level Inherent Maintenance Manhours}}{\text{Possessed Hours}}$$

$$\text{MMH/PH-TOTAL} = \frac{\text{Total Base Level Maintenance Manhours}}{\text{Possessed Hours}}$$

$$\text{M-MMH TO REPAIR} = \frac{\text{Total Base Level Corrective Maintenance Manhours}}{\text{Total on Equipment Maintenance Events}}$$

$$\text{MMH/FH TOTAL} = \frac{\text{Total Base Level Maintenance Manhours}}{\text{Flight Hours}}$$

Notes:

1. MTBM: Mean-Time-Between-Maintenance
   MMH/PH: Maintenance Manhours per Possessed Hour
   M-MMH: Mean Maintenance Manhours
   MMH/FH: Maintenance Manhours per Flight Hour
2. Inherent maintenance events are those events caused by design or manufacturing defects.
3. MTBM-Total consists of inherent, induced and no defect found actions.

Examples of Operational Parameter Translation:

Example 1. Contract to operational reliability. A program manager is requested to provide an estimate of the total maintenance frequency load on a certain equipment to be installed in a fighter aircraft to assist in projecting base level maintenance requirements. The equipment bay is not environmentally controlled resulting in a classification of the environment as airborne uninhabited fighter (A_{UF}). A reliability prediction of the series MTBF has been developed with a value of 1000 hours. What MTBM-TOTAL can be expected in the field?

Solution: From Table 1.4 the equation needed is: MTBM-TOTAL $= .59\ (\text{MTBF})^{.70}$. Since a 1000 hour MTBF is within the upper and lower model limits of 65 hours and 1800 hours, respectively, the translation can be performed and results in an MTBM-TOTAL of 74 hours.

Example 2. Operational to contract reliability—Ground Fixed (possessed hours are greater than operating hours). A ground fixed equipment is to be replaced. The new equipment must meet or exceed a field MTBM-INH of 1000 hours, which is based on a system life of possessed hours, to ensure improvement of the current system's field performance. The current system, as well as the new system, will be on-line approximately 50 percent of its possessed time (i.e., operating hours less than possessed hours). The program manager is given the task of identifying a series MTBF requirement that will ensure meeting the MTBM-INH goal.

Solution: Since the system is only on-line performing its intended function 50 percent of the time, the adjustment steps listed in Row 1 of Table 1.2A are used since the translation is from MTBM to MTBF. Since the system is operated one hour for every two possessed hours, the ratio of possessed hours to operating hours is 2:1. The mean-possessed-time-between-maintenance (1000 hours) is then divided by this ratio to yield an MTBM-INH of 500 hours. From Table 1.2 the appropriate equation is MTBF $= .028\ (\text{MTBM-INH})^{1.52}$. Since an MTBM-INH of 500 hours is within the model limits of 275 hours and 2600 hours, the translation can be performed to yield a specification MTBF requirement of 355 hours.

Table 1.2: Summary of *Ground Fixed* Operational Parameter Translations

Required Translation	Equation	Model Limits		
		Independent Variable Lower Limit (Hrs)	Independent Variable	Independent Variable Upper Limit (Hrs)
MTBF to MTBM	$MTBF = .066\ (MTBM\text{-}TOTAL)^{1.43}$	225	MTBM-TOTAL	2400
	$MTBF = .028\ (MTBM\text{-}INHERENT)^{1.52}$	275	MTBM-INHERENT	2600
	$MTBF = .014\ (MTBM\text{-}NO\ DEFECT)^{1.25}$	1400	MTBM-NO DEFECT	25,000
MTBM to MTBF	$MTBM\text{-}TOTAL = 6.67\ (MTBF)^{.7}$	125	MTBF	4400
	$MTBM\text{-}INHERENT = 10.70\ (MTBF)^{.66}$	125	MTBF	4400
	$MTBM\text{-}NO\ DEFECT = 31.17\ (MTBF)^{.80}$	125	MTBF	4000
MTBF to MMH/PH	$MTBF = 8.82\ (MMH/PH\text{-}TOTAL)^{-1.02}$	0.25	MMH/PH	.07
	$MTBF = 10.47\ (MMH/PH\text{-}INHERENT)^{-.90}$	.0012	MMH/PH-INHERENT	.06
MMH/PH to MTBF	$MMH/PH\text{-}TOTAL = 8.44\ (MTBF)^{-.98}$	140	MTBF	4300
	$MMH/PH\text{-}INHERENT = 13.55\ (MTBF)^{-1.11}$	140	MTBF	4300
MTBF to M-MMH	$MTBF = (1.75 \times 10^{6})\ (M\text{-}MMH\ TO\ REPAIR)^{-3.57}$	5	M-MMH TO REPAIR	20
M-MMH to MTBF	$M\text{-}MMH\ TO\ REPAIR = 55.96\ (MTBF)^{-.28}$	140	MTBF	4400

Notes:

1. If possessed time does not equal operating time, then see Table 1.2A for necessary adjustment steps.
2. Inherent maintenance events are those events caused by design or manufacturing defects.
3. Base level maintenance includes both on-equipment (organizational) and shop level maintenance.
4. Possessed hours are the number of hours the system is actually on-line performing its intended function.
5. **Caution:** MTBF refers to series (logistics) MTBF. Do not apply to MTBCF.

Table 1.2A: Possessed to Operating Time Adjustment Steps for Ground Fixed Environment

If Possessed Time Does Not Equal Operating Time and You Are Translating From:	Adjustment Steps Are:
1. Mean "Possessed" Time Between Maintenance to MTBF.	a. Determine ratio of possessed hours to operating hours. b. Divide mean possessed time between maintenance by this ratio to obtain mean operating time between maintenance. c. Perform translation.
2. Mean "Operating" Time Between Maintenance to MTBF.	No adjustment necessary.
3. Maintenance Manhours per "Possessed Hours" to MTBF.	a. Determine ratio of possessed hours to operating hours. b. Multiply maintenance manhours per possessed hours by the ratio to obtain maintenance manhours per operating hours. c. Perform translation.
4. Maintenance Manhours per "Operating Hours" to MTBF.	No adjustment necessary.
5. MTBF to Mean "Possessed" Time Between Maintenance.	a. Perform translation. b. Determine ratio of possessed hours to operating hours. c. Multiply translation result by ratio to obtain mean possessed time between maintenance.
6. MTBF to Mean Operating Time Between Maintenance.	No adjustment necessary.
7. MTBF to Maintenance Manhours per Possessed Hour.	a. Perform translation. b. Determine ratio of possessed hours to operating hours. c. Divide translation result by ratio to obtain maintenance manhours per possessed hours.
8. MTBF to Maintenance Manhours per Operating Hour.	No adjustment necessary.

Table 1.3: Summary of *Airborne Inhabited Transport* Operational Parameter Translations

		Model Limits		
Required Translation	Equation	Independent Variable Lower Limit (Hrs)	Independent Variable	Independent Variable Upper Limit (Hrs)
MTBF to MTBM	$MTBF = .57\ (MTBM\text{-}TOTAL)^{1.43}$	125	MTBM-TOTAL	2000
	$MTBF = .18\ (MTBM\text{-}INHERENT)^{1.52}$	180	MTBM-INHERENT	2700
	$MTBF = .38\ (MTBM\text{-}NO\ DEFECT)^{1.25}$	300	MTBM-NO DEFECT	9000
MTBM to MTBF	$MTBM\text{-}TOTAL = 1.48\ (MTBF)^{.70}$	500	MTBF	30,000
	$MTBM\text{-}INHERENT = 3.09\ (MTBF)^{.66}$	475	MTBF	30,000
	$MTBM\text{-}NO\ DEFECT = 2.18\ (MTBF)^{.80}$	500	MTBF	30,000
MTBF to MMH/FH	$MTBF = 45.37\ (MMH/FH\text{-}TOTAL)^{-1.02}$	.0018	MMH/FH-TOTAL	.090
	$MTBF = 51.24\ (MMH/FH\text{-}INHERENT)^{-.90}$	.001	MMH/FH-INHERENT	.065
MMH/FH to MTBF	$MMH/FH\text{-}TOTAL = 42.04\ (MTBF)^{-.98}$	500	MTBF	30,000
	$MMH/FH\text{-}INHERENT = 79.01\ (MTBF)^{-1.11}$	600	MTBF	30,000
MTBF to M-MMH	$MTBF = (2.49 \times 10^{6})\ (M\text{-}MMH\ TO\ REPAIR)^{-3.57}$	3.5	M-MMH TO REPAIR	12
M-MMH to MTBF	$M\text{-}MMH\ TO\ REPAIR = 61.80\ (MTBF)^{-.28}$	450	MTBF	30,000

Notes:

1. Inherent maintenance events are those events caused by design or manufacturing defects.
2. Base level maintenance includes both on-equipment (organizational) and shop level maintenance.
3. **Caution:** MTBF refers to series (logistics) MTBF. Do not apply to MTBCF.
4. Current version of MIL-HDBK-217 designates this environment as Airborne Inhabited Cargo (A_{IC})

Table 1.4: Summary of *Airborne Uninhabited Fighter* Operational Parameter Translations

Required Translation	Equation	Model Limits: Independent Variable Lower Limit (Hrs)	Model Limits: Independent Variable	Model Limits: Independent Variable Upper Limit (Hrs)
MTBF to MTBM	$\text{MTBF} = 2.12\,(\text{MTBM-TOTAL})^{1.43}$	12	MTBM-TOTAL	120
	$\text{MTBF} = .27\,(\text{MTBM-INHERENT})^{1.52}$	14	MTBM-INHERENT	200
	$\text{MTBF} = 2.57\,(\text{MTBM-NO DEFECT})^{1.25}$	40	MTBM-NO DEFECT	350
MTBM to MTBF	$\text{MTBM-TOTAL} = .59\,(\text{MTBF})^{.70}$	65	MTBF	1800
	$\text{MTBM-INHERENT} = 2.39\,(\text{MTBF})^{.66}$	65	MTBF	1800
	$\text{MTBM-NO DEFECT} = .47\,(\text{MTBF})^{.80}$	65	MTBF	1800
MTBF to MMH/FH	$\text{MTBF} = 125.29\,(\text{MMH/FH TOTAL})^{-1.02}$	.08	MMH/FH-TOTAL	1.75
	$\text{MTBF} = 76.15\,(\text{MMH/FH-INHERENT})^{-.90}$	.04	MMH/FH-INHERENT	1.1
MMH/FH to MTBF	$\text{MMH/FH-TOTAL} = 113.75\,(\text{MTBF})^{-.98}$	70	MTBF	1750
	$\text{MMH/FH-INHERENT} = 122.65\,(\text{MTBF})^{-1.11}$	70	MTBF	1750
MTBF-M-MMH	$\text{MTBF} = (3.15 \times 10^{6})\,(\text{M-MMH TO REPAIR})^{-3.57}$	8	M-MMH TO REPAIR	20
M-MMH to MTBF	$\text{M-MMH TO REPAIR} = 65.99\,(\text{MTBF})^{-.28}$	75	MTBF	1750

Notes:

1. Inherent maintenance events are those events caused by design or manufacturing defects.
2. Base level maintenance includes both on-equipment (organizational) and shop level maintenance.
3. **Caution:** MTBF refers to series (logistics) MTBF. Do not apply to MTBCF.

Appendix 2

Example R&M Requirement Paragraphs

Example Reliability Requirements for the System Specification

R.1 Reliability Requirements

Guidance: The use of the latest versions and notices of all military specifications, standards and handbooks should be specified.

Guidance: *When specifying an MTBF, it should be the "upper test MTBF (θ_0)" as* defined in MIL-STD-781. When specifying MTBCF, the maintenance concept needs to be clearly defined for purposes of calculating reliability of redundant configurations with periodic maintenance. If immediate maintenance will be performed upon failure of a redundant element then specifying the system MTTR is sufficient. If maintenance is deferred when a redundant element fails, then the length of this deferral period should be specified.

R.1.1 Mission Reliability. The *(system name)* shall achieve a mean-time-between-critical-failure (MTBCF) of ____ hours under the worst case environmental conditions specified herein. MTBCF is defined as the total uptime divided by the number of critical failures that degrade full mission capability (FMC). FMC is that level of performance which allows the system to perform its primary mission without degradation below minimum levels stated herein. For purposes of analyzing redundant configurations, calculation of MTBCF shall reflect the expected field maintenance concept.

R.1.2 Basic Reliability. The *(system name)* shall achieve a series configuration mean-time-between-failure (MTBF) of ____ hours under the worst case environmental conditions specified herein. The series configuration MTBF is defined as the total system uptime divided by the total number of part failures.

R.1.3 Reliability Configuration. The reliability requirements apply for the delivered configuration of the system. Should differences exist between this configuration and a potential production configuration, all analyses shall address the reliability effects of the differences.

Guidance: If Equipment or system performance criteria are not stated elsewhere in statement of work or specification, the following paragraph must be included.

R.1.4 Reliability Performance Criteria. The minimum performance criteria that shall be met for full mission capability of the *(system name)* system is defined as (specify full mission capability).

R.1.5 Reliability Design Requirements. Design criteria and guidelines shall be developed by the contractor for use by system designers as a means of achieving the required levels of reliability.

Guidance: For more critical applications, level 2 or 1 derating should be specified. See Topic D1 for derating level determination. Baseline thermal requirements such as ambient and extreme temperatures, pressure extremes, mission profile and duration, temperature/pressure rates of change and maximum allowable temperature rise should be specified.

R.1.5.1 Thermal Management and Derating. Thermal management (design, analysis and verification) shall be performed by the contractor such that the reliability quantitative requirements are assured. RADC-TR-82-172, "RADC Thermal Guide for Reliability Engineers," shall be used as a guide. Derating criteria shall be established for each design such that all parts used in the system are derated to achieve reliability requirements. As a minimum, Level 3 of AFSC Pamphlet 800-27 "Part Derating Guidelines" shall be used for this design.

Guidance: If the system is for airborne use, MIL-STD-5400 must be referenced in place of MIL-E-4158 (ground equipment).

R.1.5.2 Parts Selection. All parts employed in the manufacture of the system shall be selected from the government generated and maintained Program Parts Selection List (PPSL), Electrical/Electronic Parts and the PPSL for Mechanical Parts. Parts not covered by the above referenced PPSLs shall be selected in accordance with MIL-E-4158 and MIL-STD-454 and require approval by the procuring activity.

a. *Microcircuits.* Military standard microcircuits must be selected in accordance with Requirement 64 of MIL-STD-454. All non-JAN devices shall be tested in accordance with the Class B screening requirements of MIL-STD-883, Method 5004 and 5008, as applicable. All device types shall be tested to the quality conformance requirements of MIL-STD-883, Method 5005 and 5008 Class B.

b. *Semiconductors.* Military standard semiconductors must be selected in accordance with Requirement 30 of MIL-STD-454. All non-JANTX devices shall be screened in accordance with Table II of MIL-S-19500. All device types shall be tested to the Group A, Table III and Group B, Table IV quality conformance requirements of MIL-S-19500, as a minimum. The following device restrictions apply:

   (1) Only solid glass metallurgically bonded axial lead diodes and rectifiers shall be used.

   (2) TO-5 packages shall be limited to the solid metal header type.

   (3) All semiconductor device junctions must be protected and no organic or desiccant materials shall be included in the package.

   (4) Devices using aluminum wire shall not use thermocompression wedge bonding.

   (5) Aluminum TO-3 packages shall not be used.

   (6) Germanium devices shall not be used.

c. *Electrostatic Sensitive Parts.* Certain types of integrated circuits are susceptible to electrostatic discharge damage. Appropriate discharge procedures are necessary when handling, storing or testing these parts and design selections of desired devices should include a consideration of the effectiveness of the input or other protective elements included in the device design.

R.1.6 Reliability Test and Evaluation. The quantitative reliability levels required by paragraph (R.1) shall be verified by the following:

R.1.6.1 The final approved reliability analyses for the various configurations and worst case environments shall demonstrate compliance with the quantitative requirements cited in paragraph (R.1).

R.1.6.2 The contractor shall demonstrate that the reliability *(mission and/or basic)* requirements have been achieved by conducting a controlled reliability test in accordance with MIL-HDBK-781 Test Plan (specify MIL-HDBK-781 Test Plan. See Topic T5 for Plan Selection.) The lower test (MTBCF and/or MTBF) to be demonstrated shall be ____ hours tested in a ____ environment. Relevant failures are defined as any malfunction which causes loss or degradation below the performance level specified for the *(equipment/system)* and can be attributed to design defect, manufacturing defect, workmanship defect, adjustment, deterioration or unknown causes. Nonrelevant failures are failures caused by installation damage, external test equipment failures, mishandling, procedural errors, dependent failures and external prime power failures.

Guidance: A growth test may apply if the next phase is production. If one is required, it's appropriate to require a higher risk (e.g., 30 percent) demonstration test. See RADC-TR-84-20 "Reliability Growth Testing Effectiveness," Topic T4 and Appendix 6 for further guidance.

R.1.6.3 The contractor shall conduct a controlled fixed length dedicated reliability growth test of ____ hours using MIL-HDBK-189 as a guide. The test shall be at the same environmental conditions as the RQT. Although there is no pass/fail criteria, the contractor shall track the reliability growth process to ensure improvement is taking place by effective implementation of corrective action.

Guidance: See Electronic Systems Division TR-85-148, "Derated Application of Parts for ESD Systems Development" (Attachment 2) for a recommended derating verification procedure.

R.1.6.4 The contractor shall verify the thermal and electrical stresses on ____ percent (3 to 5 percent sample is typical) of the semiconductor and microcircuit parts by measurement while the equipment is operated at the worst case environment, duty cycle and load. The results of the measurements shall be compared to the derating requirements and the verification shall be considered successful if measured values are less than specified derated levels.

Example Reliability Requirements for the Statement of Work

R.2 Reliability Program Tasks

R.2.1 Reliability Program. The contractor shall conduct a reliability program in accordance with MIL-STD-785 including the following tasks as a minimum to assure reliability consistent with state-of-the-art.

R.2.2 Subcontractor Control. The contractor shall establish management procedures and design controls including allocation of requirements in accordance with Task 102 of MIL-STD-785 which will insure that products obtained from subcontractors will meet reliability requirements.

R.2.3 Reliability Design Reviews. The status of the reliability design shall be addressed at all internal and external design reviews. Task 103 of MIL-STD-785 shall be used as a guide.

R.2.4 Failure Reporting, Analysis and Corrective Action System (FRACAS). The contractor shall establish, conduct and document a closed loop failure reporting, analysis and corrective action system for all failures occurring during system debugging, checkout, engineering tests and contractor maintenance. Failure reports shall be retained by the contractor and failure summaries provided to the procuring activity thirty days after start of system engineering test and evaluation, and updated monthly thereafter. Failure reporting shall be to the piece part level.

R.2.5 Reliability Modeling. The contractor shall develop reliability models for all system configurations in accordance with Task 201 of MIL-STD-785 and Task 101 and 201 of MIL-STD-756. The specific mission parameters and operational constraints that must be considered are: _____ (or reference applicable SOW and specification paragraphs).

R.2.6 Reliability Allocations. Reliability requirements shall be allocated to the LRU level in accordance with Task 202 of MIL-STD-785.

R.2.7 Reliability Prediction. The contractor shall perform reliability predictions in accordance with *(Task 201 (basic reliability))* and/or *(Task 202 (mission reliability))* of MIL-STD-756. The specific technique to be used shall be method 2005 parts stress analysis of MIL-STD-756. Electronic part failure rates shall be used from MIL-HDBK-217 and nonelectronic part failure rates from RADC-TR-85-194. All other sources of part failure rate data shall require review and approval of the procuring activity prior to use. A _____ environmental factor, worst case operating conditions and duty cycles shall be used as a baseline for developing part failure rates. The results of the thermal analysis shall be included and shall provide the temperature basis for the predicted reliability. The part quality grade adjustment factor used shall be representative of the quality of the parts selected and applied for this system procurement.

R.2.8 Parts Program. The contractor shall establish and maintain a parts control program in accordance with Task 207 of MIL-STD-785 and Procedure 1 of MIL-STD-965. Requests for use of parts not on the government generated and maintained PPSL shall be submitted in accordance with the CDRL. Amendments to the PPSL as a result of such requests, after procuring activity approval, shall be supplied to the contractor by the Program Contracting Officer not more often than once every 30 days.

Guidance: The level of detail of the FMECA must be specified (e.g., part, circuit card, etc.). The closer the program is to full scale engineering development, the greater the level of detail needed.

R.2.9 Failure Modes, Effects and Criticality Analysis (FMECA). The contractor shall perform a limited FMECA to the ____ level to identify design weaknesses and deficiencies. Potential failure modes shall be identified and evaluated to determine their effects on mission success. Critical failures shall be investigated to determine possible design improvements and elimination means. MIL-STD-785, Task 204 shall be used as a guide.

Guidance: Reliability critical items should be required where it's anticipated that the design will make use of custom VLSI, hybrids, microwave hybrids and other high technology nonstandard devices. See Topic D5 for a critical item checklist.

R.2.10 Reliability Critical Items. Task number 208 of MIL-STD-785 applies. The contractor shall prepare a list of critical items and present this list at all formal reviews. Critical items shall include: items having limited operating life or shelf life, items difficult to procure or manufacture, items with unsatisfactory operating history, items of new technology with little reliability data, single source items, parts exceeding derating limits, and items causing single points of failure.

R.2.11 Effects of Storage, Handling, Transportation. The contractor shall analyze the effects of storage, handling and transportation on the system reliability.

R.2.12 Reliability Qualification Test. The contractor shall demonstrate compliance with the quantitative reliability requirements in accordance with MIL-STD-785 Task 302. Test plans and reports shall be developed and submitted.

R.2.13 Reliability Development/Growth Test. Test plans that show data tracking growth, testing methods and data collection procedures shall be developed and submitted for the Growth Test Program.

Guidance: When specifying ESS, the level (circuit card, module, assembly, etc.) at which the screening is to be performed must be specified. Different levels of screening should be performed at different hardware assembly levels. See R&M 2000 guidelines in Section T for recommended screening as a function of hardware assembly level.

R.2.14 Environmental Stress Screening. Task number 301 of MIL-STD-785 applies. A burn-in test of ____ (specify the number of hours or temperature cycles) at ____ temperature and ____ vibration level extremes shall be performed at the ____ level. At least ____ (hours/cycles) of failure free operation shall be experienced before termination of the burn-in test for each unit. DOD-HDBK-344, ESS of Electronic Equipment, shall be used as a guide.

Example Maintainability Requirements for the System Specification

M.1 Maintainability Requirements

M.1.1 Maintainability Quantitative Requirements. The *(system name)* shall be designed to achieve a mean-corrective-maintenance-time (M_{CT}) of no greater than ____ minutes and a maximum-corrective maintenance-time (M_{MAXCT}) of no greater than ____ minutes (95th percentile) at the *(specify organization, intermediate or depot level)*, when repaired by an Air Force maintenance technician of skill level ____ or equivalent.

Guidance: Preventive maintenance requirements are considered an option to be implemented when items are used in the design that are subject to wearout, alignment, adjustment or have fault tolerance that must be renewed. If the option is exercised, then attach the paragraph below to M.1.1.

M.1.2 Preventive maintenance shall not exceed ____ minutes for each period and the period shall not be more frequent than every ____ .

M.1.3 The mean time to restore system (MTTRS) following a system failure shall not be greater than ____ . MTTRS includes all corrective maintenance time and logistics delay time.

M.1.4 The mean maintenance manhours (M-MMH) shall not be greater than ____ hours per year. M-MMH is defined as follows: (operating hours per year) ÷ (system MTBF) (system MTTR) (number of maintenance personnel required for corrective action).

Caution: Above definition of M-MMH assumes that a repair is made when each failure occurs. If a delayed maintenance concept is anticipated through the use of fault tolerance, then MTBCF should be used (instead of MTBF) in the above definition. If only a limited number of site visits are allowed, then this value should be used in the above definition in place of "operating hours per year ÷ system MTBF."

M.1.5 Maintainability Design. The system design shall provide modularity, accessibility, built-in-test (BIT) and other maintainability features to provide installation simplicity, ease of maintenance and the attainment of the maintainability requirements (both corrective and preventive). Line Replaceable Units (LRUs) such as printed circuit boards or assemblies shall be replaceable without cutting or unsoldering connections. All plug-in modules shall be mechanically keyed/coded to prevent insertion of a wrong module.

M.1.5.1 Testability. The system design shall be partitioned based upon the ability to isolate faults. Each item shall have sufficient test points for the measurement or stimulus of internal circuit nodes to achieve the capability of detecting 100 percent of all permanent failures using full resources. Automatic monitoring and diagnostic capabilities shall be provided to show the system status (operable, inoperable, degraded) and to detect 90 percent of all permanent failures. The false alarm rate due to self-test circuitry shall be less than 1 percent of the series failure rate. Self-test circuitry shall be designed to correctly isolate the fault to a group of four (4) LRUs, or less, 95 percent of the time.

M.1.6 Maintainability Test and Evaluation. Maintainability requirements for the *(system name)* shall be verified by the following:

M.1.6.1 Maintainability Analysis. The results of the final maintainability prediction shall be compared to the quantitative requirements and achievement determined if the predicted parameters are less than or equal to the required parameters.

M.1.6.2 Maintainability Demonstration. A maintainability demonstration shall be performed in accordance with Test Method (test method 9 is commonly specified, see Appendix 7 for further guidance) of MIL-STD-471. A minimum sample size of 50 tasks shall be demonstrated. The consumer's risk for the maintainability demonstration shall be equal to 10 percent. Fault detection and isolation requirements shall be demonstrated as part of the maintainability test.

M.1.6.3 Testability Demonstration. A testability demonstration shall be performed on the *(system name)* in accordance with Notice 2 of MIL-STD-471A.

Example Maintainability Requirements for the Statement of Work

M.2 Maintainability Program Tasks

M.2.1 Maintainability Program. The contractor shall conduct a maintainability program in accordance with MIL-STD-470A appropriately tailored for full scale development including the following tasks as a minimum to assure maintainability consistent with the requirements.

M.2.2 Testability Program. Testability characteristics and parameters are related to, and shall be treated as part of the maintainability program. The contractor shall conduct a testability program in accordance with MIL-STD-2165 appropriately tailored for FSD including the following tasks as a minimum to assure testability consistent with the requirements.

M.2.3 Maintainability Design Review. The status of the maintainability/testability design shall be addressed at all internal and external design reviews.

M.2.4 Subcontractor Control. The contractor shall specify maintainability requirements to all subcontractors to insure that *(equipment/system name)* requirements of this program are attained. Task 102 of MIL-STD-470A shall be used as a guide.

M.2.5 Maintainability/Testability Modeling. The contractor shall establish a maintainability model using MIL-STD-470A Task 201 which reflects the construction and configuration of the FSD design. Linkages with MIL-STD-2165 Task 201 to relate testability/diagnostic design characteristics to maintainability parameters shall be provided.

M.2.6 Maintainability Prediction. The contractor shall predict maintainability figures of merit using Procedure V of MIL-HDBK-472 (Notice 1) at the on-equipment level. MIL-STD-470A, Task 203 shall be used as a guide.

M.2.7 Maintainability/Testability Design Criteria. The contractor shall develop design criteria to be used in the design process to achieve the specified maintainability and testability requirements. In addition, a design analysis showing failure modes, failure rates, ease of access, modularity and the capability to achieve the fault detection/isolation requirement shall be provided. RADC-TR-74-308 "Maintainability Engineering Design Handbook," RADC-TR-82-189 "RADC Testability Notebook," Task 202 of MIL-STD-2165 and Task 206 of MIL-STD-470A shall be used as a guide.

Guidance: Maintainability demonstration reports are only necessary if a maintainability test is specified in the maintainability specification requirements.

M.2.8 Maintainability/Testability Demonstration. A Test plan and test report shall be submitted by the contractor. Task 301 of MIL-STD-470A and Task 301 of MIL-STD-2165 shall be used as guides.

Appendix 3
Warranties

This material has been summarized from two excellent sources of information: (1) "Warranty Handbook—A Reference Guide for Use by DoD Managers in Developing, Applying, and Administering Warranties" (Available from Defense Systems Management College, Fort Belvoir, Virginia); (2) "Product Performance Agreement Guide" (Available from AFALC/XRCP, Wright-Patterson AFB, Ohio, (513) 255-5459, AV: 785-5459).

3.1 Warranty Background

The term "warranty" is defined in Federal Acquisition Regulation (FAR) as "a promise or affirmation given by a contractor to the government regarding the nature, usefulness, or condition of the supplies or performance of services furnished under the contract." The terms "warranty" and "guarantee" are used interchangeably by the Department of Defense. Until the passage of Public Law 98-212 as part of the Defense Appropriations Act of 1984, the use of warranties in military procurements was not mandatory. However, warranties have frequently been used by all military services.

3.2 Military Warranty History

3.2.1 1960 to 1980

In 1964, Section 1-324 of the Armed Services Procurement Regulation (ASPR) was issued, containing regulations on the use of warranties. The section, which has been updated periodically, has been generally interpreted to mean that use of an extensive, long-term warranty should be the exception rather than the rule. For commercial items, the military normally obtains a standard warranty if the planned usage of the item is consistent with normal usage. Early government controls against acquiring defective material included warranty control against latent defects. In the late 1960s and early 1970s, more extensive warranty forms were tried, such as on the Navy F-4 gyro (failure-free warranty (FFW), and the Air Force ARN-118 TACAN (reliability improvement warranty (RIW)). The services supported research studies to evaluate warranty applications and to develop analysis and implementation tools. After evaluating a number of early warranty problems, researchers concluded that a properly structured and implemented military warranty can offer significant potential for achieving desired operational performance at reasonable cost.

3.2.2 Warranty Initiatives in the 1980s

The successful use of such warranty forms as MTBF guarantees and RIW during the 1970s provided a basis for extending warranty applications to a broader class of programs. In 1980, the Air Force issued the first Product Performance Agreement Guide, which provided a summary of the features of various forms of warranties that could be used in military procurements. In 1982, the Product Performance Agreement Center (PPAC) was established to provide a focal point for Air Force use of product performance agreements and warranties (the term "product performance agreement" was adopted by the Air Force to mean all forms of contractural agreements relating to the performance of a product). Also in 1982, the Department of Defense issued a set of initiatives, which became known as the

Carlucci Initiatives, to improve and streamline the acquisition process. They included warranties as one means of achieving desired levels of system reliability and maintainability. Congressional interest in warranty as a means of ensuring acceptable field performance started with the passage of Public Law 98-212, which was part of the 1984 Defense Appropriations Act, mandating that warranties be included in the production contract.

3.3 Current Warranty Law

The Defense Procurement Reform Act (Public Law 98-525), effective January 1985, established Title 10, Section 2403, of the United States Code, entitled "Major Weapon Systems: Contractor Guarantees." The law requires that the prime contractor for a production weapon system provide written guarantees, starting with procurements after 1 January 1985. Table 3.1 summarizes the essential features of the law.

Table 3.1: Summary of 1985 Warranty Law

Factor	Definition	Description
Coverage	Weapon Systems	Used in combat missions; unit cost is greater than $100,000, or total procurement exceeds $10,000,000.
Warrantor	Prime contractor	Party that enters into direct agreement with US to furnish part or all of weapon system.
Warranties	Design and manufacturing requirements	Item meets structural and engineering plans and manufacturing particulars.
	Defects in materials and workmanship	Item is free from such defects at the time it is delivered to the government.
	Essential performance requirements	Operating capabilities or maintenance and reliability characteristics of item are necessary for fulfilling the military requirements.
Exclusions	GFP, GFE, GFM	Items provided to the contractor by the government.
Waivers	Necessary in the interest of national defense; warranty not cost-effective	Assistant Secretary of Defense or Assistant Secretary of the Military Department is lowest authority for granting waiver; prior notification to House and Senate committees required for major weapon system.

3.4 US Air Force Warranties

Air Force policy documents indicate that the Air Force will require a warranty plan for each procurement documenting the responsibilities, decisions, taskings and strategies for warranties. Table 3.2 lists offices that have been designated Air Force warranty focal points.

Table 3.2: Air Force Warranty Focal Points

Office	Address	Telephone Number
Warranty Contracting	HQ USAF/RDCS Pentagon Washington DC 20330	(202) 697-6400
Warranty Administration	HQ USAF/LEYE Pentagon Washington DC 20330	(202) 697-0311
Air Force Systems Command	HQ AFSC/PLE Andrews AFB DC 20334	(301) 981-4076
Air Force Logistics Command	HQ AFLC/MMA Wright-Patterson AFB OH 45433	(513) 257-7119
Warranty Data Base and Consulting	Product Performance Agreement Center Wright-Patterson AFB OH 45433	(513) 255-5459

3.5 Product Performance Agreement Center (PPAC)

The Air Force PPAC was established in 1982 to assist Air Force activities involved in the acquisition of defense systems and their components in selecting, structuring, pricing, negotiating and implementing effective Product Performance Agreements (PPAs) and related business arrangements. To promote the use of PPAs in Air Force procurements pursuant to 10 USC 2403, and to promote effective application and management of PPAs at all levels, the PPAC currently performs the following functions:

- Serves as the central repository of Air Force PPA-related data.
- Analyzes the effectiveness of existing and proposed PPAs.
- Develops improved contract clauses and related concepts.
- Provides technical assistance to Air Force activities in selecting, tailoring, pricing, negotiating and administering appropriate agreements.
- Formulates proposed policy guidance for HQ USAF consideration concerning application of PPAs to Air Force acquisitions.

3.6 Warranty Classifications

A number of warranty classification schemes have been developed to describe alternatives available to procurement activities. The usual classification scheme distinguishes between assurance and incentive forms of warranties. Table 3.3 compares the characteristics of these two types.

Table 3.3: Comparison of Assurance and Incentive Types of Warranties

Factor	Assurance Warranty	Incentive Warranty
Basic Intent	Meet minimum performance and R&M levels.	Exceed minimum levels.
Warranty Price	Expected to be minimal, from 0 up to 1 or 2 percent per year of hardware price.	May be significant, up to 7 or 8 percent per year of hardware price.
Warranty Duration	Limited—generally 1 year or less.	Can be extensive—3 or more years.
Technology Factors	Warranted item is well within state-of-the-art (SOA), or SOA is so severely "pushed" that only limited warranty protection is realistic.	Warranted item pushes SOA, so there is need to protect against failure and there is opportunity for growth.
Contractor	Contractor has limited opportunity to control and improve performance prior to and during warranty.	Contractor has significant opportunity to control and improve performance.
Competition	Should not reduce future competitive climate.	May significantly reduce competitive climate.
Administration	Generally not a severe burden.	May require complex procedures.

3.7 Product Performance Agreement Guide Warranties

In November 1985, The Air Force Product Performance Agreement Guide listed 28 forms of PPAs and provided additional background and guidance on their potential application. The four most commonly used incentive forms of warranties are listed in Table 3.4.

Table 3.4: Summary of Four Incentive Forms of Warranty

Incentive Warranty Form	Objective	Approach	Remedies	Application
Reliability Improvement Warranty (RIW)	Achieve acceptable reliability and motivate contractor to improve.	Contractor performs depot maintenance for at least two years under a fixed price.	Contractor repairs all covered failures and has the option of implementing ECPs for R&M improvement.	Units must be depot-repairable. Reduced military self-sufficiency must be tolerable.
Mean Time Between Failures Guarantee (MTBFG)	Provide assurance that required field MTBF level will be achieved.	Contractor guarantees field MTBF. Measurements are made and compared with guaranteed value.	Contractor must develop and implement solution if guarantee value is not achieved. Contractor may have to provide consignment spares in the interim.	MTBF is appropriate reliability parameter and field measurement can be made.
Availability Guarantee (AG)	Provide assurance that required operational availability will be achieved.	System availability is measured in the field or through special test and compared to guaranteed values.	Same as for MTBF guarantee.	Availability is appropriate readiness parameter and acceptable measurement methods can be implemented.
Logistics Support Cost Guarantee (LSCG)	Control logistics support costs.	Contractor "bids" target logistics support cost through use of a model. Field parameters are measured and the same model is used for obtaining measured logistics support costs and compared to target.	Contract price is adjusted based on actual versus target values; a correction of deficiency may be required.	Appropriate LSC model exists. Generally requires a special test program to obtain measured values.

3.8 Contractor Reliability Motivations

Reliability is one of the principal system performance parameters that the warranty law addresses. Reliability differs from quality in the sense that it pertains to the long-term performance of the system—or, the mean time between system failures.

Contractors generally have a positive attitude toward quality. Quality audits are normally performed on all submitted products and rejections result in added expense and reduced profit. Reliability, on the other hand, is more elusive: it cannot be measured easily, and, in some respects, it does not offer immediate, positive motivations to a contractor. In fact, one can argue, perhaps cynically, that without a warranty, failures of a deployed system mean more profit to a contractor if the contractor is providing maintenance or spares. In addition, if reliability is a serious problem, the same contractor is probably tasked to develop a fix and to retrofit existing systems. Figure 3.1 illustrates contractor profit motivation with a warranty.

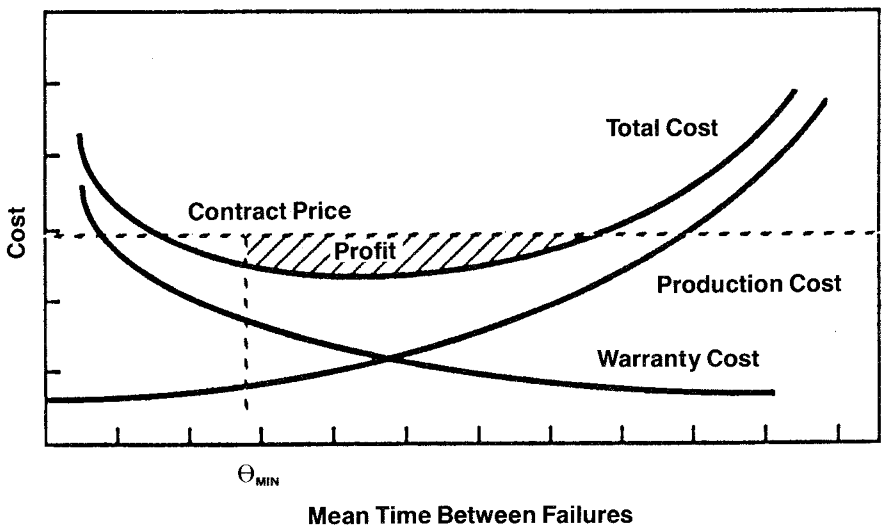


Figure 3.1: Contractor Profit Motivation—Warranty

3.9 Other Warranty Motivations

There are other motivations, besides reliability, that can be associated with a warranty. The warranty commitment forces the contractor to think seriously beyond just having the product accepted. Being involved throughout the warranty period may cause the contractor to be concerned with maintenance, diagnostics, training, data and other logistics and support factors. As an example, warranties have been *written under which the contractor is not reimbursed for processing good units* returned unless the percentage of such returns is very high. Since such processing is costly, the contractor may be motivated to improve the built-in-test equipment, technical manuals, test equipment, and other elements associated with failure detection and verification.

Another motivational factor concerns maintenance efficiency. If the contractor has to repair all warranted failures, it is important that there be an efficient and effective repair process. There have been a number of instances in which such warranties influenced the contractor to design for maintenance as well as reliability.

When the contractor views warranty as a potential profit source and a means for achieving a competitive edge, a number of positive motivational factors may be present. Producers of quality equipment need not add significant warranty contingency or risk funds to their price to cover future failures, and they need not spend all of their warranty funds to fix a poor product. A warranty environment encourages producers to achieve and maintain a quality product.

3.10 Summaries of Early Programs

Reviews of a number of warranty programs begun during the 1970s have generally concluded that long-term warranties can provide significant improvements in operational performance (R&M).

Data collected by ARINC Research Corporation compared field MTBF values under a warranty program with goal values, some of which were contractually guaranteed. The results show that the field reliability exceeded the goal value for all the programs tested but one. The data were developed over a period when field reliability for unwarranted systems often was much lower than was specified, predicted or tested. Although the results suggested that warranty programs provide a mechanism for achieving reliable equipment, there are several factors to consider:

- The data represent programs that were carefully selected for warranty application.
- Many of the warranty programs entailed fairly extensive forms of warranty, with a great deal of effort given to structuring the terms and conditions properly.
- Advertising that an equipment is to be warranted is one way to help ensure that contractor-proposed MTBF values are realistic. While this is beneficial, it can lead to misinterpretation of results when data from warranted equipment are compared with similar data from nonwarranted equipment. Without an expected warranty commitment, expected MTBF values often became inflated.

3.11 Summaries of Recent Programs

Since passage of the 1984 law, hundreds of procurements have been contracted; presumably, most comply with the statutory regulation. Unfortunately, there is very little field experience to assess the workability and effectiveness of the warranty provisions. The lack of relevant data makes evaluation of warranties difficult. A recent Air Force PPAC study assessing the effectiveness of Air Force RIW programs provided some findings on the data problems.

- Administration and tracking of warranted items vary from program to program.
- Warranty programs are diverse in the amount of reporting and relevant data available to accomplish an adequate assessment.
- Most warranty programs do not undergo the pre-RIW analyses (trade studies and cost-benefit analyses) necessary to determine the best way to apply a warranty.

In light of these findings, the reported effectiveness of warranties should be viewed with caution, and it should be recognized that the documentation and collection of warranty data has not been uniform, thereby impeding direct comparison and conclusions.

Appendix 4

Example Design Guidelines

This Appendix contains an example set of design guidelines structured to include verification methods. These guidelines are an example only and don't apply to all situations.

a. Thermal Design

(1) Integrated Circuit Junction Temperatures.

Design Guideline: The design of the environmental cooling system (ECS) should be capable of maintaining an average integrated circuit junction temperature of 55°C or less under typical operating conditions. Under worst case steady state conditions, components should operate at least 50°C below their rated maximum junction temperature.

Analysis Recommendation: Thermal finite element analysis should be performed to project operating temperatures under specified environmental conditions. The analysis should consider ECS performance, environmental impacts, and system thermal design. Average junction temperatures should include all integrated circuits within the system. Average temperature rise should include all components on an individual module.

Test Recommendation: Thermally instrumented observations should be made of components under specified environmental conditions. Instrumentation can be by direct contact measurement or by infrared photography.

(2) Thermal Gradients.

Design Guideline: The maximum allowable temperature rise from any junction to the nearest heat sink should be 25°C. The average temperature rise from integrated circuit junctions to the heat sink should be no greater than 15°C. To minimize gradients, more complex and power-intensive devices should be placed to minimize their operating temperature.

Analysis Recommendation: Automated design tools that perform component placement should be programmed to produce this result. A thermal finite element analysis should be used to evaluate the projected thermal gradient under the specified environmental conditions.

Test Recommendation: Thermally instrumented observation of components under specified environmental conditions. Instrumentation can be by direct contact measurement or by infrared photography.

(3) Thermal Expansion Characteristics.

Design Guideline: Component and board materials should be selected with compatible thermal coefficients of expansion (TCE). Additionally, coldplate materials should be selected for TCE compatibility with the attached printed wiring board. TCE mismatch results in warpage of the laminated assembly, which can reduce module clearances and stress PWB component leads and solder joints.

Analysis Recommendation: A finite element analysis should be performed to identify the stress patterns in the solder joints attaching the components to the board. TCE compatibility should be evaluated for the components, PWB, and coldplate.

Test Recommendation: Environmental stress tests should be utilized in the development phase to verify the design analysis, and environmental stress screening should be used in production to ensure consistency throughout the production cycle.

(4) Heat Transport Media.

Design Guideline: The design should use a thermal conduction medium that is integral to the mechanical design of the board or module. Heat pipes, metal rails, or internal planes are examples of thermally conductive media. The unit should meet temperature design requirements by cooling through the integral thermal conduction medium without depending on any other heat loss.

Analysis Recommendation: Thermal finite element analysis should be used to project heat flow under specified environmental conditions. Modules employing heat pipes for cooling should meet operating temperature requirements when the module heat sink is inclined at an angle of 90 degrees from the horizontal.

Test Recommendation: Thermally instrumented observation should be made of components under specified environmental conditions. Instrumentation can be by direct contact measurement or by infrared photography.

(5) Component Attachment.

Design Guideline: Surface contact should be maximized between the component and the heat transport media. This can be achieved by direct pressure, thermal compounds, or solder. The technique used should be reversible for component removal during board repairs such that damage is not induced to nearby devices. If a thermal compound is used, it should not migrate or react with other components during testing or service use.

Analysis Recommendation: Specialized stress analyses should be performed to quantify thermal and mechanical stresses involved in removing the component from the board after production installation.

Test Recommendation: Demonstration of repair techniques should be performed early in the development phase.

(6) Thermal Cycling.

Design Guideline: The unit should be designed to dampen its thermal response to the thermal excursions required by the specification. This can be achieved by using a large thermal mass or by using the cooling medium to insulate the unit from its environment to the maximum extent possible.

Analysis Recommendation: Thermal finite element analysis to project heat flow and temperature excursions under specified environmental conditions.

Test Recommendation: Thermally instrumented observation of components under specified environmental excursions. Instrumentation can be by direct contact measurement or by infrared photography.

b. Testability Design

(1) Bottom-up Fault Reporting.

Design Guideline: Incorporate autonomous self-testing at the lowest levels that are technically feasible. Utilize positive indication to report chip, module and subsystem status. The design should not depend upon external stimuli to perform fault detection or isolation to a replaceable element.

Analysis Recommendation: As soon as automated testability analysis tools become available, they should be used for the applicable engineering design workstations.

Test Recommendation: Hardware demonstration should be conducted early in the development phase to verify simulation results through the insertion of faults using the currently available version of the operational program, firmware, and microcode.

(2) Fault Logging.

Design Guideline: Modules should contain a non-volatile fault log that can be accessed by a system maintenance controller or by test equipment. The use of the fault log will improve reliability by reducing depot "Cannot Duplicates." Failure of the fault log should not cause a critical system failure, but should be observable to the maintenance controller.

Analysis Recommendation: Compliance should be verified by inspection. Operation should be verified by simulation.

Test Recommendation: Not applicable.

(3) Start-up Built-In-Test (BIT)

Design Guideline: The module should execute a BIT internal diagnostic routine immediately after power-up or receipt of an "Execute BIT" command. BIT should provide a complete functional test of the module to the maximum extent possible without transmitting any signals on external interface media. BIT should provide a complete functional test of the module and should include:

(1) Verification of internal data paths.

(2) Verify station physical address.

(3) Verify message identification process from system.

(4) Verify proper functioning of all internal memory and other components.

Any failures encountered during execution of BIT should be retried at least once to confirm the response. Any confirmed failures should prevent the module from becoming enabled. A failed module should respond only to "RESET," "Execute BIT," and "Report Status" commands.

Analysis Recommendation: System design simulation tools should be used to verify operation of the BIT. These tools should include fault simulations as well as operational simulation.

Test Recommendation: Hardware demonstration should be conducted early in the development phase to verify simulation results through insertion of faults using currently available versions of the operational program, firmware, and microcode.

(4) Background Diagnostics.

Design Guideline: During normal operation, the module should continuously monitor itself through a background diagnostic test. The background diagnostic should provide coverage to the maximum extent possible without interfering with normal station operation. Failure of any test in the background diagnostic should cause the module to re-execute the failed test to screen out transient anomalous responses. If the failure is confirmed, the module should become immediately disabled.

Analysis Recommendation: System design simulation tools should be used to verify operation of the BIT. These tools should include fault simulations as well as operational simulation.

Test Recommendation: Hardware demonstration should be conducted early in the development phase to verify simulation results through insertion of faults using currently available versions of the operational program, firmware, and microcode. Hardware demonstration may be performed by physically inserting faults in a module or by instrumenting a module to allow insertion of faults through external methods.

c. Mechanical Packaging Design

(1) Mechanical Insertion/Extraction-Induced Stresses.

Design Guideline: Each module should withstand, without damage or separation, a minimum force equal to at least 100 pounds on insertion and four ounces per contact on extraction. Additionally, the backplane for the assembly should withstand the same forces at all module positions applied repeatedly in any sequence with any combination of modules present or missing.

Analysis Recommendation: A mechanical loads analysis should be performed to verify compliance with the mechanical requirements.

Test Recommendation: The total computed force should be applied to simulate module insertion and extraction. The force should be applied in 2 seconds and maintained for 15 seconds.

(2) Insertion/Extraction Durability.

Design Guideline: Modules should be capable of withstanding 500 cycles of mating and unmating with no degradation of module performance. The module should also be capable of withstanding 500 cycles of lateral displacement to simulate the use of thermal clamping devices. The backplane of the module's host assembly should be capable of withstanding 500 of the same cycles on each of its module positions.

Analysis Recommendation: A mechanical loads analysis should be performed to verify compliance with the mechanical requirements.

Test Recommendation: Each module/backplane position should be subjected to 500 cycles of insertion/extraction. The maximum specified insertion and extraction forces should be applied in 2 seconds and maintained for 15 seconds. Five hundred lateral displacement cycles should be applied to the module.

(3) Mechanical Vibration-Induced Stresses.

Design Guideline: The larger components are more susceptible to mechanical stresses because they have a larger mass and because they are more constrained by the high number of pin-outs that act as attachment points. Module stiffness should be maximized to prevent board flexing resulting in stress fractures at the solder joints or component leadframe.

Analysis Recommendation: Mechanical finite element analysis should be performed to identify module characteristics throughout the specified vibrational environment.

Test Recommendation: Developmental units should be specially instrumented with accelerometers early in the development program. These units could use dummy masses attached using the intended production technique. Standard endurance and qualification tests should be performed in accordance with MIL-STD-810, "Environmental Test Methods and Engineering Guidelines."

(4) Module Torque Stresses.

Design Guideline: The module should be capable of withstanding a 6 inch-pound torque applied in 2 seconds and maintained for 15 seconds in both directions along the header in a direction perpendicular to the plane of the header without detrimental effect to the mechanical or electrical properties of the module.

Analysis Recommendation: A mechanical loads analysis should be performed to verify compliance with the mechanical requirements.

Test Recommendation: The required torque should be applied in 2 seconds and maintained for 15 seconds. During the time the torque is applied, the module should be rigidly supported within a zone between the interface plane and 0.5 inch above the interface panel.

(5) Module Cantilever Load.

Design Guideline: The module should be capable of withstanding a force of 2 pounds applied perpendicular to the header height along the center line midway between the two extractor holes.

Analysis Recommendation: A mechanical loads analysis should be performed to verify compliance with the mechanical requirements.

Test Recommendation: The required force should be applied in two directions and should be applied in 2 to 10 seconds and maintained for 10 to 15 seconds without detrimental effect to the header structure.

(6) Module Retention.

Design Guideline: Module retention techniques must be carefully designed to integrate the insertion mechanism, required connector insertion force, thermal contact area, and extraction mechanism. Conventional electronics have required the same considerations, but to a lesser degree because of their more conventional housings.

Analysis Recommendation: Specialized analyses should be used to quantify torque requirements and limitations of the wedge-clamping device, lever moments of insertion or extraction devices, tolerance buildups of the module slot and connector placement, and mechanical deflections of the backplane.

Test Recommendations: Standard endurance and qualification tests in accordance with MIL-STD-810, "Environmental Test Methods and Engineering Guidelines."

(7) Connector Contact Integrity.

Design Guideline: Each contact pin, as mounted in the connector, should withstand a minimum axial force of 20 ounces.

Analysis Recommendation: A mechanical loads analysis should be performed to verify compliance with the mechanical requirements.

Test Recommendation: The required force should be applied in 2 seconds along the length of the contact in either direction and maintained for 15 seconds.

(8) Connector Float.

Design Guideline: The connector-to-module interface should be sufficiently flexible to compensate for specified misalignments or tolerance buildup between the module and the backplane connector shells.

Analysis Recommendation: Tolerance review should be performed early in design process.

Test Recommendation: Demonstration testing can be performed easily during the initial mechanical design phase.

(9) Keying Pin Integrity.

Design Guideline: When installed in the module, the keying pins should meet the following integrity requirements. Each keying pin should withstand a:

- torque of 20 inch-ounces
- pullout force of 9 pounds
- pushout force of 40 pounds
- cantilever load of 10 pounds

Analysis Recommendation: A mechanical loads analysis should be performed to verify compliance with the mechanical requirements.

Test Recommendation: The required forces should be applied to the keying pin in 2 seconds and maintained for 15 seconds.

d. Power Supply Design

(1) Overcurrent Protection:

Design Guideline: The power supply should supply 125 percent of its rated output for 2 $\pm$ 0.25 seconds, after which the power supply will shut down (shut down is defined as all outputs at less than 1 mv and 1 ma current, but all status and control lines still operating). Operation should not resume until the power supply is reset. In addition, the power supply outputs should be short circuit protected.

Analysis Recommendation: Compliance with the specified operation should be verified throughout the design process.

Test Recommendation: Specified operation of the protective device should be induced by application of the anomalous condition protected against. Correct operation of the protective device should be observed. Normal specified power supply operation should be verified after removal of the anomalous condition.

(2) Overvoltage Protection.

Design Guideline: The output should be sensed for overvoltage. An overvoltage on the output should immediately shut down the power supply. Operation should not resume until the power supply is reset. The overvoltage limits should be compatible with device logic absolute maximum limits. The overvoltage protection and sense circuits should be constructed such that an overvoltage on a failed power supply will not cause any other paralleled power supply to also shut down.

Analysis Recommendation: Compliance with the specified operation should be verified throughout the design process.

Test Recommendation: Specified operation of the protective device should be induced by application of the anomalous condition protected against. Correct operation of the protective device should be observed. Normal specified power supply operation should be verified after removal of the anomalous condition.

(3) Abnormal Thermal Operation.

Design Guideline: In the event of an above-normal internal temperature, the power supply should be capable of continued operation at a reduced power output. Thermal sense circuits should regulate the output to the extent necessary to keep semiconductor junctions at or below specified levels. The power supply should resume operation at rated output if internal temperatures return to normal.

Analysis Recommendation: Compliance with the specified operation should be verified throughout the design process.

Test Recommendation: Specified operation of the protective device should be induced by application of the anomalous condition protected against. Correct operation of the protective device should be observed. Normal specified power supply operation should be verified after removal of the anomalous condition.

(4) Thermal Shutdown.

Design Guideline: When thermal limiting is no longer capable of maintaining internal temperature at an acceptable level, the power supply should automatically shut down. Operation should not resume until the power supply is reset. Temperature sense circuits should remain active during shut down.

Analysis Recommendation: Compliance with the specified operation should be verified throughout the design process.

Test Recommendation: Specified operation of the protective device should be induced by application of the anomalous condition protected against. Correct operation of the protective device should be observed. Normal specified power supply operation should be verified after removal of the anomalous condition.

(5) Power Supply Status Reporting.

Design Guideline: There should be an interface on each power supply module that will allow data communication between the power supply and a CPU located on a separate module. Each power supply module will be addressed individually. The data and control lines should interface to the power supply module through the backplane connector. The following power supply parameters should be read by the CPU:

- overcurrent status
- overvoltage status
- thermal limiting mode status
- thermal shutdown status
- percentage of full output power available.

The following commands should be issued by the CPU to the power supply module:

- reset
- percentage of full output power required

Analysis Recommendation: Compliance with the specified operation should be verified throughout the design process.

Test Recommendation: Specified operation of the protective device (i.e., monitoring mechanism and control) should be induced by application of the anomalous condition protected against. Correct operation of the protective device should be observed. Normal specified power supply operation should be verified after removal of the anomalous condition.

(6) Power Supply Input Protection.

Design Guideline: The power supply should automatically shut down if the input voltage is not within the specified allowable range, and at any time when the control circuits in the power supply do not have adequate voltage to regulate the outputs. This should include the time during normal start-up when generators are not producing their normal output voltage.

Analysis Recommendation: Compliance with the specified operation should be verified throughout the design process.

Test Recommendation: Specified operation of the protective device should be induced by application of the anomalous condition protected against. Correct operation of the protective device should be observed. Normal specified power supply operation should be verified after removal of the anomalous condition.

(7) Backplace Conditions.

Design Guideline: A sufficient number of connector pins should be paralleled so that no backplane connector pin carries more than 5 amps of current.

Analysis Recommendation: Compliance with the specified operation should be verified throughout the design process.

Test Recommendation: Not applicable.

(8) M-of-N Power Supply Redundancy.

Design Guideline: The quantity of power supplies for a system of functional elements should be determined to allow uninterrupted operation if one of the power supplies fails. When all power supplies are functional, they should share the system load equally by operating at reduced output. If the system power requirement is less than that available from one power supply, redundancy should not be used unless a critical function is involved.

Analysis Recommendation: Compliance should be verified by electrical loads analysis.

Test Recommendation: Not applicable.

(9) Current Sharing.

Design Guideline: The power supplies should be constructed so that units which have the same output voltage may operate in parallel. The design should be such that power supply failures will not cause degradation of parallel power supplies. Each power supply should provide its proportional share ($\pm$ 10%) of the total electric load required at the configured output voltage.

Analysis Recommendation: Compliance with the specified operation should be verified as a part of the design process.

Test Recommendation: A demonstration should be conducted under load to verify that the parallel power supplies power up and power down in unison. Failure and reset of one of the power supplies should be simulated or induced to demonstrate proper operation of the remaining units through the transition.

(10) Protective Device Operation.

Design Guideline: During parallel operation, each power supply protective device should be capable of sensing and operating independently of the other power supplies. Master-slave type operation should not be permitted under any circumstances.

Analysis Recommendation: Compliance with the specified operation should be verified as a part of the design process.

Test Recommendation: A demonstration should be conducted under load to verify proper operation of each protective device during parallel operation.

e. Memory Fault Tolerance

(1) Block Masking.

Design Guideline: Known locations of defective memory should be mapped out of the memory directories. In this manner, permanently failed cells can be prevented from contributing to double error occurrences in combination with soft errors. At power-up or reinitialization, BIT should perform a memory test routine and leave a memory map of all good blocks. At the conclusion of the memory test routine, all words contained in the memory blocks marked good should have been initialized in an error free data pattern. Program loader software should make use of the good memory block map, the processor memory mapping registers, and information stored in program file headers to load distributed operating systems and application programs into the remaining good areas of main memory. Repair or replacement of the module should not be required until the number of remaining good blocks of memory are insufficient to meet operational requirements.

Analysis Recommendation: An analysis should be performed to identify the optimum combination of component/bit mapping, hardware control, and software control.

Test Recommendation: Not applicable.

(2) Error Detection/Correction.

Design Guideline: As a minimum, single error correct/double error detect code should be used in large bulk semiconductor memories. It should be considered in any application involving large amounts of semiconductor memory, but may impose unacceptable speed and complexity penalties in some applications (e.g., CPU).

Analysis Recommendation: A detailed timing analysis should be conducted to determine the impact of this technique on the specific application.

Test Recommendation: System bench testing should be used to insert faults and to confirm expected system operation.

Appendix 5

Reliability Demonstration Testing

5.1 Reliability Demonstration Testing. This appendix presents tables and examples which summarize the following:

- MIL-HDBK-781 "Reliability Design Qualification and Production Acceptance Tests: Exponential Distribution . . . "
- Confidence Interval Calculations
- Poisson's Exponential Binomial Limits

5.2 MIL-HDBK-781D Test Plans. Tables 5.1 and 5.2 summarize standard test plans as defined in MIL-HDBK-781D. These plans assume an exponential failure distribution. For nonexponential situations the risks are different.

The fixed length test plans (Table 5.1) must be used when the exact length and cost of the test must be known beforehand and when it is necessary to demonstrate a specific MTBF to a predetermined confidence level by the test as well as reach an accept/reject decision.

The probability ratio sequential test (PRST) plans (Table 5.2) will accept material with a high MTBF or reject material with a very low MTBF more quickly than fixed length test plans having similar risks and discrimination ratios. However, different MTBF's may be demonstrated by different accept decision points for the same test plan and the total test time may vary significantly.

Additional guidance on test plan selection is provided in Section T, Topic T5.

5.2.1 Fixed Length Test Plan Example: If the design goal MTBF (θ_0) for a system is specified as 750 hours and Test Plan XID is chosen, the following statements can be made:

a. There is a 20 percent probability of rejecting a system whose true MTBF is 750 hours (producers risk).

b. There is a 20 percent probability of accepting a system whose true MTBF is 500 hours (consumers risk).

c. The lower test MTBF (θ_1) is 500 hours (750/1.5).

d. The duration of the test is 10,750 hours (21.5×500).

e. The test will reject any system which experiences 18 or more failures.

f. The test will accept any system which experiences 17 or less failures.

5.2.2 PRST Test Plan Example: If the design goal MTBF (θ_0) for a system is specified as 750 hours and Test Plan IID is chosen, the following statements can be made:

a. There is a 20 percent probability of rejecting a system whose true MTBF is 750 hours (producers risk).

b. There is a 20 percent probability of accepting a system whose true MTBF is 500 hours (consumers risk).

c. The lower test MTBF (θ_1) is 500 hours (750/1.5).

d. The minimum time to an accept decision is 2095 hours (4.19×500).

e. The expected time to an accept decision is 5700 hours (11.4×500). (Expected time to decision based on assumption of a true MTBF equal to θ_0.)

f. The maximum time to reach an accept decision is 10950 hours (21.9×500).

Table 5.1: Fixed Length MIL-HDBK-781D Reliability Demonstration Test Plans

Test Plan	Nominal Decision Risks		Discrimination Ratio	Test Duration	Test Duration	Accept-Reject Failures	
	α	β	θ_0/θ_1	(Multiples of θ_1)	(Multiples of θ_0)	Reject (Equal or More)	Accept (Equal or Less)
IXD	10%	10%	1.5	45.0	30.0	37	36
XD	10%	20%	1.5	29.9	19.93	26	25
XID	20%	20%	1.5	21.5	14.33	18	17
XIID	10%	10%	2.0	18.8	9.4	14	13
XIIID	10%	20%	2.0	12.4	6.2	10	9
XIVD	20%	20%	2.0	7.8	3.9	6	5
XVD	10%	10%	3.0	9.3	3.1	6	5
XVID	10%	20%	3.0	5.4	1.8	4	3
XVIID	20%	20%	3.0	4.3	1.43	3	2
XIXD*	30%	30%	1.5	8.0	5.33	7	6
XXD*	30%	30%	2.0	3.7	1.85	3	2
XXID*	30%	30%	3.0	1.1	.37	1	0

*Short Run High Risk Test Plans.

Notes:

1. Lower Test MTBF (θ_1) is that value of MTBF which is *unacceptable* and will result in a high probability of equipment rejections using MIL-HDBK-781 test plans.
2. Upper Test MTBF (θ_0) is that value of MTBF which is *acceptable* and will result in a high probability of equipment acceptance using MIL-HDBK-781 test plans.
3. Consumers Risk (β) is the probability of accepting equipment with a true MTBF equal to the lower test MTBF (θ_1) (probability of accepting a bad equipment).
4. Producers Risk (α) is the probability of rejecting equipment with a true MTBF equal to the upper test MTBF (θ_0) (probability of rejecting a good equipment).
5. Discrimination Ratio ($d = \theta_0/\theta_1$) is one of the test plan parameters which is a measure of the power of the test in reaching an accept/reject decision quickly. In general, the higher the discrimination ratio, the shorter the test.

Table 5.2: MIL-HDBK-781D PRST Reliability Demonstration Test Plan Summary

Test Plan	Nominal Decision Risks		Discrimination Ratio	Time to Accept Decision in MTBF (θ_1 Multiples)			Time to Accept Decision in MTBF (θ_0 Multiples)		
	α	β	θ_0/θ_1	Min	Exp[1]	Max	Min	Exp[1]	Max
ID	10%	10%	1.5	6.6	25.95	49.5	4.4	17.3	33.0
IID	20%	20%	1.5	4.19	11.4	21.9	2.79	7.6	14.6
IIID	10%	10%	2.0	4.40	10.2	20.6	2.2	5.1	10.3
IVD	20%	20%	2.0	2.80	4.8	9.74	1.4	2.4	4.87
VD	10%	10%	3.0	3.75	6.0	10.35	1.25	2.0	3.45
VID	20%	20%	3.0	2.67	3.42	4.5	.89	1.14	1.5
VIID	30%	30%	1.5	3.15	5.1	6.8	2.1	3.4	4.53
VIIID	30%	30%	2.0	1.72	2.6	4.5	.86	1.3	2.25

Notes:

1. Expected test time assumes a true MTBF is equal to θ_0.
2. Test length should be assumed to be the maximum test time for planning purposes.
3. Lower Test MTBF (θ_1) is that value of MTBF which is *unacceptable* and will result in a high probability of equipment rejections using MIL-HDBK-781 test plans.
4. Upper Test MTBF (θ_0) is that value of MTBF which is *acceptable* and will result in a high probability of equipment acceptance using MIL-HDBK-781 test plans.
5. Consumers Risk (β) is the probability of accepting equipment with a true MTBF equal to the lower test MTBF (θ_1) (probability of accepting a bad equipment).
6. Producers Risk (α) is the probability of rejecting equipment with a true MTBF equal to the upper test MTBF (θ_0) (probability of rejecting a good equipment).
7. Discrimination Ratio ($d = \theta_0/\theta_1$) is one of the test plan parameters which is a measure of the power of the test in reaching an accept/reject decision quickly. In general, the higher the discrimination ratio, the shorter the test.

5.3 Confidence Level Calculation (Exponential Distribution): There are two ways to end a reliability test, either on a specified number of failures occurring (failure truncated), or on a set period of time (time truncated). There are usually two types of confidence calculations of interest, either one sided (giving the confidence that an MTBF is above a certain value) or two sided (giving the confidence that an MTBF is between an upper and lower limit). The four combinations of possibilities are summarized by the chi-squared models given in Table 5.3. Each of the possibilities will be briefly expanded on.

Table 5.3: Summary of Chi-Squared Models

	Two-Sided Confidence Level Models	Single-Sided Confidence Level Models
Failure Truncated Tests	$\dfrac{2C\hat{\theta}}{\chi^2_{(1-\frac{\alpha}{2}),2C}} \leq \theta \leq \dfrac{2C\hat{\theta}}{\chi^2_{\frac{\alpha}{2},2C}}$	$\theta \geq \dfrac{2C\hat{\theta}}{\chi^2_{(1-\alpha),2C}}$
Time Truncated Tests	$\dfrac{2C\hat{\theta}}{\chi^2_{(1-\frac{\alpha}{2}),(2C+2)}} \leq \theta \leq \dfrac{2C\hat{\theta}}{\chi^2_{\frac{\alpha}{2},2C}}$	$\theta \geq \dfrac{2C\hat{\theta}}{\chi^2_{(1-\alpha),(2C+2)}}$

Notes:

C = number of failures occurring during the test.

α = risk = 1 − confidence level

$\hat{\theta}$ = point estimate MTBF = C/test time

$\chi^2_{P,f}$ = chi-squared statistical distribution value from Table 5.4. P and f are calculated based on the subscripts shown in the above table. P depends on the confidence interval desired and f depends on the number of failures occurring.

CAUTION: Chi-Squared confidence interval calculation applies only to systems with exponential failure distributions. Do not apply to MTBCF.

Table 5.4: Fractiles of the χ^2 Distribution

f	Probability in Percent											
	2.5	5.0	10.0	20.0	30.0	40.0	60.0	70.0	80.0	90.0	95.0	97.5
1	.000982	.00393	.0158	.0642	.148	.275	.708	1.07	1.64	2.71	3.84	5.02
2	.0506	.103	.211	.446	.713	1.02	1.83	2.41	3.22	4.61	5.99	7.38
3	.216	.352	.584	1.00	1.42	1.87	2.95	3.67	4.64	6.25	7.81	9.35
4	.484	.711	1.06	1.65	2.19	2.75	4.04	4.88	5.99	7.78	9.49	11.1
5	.831	1.15	1.61	2.34	3.00	3.66	5.13	6.06	7.29	9.24	11.1	12.8
6	1.24	1.64	2.20	3.07	3.83	4.57	6.21	7.23	8.56	10.6	12.6	14.4
7	1.69	2.17	2.83	3.82	4.67	5.49	7.28	8.38	9.80	12.0	14.1	16.0
8	2.18	2.73	3.49	4.59	5.53	6.42	8.35	9.52	11.0	13.4	15.5	17.5
9	2.70	3.33	4.17	5.38	6.39	7.36	9.41	10.7	12.2	14.7	16.9	19.0
10	3.25	3.94	4.87	6.18	7.27	8.30	10.5	11.8	13.4	16.0	18.3	20.5
11	3.82	4.57	5.58	6.99	8.15	9.24	11.5	12.9	14.6	17.3	19.7	21.9
12	4.40	5.23	6.30	7.81	9.03	10.2	12.6	14.0	15.8	18.5	21.0	23.3
13	5.01	5.89	7.04	8.63	9.93	11.1	13.6	15.1	17.0	19.8	22.4	24.7
14	5.63	6.57	7.79	9.47	10.8	12.1	14.7	16.2	18.2	21.1	23.7	26.1
15	6.26	7.26	8.55	10.3	11.7	13.0	15.7	17.3	19.3	22.3	25.0	27.5
16	6.91	7.96	9.31	11.2	12.6	14.0	16.8	18.4	20.5	23.5	26.3	28.8
17	7.56	8.67	10.1	12.0	13.5	14.9	17.8	19.5	21.6	24.8	27.6	30.2
18	8.23	9.39	10.9	12.9	14.4	15.9	18.9	20.6	22.8	26.0	28.9	31.5
19	8.91	10.1	11.7	13.7	15.4	16.9	19.9	21.7	23.9	27.2	30.1	32.9
20	9.59	10.9	12.4	14.6	16.3	17.8	21.0	22.8	25.0	28.4	31.4	34.2

21	10.3	11.6	13.2	15.4	17.2	18.8	22.0	23.9	26.2	29.6	32.7	35.5
22	11.0	12.3	14.0	16.3	18.1	19.7	23.0	24.9	27.3	30.8	33.9	36.8
23	11.7	13.1	14.8	17.2	19.0	20.7	24.1	26.0	28.4	32.0	35.2	38.1
24	12.4	13.8	15.7	18.1	19.9	21.7	25.1	27.1	29.6	33.2	36.4	39.4
25	13.1	14.6	16.5	18.9	20.9	22.6	26.1	28.2	30.7	34.4	37.7	40.6
26	13.8	15.4	17.3	19.8	21.8	23.6	27.2	29.2	31.8	35.6	38.9	41.9
27	14.6	16.2	18.1	20.7	22.7	24.5	28.2	30.3	32.9	36.7	40.1	43.2
28	15.3	16.9	18.9	21.6	23.6	25.5	29.2	31.4	34.0	37.9	41.3	44.5
29	16.0	17.7	19.8	22.5	24.6	26.5	30.3	32.5	35.1	39.1	42.6	45.7
30	16.8	18.5	20.6	23.4	25.5	27.4	31.3	33.5	36.3	40.3	43.8	47.0
31	17.5	19.3	21.4	24.3	26.4	28.4	32.3	34.6	37.4	41.4	45.0	48.2
32	18.3	20.1	22.3	25.1	27.4	29.4	33.4	35.7	38.5	42.6	46.2	49.5
33	19.0	20.9	23.1	26.0	28.3	30.3	34.4	36.7	39.6	43.7	47.4	50.7
34	19.8	21.7	24.0	26.9	29.2	31.3	35.4	37.8	40.7	44.9	48.6	52.0
35	20.6	22.5	24.8	27.8	30.2	32.3	36.5	38.9	41.8	46.1	49.8	53.2
36	21.3	23.3	25.6	28.7	31.1	33.3	37.5	39.9	42.9	47.2	51.0	54.4
37	22.1	24.1	26.5	29.6	32.1	34.2	38.5	41.0	44.0	48.4	52.2	55.7
38	22.9	24.9	27.3	30.5	33.0	35.2	39.6	42.0	45.1	49.5	53.4	56.9
39	23.7	25.7	28.2	31.4	33.9	36.2	40.6	43.1	46.2	50.7	54.6	58.1
40	24.4	26.5	29.1	32.3	34.9	37.1	41.6	44.2	47.3	51.8	55.8	59.3
41	25.2	27.3	29.9	33.3	35.8	38.1	42.7	45.2	48.4	52.9	56.9	60.6
42	26.0	28.1	30.8	34.2	36.8	39.1	43.7	46.3	49.5	54.1	58.1	61.8
43	26.8	29.0	31.6	35.1	37.7	40.0	44.7	47.3	50.5	55.2	59.3	63.0
44	27.6	29.8	32.5	36.0	38.6	41.0	45.7	48.4	51.6	56.4	60.5	64.2

Table 5.4 (continued)

f	Probability in Percent											
	2.5	5.0	10.0	20.0	30.0	40.0	60.0	70.0	80.0	90.0	95.0	97.5
45	28.4	30.6	33.4	36.9	39.6	42.0	46.8	49.5	52.7	57.5	61.7	65.4
46	29.2	31.4	34.2	37.8	40.5	43.0	47.8	50.5	53.8	58.6	62.8	66.6
47	30.0	32.3	35.1	38.7	41.5	43.9	48.8	51.6	54.9	59.8	64.0	67.8
48	30.8	33.1	35.9	39.6	42.4	44.9	49.8	52.6	56.0	60.9	65.2	69.0
49	31.6	33.9	36.8	40.5	43.4	45.9	50.9	53.7	57.1	62.0	66.3	70.2
50	32.4	34.8	37.7	41.4	44.3	46.9	51.9	54.7	58.2	63.2	67.5	71.4

5.3.1 Failure Terminated Tests:

5.3.1.1 Two-Sided Confidence Level for a Test Terminated On a Failure. Two-sided confidence levels are calculated if it is desired to put both upper and lower bounds on a point estimate MTBF ($\hat{\theta}$).

5.3.1.1.1 Failure Terminated (Two-Sided) Example: A reliability demonstration test is terminated at the seventh failure which occurs at 820 hours total test time. What are the two-sided 80 percent confidence limits?

Solution: $C = 7$

$$\hat{\theta} = 820/7 = 117.14$$

$$\text{Confidence} = 1 - \text{risk} = 1 - \alpha = .8$$

$$\alpha = 1 - .8 = .2$$

From Table 5.3: $\dfrac{2 \times 7 \times 117.14}{\chi^2_{(1-\frac{.2}{2}),\, 2\times 7}} \leq \theta \leq \dfrac{2 \times 7 \times 117.14}{\chi^2_{\frac{.2}{2},\, 2\times 7}}$

Simplifying: $\dfrac{1639.96}{\chi^2_{.9,\,14}} \leq \theta \leq \dfrac{1639.96}{\chi^2_{.1,\,14}}$

From Table 5.4: $\chi^2_{.9,\,14} = 21.1$ $\quad \chi^2_{.1,\,14} = 7.79$

Calculating the Confidence Limits: $\dfrac{1639.96}{21.1} \leq \theta \leq \dfrac{1639.96}{7.79}$

$$77.7 \leq \theta \leq 210.5$$

There is an 80 percent probability that the true MTBF, θ, is between 77.7 hours and 210.5 hours.

5.3.1.2 One-Sided Confidence Level for a Test Terminated on a Failure. A majority of confidence level calculations are concerned only with determining whether a minimum level of MTBF has been exceeded with a certain level of confidence. This is without regard to what the upper bound may be.

5.3.1.2.1 Failure Terminated (One-Sided) Example: A reliability demonstration test is terminated at 820 hours total test time after the occurrence of the seventh failure. What is the one-sided lower 80 percent confidence limit?

Solution: $C = 7$

$$\hat{\theta} = 117.14$$

$$\text{Confidence} = 1 - \text{risk} = 1 - \alpha = .8$$

$$\alpha = 0.2$$

From Table 5.3: $\theta \geq \dfrac{2 \times 7 \times 117.14}{\chi^2_{(1-.2),\, 2\times 7}}$

Simplifying: $\theta \geq \dfrac{1639.96}{\chi^2_{.8,\,14}}$

From Table 5.4: $\chi^2_{.8,\,14} = 18.2$

Calculating the lower confidence level: $\theta \geq \dfrac{1639.96}{18.2} = 90.1$

There is an 80 percent probability that the true MTBF, θ, is at least 90.1 hours.

5.3.2 Time Terminated Tests: The procedure for calculating either one sided or two sided confidence intervals for a time terminated test is analogous to the procedure just presented for the failure terminated cases.

5.4 Poisson Distribution. The Poisson distribution is useful in calculating the probability that a certain number of failures will occur over a certain length of time for systems exhibiting exponential failure distributions (i.e., non-redundant systems). The Poisson model can be stated as follows:

$$P(r) = \frac{e^{-\lambda t}(\lambda t)^r}{r!}$$

Where: P(r) = probability of *exactly* r failures occurring

λ = the true failure rate per hour (i.e., the failure rate which would be exhibited over an infinite period)

t = the test time

r = the number of failure occurrences

e = 2.71828 . . . ,

! = factorial symbol (e.g., $4! = 4 \times 3 \times 2 \times 1 = 24$, $0! = 1$, $1! = 1$)

The probability of exactly 0 failures results in the exponential form of this distribution which is used to calculate the probability of success for a given period of time (i.e., $P(0) = e^{-\lambda t}$). The probability of more than one failure occurring is the sum of the probabilities of individual failures occurring. For example, the probability of two or less failures occurring is $P(0) + P(1) + P(2)$. Table 5.5 is a tabulation of *exact* probabilities used to find the probability of an exact number of failures occurring. Table 5.6 is a tabulation of *cumulative* probabilities used to find the probability of a specific number of failures, or less, occurring.

5.4.1 Poisson Example 1: If the true MTBF of a system is 200 hours and a reliability demonstration test is conducted for 1000 hours, what is the probability of accepting the system if three or less failures are allowed?

Solution: Expected number of failures $= \lambda t = \frac{t}{MTBF} = \frac{1000}{200} = 5$

From Table 5.6, the probability of three or less failures (probability of acceptance) given that five are expected is .265. Therefore, there is only a 26.5 percent chance that this system will be accepted if subjected to this test.

5.4.2 Poisson Example 2: A system has an MTBF of 50 hours. What is the probability of two or more failures during a 10 hour mission?

Solution: Expected number of failures $= \frac{t}{MTBF} = \frac{10}{50} = .2$

The probability of two or more failures is one minus the probability of one or less failures. From Table 5.6, $P(r \leq 1)$ when .2 are expected is .982.

$P(r \geq 2) = 1 - P(r \leq 1)$

$1 - .982 = .018$

Therefore, there is a very remote chance (1.8 percent) that a system with a 50 hour MTBF will experience two or more failures during a 10 hour mission.

5.4.3 Poisson Example 3: A system has an MTBF of 50 hours. What is the probability of experiencing two failures during a 10 hour mission?

Solution: Expected number of failures $= \frac{t}{MTBF} = \frac{10}{50} = .2$

From Table 5.5, the probability of experiencing *exactly two* failures when .2 are expected is .017 or 1.7 percent. It should be noted that the probability of experiencing two or more failures, as determined in the last example, can also be determined from this table by adding $P(r=2) + P(r=3)$ when .2 are expected.

Table 5.5: Summation of Terms of Poisson's Exponential Binomial Limit

1000 times the probability of **exactly r** failure occurrences given an average number of occurrences equal to λt.

Exp Fail	r																					
λt	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0.02	980	020																				
0.04	961	0.38	001																			
0.06	942	056	002																			
0.08	923	074	003																			
0.10	905	090	005																			
0.15	861	129	009	001																		
0.20	819	163	017	001																		
0.25	779	195	024	002																		
0.30	741	222	033	004																		
0.35	705	246	043	006																		
0.40	670	268	054	007	001																	
0.45	638	287	064	010	001																	
0.50	607	303	076	012	002																	
0.55	577	317	088	016	002																	
0.60	549	329	099	020	003																	
0.65	522	339	111	024	003	001																
0.70	497	347	122	028	005	001																
0.75	472	355	132	034	006	001																
0.80	449	360	144	038	008	001																

0.85	427	364	154	044	009	002							
0.90	407	365	165	050	011	002							
0.95	387	367	175	055	013	003							
1.00	368	368	184	061	015	003	001						
1.1	333	366	201	074	021	004	001						
1.2	301	362	216	087	026	006	002						
1.3	273	354	230	100	032	009	002						
1.4	247	345	241	113	040	011	002	001					
1.5	223	335	251	125	047	015	003	001					
1.6	202	322	258	138	055	018	005	001					
1.7	183	310	264	150	063	022	006	002					
1.8	165	298	268	160	073	026	007	002	001				
1.9	150	284	270	171	081	031	010	002	001				
2.0	135	271	271	180	090	036	013	004	001				
2.2	111	244	268	196	109	047	018	005	002				
2.4	091	217	262	209	125	060	024	009	002	001			
2.6	074	193	251	218	141	074	032	012	004	001			
2.8	061	170	238	223	156	087	041	016	006	001	001		
3.0	050	149	224	224	168	101	050	022	008	003	001		
3.2	041	130	209	223	178	114	060	028	011	004	002		
3.4	033	114	103	218	186	127	071	035	015	005	002	001	
3.6	027	099	177	212	191	138	083	042	019	008	003	001	
3.8	022	085	162	204	195	148	093	051	024	010	004	001	001
4.0	018	073	147	195	195	156	104	060	030	013	005	002	001
4.2	015	063	132	185	194	163	114	069	036	017	007	003	001

Table 5.5 (continued)

Exp Fail λt	r																					
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
4.4	012	054	119	174	192	169	124	078	043	021	009	004	001									
4.6	010	046	106	163	188	173	132	087	050	026	012	005	002	001								
4.8	008	040	095	152	182	175	140	096	058	031	015	006	003	001								
5.0	007	034	084	140	175	175	146	104	065	036	018	008	003	001								
5.2	005	029	074	130	168	175	151	112	073	042	022	010	004	002	001							
5.4	004	024	066	119	160	173	155	120	081	048	026	013	006	002	001							
5.6	004	021	058	108	141	170	158	127	089	055	030	016	007	003	001							
5.8	003	017	051	098	143	165	160	133	096	062	036	019	009	004	001	001						
6.0	002	015	045	089	134	161	161	138	103	069	041	022	011	005	002	001						
6.2	002	012	039	081	125	155	160	142	110	076	047	026	014	006	003	001						
6.4	002	011	034	072	116	149	158	145	116	082	052	031	016	008	004	002	001					
6.6	001	009	030	065	107	142	156	147	121	089	059	035	019	010	005	002	001					
6.8	001	007	026	058	099	135	153	149	126	095	064	040	023	012	006	003	001					
7.0	001	006	022	052	091	128	149	149	130	101	070	045	026	014	007	003	001	001				
7.2	001	005	019	046	083	120	144	148	134	107	077	050	030	017	009	004	002	001				
7.4	001	005	017	041	076	113	139	147	136	112	083	056	034	020	010	005	002	001				
7.6	001	003	014	037	070	106	134	145	138	117	089	061	039	023	012	006	003	001	001			
7.8	000	003	012	032	063	099	128	143	139	121	094	067	043	026	014	007	004	002	001			
8.0	000	002	010	029	057	092	122	139	139	124	099	072	048	029	017	009	004	002	001			
8.2	000	002	009	025	041	084	115	136	139	127	104	077	052	033	019	010	005	003	001			

8.4	000	002	008	022	047	078	109	131	138	129	108	082	058	037	022	013	006	003	001	001		
8.6	000	002	007	019	042	072	103	127	137	130	112	088	162	042	025	015	008	004	002	001		
8.8	000	001	006	017	038	066	097	122	134	131	116	092	068	046	029	017	009	005	002	001		
9.0	000	001	005	015	034	061	091	117	132	132	118	098	072	050	032	019	011	006	003	001	001	
9.2	000	001	004	013	030	055	085	111	128	131	120	101	077	055	036	022	013	007	003	002	001	
9.4	000	001	004	011	027	050	080	106	125	131	123	105	082	059	040	025	014	008	004	002	001	
9.6	000	001	003	009	023	045	073	101	121	129	124	108	087	064	044	028	017	009	005	002	001	001
9.8	000	000	002	009	021	041	068	095	117	127	125	111	091	068	048	031	019	011	006	003	001	001
10.0	000	000	002	007	018	037	063	090	112	125	125	114	094	073	052	035	022	013	007	004	002	001

Table 5.6: Summation of Terms of Poisson's Exponential Binomial Limit

1000 times the probability of **r or less** failure occurrences given an average number of occurrences equal to λt.

Exp Fail	r																						
λt	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0.02	980	1000																					
0.04	961	999	1000																				
0.06	942	998	1000																				
0.08	923	997	1000																				
0.10	905	995	1000																				
0.15	861	990	999	1000																			

Table 5.6 (continued)

Exp Fail λt	r																						
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0.20	819	982	999	1000																			
0.25	779	974	998	1000																			
0.30	741	963	996	1000																			
0.35	705	951	994	1000																			
0.40	670	938	992	999	1000																		
0.45	638	925	989	999	1000																		
0.50	607	910	986	998	1000																		
0.55	577	894	982	998	1000																		
0.60	549	878	977	997	1000																		
0.65	522	861	972	996	999	1000																	
0.70	497	844	966	994	999	1000																	
0.75	472	827	959	993	999	1000																	
0.80	449	809	953	991	999	1000																	
0.85	427	791	945	989	998	1000																	
0.90	407	772	937	987	998	1000																	
0.95	387	754	929	984	997	1000																	
1.00	368	736	920	981	996	999	1000																
1.1	333	699	900	974	995	999	1000																
1.2	301	663	879	966	992	998	1000																
1.3	273	627	857	957	989	998	1000																
1.4	247	592	833	946	986	997	999	1000															

1.5	223	558	809	934	981	996	999	1000								
1.6	202	525	783	921	976	994	999	1000								
1.7	183	493	757	907	970	992	998	1000								
1.8	165	463	731	891	964	990	999	1000								
1.9	150	434	704	875	956	987	997	999	1000							
2.0	135	406	677	857	947	983	996	999	1000							
2.2	111	355	623	819	928	975	993	998	1000							
2.4	091	308	570	779	904	964	988	997	999	1000						
2.6	074	267	518	736	877	951	983	995	999	1000						
2.8	061	231	469	692	848	935	976	992	998	999	1000					
3.0	050	199	423	647	815	916	966	988	996	999	1000					
3.2	041	171	380	603	781	895	955	983	994	998	1000					
3.4	033	147	340	558	744	871	942	977	992	997	999	1000				
3.6	027	126	303	515	706	844	927	969	988	996	999	1000				
3.8	022	107	269	473	668	816	909	960	984	994	998	999	1000			
4.0	018	092	238	433	629	785	889	949	979	992	997	999	1000			
4.2	015	078	210	395	590	753	867	936	972	989	996	999	1000			
4.4	012	066	185	359	551	720	844	921	964	985	994	998	999	1000		
4.6	010	056	163	326	513	686	818	905	955	980	992	997	999	1000		
4.8	008	048	143	294	476	651	791	887	944	975	990	996	999	1000		
5.0	007	040	125	265	440	616	762	867	932	968	986	995	998	999	1000	
5.2	006	034	109	238	406	581	732	845	918	960	982	993	997	999	1000	
5.4	005	029	095	213	373	546	702	822	903	951	977	990	996	999	1000	
5.6	004	024	082	191	342	512	670	797	886	941	972	988	995	998	999	1000

Table 5.6 (continued)

Exp Fail λt	r: 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
5.8	003	021	072	170	313	478	638	771	867	929	965	984	993	997	999	1000							
6.0	002	017	062	151	285	446	606	744	847	916	957	980	991	996	998	999	1000						
6.2	002	015	054	134	259	414	574	716	826	902	949	975	989	995	998	999	1000						
6.4	002	012	046	119	235	384	542	687	803	886	939	969	986	994	997	999	1000						
6.6	001	010	040	105	213	355	511	658	780	869	927	963	982	992	997	999	999	1000					
6.8	001	009	034	093	192	327	480	628	755	850	915	955	978	990	996	998	999	1000					
7.0	001	007	030	082	173	301	450	599	729	830	901	947	973	987	994	998	999	1000					
7.2	001	006	025	072	156	276	420	569	703	810	887	937	967	984	993	997	999	999	1000				
7.4	001	005	022	063	140	253	392	539	676	788	871	926	961	980	991	996	998	999	1000				
7.6	001	004	019	055	125	231	365	510	648	765	854	915	954	976	989	995	998	999	1000				
7.8	000	004	016	048	112	210	338	481	620	741	835	902	945	971	986	993	997	999	1000				
8.0	000	003	014	042	100	191	313	453	593	717	816	888	936	966	983	992	996	998	999	1000			
8.5	000	002	009	030	074	150	256	386	523	653	763	849	909	949	973	986	993	997	999	999	1000		
9.0	000	001	006	021	055	116	207	324	456	587	706	803	876	926	959	978	989	995	998	999	1000		
9.5	000	001	004	015	040	089	165	269	392	522	645	752	836	898	940	967	982	991	996	998	999	1000	
10.0	000	000	003	010	029	067	130	220	333	458	583	697	792	864	917	951	973	986	993	997	998	999	1000

Appendix 6

Reliability Growth Testing

6.1 RGT Definition. MIL-STD-785 distinguishes reliability growth testing (RGT) from reliability qualification testing (RQT) as follows:

Reliability Growth Test (RGT): A series of tests conducted to disclose deficiencies and to verify that corrective actions will prevent recurrence in the operational inventory. (Also known as "TAAF" testing).

Reliability Qualification Test (RQT): A test conducted under specified conditions, by, or on behalf of, the government, using items representative of the approved production configuration, to determine compliance with specified reliability requirements as a basis for production approval. (Also known as a "Reliability Demonstration," or "Design Approval" test.)

6.2 RGT Application Effectiveness. An effective way to explain the concept of RGT is by addressing the most frequently asked questions relative to its use as summarized from "Reliability Growth Testing Effectiveness" (RADC-TR-84-20). For more information consult this reference and MIL-HDBK-189, "Reliability Growth Management."

Who pays for the RGT? Does the government end up paying more?

The usual case is that the government pays for the RGT as an additional reliability program cost and in stretching out the schedule. The savings in support costs (recurring logistics costs) exceed the additional initial acquisition cost, resulting in a net savings in LCC. The amount of these savings is dependent on the quantity to be fielded, the maintenance concept, the sensitivity of LCC to reliability and the level of development required. It is the old "pay me now or pay me later situation" which in many cases makes a program manager's situation difficult because his performance is mainly based on the "now" performance of cost and schedule.

Does RGT allow contractors to "get away with" a sloppy initial design because they can fix it later at the government's expense?

It has been shown that *unforeseen problems account for 75% of the failures due to the complexity of today's equipment.* Too low an initial reliability (resulting from an inadequate contractor design process) will necessitate an unrealistic growth rate in order to attain an acceptable level of reliability in the allocated amount of test time. The growth test should be considered as an organized search and correction system for reliability problems that allows problems to be fixed when it is least expensive. It is oriented towards the efficient determination of corrective action. Solutions are emphasized rather than excuses. It can give a nontechnical person an appreciation of reliability and a way to measure its status.

Should all development programs have some sort of growth program?

The answer to this question is yes in that all programs should analyze and correct failures when they occur in prequalification testing. A distinction should be in the level of formality of the growth program. The less challenge there is to the state-of-the-art, the less formal (or rigorous) a reliability growth program should be. An extreme example would be the case of procuring off-the-shelf equipment to be part of a military system. In this situation, which really isn't a development, design flexibility to correct reliability problems is mainly constrained to newly developed interfaces between the "boxes" making up the system. A rigorous growth program would be inappropriate but FRACAS should still be implemented. The other extreme is a developmental program applying technology that challenges the state-of-the-art. In this situation a much greater amount of design flexibility to correct unforeseen problems exists. Because the technology is so new and challenging, it can be expected that a greater number of unforeseen problems will be surfaced by growth testing. All programs can benefit from testing to find reliability problems and correcting them prior to deployment, but the number of problems likely to be corrected and the cost effectiveness of fixing them is greater for designs which are more complex and challenging to the state-of-the-art.

How does the applicability of reliability growth testing vary with the following points of a development program?

(1) Complexity of equipment and challenge to state-of-the-art?

The more complex or challenging the equipment design is, the more likely there will be unforeseen reliability problems which can be surfaced by a growth program. However, depending on the operational scenario, the number of equipments to be deployed and the maintenance concept, there may be a high LCC payoff in using a reliability growth program to fine tune a relatively simple design to maximize its reliability. This would apply in situations where the equipments have extremely high usage rates and LCC is highly sensitive to MTBF.

(2) Operational environment?

All other factors being equal, the more severe the environment, the higher the payoff from growth testing. This is because severe environments are more likely to inflict unforeseen stress associated reliability problems that need to be corrected.

(3) Quantity of equipment to be produced?

The greater the quantities of equipment, the more impact on LCC by reliability improvement through a reliability growth effort.

What reliability growth model(s) should be used?

The model to be used, as MIL-HDBK-189 says, is the simplest one that does the job. Certainly, the Duane is most common, probably with the AMSAA (Army Materiel Systems Analysis Activity) second. They both have advantages; the Duane being simple with parameters having an easily recognizable physical interpretation, and the AMSAA having rigorous statistical procedures associated with it. MIL-HDBK-189 suggests the Duane for planning and the AMSAA for assessment and tracking. When an RQT is required, the RGT should be planned and tracked using the Duane model; otherwise, the AMSAA model is recommended for tracking because it allows for the calculation of confidence limits around the data.

Should there be an accept/reject criteria?

The purpose of reliability growth testing is to *uncover* failures and take corrective actions to prevent their recurrence. Having an accept/reject criteria is a negative contractor incentive towards this purpose. Monitoring the contractor's progress and loosely defined thresholds are needed but placing accept/reject criteria, or using a growth test as a demonstration, defeat the purpose of running them. A degree of progress monitoring is necessary even when the contractor knows that following the reliability growth test he will be held accountable by a final RQT. Tight thresholds make the test an RQT in disguise. Reliability growth can be incentivized but shouldn't be. To reward a contractor for meeting a certain threshold in a shorter time or by indicating "if the RGT results are good, the RQT will be waived," the contractor's incentive to "find and fix" is diminished. The growth test's primary purpose is to improve the design, not to evaluate the design.

What is the relationship between an RQT and RGT?

The RQT is an "accounting task" used to measure the reliability of a fixed design configuration. It has the benefit of holding the contractor accountable some day down the road from his initial design process. As such, he is encouraged to seriously carry out the other design related reliability tasks. The RGT is an "engineering task" designed to improve the design reliability. It recognizes that the drawing board design of a complex system cannot be perfect from a reliability point of view and allocates the necessary time to fine tune the design by finding problems and designing them out. Monitoring, tracking and assessing the resulting data gives insight into the efficiency of the process and provides nonreliability persons with a tool for evaluating the development's reliability status and for reallocating resources when necessary. The forms of testing serve very different purposes and complement each other in development of systems and equipments. **An RGT is not a substitute for an RQT, or other reliability design tasks.**

How much validity/confidence should be placed on the numerical results of RGT?

Associating a hard reliability estimate from a growth process, while mathematically practical, has the tone of an assessment process rather than an improvement process, especially if an RQT assessment will not follow the RGT. In an ideal situation, where contractors are not driven by profit motives, a reliability growth test could serve as an improvement and assessment vehicle. Since this is not the real world, the best that can be done if meaningful quantitative results are needed without an RQT, is to closely monitor the contractor RGT. Use of the AMSAA model provides the necessary statistical procedures for associating confidence levels with reliability results. In doing so, closer control over the operating conditions and failure determinations of the RGT must be exercised than if the test is for improvement purposes only. A better approach is to use a less closely controlled growth test as an improvement technique (or a structured extension of FRACAS, with greater emphasis on corrective action) to fine tune the design as insurance of an accept decision in an RQT. With this approach, monitoring an improvement trend is more appropriate than development of hard reliability estimates. Then use a closely controlled RQT to determine acceptance and predict operational results.

6.3 Duane Model. Because the Duane model is the one most commonly used, it will be further explained. The model assumes that the plot of MTBF versus time is a straight line when plotted on log-log paper. The main advantage of this model is that it is easy to use. The disadvantage of the model is it assumes that a fix is incorporated immediately after a failure occurs (before further test time is accumulated). Because fixes are not developed and implemented that easily in real life, this is rarely the case. Despite this problem, it is still considered a useful planning tool. Below is a brief summary of the Duane model.

a. Growth Rate $$\alpha = \frac{\Delta MTBF}{\Delta TIME}$$

b. Cumulative MTBF $$MTBF_C = \frac{1}{K} T^{\alpha}$$

c. Instantaneous MTBF $$MTBF_I = \frac{MTBF_C}{1-\alpha}$$

d. Test Time $$T = [(MTBF_I)(K)(1-\alpha)]^{\frac{1}{\alpha}}$$

e. Preconditioning period at which system will realize an initial MTBF of $MTBF_c$

$$T_{pc} = \frac{1}{2}(MTBF_{PRED})$$

Where: k = a constant which is a function of the initial MTBF

α = the growth rate

T = the test time

The instantaneous MTBF is the model's mathematical representation of the MTBF if all previous failure occurrences are corrected. Therefore, there is no need to selectively purge corrected failures from the data.

The scope of the up-front reliability program, severity of the use environment and system state-of-the-art can have a large effect on the initial MTBF and, therefore, the test time required. The aggressiveness of the test team and program office in ensuring that fixes are developed and implemented can have a substantial effect on the growth rate and, therefore, test time. Other important considerations for planning a growth test are provided in Table 6.1.

Table 6.1 RGT Planning Considerations

- **To account for down time, calendar time should be estimated to be roughly twice the number of test hours.**
- **A minimum test length of 5 times the predicted MTBF should always be used (if the Duane Model estimates less time). Literature commonly quotes typical test lengths of from 5 to 25 times the predicted MTBF.**
- **For large MTBF systems (e.g., greater than 1000 hours), the preconditioning period equation does not hold; 250 hours is commonly used.**
- **The upper limit on the growth rate is .6 (growth rates above .5 are rare).**

6.4 Prediction of Reliability Growth Expected. It is possible to estimate the increase in reliability that can be expected for an equipment undergoing a reliability growth development program. The methodology to do this is documented in RADC-TR-86-148 "Reliability Growth Prediction."

6.4.1 Terms Explained:

λ_p = MIL-HDBK-217 predicted equipment failure rate (failures per hour).

F_m = Equipment maturity factor. Estimated as the percentage of the design which is new.

K_1 = Number of failures in the equipment prior to test.

$K_1 = 30{,}000 \times F_m \times \lambda_p$

F_A = Test acceleration factor, based on the degree to which the test environment cycle represents the operational environmental cycle.

$$F_A = \frac{T_{OPERATIONAL}}{T_{TEST}} = \frac{\text{Length of operational life}}{\text{Length of test cycle}}$$

$$K_2 = \frac{00005}{6.5}(F_A)$$

6.4.2 Prediction Procedure:

a. Calculate the equipment MTBF prior to test, MTBF(o):

$$\text{MTBF(o)} = \left[\lambda_p + \frac{0.0005\,K_1}{6.5}\right]^{-1}$$

b. Calculate the equipment MTBF after "t" hours of growth testing:

$$\text{MTBF(t)} = \frac{F_A}{(F_A)(\lambda_p) + K_1 K_2 e^{-K_2 t}}$$

c. Percent MTBF Improvement $= \frac{\text{MTBF(t)}}{\text{MTBF(o)}} \times 100$

6.4.3 Example:

To illustrate application of the reliability growth prediction procedure, consider the following hypothetical example of an avionics equipment to be subjected to reliability growth testing during full-scale development. The following assumptions are made:

- 40 percent of the equipment is new design; the remainder is comprised of mature, off-the-shelf items.
- The MIL-HDBK-217 MTBF prediction is 300 hours ($\lambda_p = 1/300$).
- An RGT program is to be conducted during which 3000 hours will be accumulated on the equipment.
- The operational cycle for the equipment is a ten-hour aircraft mission.
- The test profile eliminates the period of operation in a relatively benign environment (e.g., the cruise portion of the mission) resulting in a test cycle of two hours.

The predicted number of failures in the equipment prior to testing is:

$$K_1 = 30{,}000 \times (0.4) \times (1/300) = 40$$

The initial MTBF is:

$$\text{MTBF(o)} = \left[1/300 + \frac{0.0005\,(40)}{6.5}\right]^{-1} = 156 \text{ hours}$$

The test acceleration factor is:

$$F_A = 10/2 = 5$$

The rate of surfacing failures during the test is:

$$K_2 = (0.0005/6.5) \times 5 = 0.0003846$$

The equipment MTBF after incorporation of corrective actions to eliminate those failures identified in the RGT program is:

$$\text{MTBF(3000)} = 5/(5 \times 1/300 + 40 \times 0.0003846\, e^{-0.0003846 \times 3000}) = 232 \text{ hours}$$

Hence, the predicted reliability growth is from an initial MTBF of 156 hours to an improved MTBF of 232 hours, approximately a 50 percent improvement.

Appendix 7

Maintainability/Testability Demonstration Testing

7.1 Testing. This appendix presents a listing of the possible maintainability demonstration plans as determined from MIL-STD-471 "Maintainability Verification Demonstration/Evaluation" and general plans for testability demonstrations. In most circumstances, maintainability and testability demonstrations are linked together and tested concurrently. Concurrent testing is cost effective and reduces the total number of tasks that must be demonstrated.

7.2 Maintainability. For maintainability there are two general classes of demonstration: tests that use naturally occurring failures, and tests that require induced failures. Natural failure testing requires a long test period, while induced testing is only limited to the time to find fix the fault. To run a thirty task test using induced faults, the test time should be less than a week while a natural failure test could require six months or more depending on the failure frequency.

7.2.1 Maintainability Test Recommendations (See Table 7.1 for complete MIL-STD-471 Test Plan listing.)

- Test plan *eight* should be used if dual requirements of the mean and either 90th or 95th percentile of maintenance times are specified and a lognormal distribution is expected.
- Test plan *nine* should be used for mean corrective maintenance, mean preventive maintenance or combination of corrective and preventive maintenance testing. Any underlying distribution can be used in this test plan.
- The sample size of the tasks to be demonstrated should exceed 400 to reduce the risk of biasing the test results.
- The task samples must be based on the failure rate distribution of the equipment to be tested.
- Final selection of the tasks to be demonstrated must be performed by the procuring activity just prior to test.

7.3 Testability. Three parameters which are usually tested in a testability demonstration are: the fault detection capability, the fault isolation capability, and the false alarm rate. Fault detection and isolation parameters are demonstrated using induced faults, while false alarm demonstrations are based on naturally occurring events. (See Table 7.2 for more information on testability demonstration.)

7.3.1 Testability Test Recommendations.

- Fault detection and isolation testing should be combined.
- Test samples should exceed 400 to reduce any bias.
- The test samples should be based on the failure rate distribution of the equipment to be tested.
- False alarm demonstration should be a data collection effort using all the contractor planned tests such as acceptance testing and initial operating tests (IOT).

Table 7.1: Maintainability Demonstration Test Plan Summary

MIL-STD-471

Test Method	Test Variable	Distribution Assumptions	Sample Size	Repair Sample Selection	Confidence Level
1-A	Mean	• Log Normal Distribution • Prior Knowledge of Variance	Note 1	Natural Occurring Failures or Stratified Random Sampling	Note 3
1-B	Mean	• No Distr. Assumption • Prior Knowledge of Variance	Note 1	Natural Occurring Failures or Stratified Random Sampling	Note 3
2	Critical Percentile	• Log Normal Distribution • Prior Knowledge of Variance	Note 2	Natural Occurring Failures or Stratified Random Sampling	Note 3
3	Critical Maint. Time or Manhours	• None	Note 2	Natural Occurring Failures or Stratified Random Sampling	Note 3
4	Median	• A Specific Variance • Log Normal Distribution	20	Natural Occurring Failures or Stratified Random Sampling	.90*
5	Chargeable Maint. Downtime per Flight	• None	Variable, 50 minimum	Natural Occurring Failures	Note 3
6	Man-hour Rate	• None	Variable	Natural Occurring Failures	Note 3

Table 7.1 (continued)

MIL-STD-471 Test Method	Test Variable	Distribution Assumptions	Sample Size	Repair Sample Selection	Confidence Level
7	Man-hour Rate	• None	30 Minimum	Natural Occurring Failures or Stratified Random Sampling	Note 3
8	Mean and Percentile Dual Percentile	• Log Normal • None	Variable (Sequential Test Plan)	Natural Occurring or Simple Random Sampling	Moderate to High
9	Mean (Corrective Task Time, Prev. Maint. Time, Downtime) M_{max} (90 or 95 percentile)	• None	30 Minimum	Natural Occurring or Stratified Random Sampling	Note 3
10	Median (Corrective Task Time, Prev. Maint. Task Time) M_{max} (95 percentile) Corrective Maint. Task Time, Prev. Maint. Task Time	• None	50 Minimum	Natural Occurring Failure or Stratified Random Sampling	Note 3
11	Mean (Prev. Maint. Task Time) M_{max} (Prev. Maint. Task Time, at any percentile)	• None	All Possible tasks	All	NA

Notes:

1. 30 minimum, depends on confidence interval required
2. Depends on confidence interval required
3. Must be defined as part of requirement
4. See Topic T6 for Maintainability Demonstration Plan Selection

*Based on empirical data over 25 years old

Table 7.2: Testability Demonstration Plans

Test Variable	Distribution Assumptions	Sample Size	Procedure	Consumer/Producer Risks
Fraction of Faults Detectable (FFD)	none	Same as maint. demonstration (4 times sample size required)	Failure modes and effects analysis on maint. demonstration samples selected	10% producer 30–40% consumer
Fraction of Faults Isolatable (FFI) to given level of ambiguity	none	Same as maint. demonstration (4 times sample size required)	Failure modes and effects analysis on maint. demonstration samples selected	10% producer 30–40% consumer
False Alarm Rate (FAR)	none	Actual occurring false alarms over given period of operating time	Collect data on false alarms during maint. demonstration	25% consumer risk producer risk sample size dependent

Notes:

1. Since each plan demonstrates a different testability parameter, usually all three plans are used.
2. See MIL-STD-471A (page 78) for specific demonstration procedures.

Appendix 8

Reliability and Maintainability Data Sources

8.1 Reliability Analysis Center (RAC)

RAC is a Department of Defense Information Analysis Center sponsored by the Defense Logistics Agency, managed by the Rome Air Development Center (RADC), and currently operated at RADC by IIT Research Institute (IITRI). RAC is chartered to collect, analyze and disseminate reliability information pertaining to electronic systems and parts used therein. The present scope includes integrated circuits, hybrids, discrete semiconductors, microwave devices, opto-electronics and nonelectronic parts employed in military, space and commercial applications.

Data is collected on a continuous basis from a broad range of sources, including testing laboratories, device and equipment manufacturers, government laboratories and equipment users (government and non-government). Automatic distribution lists, voluntary data submittals and field failure reporting systems supplement an intensive data solicitation program.

Reliability data and analysis documents covering most of the device types mentioned above are available from the RAC. Also, RAC provides reliability consulting, training, technical and bibliographic inquiry services.

For Further Technical Assistance and Information on Available RAC Services, Contact:

Reliability Analysis Center
PO Box 4700
Rome NY 13440-8200
Technical Inquiries: (315) 330-9933
Non-Technical Inquiries: (315) 330-4151
Autovon: 587-4151

All Other Requests Should Be Directed to:

Rome Air Development Center
RBE/Preston R. MacDiarmid
Griffiss AFB NY 13441-5700
Telephone: (315) 330-7095
Autovon: 587-7095

8.2 Government Industry Data Exchange Program (GIDEP)

The GIDEP program is a cooperative activity between government and industry participants for the purpose of compiling and exchanging technical data. It provides an on-line menu driven means for searching for desired information. There are several separate data banks which contain R&M related information:

Data Bank	Content
Engineering	Test reports, nonstandard part justification data, failure analysis data, manufacturing processes.

Data Bank	Content
Reliability and Maintainability	Failure mode and replacement rate data on parts, reports on theories, methods, techniques and procedures related to reliability and maintainability practices.
Failure Experience	Failure information generated on significant problems on parts, processes, materials, etc. Includes ALERTS and failure analysis information.

GIDEP provides special services such as the ALERT system which notifies all participants of significant problem areas and the Urgent Data Request System which allows all participants to be queried for information to solve a specific problem. The information found on-line is usually a brief summary of a report or collected data which provides a reference for further detailed information found on microfilm.

For further information on how to access and use GIDEP, contact:

GIDEP Operation Center
Corona CA 91720-5000
(714) 736-4677
Autovon: 933-4677

8.3 Maintenance and Operational Data Access System (MODAS)

MODAS is an Air Force on-line data storage and access system to track field maintenance events for purposes of product improvement, monitoring product performance and enhancing reliability and maintainability. The data base is menu driven and contains data on both ground and airborne equipment. Data can be sorted and accessed in several ways. For example, data on the top 50 most maintained subsystems on an aircraft can be viewed for a specific geographical area or for a specific aircraft platform. Mean-time-between-maintenance actions (MTBMA) can be calculated from the data on airborne systems because flight hours are also provided with the number of maintenance actions. For further information on MODAS content and access, contact:

Air Force Logistics Command/MMTS
Wright-Patterson AFB OH 45433
(513) 257-6906
Autovon: 787-6906

8.4 Other Data Sources

Air Force

Aircraft Modification Performance Tracking (AMPTS)
AFLC/MME (Perry French)
Autovon: 787-7886
SA-ALC/MMEAI (Herb Cheesman)
Autovon: 945-4225

D041: Recoverable Consumption Item Requirements System
AFLC/MMRS (Sandra Kirby)
Autovon: 787-3460

D066: Commodity Configuration Management System
AFLC/MME (Perry French)
Autovon: 787-7886

D065 MAJCON On-Line Aerospace Vehicle Trainer Reporting System
AFLC (Elizabeth Hayes)
Autovon: 787-7705

G311: Aerospace Vehicle, Inventory and Utilization
HQ USAF (Mr. Robinson)
Autovon: 227-5405

G021: Quality and Reliability Assurance
AFLC/QAA (Jerry Swanson)

B456: System Effectiveness Data System (SEDS)
AFFIC/TEEES (Jan Howell)
Autovon: 527-3066

CDS: F-16 Central Data Base
Dynamics Research (Vern Vutech)
AFLC LOC/TLPO (Robert DeSauty)
Autovon: 787-5646

Maintenance Information Logically Analyzed and Produced (MILAP)
Langley AFB VA (Sgt Young)

Automated Maintenance System (AMS)
WR-ALC (Mike Creasy)
Robins AFB GA

Navy

3M: Maintenance Material Management (Avionics)
NAMSO (Manny Pierucci)
(717) 790-2031

3M: Maintenance Material Management (Ships)
NAMSO (Larry Costelac)
(717) 790-7225

NALDA: Naval Aviation Logistics Data Analysis (AMPAS)
NALC Dept NAM031 (Chuck Carnobas)
(800) 624-6621

NALDA: Naval Aviation Logistics Data Analysis (FOJ)
NALC Dept NAM031 (Chuck Carnobas)
(800) 624-6621

QDEAS: Quality Deficiency Evaluation and Analysis System
Navair (Norman Clark)
(202) 422-4520

AERMIP: Aircraft Equipment Reliability and Maintainability Analysis System
NAVAIR or NAC
Autovon: 724-7284

Army

Feedback Analysis Network (FAN)
AMCCOM (Robert Miller)
(309) 782-2421

Equipment Improvement Recommendations (EIR)
Part of FAN

Equipment Performance Reports (EPR)
Part of FAN

Quality of Deficiency Reports
Part of FAN

Sample Data Collection Reports (SDC)
Part of FAN

Test Incident Reports (TIR)
Part of FAN

Appendix 9

Reliability and Maintainability Education Sources

9.1 R&M Education Sources

This appendix summarizes the following R&M educational sources:

- DoD Academic Offerings
- Private Institution Academic Offerings
- Short Courses/Home Study
- Periodicals
- Symposia and Workshops
- Textbooks

9.2 DoD Academic Offerings

Air Force Offerings:

Air Force Institute of Technology (AFIT) School of Systems & Logistics
Wright-Patterson AFB OH 45433-6583
Autovon: 785-6335/6336/3532
Commercial: (513) 255-6335/6336/3532

The Air Force Institute of Technology offers a Systems Engineering Masters Degree with a reliability specialization. They also offer 16 hours of engineering post graduate study in Professional Specialized Education for R&M, as well as an assortment of graduate and Professional Continuing Education reliability courses in engineering and management.

These courses are primarily for DoD personnel but if certified as beneficial to the DoD, contractor personnel may attend on a space available basis.

Course Title: **Reliability and Maintainability Executive Overview, QMT 020 (JT)**

Length: 3 Class Days

Scope: Basic R&M principles, procedures and techniques applied to design, development, testing and management are explained and related to the system acquisition process, life cycle cost and mission effectiveness.

Course Title: **Reliability Centered Maintenance Analysis (AFLC), LOG 032 (AF)**

Length: 5 Class Days

Scope: The course is limited to the AFLC recommended RCM analysis procedures and presented only on site at AFLC and logistics centers.

Course Title: **Reliability and Maintainability Design in Systems Acquisition, QMT 335 (AF)**

Length: 10 Class Days

Scope: Provides an in-depth explanation of the principles, procedures and techniques of engineering design which can be used to ensure the development of reliable and maintainable systems. Design related subjects include derating, stress analysis, failure modes effect and criticality analysis, sneak circuit analysis, testability and accessibility. Achieving R&M through test-analyze-and-fix, combined environment reliability testing, and environmental stress screening are studied. The course also includes contracting for R&M through discussions of requirements development, contractual documentation, source selection and post contract tasks. Case problems and workshops are used extensively throughout the course to enable the student to apply the theory explained in the classroom.

Course Title: **Reliability, QMT 372 (AF)**

Length: 15 Class Days

Scope: Includes a study of the statistical distributions used in reliability including the binomial, Poisson, normal, exponential and Weibull; reliability allocation and prediction techniques; test plans, O.C. curves and the use of military standards; data analysis and the construction and interpretation of confidence intervals; applications of mathematical models; reliability program management; and current problems of reliability. The participants spend the last week applying these principles and techniques to life cycle costing in a reliability management simulation exercise.

Course Title: **Mathematical Statistics and Probability, QMT 577 (AF)**

Length: 15 Class Days

Scope: An educational program in graduate level mathematical statistics, probability theory, and computer programming. Course includes material on discrete and continuous random variables and their probability distributions, multivariate probability distributions, estimation, hypothesis testing, and order statistics.

Course Title: **Reliability and Maintainability Research and Applications, QMT 578 (AF)**

Length: 15 Class Days

Scope: Includes material on the acquisition process, life cycle costing, data management, military standards and handbooks for reliability and maintainability, simulation, models, reliability and maintainability management and quality control. Students are required to do research on an R&M program and spend 5 days on a simulation exercise performing tasks that they will be required to do as R&M engineers.

Course Title: **Reliability Theory, QMT 579 (AF)**

Length: 20 Class Days

Scope: A graduate level course with primary emphasis on probabilistic engineering design, stress strength analysis, Bayesian methods, Weibull applications, estimation, dynamic reliability models, decision theory, simulation, and recent developments in reliability and maintainability. Several typical examples will be presented and discussed to illustrate how the course material can be applied.

Army Offerings:

U.S. Army Management Engineering Training Activity (AMETA)
Director, AMXOM/PMR
Rock Island IL 61299-7040
Autovon: 793-4041
Commercial: 309-782-4041

These courses are primarily for DoD personnel but if certified as beneficial to the DoD, contractor personnel may attend on a space available basis.

Course Title: **Reliability and Maintainability Orientation Seminar, 8A-F30 (JT)**

Length: 2½ Days

Scope: The course provides an overview of the R&M activities associated with each of the life cycle phases for systems/equipment. It is a non-technical course based on DoD Directive 5000.40. DoD R&M concepts and definitions, engineering activities, accounting activities appropriate for sound decision making, and management activities are discussed along with the relationship of reliability, availability and maintainability to factors such as cost and logistics support. Interrelationships between R&M, and disciplines such as configuration management, system engineering, logistics, and procurement are portrayed. Throughout the course emphasis is placed on successful accomplishment of Governmental R&M functions as distinguished from contract responsibilities.

Course Title: **Workshop in Reliability & Maintainability Program Management, 7A-F28 (JT)**

Length: 2½ Days

Scope: Each workshop will examine high visibility topics which are of current interest to the R&M program manager. The format and content of the workshop will be flexible but will address topics with the goal of developing solutions to problems of immediate interest and concern. Presentations will be made by AMETA faculty and recognized individuals from Government, industry, and the academic community. Attendees should be prepared for active participation in discussions of R&M applications for maximum benefits from the workshop.

Course Title: **Special Topics in Quality and Reliability, AMETA-45**

Length: 1–5 Days

Scope: Course content is flexible and may include modules selected from current AMETA course offerings, or the course content can be specially developed material for a particular situation or group of attendees. The type of educational format can be varied to fit the subjects selected and learning objectives of the class. The course configuration will be based upon mutual agreement between AMETA and the requesting organization.

Course Title: **Design for Reliability and Maintainability, AMETA-118**

Length: 1 Week

Scope: The course is offered as three separate 40 hour modules. All modules consider design from an "engineering" perspective and minimize the use of statistical approaches. Module A presents topics associated with basic reliability techniques, Module B presents basic maintainability techniques, and Module C presents specialized design techniques. Topics covered in each module are:

Module DRM (A), "Basic Reliability Design"—(1) Overview of the Concept of Designing for Reliability; (2) Reliability Modeling, Allocation and Prediction; (3) Failures Modes, Effects and Criticality Analysis (FMECA), Fault-tree Analysis, Cause-Consequence Diagrams; (4) Design Techniques (Operating and Stress); (5) Effects of Functional Testing, Storage, Handling; and (6) Design Review.

Module DRM (B), "Basic Maintainability Design"—(1) Overview of Maintainability Design Concepts; (2) Maintainability Modeling, Allocation, and Prediction; (3) Equipment Design Guidelines; (4) Automated Diagnostics (BIT, BITE, ATE); and (5) Design for Testability.

Module DRM (C), "Specialized Reliability Design"—(1) Introduction to Specialized Reliability Design, (2) Sneak Circuit Analysis, (3) Environmental Stress Analysis, (4) Thermal/Reliability Design & Analysis Techniques, (5) Tolerance Analysis, and (6) Additional Special Reliability Design Subjects—Electrostatic Discharge Control & Software Considerations.

Course Title: **Software Reliability Test and Evaluation, AMETA-120**

Length: 1 Week

Scope: The enrollee will be exposed to material that provides the basis for exploring such software topics as: software terminology and general applications, DoD acquisition policy, the development process, engineering methods, management and planning, MIL-STD-52779A, content and analysis of SQA plans, reviews and audits, and future trends. Throughout the course, emphasis is placed on successful implementation of Governmental reliability and quality software development programs. Exercises and case studies are designed to give students an opportunity to respond to actual situations.

Course Title: **Reliability and Maintainability Engineering Management, AMETA-101**

Length: 2 Weeks

Scope: This is a core course in the R&M fundamentals which are necessary to support the development of program requirements and the administration and control of R&M programs throughout the life cycle. Content stresses Government R&M responsibilities in the areas of establishing and overseeing major programs. Coverage will review DoD R&M programs and policies, address tailoring of R&M program requirements, discuss roles and relationships of functional groups, and identify system life cycle activities having significant impact on R&M. In addition, R&M engineering and accounting tasks, practices and techniques will be discussed to suggest when, how and why they should be applied in a given program.

Course Title: **Production Reliability Assurance, AMETA-100**

Length: 2 Weeks

Scope: Topical coverage includes an introduction to and a brief history of reliability; DoD reliability policy and definitions; reliability assurance in the production process; control and improvement of processes; the importance of activities such as quality assurance, systems engineering, and configuration management; probabilistic and non-probabilistic testing; and management and control of production reliability programs. Coverage addresses Government and contractor efforts required to assure product and replacement part reliability in both new manufacture and rebuild activities. Formal assessment is made of the enrollee's mastery of the course content.

Course Title: **Reliability and Maintainability Requirements, Testing and Evaluation, AMETA-122**

Length: 2 Weeks

Scope: Content of the course will include modules that present, consistent terminology for R&M concepts and relationships, the methods for determining system level R&M testing, and how to conduct R&M test evaluations. State-of-the-art methodologies will be presented in lecture and practical exercises.

Course Title: **Reliability and Maintainability Testing, 8A-F27 (JT)**

Length: 2 Weeks

Scope: Testing concepts and definitions, testing and screening methods, R&M tests from military standards and handbooks, and selection and application of specific testing and screening methods, including shock, vibration, and temperature as stress parameters are addressed. System level testing is *not* addressed in this course.

Course Title: **Quality and Reliability Assurance Intern Program, AMETA-4**

Length: 26 Weeks

Scope: This is a 3-year (maximum) training program structured in three phases. Phase I consists of formal classroom training conducted at AMETA (26 weeks). Phase II consists of OJT involving rotational assignments at the interns PDL (66 weeks). Phase III consists of specialized OJT at the PDL (64 weeks).

Course Title: **Army R&M Requirements, AMETA-121**

Length: 2 Weeks

Scope: This course will address the development, optimization, evaluation and review of system R&M characteristics. It will also address the establishment and testing of user relevant operational R&M requirements. (These are Minimum Acceptable Value (MAV) requirements.) This course will not cover the engineering methods that are used to determine Best Operational Capability (BOC) values.

9.3 Private Institution Academic Offerings

The University of Arizona has long offered a Master of Science degree with a reliability engineering option. They also conduct an annual five day Reliability Engineering and Management Institute, provide short courses and video taped instruction. Contact Dr. Dimitri Kececioglu, Aerospace and Mechanical Engineering Department, Bldg 16, Rm 200B, University of Arizona, Tucson AZ 85721.

The University of Maryland has offered a Master of Science in Reliability Engineering since the fall of 1986. They also provide video taped instruction. Contact Dr. Marvin L. Roush, Center for Reliability Engineering, Chemical and Nuclear Engineering Building, University of Maryland, College Park MD 20742.

The New Jersey Institute of Technology has a long standing graduate program in reliability engineering. Contact Raj Misra, PhD, Professor of Electrical Engineering and Reliability, NJIT, Newark NJ 07102, (201) 596-3511.

Individual courses on R&M subjects have been included in the curricula of many schools, including Pennsylvania State University, VPI, USC, Virginia Tech, SMU and Syracuse University. There are probably many more.

9.4 Short Courses/Home Study

Each year, many short courses and seminars of interest to the R&M community are presented. Most presenters will arrange to bring their courses to any specified location, if the interest is sufficient.

Besides the Universities of Arizona and Maryland, frequent offerings of short courses on Reliability Engineering topics have been made by the Short Course Program Office, UCLA Extension, 10995 LaConte Ave, Los Angeles CA 90024, and The Continuing Engineering Education Center, George Washington University, Washington DC 20052.

The Reliability Analysis Center (a DoD Information Analysis Center managed by RADC), PO Box 4700, Rome NY 13440, offers short courses in Testability Practices Today, Statistical Process Control, Design Reliability, and Practical Statistical Analysis with Reliability Applications. Contact Mr. S. Flint at (315) 330-4151.

The American Society for Quality Control (ASQC) provides a four day course in Reliability Engineering as well as a variety of short courses on Quality Engineering and Management, including one on Software Quality Assurance. ASQC also offers home study courses, video tapes on selected topics, and a variety of textbooks. An ASQC Education and Training Catalog may be obtained from the ASQC Education and Training Institute, 310 West Wisconsin Ave, Milwaukee WI 53203.

The IEEE Reliability Society is preparing a home study course in Reliability Engineering, which is scheduled for completion in September 1987 and release in early 1988. Availability will be announced in the IEEE Spectrum. Contact Mr. Henry Malec, Digital Equipment Corp., 550 King Street, Mailstop: LKG 1-2/C12, Littleton MA 01460-1289.

9.5 Periodicals

The IEEE Transactions on Reliability, which also serves as the journal of the Electronics Division of ASQC, is published five times a year. Subscriptions are free to members of the IEEE Reliability Society and the Electronics Division of ASQC. Others may obtain copies or subscriptions from the IEEE, 345 E. 47th Street, New York City NY 10017.

Reliability Review is published by the Reliability Division of ASQC. It is free to members. Subscriptions to others are $20 per year. Contact Reliability Review, Subscriptions, American Society for Quality Control, 310 W. Wisconsin Ave., Milwaukee WI 53203.

Reliability Engineering is a monthly international journal published by Applied Sciences Publications Ltd., Linton Road, Barking, Essex, England 1G118JU. Subscriptions can be obtained from Elsevier Science Publishing Co., 52 Vanderbilt Ave, New York City NY 10017. Cost is $255 per year.

John Wiley & Sons Ltd, Baffins Lane, Chichester, Sussex P0191UD, England publishes the Quarterly Quality and Reliability Engineering International. Current subscription cost is $89 US currency, which can be sent to Subscription Dept C, John Wiley & Sons Inc., 605 Third Ave, New York City NY 10158.

Evaluation Engineering Magazine is published by A. Verner Nelson Associates, the Nelson Building, 1282 Old Skokie Road, Highland Park IL 60035.

News of current activities in reliability can be found in the RAC NEWSLETTER which is published quarterly and distributed free-of-charge by the Reliability Analysis Center, P.O. Box 4700, Rome, NY 13440.

The RELIABILITY/MAINTAINABILITY TECHNOLOGY TRANSITION-FACT SHEET is published twice a year by the Rome Air Development Center, Systems Reliability and Engineering Division. A letter to RADC/RBE-2, Griffiss AFB NY 13441-5700 requesting the publication is all that is required for inclusion on the regular distribution list.

9.6 Symposia and Workshops

The Annual Reliability and Maintainability Symposium is the premier forum for R&M information exchange. Sponsored by 10 professional societies, it is held every year in January, and includes tutorial sessions. For further information contact IEEE Reliability Society, % IEEE, 345 E. 47th Street, New York, NY 10017, (212) 705-7484 or (212) 705-7900. Back copies of the Symposium Proceedings can be ordered from RAMS, % Evans Associates, 804 Vickers Ave., Durham NC 27701.

The Annual Reliability Physics Symposium is held each April under the sponsorship of the IEEE Reliability and Electron Device Societies. For further information, contact Dr. Robert W. Thomas, RADC/RBRE, Griffiss AFB NY 13441-5700. Since 1985, the conference has been recorded on video tape, available from SAR Associates, RR 2-Box 500, Rome NY 13440.

An Annual Spring Reliability Seminar is presented by the Reliability Society Chapter of the IEEE Central New England Council. The most recent was held April 1987, and the contact listed was Miss Vivian Thorsen, Raytheon Corporation (MET-5-1-210), 528 Boston Post Road, Sudbury MA 01776.

The Institute of Environmental Sciences holds an annual workshop on Environmental Stress Screening. Reliability issues are also included in the annual technical meeting and equipment exposition, held every May. Contact IES at 940 East Northwest Highway, Mount Prospect IL 60056, (312) 255-1561.

The exchange of information on design, engineering, reliability, and standardization relative to microcircuit applications is one of the principal objectives of the annual Government Microcircuit Applications Conference (GOMAC). All sessions are ITAR controlled and one session is classified. The conference alternates between the east and west coasts and is held every October. For more information contact Jay Morreale at Palisades Institute for Research Services, Inc., 201 Varick Street, 11th Floor, New York NY 10014-4889 or Mark Goldfarb, Palisades Institute for Research Services, Inc., Suite 307, One Crystal Park, 2011 Crystal Drive, Arlington VA 22202.

Air Force Systems Command and Air Force Logistics Command sponsor a joint R&M Workshop in October or November each year. The workshop is usually held at Wright-Patterson AFB OH. The focal point for the conference rotates between

AFSC and AFLC. For more information contact: (1) AFSC/PLE, Andrews AFB DC 20334-5000, (301) 981-6429 or Autovon: 858-6429; (2) AFLC-MM, Wright-Patterson AFB OH 45432, (513) 257-2733 or Autovon: 787-2733.

9.7 Textbooks

There are too many textbooks on Reliability to list here. A broad coverage of the technology is found in MIL-HDBK-338, Electronic Reliability Design Handbook, available from the Naval Publication and Forms Center, 5801 Tabor Ave, Philadelphia PA 19120-5099.

Appendix 10

R&M Specifications, Standards, Handbooks and RADC Technical Reports

10.1 Specifications, Standards and Handbooks

As the DoD's Lead Standardization Activity for the Reliability Standardization Area (RELI) and the Maintainability Standardization Area (MNTY), RADC publishes, every two years, the status of all standardization documents in each of these areas. The current plans are Reliability Standardization Document Program Plan (Revision 4 dated 24 April 1987) and Maintainability Standardization Document Program Plan (Revision 2 dated 16 September 1985). This appendix provides a summary of military documents related to the R&M discipline. Table 10.1 lists reliability standards and handbooks along with an abbreviation to cross reference the custodial agencies which are listed in Table 10.3. Table 10.2 lists maintainability standards and handbooks along with abbreviations of custodial agencies which are listed in Table 10.3. Table 10.4 lists other R&M related standards, specifications, pamphlets and regulations.

Table 10.1 Reliability Standards and Handbooks

	Date	Title	Preparing Activity	Custodians		
				Army	Navy	Air Force
Standards						
DoD-STD-1686	2 May 80	Electrostatic Discharge Control Program for Protection of Electrical & Electronic Parts, Assemblies & Equipment (Excluding Electrically Initiated Explosive Devices)	SH	ER	SH	17
MIL-STD-690B Notice 2	1 Aug 74	Failure Rate Sampling Plans & Procedures	CR	CR	EC	11
MIL-STD-721C	12 Jun 81	Definition of Terms for R&M	AS	CR	AS	17
MIL-STD-756B Notice 1	31 Aug 81	Reliability Modeling & Prediction	AS	CR	AS	17
MIL-STD-781D	17 Oct 86	Reliability Testing for Engineering Development, Qualification & Production	EC	CR	EC	11
MIL-STD-785B Notice 1	3 Jul 86	Reliability Program for Systems & Equipment Development & Production	11	CR	AS	11
MIL-STD-790D Notice 1	30 May 86	Reliability Assurance Program for Electronic Parts Specifications	EC	CR	EC	11
MIL-STD-1543A (USAF)	25 Jun 82	Reliability Program Requirements for Space & Missile Systems	19	—	—	19
MIL-STD-1626 (SH)	1 Jun 74	Fitting-Out Management Information System, General Requirements	SH	—	SH	—
MIL-STD-1629A Notice 2	28 Nov 84	Procedures for Performing a Failure Mode, Effects & Criticality Analysis	AS	CR	AS	17
MIL-STD-1635(EC)	3 Feb 78	Reliability Growth Testing (Superseded by MIL-STD-781D)	EC	—	EC	—
MIL-STD-2068(AS)	21 Mar 77	Reliability Development Tests (Superseded by MIL-STD-781D)				
MIL-STD-2074(AS)	15 Feb 78	Failure Classification for Reliability Testing	AS	—	AS	—

MIL-STD-2155(AS)	24 Jul 85	Failure Reporting, Analysis & Corrective Action System (FRACAS)	AS	—	AS	—
MIL-STD-2164(EC)	5 Apr 85	Environmental Stress Screening Process for Electronic Equipment	EC	—	EC	—
Handbooks						
DoD-HDBK-344	20 Oct 86	Environmental Stress Screening of Electronic Equipment	17	CR	EC	17
MIL-HDBK-189	13 Feb 81	Reliability Growth Management	CR	CR	EC	17
MIL-HDBK-217E	27 Oct 86	Reliability Prediction of Electronic Equipment	17	CR	EC	17
MIL-HDBK-251	19 Jun 78	Reliability/Design Thermal Applications	EC	CR	EC	11
DoD-HDBK-263	2 May 80	Electrostatic Discharge Control Handbook for Protection of Electrical & Electronic Parts, Assemblies & Equipment (Excluding Electrically Initiated Explosive Devices)	SH	ER	SH	17
MIL-HDBK-338 Vols I&II	15 Oct 84	Electronic Reliability Design Handbook	17	CR	EC	17
MIL-HDBK-781D	14 Jul 87	Reliability Test Methods, Plans and Environments for Engineering Development, Qualification, and Production	EC	CR	EC	11

Table 10.2 Maintainability Standards and Handbooks

				Custodians		
	Date	Title	Preparing Activity	Army	Navy	Air Force
Standards						
MIL-STD-470A	3 Jan 83	Maintainability Program for Systems & Equipment	17	MI	AS	17
MIL-STD-471A Notice 2	8 Dec 78	Maintainability Verification/Demonstration/Evaluation	17	MI	AS	17
MIL-STD-1591	3 Jan 77	On-Aircraft, Fault Diagnosis, Subsystems Analysis/Synthesis of	17	AV	AS	17

Table 10.2 (continued)

	Date	Title	Preparing Activity	Custodians Army	Custodians Navy	Custodians Air Force
Standards						
MIL-STD-001591A (USAF)	8 Dec 78	Command, Control & Communication (C^3) System Component Fault Diagnosis, Subsystem Analysis/Synthesis of	17	—	—	17
MIL-STD-2084(AS) Notice 1	14 Jun 83	General Requirements for Maintainability of Avionic & Electronic Systems & Equipment	AS	—	AS	—
MIL-STD-2165	26 Jan 85	Test Programs for Electronic Systems & Equipment	EC	CR	EC	17
Handbooks						
MIL-HDBK-472	12 Jan 84	Maintainability Prediction	AS	MI	AS	17

Table 10.3 Custodial Agencies for R&M Documents

Army		Navy		Air Force	
CR	Commander US Army Comm—Elect Command Attn: AMSEL-ED-TO Fort Monmouth NJ 07703-5000 (201) 532-5851	AS	Commanding Officer Naval Air Engineering Center Sys Engrg & Standardization Department (SESD) Code 93 Lakehurst NJ 08733-5100 (201) 323-2326	11	ASD/ENES Wright-Patterson AFB OH 45433-6503 (513) 255-6295
ER	Commander US Army Laboratory Command Industrial Engrg & Devel Div Attn: SLCET-R Fort Monmouth NJ 07703-5302 (201) 544-2882	SH	Commander Naval Sea Sys Command (SEA 55Z3)	17	RADC/RBE-2 Griffiss AFB NY 13441-5700 (315) 330-2101
		DoD	Standardization Prog & Doc Div Department of Navy Washington DC 20362-5101 (202) 692-0160	19	SD/ALM PO Box 92960 Worldway Postal Center Los Angeles CA 90009-2960 (213) 643-1966

AV Commander
US Army Aviation Sys Command
Attn: AMSAV-ELSS
4300 Goodfellow Blvd
St Louis MO 63120-1798
(314) 263-1675

MI Commander
US Army Missile Command
Attn: AMSMI-EDS
Redstone Arsenal AL 35898-5270
(205) 876-1335

EC Commander
Space & Naval Warfare Sys Command
(SPAWAR 003-021)
Washington DC 20363-5100
(202) 692-3535

Table 10.4: Other R&M Related Standards, Specifications, Pamphlets and Regulations

Document	Date	Title
MIL-STD-454K	14 Feb 86	Standard General Requirements for Electronic Equipment
MIL-STD-883C Notice 4	29 Nov 85	Test Methods and Procedures for Microcircuits
MIL-STD-965 Notice 3	26 Aug 83	Parts Control Program
MIL-STD-1309	18 Nov 83	Definition of Terms for Test Measurement and Diagnostic Equipment
MIL-STD-1388/1A	11 Apr 83	Logistics Support Analysis
MIL-STD-1388/2A	20 Jul 84	Logistics Support Analysis Record, DoD Requirements for a
MIL-STD-1547	10 Apr 81	Parts, Materials and Processes for Space and Launch Vehicles
MIL-STD-1562J	31 Jan 86	Lists of Standard Microcircuits

Table 10.4 (continued)

Document	Date	Title
MIL-STD-2165	26 Jan 85	Testability Program for Electronic Systems and Equipment
MIL-E-4158E Amendment 3	11 Jan 73 31 Dec 85	Electronic Equipment, Ground; General Specification for
MIL-E-5400T Amendment 2	9 May 86	Electronic Equipment, Aerospace; General Specifications for
MIL-E-16400(SH) Amendment 1	24 Dec 74 1 Dec 76	Electronic, Interior Communication and Navigation Equipment Naval Ship and Shore, General Specifications for
MIL-M-38510 Amendment 1	31 Oct 83 29 Nov 85	Microcircuits, General Specification for
MIL-S-19500 Amendment 4 Supplement 1B	15 Dec 77 12 Apr 82 17 Feb 83	Semiconductor Devices, General Specifications for
AFSC Pamphlet 800-27	5 Dec 83	Part Derating Guidelines
ESD-TR-85-148	Mar 85	Derating Application of Parts for ESD System Development
PPSL 01, GFB-01 Rev G	25 Jan 88	Program Parts Selection List—Electrical/Electronic Parts DESC/EPA 1507 Wilmington Pike Dayton OH 45444 (513) 296-5431 AV: 986-5431
PPSL 01, Rev B	Feb 84	Program Parts Selection List—Mechanical Parts DISC/ESM 700 Robins Ave. Philadelphia PA 19111 (215) 697-4395 AV: 442-4395

RADC MRAP/SRAP	Updated Quarterly	Microcircuit Reliability Assessment Program/Semiconductor Reliability Assessment Program
AF REG 800-18	15 Jul 82	Air Force Reliability and Maintainability Program
DoD Directive 5000.40	8 July 80	Reliability and Maintainability
RELI	24 Apr 87	DoD Reliability Standardization Document Program Plan, Revision 4
MNTY	16 Sep 85	DoD Maintainability Standardization Document Program Plan, Revision 2
H108	29 Apr 60	Sampling Procedures and Tables for Life & Reliability Testing (Based on Exponential Distribution)

10.2 RADC Technical Reports

Table 10.5 summarizes RADC Technical Reports published from 1975 through this writing which are related to R&M design. Documents with a prefix of "A" in the AD number may be obtained by the general public from:

National Technical Information Service
Department of Commerce
5285 Part Royal Road
Springfield VA 22151
Phone: (703) 487-4650

United States Defense contractors registered with the Defense Technical Information Center may obtain RADC reports from:

Defense Technical Information Center
Cameron Station
Alexandria Station
Alexandria VA 22304
Phone: (202) 274-7633

Table 10.5 RADC Reliability/Maintainability Technical Reports

RADC-TR-	AD No.	Title
75-149	AD-A012196	Reliability, Maintainability and Availability Analysis Trade-Off Tool
75-206	AD-B031785	Maintainability Design of Digital Systems/Equipments
75-253	AD-A023926	Reliability Growth Studies
76-32	AD-A023956	Guidelines for Application of Warranties to Air Force Electronic Systems
76-38	AD-A022669	Mathematical Methods of Resource Allocation for Optimizing Reliability
76-366	AD-A035016	Operational Influences on Reliability
77-12	AD-A036683	A Survey of Network Approaches to Complex System Reliability
77-13	AD-A036868	System Modularization to Minimize Life Cycle Costs
77-49	AD-A039344	Implementation of Operational Procedures for Optimized Reliability and Component Life Estimator
77-193	AD-A042983	Operational Influences on Maintainability
77-287	AD-A050837	A Redundancy Notebook
78-55	AD-A053561	Electronic Equipment Screening and Debugging Techniques
78-169	AD-A059753	Maintainability Prediction and Analysis Study
78-207	AD-A061636	Multilevel Modularization of Systems to Minimize Life Cycle Cost
78-224	AD-A069384	A Design Guide for Built-in Test (BIT)
79-103	AD-A069920	The Use of Air Force Field Maintenance Data for R&M Assessment of Air Force Ground Electronic Systems
79-200	AD-A073299	Reliability and Maintainability Management Manual
79-287	AD-A082318	Warranty-Guarantee Application Guidelines for Air Force Ground Electronic Equipment
79-309	AD-A081128	BIT/External Test Figures of Merit and Demonstration Techniques
79-327	AD-A082329	An Objective Printed Circuit Board Testability Design and Rating System

Table 10.5 (continued)

RADC-TR-	AD No.	Title
80-32	AD-A083488	Built-in-Test and External Tester Reliability Characteristics
80-111	AD-A087059	Design Guidelines and Optimization Procedures for Test Subsystem Designs
81-87	AD-A099207	Burn-in: Which Environmental Stress Screens Should be Used
81-220	AD-A108752	Analysis of Built-in-Test False Alarm Conditions
81-329	AD-A111258	Correlation of Field Data With Reliability Prediction Models
82-68	AD-A116566	Combined Hardware/Software Reliability Models
82-87	AD-A118261	Stress Screening of Electronic Hardware
82-133	AD-A117979	Finite Element Analysis of Microelectronic Packages
82-141	AD-A120368	R&M Analysis of Electromechanical Equipments
82-172	AD-A118839	RADC Thermal Guide for Reliability Engineers
82-177	AD-A120367	Reliability Parts Derating Guidelines
82-179	AD-A118479L	Sneak Analysis Application Guidelines
82-189	AD-A118881L	RADC Testability Notebook
83-2	AD-A127546	Study of Causes of Unnecessary Removals of Avionic Equipment
83-4	AD-A126167	Analytical Procedures for Testability
83-13	AD-A129328	Missile and Space Systems Reliability vs Cost Trade-Off Study
83-36	AD-A129438	Fault Tolerance, Reliability and Testability of Distributed Systems
83-49	AD-A130465	Guide to Government Reliability, Maintainability and Quality Assurance Organizations
83-72	AD-A131358	The Evolution and Practical Applications of Failure Modes and Effects Analyses
83-85	AD-A133624 Vol I AD-A133625 Vol II	Reliability Programs for Nonelectronic Designs

83-108	AD-A135705	Reliability Modeling of Critical Electronic Devices
83-180	AD-A138576	Condition Monitoring Techniques for Electromechanical Equipment Used in AF Ground C3I Systems
83-257	AD-A149683	Computer Aided Testability Design Analysis
83-291	141147	Advanced Applications of the Printed Circuit Board Testability Design and Rating System
83-316	AD-B083630	Hardware/Software Tradeoffs for Test Systems
84-20	AD-A141232	Reliability Growth Testing Effectiveness
84-25	AD-B087426 Vol I AD-B087507 Vol II	Reliability/Maintainability Operational Parameter Translation
84-57	AD-B086070L	Reliability, Testability Design Considerations for Fault Tolerant Systems
84-100	AD-B086478L	Thermal Stress Analysis of Integrated Circuits Using Finite Element Methods
84-165	AD-A149684	Maintainability Time Standards for Electronic Equipment
84-203	AD-A150694	Artificial Intelligence Applications to Testability
84-244	AD-A154161	Automated FMEA Techniques
84-254	AD-A153744	Reliability Derating Procedures
84-268	AD-A153761	Prediction of Scheduled and Preventative Maintenance Workload
85-66	AD-A157242	Study and Investigation to Update the Nonelectronic Reliability Notebook
85-91	AD-A158843	Impact of Nonoperating Periods on Equipment Reliability
85-148	AD-B098377	Smart BIT
85-150	AD-A162617	A Rationale and Approach for Defining and Structuring Testability Requirements
85-194	AD-A163900	RADC Nonelectronic Reliability Notebook
85-228	AD-A165231	Impact of Hardware/Software Faults on System Reliability—Study Results
85-228	AD-A165232	Impact of Hardware/Software Faults on System Reliability—Procedures for Use of Methodology
85-229	AD-A164747	Reliability Prediction for Spacecraft
85-268	AD-A167957	Prediction and Analysis of Testability Attributes: Organizational Level Testability Prediction
86-97	AD-B108417	Thermal Resistances of Joint Army Navy (JAN) Certified Microcircuit Packages

Table 10.5 (continued)

RADC-TR-	AD No.	Title
86-138	AD-A174333	RADC Guide to Environmental Stress Screening
86-148	AD-A176128	Reliability Growth Prediction
86-149	AD-A176847	Environmental Stress Screening
86-195	AD-B110761L Vol I AD-B111438L Vol II	Tools for Integrated Diagnostics
86-241	AD-A182335	Built-in-Test Verification Techniques
87-11	AD-A181856	Availability Equations for Redundant Systems, Both Single and Multiple Repair Capability
87-13	AD-B119216	Maintenance Concepts for VHSIC
87-50	AD-A182773	R&M Program Cost Drivers
87-55	AD-A183142	Predictors of Organizational-Level Testability Attributes
87-92	AD-B117765L	Large Scale Memory Error Detection and Correction
87-177	AD-A189488	Reliability Analyses of a Surface Mounted Package Using Finite Element Simulation
87-198	*	Automated TRD Generation
87-225	*	Improved Readiness Thru ESS
88-13	*	VHSIC Impact on System Reliability
88-72	*	Reliability Assessment of Surface Mount Technology (SMT)
TBD	*	Reliability/Maintainability/Testability Design for Dormancy

*AD numbers not yet assigned.

Appendix 11

Major Air Force R&M Focal Points

Air Force R&M Focal Points

AF Special Assistant for R&M
AF/LE-RD
Washington DC 20330-5130
(202) 695-9836/AV: 225-9836

- **Major Commands**
- **Special Operating Agencies**
- **Direct Reporting Units**

Strategic Air Command
SAC/XPR
Offutt AFB NE 68113
(402) 294-5781/AV: 271-5781

US Space Command
SPACECMD/LKYY
Peterson AFB CO 80914
(303) 554-3286/AV: 692-3286

Electronics Security Command
ESC/LGMM
Kelly AFB TX 78243-5000
(512) 925-2736/AV: 945-2736

Pacific Air Force
PACAF/DOQQ
Hickham AFB HI 96853-5001
(808) 449-6331/AV: 449-6331

Air University
AU/XPO
Maxwell AFB AL 36112-5001
(205) 293-2159/AV: 875-2159

AF Reserve Headquarters
AFRES/LGMAB
Robins AFB GA 31098
(912) 926-3672/AV: 468-3672

Military Airlift Command
MAC/LG-R
Scott AFB IL 62225
(618) 256-4041/AV: 576-4041

AF Systems Command
AFSC/PLE
Andrews AFB DC 20334-5000
(301) 981-6429/AV: 858-6429

AF Communications Command
AFCC/RE
Scott AFB IL 62225
(618) 256-4456/AV: 576-4456

AF Coordinating Off for Logistics
AFCOLR/CC
Wright-Patterson AFB OH 45433
(513) 255-4758/AV: 785-4758

AF Operational Test & Eval Center
AFOTEC/LG4W
Kirtland AFB NM 87117
(505) 846-1296/AV: 246-1296

National Guard Bureau
NGB/LGM
Washington DC 20310-2500
(202) 695-0997/AV: 225-0997

Tactical Air Command
TAC/SMO-R&M
Langley AFB VA 23665
(804) 764-7230/AV: 574-7230

AF Logistics Command
AFLC/MM-R
Wright-Patterson AFB OH 45432
(513) 257-5245/AV: 787-5245

AF Logistics Ops Center
AFLC LOC/CFE
Wright-Patterson AFB OH 45433
(513) 257-5567/AV: 787-5567

AF Acquisition Logistics Center
AFALC/ER
Wright-Patterson AFB OH 45433
(513) 225-2506/AV: 785-2506

AF Technology Application Center
AFTAC/AQE
Patrick AFB FL 32925
(305) 494-5175/AV: 854-5175

AF Engineering Services Center
AFESC/DEMM
Tyndall AFB FL 32403
(904) 283-6373/AV: 523-6373

Air Training Command
ATC/LGX
Randolph AFB TX 78150-5000
(512) 652-2526/AV: 487-2526

Alaskan Air Command
AAC/LGMM
Elmendorf AFB AK 99506-5001
(907) 552-5606/AV: 552-5606

USAF Europe
USAFE/DOQ
APO NY 09012
06371-47/AV: 480-6568

AF Institute of Technology
AFIT/XP
Wright-Patterson AFB OH 45433
(513) 255-2321/AV: 785-2321

AF Inspection & Safety Center
AFISC/SAMI
Norton AFB CA 92409-7001
(714) 382-2093/AV: 876-2093

AF Military Personnel Center
AFMPC/MPCYXX
Randolph AFB TX 78150
(512) 652-5926/AV: 487-5926

- **AFSC Divisions**

Electronics Systems Division
ESD/PL
Hanscom AFB MA 01731-5000
(617) 271-6319/AV: 478-5980
X188-6319

Aeronautical Systems Division
ASD/EN
Wright-Patterson AFB OH 45433
(513) 255-5874/AV: 785-5874

Space Division
SD/ALR
PO 92960 LA CA 90009-2960
(213) 643-1182/AV: 833-1182

Ballistic Missile Division
BMO/AWR
Norton AFB CA 92409-6468
(714) 382-7067/AV: 876-7067

Armament Division
AD/YIP
Eglin AFB FL 32542-5000
(904) 882-8652/AV: 872-8652

Space & Missile Test Organization
ETR/ROM
Patrick AFB FL 32925
(305) 494-4346/AV: 854-4346

Space & Missile Test Organization
WSMC/QA
Vandenberg AFB CA 93437
(805) 866-6286/AV: 276-6286

AF Contract Mgmt Division
AFCMD/EPL
Kirtland AFB NM 87117-5000
(505) 844-9516/AV: 244-9516

AF Flight Test Center
AFFTC/ENAR
Edwards AFB CA 93523
(805) 277-3066/AV: 527-3066

- **AFSC Laboratories**

Rome Air Development Center
RADC/RBE
Griffiss AFB NY 13441-5700
(315) 330-4921/AV: 587-4921

AF Armament Laboratory
AFATL/DLX
Eglin AFB FL 32542-5434
(904) 882-2205/AV: 872-2205

AF Wright Aeronautical Labs
AFWAL/FIX
WPAFB OH 45433
(513) 255-5423/AV: 785-5423

Aerospace Medical Laboratory
AAMRL/TID
WPAFB OH 45433
(513) 255-2423/AV: 785-2423

AF Weapons Laboratory
AFWL/SU
Kirtland AFB NM 87117-6008
(505) 244-9619/AV: 244-9619

AF Engineer Services Center
AFESC/RDXP
Tyndall AFB FL 32403
(904) 283-6288/AV: 523-6288

AF Human Resources Lab
AFHRL/LR
WPAFB OH 45433
(513) 255-3713/AV: 785-3713

AF Geophysics Laboratory
AFGL/XO
Hanscom AFB MA 01731-5000
(617) 861-3006/AV: 478-3006

AF Astronautical Lab
AFRPL/XR
Edwards AFB CA 93523-5000
(805) 277-5340/AV: 525-5340

AF Space Technology Center
AFSTC/XRN
Kirtland AFB NM 87117-6008
(515) 846-5545/AV: 246-5545

Appendix 12

Acronyms

μ	Repair Rate ($1/M_{CT}$)
λ	Failure Rate (1/MTBF)
$\propto$	Producers Risk
β	Consumers Risk
θ_{c-a}	Case to Ambient Thermal Resistance
θ_{j-c}	Junction to Case Thermal Resistance
θ_{j-a}	Junction to Ambient Thermal Resistance
$\hat{\theta}$	Observed Point Estimate MTBF
θ_0	Upper Test (Design Goal) MTBF
θ_1	Lower Test (Unacceptable) MTBF
θ_p	Predicted MTBF
AAA	Allocations, Assessment and Analysis (report)
ADAS	Architecture Design and Assessment System
ADM	Advanced Development Model
ADP	Automatic Data Processing
ADPE	Automatic Data Processing Equipment
AFALC	Air Force Acquisition Logistics Center
AFLC	Air Force Logistics Command
AFR	Air Force Regulation
AFSC	Air Force Systems Command
AFTO	Air Force Technical Order
AGS	Ambiguity Group Size
AI	Artificial Intelligence
AJ	Antijam
ALU	Arithmetic Logic Unit
AMGS	Automatic Microcode Generation System
AMSDL	Acquisition Management Systems and Data Control List
AP	Array Processor
APTE	Automatic Programmed Test Equipment
APU	Auxiliary Power Unit
ARM	Antiradiation Missile
ASA	Advanced Systems Architecture

ASD	Aeronautical Systems Division
ASIC	Application Specific Integrated Circuit
ATE	Automatic/Automated Test Equipment
ATF	Advanced Tactical Fighter
ATG	Automatic Test Generation
ATP	Acceptance Test Procedure
Ai	Inherent Availability
Ao	Operational Availability
B	Bit
BB, B/B	Brass Board
BCC	Block Check-Sum Character
BCS	Bench Check Serviceable
BIT	Built-In-Test
BITE	Built In Test Equipment
BIU	Bus Interface Unit
BLER	Block Error Rate
BPS	Bits Per Second
C	Centigrade
C-ROM	Control ROM
C^3	Command, Control and Communications
C^3CM	Command, Control, and Communications Countermeasures
C^3I	Command, Control, Communications and Intelligence
CA	Contracting Activity
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Content Addressable Memory
CAS	Column Address Strobe
CASS	Computer Aided Schematic System
CAT	Computer Aided Test
CB	Chip Boundary
CCB	Capacitive Coupled Bit

CCC	Ceramic Chip Carrier
CCD	Charged Coupled Device
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CFAR	Constant False Alarm Rate
CGA	Configurable Gate Array
CIM	Computer Integrated Manufacturing
CISC	Complex Instruction Set Computer
CIU	Control Interface Unit
CLCC	Ceramic Leaded Chip Carrier
CML	Current Mode Logic
CMOS	Complementary Metal Oxide Semiconductor
CND	Can Not Duplicate
CNI	Communications, Navigation, and Identification
CODEC	Coder Decoder
COMM	Communications
COMSEC	Communications Security
COPS	Complex Operations Per Second
CPM	Control Processor Module
CPU	Central Processing Unit
CRC	Cyclic Redundance Check
CS	Chip Select
CSCI	Computer Software Configuration Item
CSP	Common Signal Processor
CSR	Control Status Register
CTE	Coefficient of Thermal Expansion
CV	Capacitance-Voltage
D/A	Digital-to-Analog
dB	Decibel
dc	Direct Current
DECTED	Double Error Correcting, Triple Error Detecting
DED	Double Error Detection

DESC	Defense Electronics Supply Center
DID	Data Item Description
DIP	Dual In-Line Package
DISC	Defense Industrial Supply Center
DP	Data Processor
DPA	Destructive Physical Analysis
DRAM	Dynamic Random Access Memory
DUT	Device Under Test
DoD	Department of Defense
DoD-ADL	DoD Authorized Data List
EAROM	Electrically Alterable ROM
ECC	Error Checking and Correction
ECCM	Electronic Counter Countermeasures
ECM	Electronic Counter Measures
EDA	Electronic Design Automation
EDAC	Error Detection and Correction
EDM	Engineering Development Model
EEPROM	Electrically Erasable PROM
EEPROM	Electrically Erasable Programmable Read Only Memory
EGC	Equivalent Gate Count
EGS	Electronic Ground System
EGSE	Electronic Ground Support Equipment
EMC	Electromagnetic Compatibility
EMP	Electronic Magnetic Pulse
EP	Electrical Parameter
EPROM	Erasable PROM
ER Part	Established Reliability Part
ERC	Electrical Rule Check
ESD	Electronic Systems Division
ESD	Electrostatic Discharge
ESM	Electronics Support Measure
ESS	Environmental Stress Screening

eV	Electron Volt
EW	Electronic Warfare
EXP	Exponent
F/W	Firmware
FAB	Fabrication
FAR	False Alarm Rate
FARR	Forward Area Alerting Radar Receiver
FBT	Functional Board Test
FD	Fault Detection
FDI	Fault Detection and Isolation
FFT	Fast Fourier Transform
FFTAU	FFT Arithmetic Unit
FFTCU	FFT Control Unit
FI	Fault Isolation
FIFO	First In First Out
FILO	First In Last Out
FITS	Failures Per 10^9 Hours
FIT	Fault Isolation Test
FLIR	Forward Looking Infrared
FMC	Full Mission Capability
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FOM	Figure of Merit
FP	Floating Point
FPAP	Floating Point Array Processor
FPLA	Field Programmable Logic Array
FPMH	Failures Per Million Hours
FQT	Final Qualification Test
FRACAS	Failure Reporting and Corrective Action System
FRB	Failure Review Board
FS	Full Scale
FSD	Full Scale Development

FSED	Full Scale Engineering Development
FT	Fourier Transform
GD	Global Defect
GFE	Government Furnished Equipment
GIDEP	Government Industry Data Exchange Program
GM	Global Memory
GOMAC	Government Microcircuit Applications Conference
GSPA	Generic Signal Processor Architecture
GaAs	Gallium Arsenide
H/W	Hardware
HDL	Hardware Description Language
HDS	Hierarchical Design System
HFTA	Hardware Fault Tree Analysis
HHDL	Hierarchical Hardware Description Language
HOL	Higher Order Language
Hz	Hertz
I	Current
I/F	Interface
IAC	Information Analysis Center
IAW	In Accordance With
IC	Integrated Circuit
ICT	In Circuit Testing
ICWG	Interface Control Working Group
IDAS	Integrated Design Automation System
IES	Institute of Environmental Sciences
IFF	Identification Friend or Foe
IFFT	Inverse FFT
ILS	Integrated Logistics Support
IMPATT	Impact Avalanche and Transit Time
INEWS	Integrated EW System
ISA	Instruction Set Architecture

ISPS	Instruction Set Processor Specification
ITAR	International Traffic In Arms Regulation
ITM	Integrated Test and Maintenance
JAN	Joint Army Navy
K	Thousand
KOPS	Kilo Operations Per Second
LAN	Local Area Network
LCC	Life Cycle Cost
LCCC	Leadless Ceramic Chip Carrier
LED	Light Emitting Diode
LFR	Launch and Flight Reliability
LHR	Low Hop Rate
LIF	Low Insertion Force
LIFO	Last In First Out
LISP	List Processing
LRM	Line Replaceable Module
LRU	Line Replaceable Unit
LSA	Logistics Support Analysis
LSB	Least Significant Bit
LSE	Lead System Engineer
LSI	Large Scale Integration
LUT	Look Up Table
M	Maintainability
M	Million
mA	Milliampere
Mct	Mean Corrective Maintenance Time
M-MM	Mean Maintenance Manhours
MAC	Multiplier Accumulator Chip
MAP	Modular Avionics Package
MBPS	Million Bits Per Second
MCFOS	Military Computer Family Operating System

MCOPS	Million Complex Operations Per Second
MCTL	Military Critical Technology List
MCU	Microcontrol Unit
MDCS	Maintenance Data Collection System
MDM	Multiplexer/Demultiplexer
MDT	Maintainability Demonstration
MDT	Mean Down Time
MENS	Mission Element Needs Statement
MENS	Mission Equipment Needs Statement
MFLOPS	Million Floating Point Operations Per Second
MHz	Megahertz
MIMIC	Microwave Millimeter Wave Monolithic IC
MIPS	Million Instructions Per Second
MISD	Multiple Instructions Single Data
MLB	Multilayer Board
MLIPS	Million Logic Inferences/Instructions Per Second
mm	Millimeter
MMBF	Mean Miles Between Failure
MMD	Mean Mission Duration
MMH/FH	Maintenance Manhours Per Flight Hour
MMH/PH	Mean Manhours Per Possessed Hour
MMM	Mass Memory Module
MMPS	Million Multiples Per Second
MMR	Multimode Radar
MMS	Mass Memory Superchip
MMW	Millimeter Wave
MN	Maintenance Node
MIN	Maintenance Interface Network
MNN	Maintenance Network Node
MODEM	Modulator Demodulator
MOPS	Million Operations Per Second
MOS	Metal Oxide Semiconductor

MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MP	Maintenance Processor
MPCAG	Military Parts Control Advisory Group
MRAP	Microcircuit Reliability Assessment Program
ms	Millisecond
MSB	Most Significant Bit
MSI	Medium Scale Integration
MTBCF	Mean Time Between Critical Failures
MTBD	Mean Time Between Demand
MTBDE	Mean Time Between Downing Events
MTBF	Mean Time Between Failure
MTBFF	Mean Time Between Functional Failure
MTBM-IND	Mean Time Between Maintenance-Induced (Type-2 Failure)
MTBM-INH	Mean Time Between Maintenance-Inherent (Type-1 Failure)
MTBM-ND	Mean Time Between Maintenance-No Defect (Type-6 Failure)
MTBM-P	Mean Time Between Maintenance-Preventive
MTBM-TOT	Mean Time Between Maintenance-Total
MTBMA	Mean Time Between Maintenance Actions
MTBR	Mean Time Between Removals
MTBUMA	Mean Time Between Unscheduled Maintenance Actions
MTE	Multipurpose Test Equipment
MTE	Minimal Test Equipment
MTI	Moving Target Indicator
MTTE	Mean Time To Error
MTTF	Mean Time To Failure
MUX	Multiplexer
MW	Milliwatt
MWPS	Million Words Per Second
Mb	Megabit
Mil	1000th of an inch
NDT	Nondestructive Testing
NMOS	N-Channel Metal Oxide Semiconductor

ns	Nanosecond
OPS	Operations Per Second
OROM	Optical ROM
OTS	Off-The-Shelf
PAL	Programmable Array Logic
PAT	Programmable Alarm Thresholds
PC	Printed Circuit
PCB	Printed Circuit Board
PD	Power Dissipation
PDL	Program Design Language
PDR	Preliminary Design Review
PGA	Pin Grid Array
PLA	Programmable Logic Array
PLCC	Plastic Leadless Chip Carrier
PLD	Programmable Logic Device
PMD	Program Management Directive
PMOS	P-Channel Metal Oxide Semiconductor
PMP	Program Management Plan
PMP	Parts, Materials and Processes
PPB	Parts Per Billion
PPM	Parts Per Million
PPSL	Preferred Parts Selection List
PRR	Production Readiness Review
PRST	Probability Ratio Sequential Test
PW	Pulse Width
PWB	Printed Wiring Board
Poly	Polycrystalline Silicon
QA	Quality Assurance
QC	Quality Control
QPL	Qualified Parts List
QUMR	Quality Unsatisfactory Material Report

R	Reliability
R&M	Reliability and Maintainability
RAD	Measurement of Radiation
RAM	Random Access Memory
RAMS	Reliability and Maintainability Symposium
RD	Random Defect
RDT	Reliability Demonstration Test
REG	Register
RETOK	Retest Okay
RFP	Request For Proposal
RISA	Reduced Instruction Set Architecture
RISC	Reduced Instruction Set Computer
RIW	Reliability Improvement Warranty
RMS	Remote Monitoring System
RMS	Root Mean Square
ROM	Read Only Memory
RQT	Reliability Qualification Test
RSA	Rapid Simulation Aids
RSR	Runtime Status Register
RTL	Register Transfer Language
RTOK	Retest Okay
RTQC	Real Time Quality Control
Rads(Si)	Rads Silicon (Total Dose)
S/N	Signal to Noise Ratio
S/W	Software
SAMSO	Space and Missile Systems Organization
SAR	Synthetic Aperture Radar
SAW	Surface Acoustic Wave
SCD	Specification Control Drawing
SD	Space Division
SDI	Strategic Defense Initiative
SDL	System Description Language

SDS	Structured Design System
SE	Support Equipment
SECDED	Single Error Correction, Double Error Detection
SED	Single Error Detection
SEM	Standard Electronic Module
SER	Soft Error Rate
SEU	Single Event Upset
SIP	Single In-Line Package
SMD	Standard Military Drawing
SMD	Surface Mounted Device
SMT	Surface Mounted Technology
SOI	Silicon On Insulator
SOIC	Small Outline IC
SOS	Silicon On Sapphire
SOW	Statement of Work
SPAD	Scratch Pad Memory
SR	Slew Rate
SRA	Shop Replaceable Assembly
SRAM	Static RAM
SRAP	Semiconductor Reliability Assessment Program
SRL	Shift Register Latch
SRR	Systems Requirements Review
SRU	Shop Replaceable Unit
SRU	Shop Repairable Unit
SSEB	Source Selection Evaluation Board
SSI	Small Scale Integration
SSPA	Submicron Signal Processor Architecture
ST	Self Test
STE	Special Test Equipment
TBD	To Be Determined
TC	Temperature Coefficient
TCE	Thermal Coefficient of Expansion

TCR	Temperature Coefficient of Resistance
TDM	Time Division Multiplexing
TET	Technical Evaluation Team
TM	Test Modules
TMDE	Test Measurement and Diagnostic Equipment
TMP	Test and Maintenance Processor
TPS	Test Program Set
TRD	Test Requirements Document
TRR	Test Readiness Review
TSMD	Time Stress Measurement Device
TTL	Transistor-Transistor Logic
Ta	Ambient Temperature
Tj	Junction Temperature
Tstg	Storage Temperature
UHF	Ultra High Frequency
ULSI	Ultra Large Scale Integration
UMF	Universal Matched Filter
UUT	Unit Under Test
V	Volt
VCP	VHSIC Communications Processor
VHDL	VHSIC Hardware Description Language
VHSIC	Very High Speed Integrated Circuit
VIA	Interconnection point between different metal conduction layers.
VIM	VHSIC Insertion Module
VLSI	Very Large Scale Integration
VSM	VHSIC Submicron
VSP	Variable Site Parameters
VTB	VHSIC Technology Brassboard
WAM	Window Addressable Memory
WSI	Wafer-Scale Integration
WSIC	Wafer Scale Integrated Circuit

X	Reactance
Y	Admittance
Z	Impedance