

Engineering Standard Practice

RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

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Issue. 2

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

PREFACE

The de Havilland Reliability and Maintainability (R&M) Policies and Procedures document defines the R&M and Safety requirements and guidelines to be used by de Havilland and the suppliers thereto. The document standardizes necessary R&M activities and defines the methodologies to ensure that an optimized level of designed in and sustained product safety, reliability, maintainability and minimum life cycle cost are achieved.

The information contained herein has primarily been developed for the de Havilland Dash 8 Series 400 aircraft program, however, it is not precluded from application to all other existing or future de Havilland products.

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**RELIABILITY AND MAINTAINABILITY POLICIES AND
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1996-07-05

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Chapter 1

RELIABILITY PROGRAM PLAN

1996-07-05

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 1

1 RELIABILITY PROGRAM PLAN

1.1 INTRODUCTION

This procedure outlines DHI's requirements for Supplier Reliability Control Plans.

The Reliability Program Plan demonstrates to DHI the Supplier's capability to manage the Reliability program and provides Suppliers with a formal approach for managing the elimination or minimization and control of hazards, and optimizing inherent system reliability for minimum life cycle costs. It ensures acceptable methods are used for evaluating and reporting design, test and in-service data, the timely accomplishment of Reliability deliverables and provides DHI with an overview of the organization responsible for Reliability.

The Program Plan shall address all Reliability deliverables listed in the R&M Control Plan Supplier schedule.

1.2 APPLICABLE DOCUMENTS

EPS 1-18 R&M Specification Requirements

1.3 DEFINITIONS & ABBREVIATIONS / ACRONYMS

DHI de Havilland Inc.

1.4 PROCEDURES (REQUIREMENTS)

The following requirements shall be included in the Reliability Program Plan:

1.4.1 Introduction

This section shall introduce the Supplier and aircraft system/structure they are providing.

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CHAPTER 1

1.4.2 Reliability Organization, Responsibility and Authority

This section shall identify the organization for the overall reliability function and its place in the management hierarchy and define its responsibility for both policy and action. The responsibilities of those directly associated with reliability policies and implementation of the control program shall be clearly defined.

The Supplier shall be responsible for managing and completing all pertinent reliability deliverables.

1.4.3 Reliability Control Methods

This section shall discuss the means of monitoring, evaluating and controlling reliability through all phases of design (e.g. design reviews), development/test (e.g. reliability growth testing), production and operation for the life of the aircraft (e.g. FRACAS).

1.4.4 Reliability Deliverables & Milestones

This section shall identify and schedule all Reliability deliverables to be submitted to DHI along with pertinent milestones which shall align with the R&M Control Plan.

1.5 FORMAT

There are no restrictions on the Reliability Program Plan format; however, Suppliers shall include headings 1.4.1 - 1.4.4.

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Chapter 2

MAINTAINABILITY PROGRAM PLAN

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 2

2 MAINTAINABILITY PROGRAM PLAN

2.1 INTRODUCTION

This procedure outlines DHI's requirements for Supplier Maintainability Program Plans.

The Maintainability Program Plan demonstrates to DHI the Supplier's capability to manage the Maintainability program and provides Suppliers with a formal approach for managing the optimization of equipment maintainability and minimizing equipment life cycle costs. It ensures acceptable methods are used for evaluating and reporting design, test and in-service data, the timely accomplishment of Maintainability deliverables and provides DHI with an overview of the organization responsible for Maintainability.

The Control Plan shall address all Maintainability deliverables listed in the R&M Control Plan Supplier schedule.

2.2 APPLICABLE DOCUMENTS

EPS 1-18 R&M Specification Requirements

2.3 DEFINITIONS & ABBREVIATIONS / ACRONYMS

DHI de Havilland Inc.

2.4 PROCEDURES (REQUIREMENTS)

The following requirements shall be included in the Maintainability Program Plan:

2.4.1 Introduction

This section shall introduce the Supplier and aircraft system/structure they are providing.

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CHAPTER 2

2.4.2 Maintainability Organization, Responsibility and Authority

This section shall identify the organization for the overall maintainability function and its place in the management hierarchy and define its responsibility for both policy and action. The responsibilities of those directly associated with maintainability policies and implementation of the control program shall be clearly defined.

The Supplier shall be responsible for managing and completing all pertinent maintainability deliverables.

2.4.3 Maintainability Control Methods

This section shall discuss the means of monitoring, evaluating and controlling maintainability through all phases of design (e.g. design reviews), development/test, production and operation for the life of the aircraft.

2.4.4 Maintainability Deliverables & Milestones

This section shall identify and schedule all Maintainability deliverables to be submitted to DHI along with pertinent milestones, which shall align with the R&M Control Plan.

2.5 FORMAT

There are no restrictions on the Maintainability Program Plan format; however, Suppliers shall include headings 2.4.1 - 2.4.4.

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Chapter 3

FUNCTIONAL HAZARD ANALYSIS

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 3

3 FUNCTIONAL HAZARD ANALYSIS

3.1 INTRODUCTION

New or modified systems require an evaluation of their potential effects on aircraft safety. The Functional Hazard Analysis (FHA) is the initial fundamental safety assessment used for such an evaluation and establishes the safety requirements and scope of additional safety analyses.

A FHA is a systematic, comprehensive examination of system functions to identify potential minor, major, hazardous and catastrophic failure conditions which systems may cause or contribute to, not only if they malfunction or fail to function, but also in their normal response to unusual or abnormal external factors.

The FHA is performed using two separate approaches (i.e. evaluation of **aircraft level** and **system level** functions), having a common purpose; although different in scope and format. Both approaches result in some duplication; however, they produce complimentary documents which are to be considered in unison.

The aircraft function approach is a top-down methodology which identifies primary (highest level) aircraft functions involving single or multiple systems and the hazards associated with these functions and evaluates potential failure conditions. Since the aircraft level FHA also evaluates common mode causes, loss of services, etc., it is referred to as the General Hazard Analysis (GHA).

The system function approach is a bottom-up methodology which identifies all primary system functions, their failure conditions and corresponding aircraft hazards.

When identifying a failure conditions effect, mitigating or aggravating factors influencing the effect must be taken into account. These factors include, but are not limited to, flight phase, incipient failure indications to flight crew, weather and human error. In general, if a function is designed to operate during specific conditions, then it always must be assumed that those conditions are present when considering the functions failure.

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Preliminary & final versions of the Aircraft & System FHA shall be produced. Due to incomplete system definitions when the preliminary FHA's are required, these versions shall be based on available knowledge of primary aircraft functions. The final FHA's shall reflect system definitions after the Preliminary Design Review.

3.2 APPLICABLE DOCUMENTS

AC 25.1309-1A System Design Analysis Advisory Circular

AMJ 25.1309 System Design and Analysis Advisory Material

EPS 1-18 R&M Specification Requirement

3.3 DEFINITIONS & ABBREVIATIONS / ACRONYMS

3.3.1 Definitions

Failure Condition: The effect on the airplane and its occupants, both direct and consequential, caused or contributed to by one or more failures, considering relevant adverse operational or environmental conditions. Failure Conditions are classified according to their severities (ref. AC 25.1309-1A and AMJ 25.1309).

3.3.2 Abbreviations / Acronyms

DHI de Havilland Inc.

FHA Functional Hazard Analysis

GHA General Hazard Analysis

FMECA Failure Mode Effects and Criticality Analysis

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3.4 PROCEDURES

3.4.1 Procedures - GHA (Aircraft Level Functions)

List all primary aircraft level functional hazards. The list shall include but not be limited to the following:

- (1) Loss or significant reduction of roll control
- (2) Loss or significant reduction of pitch control
- (3) Loss or significant reduction of yaw control
- (4) Loss or significant reduction of directional control (ground)
- (5) Obscured vision from cockpit
- (6) Failure to halt aircraft
- (7) Structural failure
- (8) Failure to achieve required lift
- (9) Loss or significant reduction of thrust
- (10) Loss of flight information
- (11) Hazardously misleading flight information
- (12) Uncontrolled fire
- (13) Uninhabitable environment
- (14) Loss of all electrical power
- (15) Loss of all hydraulic power

For each primary functional hazard;

- (1) list the systems which may contribute to the functional hazard.
- (2) list the failure conditions (or combinations thereof) which may contribute to the functional hazard.

For each failure condition, indicate the failure effect category in accordance with AC 25.1309-1A and AMJ 25.1309 (i.e. catastrophic, hazardous, etc.) and flight phases during which the failure condition may present a hazard.

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Draw a qualitative fault tree for each primary functional hazard (top event), showing the relationship to its contributing failure conditions.

3.4.2 Procedures - FHA (System Level Functions)

For each applicable ATA system, identify all airworthiness related sub-systems and their primary functions.

For each system primary function consider all potential failure conditions due to:

- (1) inability to function
- (2) malfunction
- (3) other systems
- (4) misuse/external events
- (5) human error

For each failure condition, identify:

- (1) flight phases during which the failure condition may present a hazard
- (1) effect of failure condition on aircraft
- (2) effect of failure condition on other system
- (3) failure effect category in accordance with AC 25.1309-1A and AMJ 25.1309 (i.e. catastrophic, hazardous, etc.)
- (4) applicable FAR/JAR airworthiness regulations
- (5) certification analysis requirements

Requirements for failure effect categories:

Minor: FMECA required for system Quantitative Fault Tree Analysis possibly required for failure condition if it contributes to a hazardous failure condition.

Major: FMECA required for system Quantitative Fault Tree Analysis possibly required for failure condition

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Hazardous: FMECA required for system Quantitative Fault Tree Analysis required for failure condition.

Catastrophic: FMECA required for system Quantitative Fault Tree Analysis required for failure condition.

3.4.3 Format

DHI's format for presentation of the above data:

Format - Aircraft Level Functions

As per DHI preliminary GHA

Format - System Level Functions

As per DHI preliminary FHA

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**RELIABILITY AND MAINTAINABILITY POLICIES AND
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Chapter 4

SYSTEM SAFETY ANALYSIS

1996-07-05

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 4

4 SYSTEM SAFETY ANALYSIS

4.1 INTRODUCTION

This policy and procedures document outlines guidelines for preparing System Safety Analyses which will satisfy de Havilland's requirements.

The primary objective of the System Safety Analysis is to demonstrate compliance with FAR & JAR Part 25 safety related regulations. In general this is accomplished by means of a failure mode, effects and criticality analysis to methodically identify and assesses single failure modes and by quantitative fault trees which are used to demonstrate that the probability of hazardous failure conditions is commensurate with the severity of the hazard.

Each Supplier, as identified in the Functional Hazard Analysis requirements (i.e. responsibility and scope), shall provide de Havilland with a System Safety Analysis.

4.2 APPLICABLE DOCUMENTS

ESP 92 R&M Policies & Procedures: Functional Hazard Analysis

ESP 92 R&M Policies & Procedures: Fault Tree Analysis

ESP 92 R&M Policies & Procedures: Failure Mode, Effects (and Criticality) Analysis

4.3 DEFINITIONS & ABBREVIATIONS / ACRONYMS

DHI de Havilland Inc.

AEROC DHI Certification Document

4.4 PROCEDURES (REQUIREMENTS)

The following requirements shall be included in the System Safety Analysis in the order presented:

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 4***4.4.1 Title Page**

The title page shall be formatted as indicated in Section 4.5. With the exception of "AEROC" and "Section", all other information required on the title page is self explanatory. At de Havilland, AEROCs are engineering certification reports which show compliance of designs with applicable regulations. As such, an AEROC numbering system has been developed to differentiate the various Systems Safety Analyses. The numbering system (with Section numbers), which shall be used by Suppliers, is as follows:

R&M Engineering Report Description	AEROC No.	Section
Aircraft - General Safety (Zonal Analysis)	84.9.AC.1	1
Fire Hazard	84.9.AC.1	2
Landing/Acceleration Stop	84.9.AC.1	3
Rotor Burst/Propeller Failure	84.9.AC.1	4
Certification Requirements Summary	84.9.AC.1	5
Master Warning & Caution Lights	84.9.AC.1	6
Software Accomplishment Summary	84.9.AC.1	7
APU Installation	84.9.AP.1	1
Bleed Air	84.9.CA.1	2
Pressurization Control	84.9.CA.1	3
Elevator Control	84.9.CF.1	1
Aileron Control	84.9.CF.1	2
Rudder Control	84.9.CF.1	3
Wing Flaps	84.9.CF.1	4
Spoilers	84.9.CF.1	6
Ice and Rain Protection	84.9.DE.1	1
Elevator Horn Heat	84.9.DE.1	2
Engine Start Control	84.9.E.1	1
DC Power System	84.9.E.1	2

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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R&M Engineering Report Description	AEROC No.	Section
Fixed Frequency AC Power	84.9.E.1	3
Variable Frequency AC Power	84.9.E.1	4
Fuselage Doors	84.9.FS.1	1
Hydraulic Power	84.9.HY.1	1
Instruments	84.9.J.1	1
Stall Warning	84.9.J.1	2
Take-off Warning	84.9.J.1	3
Fatigue Damage Tasks, Inspection		
Task Procedures	84.9.NDT.1	1
Landing Gear Extend/Retract	84.9.LG.1	1
Nose Wheel Steering	84.9.LG.1	2
Wheels and Brakes	84.9.LG.1	3
Landing Gear Proximity Sensing	84.9.LG.1	4
Engine Fire Protection	84.9.PE.1	1
Engine Oil	84.9.PE.1	2
Fuel	84.9.PF.1	1
Propulsion Controls, Airframe	84.9.PM.1	1
Propulsion Controls, Engine	84.9.PM.1	2
Propulsion Management	84.9.PM.1	3
ATPCS & Propeller Feathering	84.9.PM.1	4
Area Navigation	84.9.R.1	1
AHRS	84.9.R.1	2
AFCS	84.9.R.1	3
Ground Proximity Warning	84.9.R.1	4
Electronic Flight Instruments	84.9.R.1	5
Oxygen	84.9.SB.1	1

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 4

4.4.2 Table of Contents

See Section 4.5 for format.

4.4.3 List of Tables & List of Figures

See Section 4.5 for format.

4.4.4 List of Effective Pages

See Section 4.5 for format.

4.4.5 Introduction

Essentially the introduction should cover the subject, purpose and scope of the report. Generally the introduction can be started with "This report presents a detailed Safety Analysis of the xxxx System which shows that the System is compliant with all safety related FAR and JAR Part 25 regulations." Depending on the certification approach, the introduction should outline whether a qualitative assessment, FMECAs and/or fault trees have been used to demonstrate compliance.

4.4.6 Definition of terms

This section shall include the definitions for Probability of Occurrence, Failure Classification and Criticality Rating as outlined in the FMECA policies and procedures.

4.4.7 Applicable Regulations

Since TCA/FAA/JAA certification is being sought concurrently, this section shall indicate all FAR and JAR Part 25 safety related regulations, additional airworthiness requirements and Special Conditions which are pertinent to the system. It is the responsibility of the supplier to ensure that all applicable regulations are addressed. In general, all systems must comply with 25.1309 (a), (b), (c) & (d).

The section shall begin with "This report is addressed to the following regulations:"

Both applicable FAR and JAR regulations shall be detailed in full (i.e. regulation section and accompanying text). The regulation need only appear once if both the FAR and JAR regulations read alike.

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 4

The basis of certification for the DHC-8-400 is FAR Part 25, Amendment 83 and JAR 25, Change 14.

4.4.8 Compliance Summary

The compliance summary is a brief statement against each applicable regulation, indicating how compliance has been shown and conclusions regarding system safety. This section shall address any differences between like FAR and JAR regulations.

4.4.9 Summary of Significant Failure Mode Classifications

This section summarizes single failure modes identified by the FMECA. The section shall begin with: "A failure mode is characterized by the effects that the resulting failure condition could have on the aircraft in terms of flight safety. The effects on the aircraft in descending order of severity are defined by the terms (i) catastrophic, (ii) critical (hazardous), (iii) major and (iv) minor. See Definition of Terms."

Below this paragraph shall be the Severity headings, under which applicable failure conditions are listed:

CATASTROPHIC

(this should indicate none, otherwise the design may not be compliant).

CRITICAL (HAZARDOUS)

Indicate Failure Mode No., Failure Mode and Probability of Occurrence for each Critical Failure Mode.

MAJOR

Indicate Failure Mode No., Failure Mode and Probability of Occurrence for each Major Failure Mode.

MINOR

Minor failure modes need not be listed; however, the following statement should be made: "All other failure modes are classified as Minor."

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 4

4.4.10 Summary of Hazardous Cases

Summary of Hazardous Cases shall indicate that the report analyzed relevant hazardous failure conditions identified in the Functional Hazard Assessment and that the probability of the failure conditions occurring are commensurate with the probabilities defined in the regulations. All failure conditions shall be listed along with their calculated probabilities and hazard severity.

4.4.11 Summary of Certification Maintenance Requirements

This section shall indicate the maintenance check intervals, determined from fault tree analyses, for items which fail dormant and may contribute to **hazardous or catastrophic** failure conditions.

For each item, the purpose of the maintenance check shall be clearly indicated.

In addition, it shall be stated which failure condition the maintenance requirements relate to.

4.4.12 System Description

This section shall discuss the system description in detail, describing the system layout, control and operation, and operational parameters (i.e. pressures, temperatures, etc.).

4.4.13 Summary of Design Safety Features

Summary of Design Safety Features shall include all safety items (e.g. annunciations, redundancies, fail safe features, functional limits) which are incorporated into the design. Each feature shall be individually listed (i.e. one numbered paragraph per feature).

4.4.14 System Safety Analysis Discussion

A separate discussion shall be provided for each failure condition analyzed. The failure conditions shall be introduced, stating its commensurate probability and particular operational phases for which the condition is being considered. As such, all assumptions and exposure times shall be stated. System redundancies, incorporated to provide an inherent level of safety, shall be discussed.

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CHAPTER 4

4.4.15 Failure Mode, Effects and Criticality Analysis

This section shall include an index of the FMECA, in addition to all individual FMECA sheets.

4.4.16 Fault Tree Analysis

This section shall include fault tree models for each failure condition analyzed.

4.4.17 Block Diagrams

Functional Block diagrams shall show functional relationships among system elements. The diagrams shall consist of blocks representing system elements, connected together in a manner which traces the system function, in sufficient detail to identify all LRU and/or Equipment assembly interfaces.

Additionally, when system redundancies exist, Reliability Block diagrams shall be provided. The block diagram shall depict the alternate channels which successful operation of the Equipment can be achieved, and any 'series' elements upon which system success is directly dependent.

4.4.18 System / Components Schematics, Diagrams & Drawings

Include all schematics, diagrams and drawings which will assist the reader in understanding the system being analyzed.

4.4.19 Failure Rate Justification

All failure mode rates used in the fault trees shall be justified by indicating their source. In general, failure rate data sources (given in order of preference) are as follows:

- (1) service experience on like or similar hardware in a similar use environment.
- (2) test data on development or similar hardware.
- (3) vendor data
- (4) military/government handbooks such as;

MIL-HBDK-217 Reliability Prediction of Electronic Equipment

GIDEP Government Industry Data Exchange Program

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 4

RADC

Rome Air Development Center

NPRD

Non-Electronics Parts Reliability Data

(5) engineering judgement

Any factors which are considered when deriving a failure rate, such as derating, stress, environment, etc. shall be indicated.

In addition, the failure rates and corresponding probability of occurrence shall be included.

See Reliability Modeling and Predictions policies and procedures.

4.4.20 List of References

This section shall include all reference material used in the analysis. In addition, it may also include the sources from which failure rates are determined; however, a reference number must be provided to correlate the failure rates with their sources.

4.4.21 Vendor Safety Analysis

Vendor Safety Analyses which provide supporting documentation shall be included in this section.

4.5 FORMAT

The section numbering of the System Safety Analysis document shall correspond with this section. Sections not applicable to the report shall be included with the text "NOT APPLICABLE".

The System Safety Analysis (with the exception of FMECAs and FTAs) shall be produced using FrameMaker software. (FrameMaker templates will be made available to Suppliers).

FMECAs shall be produce using Microsoft Word Version 6.0 software; Microsoft Word 6.0 templates will be made available to suppliers.

FTAs shall be produce using FaulTrEASE™ or CAFTA software and imported into the System Safety Analysis.

1996-07-05

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Chapter 5

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 5

5 FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

5.1 INTRODUCTION

This policy and procedure document outlines guidelines for preparing Failure Mode, Effects and Criticality Analysis (FMECA).

FAR/JAR airworthiness regulations require that no single failures, unless shown to be practically impossible (i.e. not credible failures), may prevent the continued safe flight and landing of the aircraft.

Single failures are evaluated using FMECA's to systematically and exhaustively identify all modes of failure within a system design. The main purpose of the FMECA is to identify hazardous single failure effects so that they may be eliminated or minimized through design correction at the earliest possible time and to identify latent failures.

Additionally, for each final FMECA failure mode, a criticality assessment sums the failure mode's characteristics (i.e. effects, probability, detection, etc.) to provide a quantitative factor to assess the need for design changes.

Failure modes shall not be considered to occur simultaneously; only one failure mode at a time is to be studied.

Since the FMECA is a systematic process for reviewing single failures and establishing their failure data (i.e. failure modes, failure rates, latent/active failure, etc.), FMECA's are to be performed prior to constructing any associated fault trees.

5.2 APPLICABLE DOCUMENTS

FAR (Federal Aviation Regulations) Title 14, Part 25, Airworthiness Standards: Transport Category Airplanes

FAR Advisory Circular 25.1309

JAR 25, Joint Aviation Requirements for Large Aeroplanes

JAR 25, AMJ (Advisory Material Joint) 25.1309

ARP 926A, Fault/Failure Analysis Procedure

DATE: 1996-07-05

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

CHAPTER 5

5.3 DEFINITIONS & ABBREVIATIONS / ACRONYMS

ARP	Aerospace Recommended Practice
DHI	de Havilland Inc.
FMECA	Failure Mode, Effects and Criticality Analysis

5.4 PROCEDURES

In general, a “functional” FMECA, at the LRU/component level, shall be performed for all systems identified in the Functional Hazard Analysis. However, Suppliers may* be required to perform a “hardware” FMECA to ensure that all functional failure modes and causes have been identified (may also be required to determine functional failure mode failure rates).

* For complex equipment (e.g. electronic control units, air data computer, etc.) hardware FMECA's must be performed to the indenture level which separates functional assemblies / circuits, or at least to a level which ensures that all potential functional failure modes are identified.

The FMECA header shall define the component nomenclature. Each component (and its failure modes) shall be identified by a FMECA item number (starting with 1.1) for easy cross-reference. The first indenture level shall identify the component and the second indenture level shall identify the failure modes.

The following procedures detail the elements required for producing FMECA's using the DHI FMECA worksheet format (Microsoft Word Version 6.0 template to be provided).

5.4.1 Failure Mode

Potential failure modes foreseeable for each component part shall be defined and shall include all foreseeable human errors. For parts subject to 'wear-out', failure modes resulting from any succession or progressive deterioration shall be included in addition to those due to random causes.

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5.4.2 Cause of Failure

This shall identify the most likely causes of Failure including all foreseeable human errors (e.g. incorrect over-tightening of bolts, internal contamination in addition to those resulting from normal operation of the Equipment within the specified environment).

5.4.3 Flight Phases and Operating Conditions

Flight phases and operating conditions where the Failure is most critical, and known to the Supplier (e.g. an avionics system with CAT. II certification) shall be identified (Reference Functional Hazard Analysis for flight phases).

5.4.4 Effects of Failure

This shall describe the effects (local, next higher and aircraft) caused by the unit of each potential Failure as identified in "Failure Mode". The effects shall include any potential secondary (cascading) effects or consequential damage which may result from the primary Failure.

5.4.5 Failure Identification and Corrective Action

- (1) Indications to flight crew: This shall describe the Failure symptom(s) by which the flight crew would become aware that a fault existed. Where no indication is provided at any phase of a complete flight cycle (including the pilots' pre-flight check) the Failure mode shall be indicated as a "dormant (latent) Failure" in column 11 "Comments".
- (2) Other Failures with same indications: This shall describe other Failure modes which display the same or similar Failure indications (refer to failure mode identification number if known).
- (3) Failure identification, isolation and corrective action by flight crew: This shall describe how the flight crew would identify the Failure and the corrective action to be taken by the flight crew in order to isolate or alleviate the effects of the Failure.
- (4) Effect of likely incorrect action: This shall describe the effects of likely incorrect action taken by the flight crew. If it is possible to interpret the indications (symptoms) incorrectly and to apply the corrective actions appropriate to a different Failure, then the system and its Equipment shall

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be designed so that those incorrect actions will not cause additional Failures and/or malfunctions, (i.e. it should be possible to restore the system (equipment) to normal operation).

- (5) Fault isolation - maintenance crew: This shall describe symptoms by which the ground crew would realize that a fault existed, other than the flight indications of a) above. Its primary purpose is to detect those Failures which are dormant to the flight crew; for such Failures, the Supplier shall reference any relevant periodic check recommended in order to ensure detection at the recommended check frequency.
- (6) Corrective action - maintenance crew: This shall outline the basic rectification procedure, with particular mention of any aspects which may not be self-apparent, such as a single diagnostic which can be used to positively isolate the specific defective LRU, the practicability of simple in-situ rectification, any tasks which may be required in addition to unit removal/replacement (e.g. inspections or checks on other units for possible secondary damage), or any special precautions necessary for ground crew safety. Where all aspects of diagnostics, rectification, and system checkout are obvious and straight-forward, a simple statement "replace unit" will suffice.

5.4.6 Dispatch Requirements (With Failure)

These are the operational recommendations or actions to be taken to permit dispatch with a failed item of Equipment. Operating limitations (aircraft performance, environmental restrictions, pilot actions, etc.) should be identified.

5.4.7 Effect of Subsequent Detrimental Failures

This shall describe the effects of subsequent detrimental Failures when the aircraft has been dispatched with inoperative Equipment.

5.4.8 Failure Rate

Failure rates (expressed as failures per million flight hours) shall be provided for each component.

5.4.9 Failure Mode Ratio (α)

The fraction of component failure rate related to the particular failure mode under consideration.

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5.4.10 Exposure Time

Component exposure times (flight hours) shall be commensurate with their duty cycles (ref. DTRD-8-010, section 1.3.5.1, Table 1.4, for flight phase durations); however, components belonging to safety significant systems which are not required continuously (e.g. deice system, etc.) shall be considered to operate continuously.

Exposure time for continuously operating components shall be one flight hour (average flight time).

5.4.11 Probability of Occurrence (Q)

When failure rates (λ) are ≥ 0.001 , probability of occurrence (Q) = $1 - e^{-\lambda t}$. If λ is < 0.001 , the approximation $Q = \lambda t$ is sufficient.

Note: For Preliminary FMECAs, DHI will accept the following qualitative probabilities of occurrence:

- (1) Probable - Unlikely to occur often during the operation of each Aircraft of the type, but which may occur several times during the operational life of each Aircraft of the type.
- (2) Remote - Unlikely to occur to each Aircraft during its total operational life, but which may occur several times during the total operational life of all Aircraft of the type.
- (3) Extremely Remote - Unlikely to occur during the total operational life of all Aircraft of the type, but nevertheless has to be considered as being possible.
- (4) Extremely Improbable - So extremely remote that it does not have to be considered as possible to occur.

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The severity classification shall indicate the potential seriousness of each Failure mode with respect to the continued operation of the Aircraft without rectification.

TABLE 5.1 SEVERITY CLASSIFICATION

SEVERITY CLASSIFICATION	DESCRIPTION
(1) Catastrophic	Failure conditions which could prevent continued safe flight and landing.
(2) Hazardous	Failure conditions which could reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be: a. a large reduction in safety margin or functional capabilities, b. physical distress or higher workload such that the flight crew could not be relied upon to perform their tasks accurately or completely, or c. serious injuries to a relatively small number of the occupants.
(3) Major	Failure conditions which would reduce the capability of the aircraft, or the capability of the crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins of functional capabilities, a significant increase in crew work load or in conditions impairing crew efficiency, or discomfort possibly including injuries.
(4) Minor	Failure conditions which would not significantly reduce aircraft safety and which would involve crew action that are well within their capabilities. Minor failure conditions may include a slight reduction in safety margins or functional capabilities, a slight increase in crew workload or some inconvenience to occupants.

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The following criticality matrix shall be used to determine the acceptability of the failure modes probability of occurrence.

TABLE 5. 2 CRITICALITY MATRIX

Probable $\geq 10^{-5}$	A	U	U	U
Remote $10^{-5}-10^{-7}$	A	A	U	U
Ext. Remote $10^{-7}-10^{-9}$	A	A	A	U
Ext. improbable $\leq 10^{-9}$	A	A	A	U
	IV Minor	III Major	II Hazardous	I Catastrophic

Where;

A: Acceptable Criticality Level,

U: Unacceptable Criticality level, Corrective action needed.

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Chapter 6

FAULT TREE ANALYSIS

1996-07-05

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6 FAULT TREE ANALYSIS

6.1 INTRODUCTION

This policy and procedures document provides fault tree analysis guidelines.

In accordance with FAR/JAR 25.1309, MAJOR, HAZARDOUS and CATASTROPHIC failure conditions identified in the Functional Hazard Analysis (FHA) or General Hazard Analysis (GHA) generally must be shown to meet established probability requirements. To demonstrate compliance with the requirements, DHI requires that a quantitative fault tree analysis be performed for these failure conditions.

Suppliers shall analyse all failure conditions which are related to systems for which they have responsibility (responsibilities identified in FHA and GHA) and coordinate with respective Suppliers when failure conditions involve multiple systems.

When analyzing failure conditions, the analysis shall evaluate all credible modes of failure, including conditional events. All environmental conditions and aircraft flight phases pertinent to the failure condition shall also be considered.

The resolution of the tree shall be commensurate with the failure condition being analysed. In general, system fault trees should consist of a top event (failure condition), subsystems failures contributing to its occurrence and their component failures.

6.2 APPLICABLE DOCUMENTS

FAR Part 25, Airworthiness Regulations

FAR Advisory Circular 25.1309

JAR 25, Joint Aviation Requirements for Large Aeroplanes

JAR 25, AMJ (Advisory Material Joint) 25.1309

Fault Tree Handbook, NUREG-0492, U.S. Nuclear Regulatory Commission

ARP 926A, Fault/Failure Analysis Procedure

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6.3 DEFINITIONS & ABBREVIATIONS / ACRONYMS

6.3.1 Definitions

Continued Safe Flight and Landing: The capability for continued controlled flight and landing, possibly using emergency procedures, but without requiring exceptional pilot skill or strength. Some airplane damage may be associated with a Failure Condition, during flight or upon landing.

CMR (Certification Maintenance Requirement): A required periodic check to detect the presence or absence of a latent failure mode of a component that would, in combination with other specific failures identified in a safety analysis, result in a hazardous or catastrophic failure condition.

Failure Condition: The effect on the airplane and its occupants, both direct and consequential, caused or contributed to by one or more failures, considering relevant adverse operational or environmental conditions. Failure Conditions are classified according to their severities (ref. AC 25.1309-1A and AMJ 25.1309).

Latent Failure: A failure which is inherently dormant or undetected when it occurs (ie. not detected during normal flight crew activities).

6.3.2 Abbreviations / Acronyms

DHI	de Havilland Inc.
GHA	General Hazard Analysis
FHA	Functional Hazard Analysis
λ	Failure rate
Q	Probability of Occurrence
t	Exposure time (active failures)
T	Dormant failure maintenance interval

6.4 PROCEDURES

For detailed fault tree construction procedures, it is recommended that the NUREG-0492 Fault Tree Handbook (or similar) be studied. It is the intent of this section to provide guidelines, which when followed, will satisfy DHI requirements.

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6.4.1 Probability of Occurrence - Top Event Failure Condition

Fault trees containing dormant failures shall have their top event's (failure condition) probability of occurrence fixed in accordance with their failure effects category to optimize CMR intervals and consequently improve airline operating economics. When no dormancies exist (ie. all active failures), the top event's probability shall be calculated; however, the probability must not be greater than the probability associated with its failure effect category. Note that it is imperative that failure rates be thoroughly justified (ref. System Safety Analysis policies and procedures, section 4.4.19).

FAR/JAR 25 failure effect categories and their corresponding maximum allowable probabilities (per flight hour) are as follows:

FAILURE EFFECT CATEGORY PROBABILITY

Major 1×10^{-5}

Hazardous 1×10^{-7}

Catastrophic 1×10^{-9}

6.4.2 Probability of Occurrence - Failures

When failure rates (λ) are $>$ or $= 0.001$, probability of occurrence (Q) = $1 - e^{-\lambda t}$. If λ is < 0.001 , the approximation $Q = \lambda t$ is sufficient.

6.4.3 Exposure times

Component exposure times (in hours i.e. $t/60$) shall be commensurate with their duty cycles (ref. DTRD-8-010, Section 1.3.5.1, Table 1.4, for flight phase durations); however, components belonging to safety significant systems which are not required continuously (eg. deice system, etc.) shall be considered to operate continuously.

Exposure time for continuously operating components shall be 1 flight hour (average flight time)

6.4.4 Dormant Failures

Not all components which fail dormantly (ie. remain undetected during normal crew activities) and may contribute to a hazardous or catastrophic event, will be monitored via fault annunciation, if monitoring is not practical or reliable. Consequently, for hazardous and catastrophic failure conditions

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which may result from dormant failures, maintenance failure finding tasks must be implemented to determine their operational state and limit their exposure time. As per FAR (and JAR) 25.1309 advisory circular (material) dormant failures of this nature are considered as significant latent failures. Tasks used to verify operation of such components are regarded as Certification Maintenance Requirements (CMR's). CMR's are performed at intervals analytically established through fault tree analysis. Post aircraft certification, design improvements or favourable service experience may result in changed CMR intervals. However, once established, CMR intervals may not be changed without the approval of the appropriate Airworthiness Authorities Certification Office.

CMR intervals shall not be less than 50 flight hours unless approved by DHI.

When dormant failures can be logically identified with one CMR failure finding task, then only one CMR interval variable is assigned to all dormant failures (eg. T). If however, one task and/or interval is inappropriate, the dormant failures shall be appropriately grouped and variables (eg. T1, T2, etc.) assigned, each representing a CMR failure finding task interval.

In general, the following criteria should be used for grouping dormant failures into common CMR failure finding tasks:

- (1) belong to same sub-system,
- (2) can be logically checked together,
- (3) CMR interval appropriate to all dormant failures.

When only a single CMR interval variable has been assigned to a fault tree, the interval is analytically determined as follows:

- (1) assign probabilities of occurrence (Q) to all failures including top event (dormant failure in terms of CMR interval variable, ie. λT)
- (2) numerically solve fault tree (ie. calculate CMR interval)

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***CHAPTER 6***EXAMPLE**

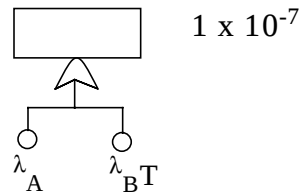
$$Q_{(\text{Failure Condition})} = 1 \times 10^{-7}$$

$$\lambda_A = 1 \times 10^{-8}$$

$$\lambda_B = 1 \times 10^{-9}$$

$$t = 1 \text{ hour}$$

$$T = ?$$



$$\lambda_A t + (\lambda_B * T) = Q_{(\text{Failure Condition})}$$

$$T = [Q_{(\text{Failure Condition})} - (\lambda_A t)] / \lambda_B$$

$$T = [(1 \times 10^{-7}) - (1 \times 10^{-8} * 1)] / (1 \times 10^{-9})$$

$$T = 90 \text{ flight hours}$$

When a fault tree contains multiple CMR interval variables, the CMR task which is most difficult and/or extensive to perform should generally have the least frequent (largest) interval. Intervals should be optimized such that the top event probability equates to the maximum permissible (ref. section 6.4.1). Where possible, CMR intervals should allow for in-phase maintenance checks with the MRB scheduled system maintenance program in addition to allowing for potential growth of the scheduled maintenance check intervals which are currently assumed as follows:

“L” check: 50 flight hours

“A” check: 400 flight hours

“C” check: 4000 flight hours

6.4.5 Numerical Assessment of Fault Trees

Fault Tree calculations shall be performed with the use of FaultTrEASE™ or CAFTA software (ref. Section 6.5.1, FaultTrEASE™ Formatting & User Instructions) and manually when specified by DHI.

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6.5 FORMAT

To facilitate drawings, calculations, revisions and combining fault trees, it is required that fault trees be constructed using FaultTrEASE™ software (ref. section 6.5.1, FaultTrEASE™ formatting and user instructions).

FaultTrEASE™ software may be purchased from:

Arthur D. Little, Inc.
Acorn Park Cambridge,
Massachusetts
02140-2390 USA
Phone (617) 498-5000
Fax (617) 498-7200

6.5.1 FaultTrEASE™ Formatting & User Instructions

These instructions provide basic guidance for producing a fault tree using FaultTrEASE™. For specific questions not covered here, reference the FaultTrEASE™ User's Manual.

6.5.1.1 New Tree Format Set-up

- (1) From header, SELECT "File" and then SELECT "New".
- (2) From header, SELECT "File" and then SELECT "Inherit".
- (3) Using mouse, DOUBLE-CLICK gate symbol to add required information (ie. label, gate, etc.).

The following format parameters should initially be used. As the fault tree grows, the formatting may require modification.

- (1) From header, SELECT "Drawing" and then SELECT "Placement".
- (2) At "Place Symbol Relative to Branches" SELECT "On Average".
- (3) At "Compact Cells" SELECT "Maximum".
- (4) From header, SELECT "Drawing" and then SELECT "Line Style".
- (5) At "Pen Size" SELECT "2".
- (6) At "Stem" SELECT single (left gate)
- (7) From header, SELECT "Math" and then SELECT "Numbers".

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- (8) At "Notation" SELECT "Scientific".
- (9) At "Exponent" SELECT "2E9".
- (10) At "Decimal Places" SELECT "2".
- (11) At "Remove Trailing Zeroes" SELECT yes (no "X").
- (12) From header, SELECT "Symbol" and then SELECT "Scale".
- (13) On vertical scale, SELECT "120%".
- (14) From header, SELECT "Symbol" and then SELECT "Cell Size".
- (15) DRAG box until width = "85" and height = 100.
- (16) From header, SELECT "Symbol" and then SELECT "Labels".
- (17) At "Center" ENTER 10.
- (18) At "Rectangle" ENTER 40.
- (19) At "Circle" ENTER 24.
- (20) At "Overflow" SELECT "Show".
- (21) CLICK gate.
- (22) From header, SELECT "Symbol" and then SELECT "Font".
- (23) SELECT "SMALL FONTS" font; size "8". Note: When branches (leaves) are added to gate, use same font/size as above.
- (24) DOUBLE-CLICK "Untitled" box located at top right hand corner of screen.
- (25) CLICK "display" such that box has no "X".
- (26) CLICK AND HOLD circle on top of gate box; DRAG to center of screen and release.

6.5.1.2 Building Fault Tree

6.5.1.2.1 Building Branches & Leaves

- (1) To build fault tree, SELECT "Operate" and then SELECT "Add Branch".
- (2) TYPE text for event and SELECT required gate/leaf symbol. If leaf is selected, ADD probability of occurrence.

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Note: The Faultrease software does not automatically convert failure rates (λ) to probabilities of occurrence (Q), therefore, this must be done manually. $Q \sim \lambda t$, if λt is < 0.001 , else, if λt is $>$ or $= 0.001$, Q must be calculated from the equation $Q = 1 - e^{-\lambda t}$.

- (3) Leaves (basic events) are ordered horizontally by FaultREASE™, therefore, accommodating numerous leaves from multiple gates on the same level can become difficult. To arrange tree such that a branch will fit onto a page it is often best to vertically stagger common level gates. This is done as follows:
- a) CLICK gate to be vertically staggered.
 - b) SELECT “Operate” and then SELECT “Insert Level”.
 - c) A new gate will appear above “clicked” gate.
 - d) DOUBLE-CLICK new gate and then SELECT “vertical line” gate.

6.5.1.2.2 Moving About Tree

To move about tree, the branches can be “tracked” using direction (arrow) keys.

To scroll one screen at a time, PRESS “Ctrl” and “direction” key simultaneously.

6.5.1.2.3 Adding Notes

To add additional information such as notes on fault tree;

- (1) SELECT “Operate” and then “Add note”.
- (2) DOUBLE-CLICK note box to add text.

6.5.1.3 Computing Probabilities

6.5.1.3.1 Fault Trees with no Dormant Failures

- (1) Ensure all basic events have an assigned probability.

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-
- (2) SELECT “Math” and then SELECT “Options”.
Note: To ensure that all repeated events are considered (ie. reduced), FaulTrEASE provides three options for identification (ie. comparison by label, reference or tag). References shall be assigned to events (eg. X1, X2, A1, etc.) and comparisons shall be done by “reference”.
 - (3) CLICK an “X” in “Reduce”.
 - (4) SELECT means of comparison (ie. reference).
 - (5) SELECT “Evaluator” to “Direct”.
 - (6) SELECT event for which probability is to be compared.
 - (7) SELECT “Math” and then SELECT “Compute”.
 - (8) A list of repeaters (if present) will be shown; SELECT “ok”.

6.5.1.3.2 Fault Trees with Dormant Failures

- (1) Ensure all basic events with an active failure have an assigned probability.
- (2) For all basic events with a dormant failure, click gate and add $\lambda * \text{Maintenance Interval (T)}$ (eg. $1\text{E-}6 * T1$) after the label. Use a line break character to ensure that $\lambda * T$ is printed on a new line. To specify a line break character;
 - a) SELECT “Symbol” and then SELECT “Line Break”.
 - b) SELECT character to be used to force a line break.
 - c) CLICK the basic event leaf and at “Statistic” insert $\lambda * T$ value.

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Chapter 7

FIRE HAZARD ASSESSMENT

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7 FIRE HAZARD ASSESSMENT

7.1 INTRODUCTION

This policy and procedures document provides guidance for performing an aircraft Fire Hazard Assessment (FRHAS) which will satisfy R&M requirements.

Fire Hazard Assessments shall be performed by Suppliers to ensure all applicable fire protection regulations and fire hazards are identified and addressed. All suppliers assessments will be incorporated into DHI's R&M Fire Hazard Analysis (FRHA) and reviewed collectively to ensure all fire hazards are fully recognized and dealt with accordingly.

Structural suppliers are responsible for systems integration and as such shall perform a FRHAS on all integrated systems and structure within the boundaries of their aircraft section.

7.2 APPLICABLE DOCUMENTS

AC 25.981-1A	Guidelines for substantiating compliance with the fuel tank temperature requirements
AC 25.994-1	Design considerations to protect fuel systems during a wheels-up landing
DTRD-8-009	Hydraulic System
DTRD-8-010	General Requirements DHC-8 Series 400
DTRD-8-025	Fire Detection and Extinguishing System
DTRD-8-026	Oxygen System
DTRD-8-028	Fuel System
ESP 84	DHC-8-400 Electromagnetic Control Plan
ESP 89	DHC-8-400 Electromagnetic Environmental Effects Requirements
ESP 91	Reliability and Maintainability Control Plan - DHC-8 Series 400
FAA	Advisory Circulars 20-53A, 135, 136, 25-8, 10, 16
FAR	Federal Aviation Regulations, Part 25.

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JAR	Joint Aviation Regulations, JAR-25
MIL-HDBK-221	(WP) Fire protection design handbook for U.S. Navy aircraft powered by turbine engines
MIL-W-5088	Wiring, Aerospace Vehicle
TSO-C42	Propeller Feathering Hose Assemblies
TSO-C53	Fuel and Engine Oil System Hose Assemblies
TSO-C75	Hydraulic Hose Assemblies

7.3 DEFINITIONS & ABBREVIATIONS / ACRONYMS

7.3.1 Definitions

Auto ignition temperature: The minimum temperature that a substance must attain to ignite spontaneously without an external source of ignition.

Compartmentation: The process of isolating components, or areas, from others with which they could combine to create a hazard.

Designated Fire Zones: Fire zones defined in FAR/JAR 25. 1181 and include:

- (1) The engine power section.
- (2) The engine accessory section.
- (3) Any complete powerplant compartment in which no isolation is provided between the engine power section and the engine accessory section.
- (4) Any auxiliary power unit compartment.
- (5) The compressor and accessory sections of turbine engines.
- (6) Combustor, turbine and tailpipe sections of turbine engine installations that contain lines or components carrying flammable fluids or gases.

Fire barrier: A compartment wall which is fireproof but not vapour and liquid tight.

Fire hazard: A situation where flammable liquid, vapours and/or materials are located or may be present, and potential ignition sources may also be present.

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Fire hazard zone: Includes fire, flammable, and flammable leakage zones.

Fire resistant: A material which will withstand heat* as well as or better than aluminum alloy in dimensions appropriate for the purpose for which it is used. Fire resistant fluid carrying lines, fluid system parts, wiring, air ducts, fittings and powerplant controls shall have the capacity to perform their intended functions under the heat and other conditions likely to occur if they are exposed to a fire.

Fire zone: An area (or compartment) containing equipment from which flammable fluids or vapors could leak and contains a potential source of ignition.

Fireproof: A material which will withstand heat* as well as or better than steel in dimensions appropriate for the purpose for which it is used. Fireproof material used in fire zones shall have the means to withstand a severe fire of extended duration.

Firewall: A compartment wall which is fireproof and vapour and liquid tight. The firewall must maintain its vapour and liquid tightness in the event of a fire in the fire zone.

Flammable: Solids, liquids, or gases which will ignite readily or explode.

Flammable leakage zone: An area where leaked flammable liquids and/or vapours can occur, but potential ignition sources are minimized. Areas include but are not limited to:

- (1) Wing areas (exclusive of fuel tanks and wing tips)
- (2) Wheel wells
- (3) Wing/Fuse fairing
- (4) Dorsal fin/Vertical fin and tailplane
- (5) Struts above engine firewall
- (6) all other unpressurized portions of the airplane accommodating components which carry combustible fluids and/or their vapors

* Must comply with standardized tests involving exposure to a 2000°F flame, producing a heat flux density at 9.5 BTU/ft²-sec or greater, for 15 minutes for “fire-proof” and for 5 minutes for “fire resistant.”

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Flammable zone: An area where flammable liquids or vapours are present during normal operation, but no ignition source is present. Areas include internal portions of:

- (1) Fuel tanks, vents and lines
- (2) Hydraulic components and lines
- (3) Any vessels containing combustible fluids and their vapor such as oil coolers and fuel heaters

Flame resistant: Materials which will not support combustion to the point of propagating a flame beyond safe limits after removal of the ignition source.

Flash point: Temperature of a body of liquid at which the vapor ignites in the presence of a source of ignition.

Flash resistant: A material which will not burn violently when ignited.

Ignition source: any spark, flame, source of heat, etc., which could cause ignition of combustible material.

Ignition zone: An area containing an ignition source, but flammable fluids or solids are not present. Areas include:

- (1) Flight deck
- (2) Passenger cabin
- (3) Electronic equipment compartments
- (4) Equipment bays in pressurized areas - Cargo and lavatory compartments

Shroud: an enclosure surrounding a flammable fluid carrying tube/pipe which will contain any fluid or vapor which may leak from the line. All shrouds should be vented and drained.

Vapour barrier: A vapour and liquid tight isolating surface or membrane used for preventing flammable fluid egress from a compartment. Isolating surface fireproofness must be commensurate with the compartment requirements.

Ventilation stop: A valve, bulkhead or other device, at least fire resistant, which is vapour and liquid tight, for the purpose of halting ventilation into or out of a compartment.

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7.3.2 Abbreviations / Acronyms

DHI	de Havilland Inc.
DTRD	de Havilland Technical Requirements Document
ESP	Engineering Standard Practice
FRHA	Fire Hazard Analysis
FRHAS	Fire Hazard Assessment

7.4 PROCEDURES

The intent of the procedures are to assist Suppliers in identifying applicable fire protection regulations which must be addressed in the R&M Fire Hazard Assessment and to provide general and system fire protection design requirements.

Suppliers shall familiarize themselves with all applicable fire protection regulations and demonstrate that their aircraft section/system is in compliance with the regulatory requirements.

The fire protection design requirements have been organized such that the General section pertains to non-system specific fire protection requirements and the System sections cover their specific fire protection requirements and also the unique requirements of interfacing systems.

Demonstration of regulation compliance shall be submitted to DHI in a report format, complete with applicable system/structures schematics. Regulation compliance for the requirements FAR 25.863 shall be presented in a tabular format for each system containing flammable fluids.

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The following are Part 25 “fire protection” related regulations. For this assessment Suppliers shall comprehensively indicate the design precautions taken to protect the aircraft from fire hazards, in order to show compliance with those regulations listed below which have an asterik in the R&M column.

**TABLE 7.1:PART 25 FIRE PROTECTION REGULATION
REQUIREMENTS**

Part 25 Section	R&M	Title/Text	Advisory Circular
581		Lightning protection	AC20-130, 25-8, ACJ25.581
721	*	Landing Gear - General	AC25.994-1
729		Retracting Mechanism	ACJ25.729(f)
733		Tires	
851		Fire Extinguishers.	ACJ25.851(a)
853		Compartment Interiors.	AC25-10, 25-16, 25.853-1, ACJ25.853(a)(l)
854		Lavatory fire protection.	AC25-9
855		Cargo or baggage compartments.	AC25-8
857		Cargo compartment classifica- tion.	AC25-8, ACJ25.857
858		Cargo compartment fire detec- tion systems.	AC25-9
863	*	Flammable fluid fire protection.	AC20-135, 25-8, 25-16, 25-994-1, ACJ25.863
865		Fire protection of Flight Con- trols, engine mounts, and other flight structure.	
867		Fire protection: other compo- nents	AC20-135, 20-136.
869		Fire protection: Systems	AC25-9, 25-10, 25-16, 25-994-1, ACJ25.869, 25.1451

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REQUIREMENTS (Cont'd)**

Part 25 Section	R&M	Title/Text	Advisory Circular
X899		Electrical bonding and protection against lightning and static electricity	
901		Installation	AC20-128, 20-136, 25-8, 25-16, ACJ25.901
903	*	Engines	AC20-128, 20-135, 20-136, 25-8, 25-16, ACJ25.903
954		Fuel system lightning protection.	AC 20-53, 20-136, 25-8, ACJ25.954
963		Fuel tanks: General.	AC25-8, 25.963-1, 994-1
967		Fuel tank installations.	AC25-8
973		Fuel tank filler connection.	AC25-8
975		Fuel tank vents and carburetor vapor vents.	AC25-8, NPRM 84-17A
981		Fuel tank temperature.	AC25-8, 25.981-1A
993		Fuel system lines and fittings.	AC25-8, 25.994-1
994		Fuel system components.	AC25-8, 25.994-1
999		Fuel system drains.	
1017		Oil lines and fittings.	
1023		Oil radiators.	
1091		Air induction.	AC20-135
1103		Induction system ducts and air duct systems.	ACJ20-135, ACJ25.1103.
1121		Exhaust System- General.	ACJ20-15, ACJ25.1121
1123		Exhaust piping.	ACJ20-135
1141		Powerplant controls: General.	
1163		Powerplant accessories.	
1165		Engine ignition systems.	AC20-135
1181		Designated fire zone: regions included.	AC20-135, ACJ25-1181

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**TABLE 7.1: PART 25 FIRE PROTECTION REGULATION
REQUIREMENTS (Cont'd)**

Part 25 Section	R&M	Title/Text	Advisory Circular
1182		Nacelle areas behind fire walls, and engine pod attaching structures containing flammable fluid lines.	AC20-135
1183		Flammable fluid-carrying components.	AC20-135
1185		Flammable fluids.	AC25-8
1187		Drainage and ventilation of fire zones	
1189		Shut-off means.	AC20-135, 25.994-1
1191		Firewalls	AC20-135
1193		Cowling and nacelle skin.	AC20-135
1195		Fire extinguishing systems.	AC20-100, ACJ25.1195
1197		Fire extinguishing agents.	
1199		Extinguishing agent containers.	
1201		Fire extinguishing system materials.	AC20-135
1203		Fire-detector system.	AC20-135
1207		Compliance	AC20-135
1305		Powerplant instruments.	
1309		Equipment, systems and installations.	AC20-136, 25-9, 25-10, 25-16, 25.1309-1A, AC(M)J25.1309 (4,8)
1316		System lightning protection.	AC20-136
1337		Powerplant instruments.	
1351		Electrical Systems and Equipment - General.	AC25-10, 25-16, ACJ25.1351(d)

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REQUIREMENTS (Cont'd)**

Part 25 Section	R&M	Title/Text	Advisory Circular
1353		Electrical Equipment and installations.	AC25-10, 25-16 ACJ25-1353(c)(6)(ii)&(iii)
X1362		Electrical supplies for emergency conditions	AC25.X1362
1435		Hydraulic systems.	AC25-16
X1436		Pneumatic Systems - High pressure.	
1453		Protection for oxygen equipment from rupture	ACJ25.1453
1461		Equipment containing high energy rotors.	
X1499		Domestic services and appliances.	ACJ25.X1499(b)
1561		Safety equipment	

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7.4.2 Regulations Applicable to R&M Fire Hazard Assessment

- **25.721 General (Landing Gear)**

a) The main landing gear system must be designed so that if it fails due to overloads during take-off and landing (assuming the overloads to act in the upward and aft directions), the failure mode is not likely to cause -

(2) For airplanes that have a passenger seating configuration, excluding pilots seats, of 10 seats or more, the spillage of enough fuel from any part of the fuel system to constitute a fire hazard.

(b) Each airplane that has a passenger seating configuration, excluding pilots seats, of 10 or more must be designed so that with the airplane under control it can be landed on a paved runway with any one or more landing gear legs not extended without sustaining a structural component failure that is likely to cause the spillage of enough fuel to constitute a fire hazard.

- **25.863 Flammable Fluid Fire Protection**

(a) In each area where flammable fluids or vapors might escape by leakage of a fluid system, there must be means to minimize the probability of ignition of the fluids and vapors, and the resultant hazards if ignition does occur.

(b) ...the following factors must be considered.

(1) Possible sources and paths of fluid leakage, and means of detecting leakage.

(2) Flammability characteristics of fluids, including effects of any combustible or absorbing materials.

(3) Possible ignition sources, including electrical faults, overheating of equipment, and malfunctioning of protective devices.

(4) Means available for controlling or extinguishing a fire, such as stopping flow [fluids, shutting down equipment, fire] containment, or use of extinguishing agents.

(5) Ability of airplane components that are critical to safety of flight to withstand fire and heat.

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(c) If action by the flight crew is required to prevent or counteract a fluid fire (e.g. equipment shutdown or actuation of a fire extinguisher) quick acting means must be provided to alert the crew.

(d) Each area where flammable fluids or vapours might escape by leakage of a fluid system must be identified and defined.

- **25.869 Fire protection: systems**

(c) Oxygen equipment and lines must-

(3) be installed so that escaping oxygen cannot cause ignition of grease, fluid, or vapour accumulations that are present in normal operation or as a result of failure or malfunction of any system.

- **25.903 Engines**

(d) Turbine engine installations. For turbine engine installations-

(1) Design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case.

7.4.3 Fire Hazard Protection Requirements

As a minimum, it shall be possible to sustain any single primary failure or human error, and any consequential failures, without a resulting fire which would prevent continued safe flight and landing. This includes single failures which may cause both an ignition source and a flammable mixture to be present.

The following shall be considered for all aircraft areas:

- (1) Sources and paths of fluid leakage/spray and means of detection.
- (2) Drainage/ventilation of leaked flammable fluids/vapours.
- (3) Flammability characteristics of fluids and/or combustible or absorbent materials in vicinity.
- (4) Possible ignition sources.

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- (5) Means to control/extinguish fire (ie. stopping flammable fluid flow, fireproof containment, extinguishing agents, etc.)
- (6) Ability of components critical to flight safety to withstand fire and heat.

7.4.3.1 General - Fire Hazards

A fire hazard is defined as a situation where flammable liquids, vapours and/or materials are or may be present and potential ignition sources may also be present. When assessing potential fire hazards, the following should be considered:

(1) Combustible substances

Combustible substances to be considered shall include:

- a) Alcohol & water mixture- Coatings
- b) Composites
- c) Fuels
- d) Greases
- e) Hydraulic fluids
- f) Oils
- g) Plastics
- h) Sealants

(2) Absorbent materials

Absorbent materials close to flammable fluid system components that might leak shall be covered or treated to prevent the absorption of hazardous quantities of fluids.

(3) Ignition sources

Potential ignition sources to be considered shall include:

- a) High temperature surfaces
- b) Hot air/gases
- c) Electrical equipment
- d) Static electricity

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-
- e) Lightning strikes
 - f) Friction sparks
 - g) Uncontained flames

7.4.3.2 General - Fire Protection

In each area where flammable fluids or vapours might escape by leakage from a fluid system, there shall be means to minimize the probability of ignition of a flammable mixture, and to minimize the resultant hazards if ignition does occur. If action by the flight crew is required to prevent or counteract a fluid fire (eg. equipment shutdown or actuation of a fire extinguisher) quick-acting means shall be provided to alert the crew.

7.4.3.2.1 Drainage

Refer to DTRD-8-010, Section 3.1.2.4, Liquid Control.

All compartments through which flammable-fluid carrying tubes/pipes pass or house flammable-fluid containing components and compartments into which flammable fluids may leak shall be drained.

Drains shall be sized and/or screened to efficiently evacuate fluids and located to prevent fluids from accumulating, especially in pockets or cavities. The minimum diameter for fire zone structural drains shall be no less than 0.375 inches.

Drain lines shall be routed such that the slope is never less than 5 degrees during all normal flight attitudes.

All drain lines shall discharge overboard and shall not allow fluids to reenter the aircraft during all normal flight attitudes.

Drain lines may be manifolded only if they discharge compatible fluids

Drain lines/fittings located in fire zones shall be fireproof and elsewhere shall as a minimum be "fire resistant."

7.4.3.2.2 Ventilation

Refer to ESP 84, Electromagnetic Control Plan.

All compartments in which potential "ignition sources" and "flammable vapours" exist shall be appropriately ventilated.

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Ventilation in fire zones shall not inhibit fire containment and extinguishing.

Ventilation shall be considered in potential ignition zones to increase the zones' air pressure above that of adjacent areas, preventing flammable vapour ingress. Ventilation stops may also be considered to prevent the flow of combustible vapours from an adjacent area.

Zones with surfaces which may be exposed to flammable fluids or vapours should be ventilated if the temperature of the surfaces may exceed (under normal operating or failure conditions) a dangerous value with regard to these fluids or vapours. Unless a higher value can be substantiated, a temperature exceeding 200°C is considered dangerous.

Vents shall be located/oriented such that flammable fluids/vapours or flames cannot enter from other areas and vented substances will not reenter the aircraft.

7.4.3.2.3 Leakage minimization

Flammable-fluid carrying lines exposed to fire zones shall be of reliable construction and fireproof, using minimal joints.

Loose fasteners which could induce flammable fluid leakage shall have approved locking features.

Adequate and appropriate flammable fluid tube/pipe support provisions shall be used to avoid fatigue failures and chafing. Line to line supports shall be avoided where possible. Attachments between lines for spacing only is acceptable

Tube bends shall be in accordance with accepted design practice and means shall be incorporated in all tube/pipe runs to accommodate thermal expansion and aircraft flexing.

7.4.3.2.4 Separation / Isolation

The primary means of fire prevention is by separating or isolating flammable substances from ignition sources.

Flammable, flammable leakage, ignition and fire zones shall be separated from each other by compartmentation. In general, compartmentation should be implemented in "zones" adjacent to fire zones.

The aircraft shall be protected from all fire zones using firewalls. Adjacent fire zones shall be isolated from each other using firewalls or fire barriers.

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The compartment walls of a fire zone shall be capable of withstanding the maximum pressure differential under failure conditions. Cowling firewalls shall have frames capable of withstanding a fire without loss of structural integrity. The frame integrity shall extend through the hinges and latches necessary to maintain fireproofness.

Firewall penetrations shall be adequately sealed using fireproof seals, grommets and sealing materials; however, by design, sealants should be minimized

Materials and components used on the protected side of a firewall shall not ignite as a result of heat transfer or radiation from a fire in an adjacent fire zone.

Flammable fluid lines penetrating firewalls shall have shut-off provisions outside the fire zone.

For areas outside of fire zones; Ignition zones shall be isolated from flammable leakage zones by vapour barriers (ventilation stops). Ignition zones shall be isolated from flammable zones by double vapour barriers, with drainage provided between the vapour barriers.

Primary structure and equipment shall be protected by shielding, insulation or cooling if heat from a fire or hot air source could prevent continued safe flight and landing of the aircraft or ground operating hazards. Shielding and insulation materials shall be non-wicking/absorbing.

Flammable zone temperatures shall not exceed 200°C to prevent auto ignition of flammable surfaces.

7.4.3.2.5 Bonding & Grounding

Electrical bonding and grounding shall be carried out as per ESP 84 and 89.

Bonding and grounding requirements shall be commensurate with their fire hazard zone. Fire and ignition zones have no special requirements as an ignition source is always assumed present.

- (1) Flammables zone requirements
 - a) All metal parts shall be bonded to eliminate static discharge.
 - b) Electrical component and wiring temperatures shall remain well below auto ignition temperatures.

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- c) Electrical circuit wire current return paths (grounds) shall not be permitted.
- d) When bonding cannot be avoided, dual bond paths shall be used.
- (2) Flammable leakage zone requirements
 - a) All required electrical circuit wire current return paths shall have dual ground terminations or full fillet sealing (potting).
 - b) Separate fault current ground wires shall be required for equipment mounted on non-conductive structure.

7.4.3.2.6 Lightning Strike Protection

Lightning strikes passing through the aircraft shall not ignite flammable substances.

For lightning strike protection guidelines, refer to ESP 84 & 89 and FAA Advisory Circular 20-53A.

Note that suppliers shall be responsible for the preparation of a "Lightning and EMC/HIRF Control Plan" and a detailed "Lightning test procedure" which shall be submitted to de Havilland for approval.

7.4.3.2.7 Detection and Extinguishment

Refer to:

DTRD-8-010, Section 2.2.1.26, Fire Protection,

DTRD-8-025, Fire Detection and Extinguishing Systems

7.4.3.3 ATA 24 (Electrical Power)

7.4.3.3.1 Electrical Equipment

Electrical system components shall be designed such that their probability of being an ignition source in the presence of flammable fluids or vapours, which may escape by leakage from fluid systems, is minimized, eg. environmentally sealed electrical connectors.

The cooling air supply for any electrical or electronic equipment should be conveyed and discharged so as not to create a hazard following failure of the equipment. Where necessary the cooling duct should be fireproof.

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Electrical equipment located in flammable leakage zones shall meet the requirements of RTCA/00-160C or MIL-STD-810E.

Electrical equipment shall be adequately grounded to prevent arcing. Refer to ESP 84 & 89.

The main electrical power centers containing the main switching and power distribution components shall be installed in physically isolated fire resistant enclosures.

Where main switching and power distribution equipment with more than one electrical power channel is within a single enclosure, fire resistant barriers or equivalent separation shall be used to separate equipment of one channel from that of another.

Wiring and equipment supplied with the electrical standby power system shall be mechanically and electrically isolated from other system wiring and equipment such that a harness or junction box fire shall not affect the alternate power, and vice versa.

7.4.3.3.2 Cables

Main power cables, including generator cables in the fuselage shall be adequately separated from flammable fluid/oxygen lines (a minimum of six inches should be maintained whenever possible) or control cables (a minimum of three inches should be maintained whenever possible).

All flammable zone power cables shall be encased in a sealed shroud which is drained and ventilated.

If wiring is routed above flammable fluid or oxygen lines, adequate separation shall be provided such that failure of a single clamp/support will not allow contact. Where practical, wiring shall not be routed below flammable fluid line fittings/ports which may leak as the result of failure or maintenance.

Insulation of electrical wires and cables installed in any area of the fuselage shall be non-absorbent and self extinguishing when tested in accordance with applicable procedures.

Electrical wiring installations shall consider lightning induced current coupling to adjacent wiring of sufficient energy to produce arcing. Refer to ESP 84, DHC-8-400, Electromagnetic Control Plan.

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7.4.3.3.3 Batteries

No explosive or toxic gases emitted by any battery in normal operation or as the result of any probable malfunction in the charging system or battery installation may accumulate in hazardous quantities within the airplane. Flammable fluid lines shall not be routed over or near to batteries unless adequate isolation is provided.

7.4.3.4 ATA 25 (Equipment / Furnishings)

7.4.3.4.1 Materials

For material (ie. seats, panels, etc.) requirements and test procedures, refer to DTRD-8-010, Section 3.3.1, Flammability, Smoke & Toxicity.

7.4.3.4.2 Galleys

The installation of galleys and cooking appliances must be such as to minimize the risk of fire. All electrical domestic appliances must be suitably bonded. Refer to ESP 84 & 89. A hand held fire extinguisher must be readily accessible.

7.4.3.4.3 Ashtrays

If smoking is allowed in any compartment (except lavatories), an adequate number of self-contained, removable ashtrays shall be provided for all seated occupants and regardless if smoking is allowed, lavatories shall have self-contained removable ashtrays located conspicuously both inside and outside each lavatory. One ashtray located outside a lavatory door may serve more than one lavatory door if the ashtray can be seen readily from the cabin side of each lavatory door served.

7.4.3.4.4 Waste Receptacles

Each receptacle used for the disposal of flammable waste material shall be fully enclosed, constructed of at least fire resistant materials, and must contain fires likely to occur under normal use. The waste receptacle shall have an automatic fire extinguisher installed.

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7.4.3.4.5 Cargo / Baggage Compartments

For material requirements and test procedures, refer to DTRD-8-010, Section 3.3.1, Flammability, Smoke & Toxicity.

Cargo compartment fire detection and protection provisions shall be commensurate with their classification (ie. A thru E). Refer to 25.857.

No cargo or baggage compartment shall contain any controls, wiring, lines, equipment, or accessories whose damage or failure would create a fire hazard.

Sources of heat within the cargo or baggage compartment shall be shielded and insulated to prevent igniting the cargo or baggage.

7.4.3.5 ATA 28 (Fuel)

7.4.3.5.1 Fuel tanks

Fuel tanks shall be able to withstand without failure, the vibration, inertia, fluid, and structural loads that they may be subjected to in operation.

Fuel tanks shall, as far as practical, be designed, located and installed so that no fuel is released in or near the fuselage or near the engines in quantities sufficient to start a serious fire in otherwise survivable crash conditions.

Fuel tanks shall meet the requirements for integral fuel tank lightning protection and be designed to eliminate sources of ignition due to lightning. Refer to ESP 84 & 89.

Electro-static charge build-up in tanks shall be minimized during fueling (ref. JAR 25X899).

All tubes penetrating fuel tank walls shall be bonded at the exit and entry points.

Wiring which enters fuel tanks for fuel quantity and low fuel sensors shall be routed separately from 28 VDC circuits.

Access covers:

To avoid loss of hazardous quantities of fuel, fuel tank access covers located in areas where a strike from tire fragments, low energy engine debris, or other debris is likely, shall be designed to minimize penetration and deformation.

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Fuel tank access covers shall be fire resistant.

7.4.3.5.2 Components

Fuel system components in the engine nacelles, fuselage or wing structure shall be protected from damage which could result in spillage of enough fuel to constitute a fire hazard as a result of a wheels-up landing on a paved runway.

Fuel isolation shut-off valves shall be located such that all external tank leakage can be stopped. All shut-off valves and solenoid valves shall be located outside fire, rotorburst tireburst and birdstrike zones and away from high energy storage tanks.

Fuel components shall be electronically bonded to the aircraft structure per ESP 84 and 89.

7.4.3.5.3 Ventilation / Drainage

Fuel tank vents or drainage provisions shall not end at a point where the discharge of fuel from the outlet would constitute a fire hazard or from which fumes could enter personnel compartments.

All fuel system drains shall:

- (1) discharge clear of all parts of the airplane.
- (2) be located or protected to prevent fuel spillage in the event of a landing with landing gear retracted.

A minimum of two dry bays or equivalent shall be provided between engine/nacelle fire zones and adjacent fuel storage units.

Dry bays adjacent to fuel tanks must be ventilated to avoid fume accumulations due to minor leakage (drainage shall be provided to prevent the accumulation of condensate).

Vents shall be installed with flame arresters or equivalent means to prevent flame entry into fuel tank or delay burn-through for post-crash ground fires.

7.4.3.5.4 Fuel lines

Fuel lines shall be installed and supported to prevent excessive vibration and to withstand loads due to fuel pressure and accelerated flight conditions.

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Fuel lines connected to components of the airplane between which relative motion could exist shall have provisions for flexibility.

Fuel line connections that may be under pressure and subjected to axial loading shall use flexible hose assemblies.

Flexible fuel hose shall be TSO-C53 approved or shall be shown to be suitable for the particular application. All hose assemblies within a fire zone shall be fire sleeved.

Flexible fuel hoses that might be adversely affected by exposure to high temperatures shall not be used where excessive temperatures will exist during operation or after engine shutdown.

Fuel lines shall not be routed inside the pressurized areas of the aircraft.

All fuel lines within the fuselage shall be designed and installed to allow a reasonable degree of deformation and stretching without leakage.

Where possible fuel lines (and components) shall be located inside tanks and outside of potential burst paths of other systems.

Fuel line connections and fittings located in areas with no fire protection shall be shrouded and drained.

Fuel line connections and fittings shall not be located above air jet sources (ie. outflow valves) to minimize vapourization and avoid torching.

All fuel hardware (ie. tubes, components) shall be electrically bonded to the aircraft structure as per ESP 84 and 89.

7.4.3.5.5 Temperature

The highest temperature allowing a safe margin below the lowest expected auto-ignition temperature of the fuel in the fuel tanks shall be determined (FAA requires temperature not to exceed 200°C (400°F)). No temperature at any place inside any fuel tank where fuel ignition is possible shall exceed the temperature determined above. This shall be shown under all probable

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operating, failure and malfunction conditions of any component whose operation, failure or malfunction could increase the temperature inside the tank.

TABLE 7.2: FUEL - TEMPERATURE

Fuel Type	Flashpoint (⁰C)	Auto -ignition temp (⁰C)
JetA/A1	38	224
Jet B	0	229
JP-4	0	229
JP-5	60	224
JP-8	38	224

7.4.3.6 ATA 29 (Hydraulic Power)

Each hydraulic element must be installed and supported to prevent excessive vibration, abrasion, corrosion and mechanical damage, and to withstand inertia loads.

Means for providing flexibility must be used to connect points in a hydraulic fluid line between which relative motion or differential vibration exists.

Hydraulic tube leakage/breakage shall not result in fluid impinging on equipment with high temperature surfaces. Such areas shall be shrouded and drained.

Hydraulic hose assemblies shall be TSO-C75 approved. All hose assemblies within a fire zone shall be fire sleeved.

Hydraulic isolation shut-off valves shall be installed in the engine driven pump return line and located outside the fire, rotorburst, tireburst and birdstrike zones and away from high energy storage tanks.

High pressure hydraulic lines shall not be located closer than 2.0 inches to any flammable fluid tank or line to avoid cutting effects in the event of a hydraulic fluid leak.

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Adequate protective means shall be provided to avoid impingement of hydraulic fluid leaks onto high temperature titanium surfaces.

TABLE 7.3: HYDRAULIC OIL - TEMPERATURE

Hydraulic Oil	Flashpoint °C	Auto -ignition temp (°C)
Skydrol 500B4	182 (high pressure mist)	507
MIL-H-5606*	182 (high pressure unit)	224

* used in shock struts and hydraulic torque compensation system (forward engine mounts).

7.4.3.7 ATA 32 (Landing Gear)

Failure of the main landing gear due to overloads shall not likely cause the spillage of enough fuel to constitute a fire hazard.

In the event one or more landing gear fails to extend, under controlled flight, the aircraft shall be capable of landing on a paved runway without sustaining a structural component failure that is likely to cause the spillage of enough fuel to constitute a fire hazard.

Tire burst damage shall be assumed to occur in any direction normal to the tire exterior surface, with landing gear either extended or stowed. Tire bursts shall not cause hazardous quantities of flammable fluids or vapours to be released. Fuel lines passing through the wheel well shall not be routed through tire burst paths; however, if this is not possible, fuel lines shall be adequately shrouded.

Adequate protection shall be provided against hazards resulting from flammable fluid lines in wheelwells. Ignition sources to be considered shall include electric arcs and hot surfaces, including brake surfaces. Systems and/or procedures for detecting and extinguishing inflight fires in main wheelwells shall be provided (Overheat detectors shall be installed; no brake temperature sensors).

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7.4.3.8 ATA 35 (Oxygen)

7.4.3.8.1 Equipment & lines

Oxygen equipment and lines shall be installed so that escaping oxygen cannot cause ignition of grease, fluid, or vapour accumulations that are present in normal operation or as a result of failure or malfunction of any system.

Oxygen equipment and lines shall be adequately separated from electrical and fluid systems.

Oxygen line length and fittings shall be kept to a minimum.

Fittings/joints should be assembled dry where possible, but where compounds are used for sealing, they should be approved for that purpose.

7.4.3.8.2 Temperature

Oxygen system zone temperatures shall not exceed 160°F (71°C).

7.4.3.8.3 Ventilation

The compartments in which high-pressure system components, including source(s) are located should have adequate ventilation to ensure the rapid dilution of leaked oxygen. Such compartments should also provide adequate protection against contamination by liquids and other products which could result in the risk of fire.

7.4.3.8.4 Charging

Where in-situ charging facilities are provided, the compartments in which they are located should be accessible from outside the aircraft and as remote as possible from other service points and equipment.

Re-charging systems, if installed, should be provided with means to prevent excessive rates of charging which could result in dangerously high temperatures with the system. The charging system should also provide protection from contamination. High pressure shut-off valves should be designed to provide effective slow opening and closing, so as to avoid the possible risk of fire or explosion.

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7.4.3.9 ATA 36 (Pneumatic)

For all bleed air systems, no fire hazard shall result if a duct failure occurs at any point between the engine port and the airplane unit served by the bleed air.

For a single failure case leading to a fire and duct rupture, consideration should be given to the possibility of fire aggravation due to air flowing into a designated fire zone of an engine from the remaining engine, or another source outside the affected fire zone.

Bleed air duct insulations shall be non-wicking/absorbing.

Bleed air ducts passing through fire zones shall be fireproof.

No element of a pneumatic system which would be liable to cause hazardous effects by exploding, if subject to a fire, may be mounted within an engine bay or other designated fire zone.

7.4.3.10 ATA 49 (APU)

7.4.3.10.1 General

Precautions shall be taken to prevent flammable fluid impingement on APU casings, primary (exhaust) nozzles or tailpipes.

7.4.3.10.2 APU Controls

All APU controls that must be used during an emergency condition must be at least fire resistant (applicable to air-operable APU). The conductors (wiring) shall be per MIL-W-25038 or equivalent (air or ground operable APU).

7.4.3.10.3 APU Induction

APU induction system ducts:

- (1) shall not ingest flammable substances.
- (2) upstream of the APU compressor shall have a drain to prevent the hazardous accumulation of fuel in the ground attitude. No drain shall discharge where it might cause a fire hazard.
- (3) shall be fireproof within the APU unit fire zone.

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- (4) shall be fireproof for a sufficient distance upstream of the APU compartment to prevent hot gas reverse flow from burning through APU ducts and entering any other compartment or area of the airplane in which a hazard would be created resulting from the entry of hot gases. The materials used to form the remainder of the induction system duct and plenum chamber of the APU shall be capable of resisting the maximum heat conditions likely to occur.
- (5) shall be constructed of materials that shall not absorb or trap hazardous quantities of flammable fluids that could be ignited in the event of a surge or reverse flow condition.

7.4.3.10.4 Shut-off: Flammable fluids

Each APU compartment must have a means to shut-off or otherwise prevent hazardous quantities of fuel, oil, deicer and other flammable fluids from flowing into, within, or through any designated fire zone, except that shut-off means are not required for:

- (1) lines, fittings and components forming an integral part of an APU.
- (2) oil systems for turbine engine installations in which all components of the system in a designated fire zone, including the oil tanks, are fireproof or located in areas not subject to APU fire conditions.

Each flammable fluid shut-off means and control must be fireproof or must be located and protected so that any fire in a fire zone will not affect its operation.

No hazardous quantity of flammable fluid may drain into any designated fire zone after shut-off.

7.4.3.10.5 Firewalls

APU's intended for operation inflight must be isolated from the rest of the airplane by firewalls, shrouds or equivalent means.

7.4.3.10.6 Fire Protection

Every designated fire zone shall have approved quick acting fire or overheat detectors in numbers and locations sufficient to ensure prompt detection of fires. There shall be means to alert the crew if a sensor or an interconnection is severed or short-circuited, unless the system continues to function

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satisfactorily. The crew shall be able to check each electrical detection circuit for proper functioning in flight. Wiring within fire zones shall be at least fire resistant. If an interconnection to a system in one designated fire zone passes through another designated fire zone, it shall either be protected against alerts caused by fires in the zone passed through, or both zones shall be protected by the same detection and extinguishing systems. Alert activation times shall not exceed the requirements in the appropriate detector Technical Standard Order (C-11e) when installed.

A fire extinguishing system shall be provided for every designated fire zone, except that one is not required in combustor, turbine and tail pipe sections with components which contain flammable liquids or vapours if it is shown that a fire can be controlled without an extinguishing system. A single discharge system may be used for APU components.

7.4.3.11 ATA 54, 71, 72 (Nacelle, Powerplant, Engine)

7.4.3.11.1 General

All components, including ducts, within a designated fire zone shall be fireproof if, when exposed to or damaged by fire, they could;

- (1) result in fire spreading to other regions of the aircraft, or
- (2) cause unintentional operation of, or inability to operate, essential services or equipment.

Hazards shall be minimized in the event of a fire originating within the engine which burns through the engine case.

Engine inlets shall not ingest flammable substances.

Precautions shall be taken to prevent flammable fluid impingement on engine cases, primary nozzles or tailpipes.

Essential flight controls, engine mounts and other flight structures located in designated fire zones or in adjacent areas which would be subjected to the effects of fire in the fire zone shall be constructed of fireproof material or shielded so that they are capable of withstanding the effects of fire.

Except for integral oil sumps, no tank or reservoir that is a part of a system containing flammable fluids or gases may be in a designated fire zone unless the fluid contained, the design of the system, the materials used in the tank,

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the shut-off means, and all connections, lines and control provide a degree of safety equal to that which would exist if the tank or reservoir were outside such a zone.

There shall be at least one-half inch of clear airspace between each flammable fluid tank or reservoir and each firewall or shroud isolating a designated fire zone.

All designated fire zones shall have fire detection and extinguishment.

Flammable fluid-carrying lines, fittings and components located in any area subject to engine fire conditions and each component which conveys or contains flammable fluid in a designated fire zone shall be fireproof. This requirement includes those lines at least 8-10 inches beyond the firewall in areas behind a fire zone.

Flammable fluid tanks and supports in a designated fire zone shall be fireproof or be enclosed by a fireproof shield unless damage by fire to any non-fireproof part will not cause leakage or spillage of flammable fluid.

Flammable fluid-carrying components shall be shielded or located to safeguard against the ignition of leaking fluid.

7.4.3.11.2 Engine / Propeller Controls

All Engine and propeller controls that must be used during an emergency condition must be at least fire resistant. The conductors (wiring) shall be per MIL-W-25038 or equivalent.

7.4.3.11.3 Drains

Drain lines and their fittings, whose failure will not result in or contribute to a fire hazard, need not be fire resistant.

There must be complete drainage of each part of each designated fire zone to minimize the hazards resulting from failure or malfunction of any component containing flammable fluids. The drainage means shall be:

- (1) Effective under conditions expected to prevail when drainage is needed.
- (2) Arranged so that no discharged fluid will cause an additional fire hazard.

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Drainage installations shall not cause backflowing as a result of a pressurized adjacent line.

7.4.3.11.4 Ventilation

Vent lines and their fittings, whose failure will not result in or contribute to a fire hazard, need not be fire resistant.

Each designated fire zone must be ventilated to prevent the accumulation of flammable vapours.

No ventilation opening may be where it would allow the entry of flammable fluids, vapours, or flame from other zones.

Each ventilation means must be arranged so that no discharged vapours will cause an additional fire hazard.

Nacelle pressure relief openings shall be located so that flammable substances or, in the event of fire, exiting flames will not adversely affect the aircraft.

Ventilation stops shall be provided to prevent the entry of air to a fire zone if that entry could constitute a significant additional fire hazard.

7.4.3.11.5 Shut-off: Flammable fluids

Each engine installation must have a means to shut-off or otherwise prevent hazardous quantities of fuel, oil, deicer and other flammable fluids from flowing into, within, or through any designated fire zone, except that shut-off means are not required for:

- (1) lines, fittings and components forming an integral part of an engine.
- (2) oil systems for turbine engine installations in which all components of the system in a designated fire zone, including the oil tanks, are fire-proof or located in areas not subject to engine fire conditions.

Each flammable fluid shut-off means and control must be fireproof or must be located and protected so that any fire in a fire zone will not affect its operation.

No hazardous quantity of flammable fluid may drain into any designated fire zone after shut-off.

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7.4.3.11.6 Firewalls

The combustion, turbine, and tailpipe sections of turbine engines, must be isolated from the rest of the airplane by firewalls, shrouds or equivalent means.

Firewalls and shrouds must be fireproof, constructed so that no hazardous quantity of air, fluid or flame can pass from the compartment to other parts of the airplane, constructed so that each opening is sealed with close fitting fireproof grommets, bushings, or firewall fittings and protected against corrosion.

7.4.3.11.7 Electrical Power

Firewall connectors and the passage of all wiring through the firewall shall be as fireproof as the firewall itself.

Electrical cables, terminals and equipment in designated fire zones, that are used during emergency procedures or critical to flight safety, shall be at least fire resistant. All other cables, unless specified, shall use high temperature wire.

Electrical equipment shall be installed with at least one case ground.

No ground wire for any engine shall be routed through a fire zone of another engine unless each part of that wire within that zone is fireproof.

All electrical terminations shall be protected to prevent arcing or sparking. Electrical equipment in designated fire zones shall not be an ignition source under normal operating conditions.

7.4.3.11.8 Oxygen

Oxygen equipment and lines shall:

- (1) not be located in any designated fire zones
- (2) be protected from heat that may be generated in, or escape from, any designated fire zone.

7.4.3.11.9 Hydraulic Power

For shut-off valve and pipe/tube requirements, refer to DTRD-8-009, Sections 2.2.1.26-00 and 3.2.2.29-00.

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7.4.3.11.10 Fire Protection

Every designated fire zone shall have approved quick acting fire or overheat detectors in numbers and locations sufficient to ensure prompt detection of fires. There shall be means to alert the crew if a sensor or an interconnection is severed or short-circuited, unless the system continues to function satisfactorily. The crew shall be able to check each electrical detection circuit for proper functioning in flight. Wiring within fire zones shall be at least fire resistant. If an interconnection to a system in one designated fire zone passes through another designated fire zone, it shall either be protected against alerts caused by fires in the zone passed through, or both zones shall be protected by the same detection and extinguishing systems. Alert activation times shall not exceed the requirements in the appropriate detector Technical Standard Order when installed.

A fire extinguishing system shall be provided for every designated fire zone, except that one is not required in combustor, turbine and tail pipe sections with components which contain flammable liquids or vapours if it is shown that a fire can be controlled without an extinguishing system. A system with two discharges, either of which is capable of extinguishing fires in worst case airflow conditions, is required for designated fire zones (except APU, which may use only one).

7.4.3.11.11 Fuel

Re/defuel lines passing through the engine nacelle shall be of double wall construction, vented and drained.

7.4.3.12 ATA 78 (Exhaust)

Exhaust systems shall ensure safe disposal of exhaust gases without fire hazard.

Each exhaust system part with a surface hot enough to ignite flammable fluids or vapours must be located or shielded so that leakage from any system carrying flammable fluids or vapours will not result in a fire caused by impingement of the fluids or vapours on any part of the exhaust system including shields for the exhaust system.

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Each component that hot exhaust gases could strike, or that could be subjected to high temperatures from exhaust system parts, must be fireproof. All exhaust system components must be separated by fireproof shields from adjacent parts of the airplane that are outside the engine and APU compartments.

No exhaust gases may discharge so as to cause a fire hazard with respect to any flammable fluid vent or drain.

Each exhaust shroud must be ventilated or insulated to avoid during normal operation, a temperature high enough to ignite any flammable fluids or vapours external to the shroud.

If necessary, each exhaust system should be provided with drains to prevent hazardous accumulations of fuel under all conditions of operation.

7.4.3.13 ATA 79 (Oil)

7.4.3.13.1 Oil lines

Oil lines shall be installed and supported to prevent excessive vibration and to withstand loads due to oil pressure and accelerated flight conditions.

Oil lines connected to components of the airplane between which relative motion could exist shall have provisions for flexibility.

Oil line connections that may be under pressure and subjected to axial loading shall use flexible hose assemblies.

Flexible oil hoses shall be approved or shall be shown to be suitable for the particular application.

Flexible oil hoses that might be adversely affected by exposure to high temperatures shall not be used where excessive temperatures will exist during operation or after engine shutdown.

All oil lines within the fuselage shall be designed and installed to allow a reasonable degree of deformation and stretching without leakage.

Propeller feathering oil hose assemblies shall be TSO C-42 approved. All hose assemblies within a fire zone shall be fire sleeved.

Engine oil hose assemblies shall be TSO C-53 approved. All hose assemblies within a fire zone shall be fire sleeved.

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Oil breather discharge shall not constitute a fire hazard if foaming occurs.

7.4.3.13.3 Oil radiator

All oil radiator air ducts must be located so that, in case of fire, flames coming from normal openings of the engine nacelle cannot impinge directly upon the radiator.

7.4.3.13.4 Temperature**TABLE 7.4: OIL - AUTO-IGNITION TEMPERATURE**

Oil Type	Flashpoint ⁰ C	Auto -ignition temp (⁰ C)
MIL-L-23699	246 (475F)	TBD
MIL-L-7808	210 (410F)	390

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1996-07-05

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CAGE CODE 71867

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MASTER MINIMUM EQUIPMENT LIST

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8 MASTER MINIMUM EQUIPMENT LIST

8.1 INTRODUCTION

This document outlines DHI's policies and procedures for identifying Master Minimum Equipment List (MMEL) candidates and appropriately substantiating these candidates.

The MMEL is a regulatory approved Part 21 operations document that establishes the aircraft equipment allowed to be inoperative, under certain conditions, for the dispatch of a flight and forms the basis of airlines Minimum Equipment Lists (MEL).

Optional equipment may be included in the MMEL; however, the MMEL does not include items such as wings, engines, and landing gear that are always required, nor is reference made to equipment such as passenger convenience and entertainment items which, when inoperative, do not affect airworthiness.

DHI shall incorporate Supplier system MMEL candidates into a draft aircraft MMEL which shall be submitted to Airworthiness Authorities for approval.

APPLICABLE DOCUMENTS

EPS 1-18	R&M Specification Requirements
FAR 121.628	Inoperable instruments and equipment FAA MMEL Policy Book
TP9155E	Master Minimum Equipment List/Minimum Equipment List, Policy and Procedures Manual Transport Canada MMEL Guidance Book
PSM 1-8-16	Dash 8 Minimum Equipment List Procedures Manual

8.2 DEFINITIONS & ABBREVIATIONS / ACRONYMS

Airplane Flight Manuals (AFM): the document required for type approval and approved by Transport Canada. The approved AFM for the specific aircraft is listed on the applicable Type Approval Data Sheet.

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As required by FAR, As required by MMEL, As required by ANO, and other similar statements: means that the listed item is subject to certain provisions (restrictive or permissive) expressed in the Federal Aviation Regulation, the Airworthiness Manual or ANO's. The items specified by these requirements must be operative. When the listed item is not required by the requirements it may be inoperative for the time specified by repair category.

Deactivated and Secured: means that the specified component must be put into an acceptable condition for safe flight. An acceptable method of securing or deactivating will be established by the operator.

Extended Range Operations (EROPS): Extended Range Operations with Transport Category Aeroplanes (EROPS) allows twin engine aircraft to operate over a route that contains a point farther than one hour flying time at the designated single engine cruise speed from an adequate airport (where "designated" and "adequate" are defined in the requirements).

Excess Items: means those items that have been installed that are redundant to the requirements.

Federal Aviation Regulations (FAR): means the applicable portions of the Federal Aviation Act and Federal Aviation Regulations.

Flight Day: means a 24-hour period (from midnight to midnight) either Universal Coordinated Time (UCT) or local time, as established by the operator, during which at least one flight is initiated for the affected aircraft.

Icing Conditions: means an atmospheric environment that may cause ice to form on the aircraft or in the engine(s).

Inoperative: means a system and/or component malfunction to the extent that it does not accomplish its intended purpose and/or is not consistently functioning normally within its approved operating limit(s) or tolerance(s).

Notes: - in Column 4 provides additional information for crew member or maintenance consideration. Notes are used to identify applicable material which is intended to assist with compliance, but do not relieve the operator of the responsibility for compliance with all applicable requirements. Notes are not a part of the provisions.

Inoperative components of an inoperative system: Inoperative items, which are components of a system which is inoperative, are usually considered components directly associated with and having no other function

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than to support that system. (Warning/caution systems associated with the inoperative system must be operative unless relief is specifically authorized per the MMEL).

Instrument Meteorological Conditions (TMC): The atmospheric environment is such that the flight cannot proceed under visual flight rules applicable to the flight.

Item: (Column 1) means the equipment, system, component, or function listed in the “Item” column.

“M” symbol: indicates a requirement for a specific maintenance procedure which must be accomplished prior to operation with the listed item inoperative. Normally these procedures are accomplished by maintenance personnel; however, other personnel may be qualified and authorized to perform certain functions. Procedures requiring specialized knowledge or skill, or requiring the use of tools or test equipment should be accomplished by maintenance personnel. The satisfactory accomplishment of all maintenance procedures, regardless of who performs them, is the responsibility of the operator. Appropriate procedures are required to be published as part of the operator’s manual or MEL.

Number Installed: (Column 2) is the number (quantity) of items normally installed in the aircraft. This number represents the aircraft configuration considered in developing this MMEL. Should the number be a variable (e.g., passenger cabin items), a number is not required.

Note: Where the MMEL shows a variable number installed, the MEL must reflect the actual number installed or an alternate means of configuration control approved by Transport Canada, or Certificating Authority.

Number Required for Dispatch: (Column 3) is the minimum number (quantity) of items required for operation provided the conditions specified in Column 4 are met.

Note: Where the MMEL shows a variable number required for dispatch, the MEL must reflect the actual number required for dispatch or an alternate means of configuration control approved by Transport Canada, or Certificating Authority.

“O” symbol: indicates a requirement for a specific operations procedure which must be accomplished in planning for and/or operating with the listed item inoperative. Normally these procedures are accomplished by the flight

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crew, however, other personnel may be qualified and authorized to perform certain functions. The satisfactory accomplishment of all procedures, regardless of who performs them, is the responsibility of the operator. Appropriate procedures are required to be published as a part of the operator's manual or MEL.

Note: The (M) and (O) symbols are required in the operator's MEL unless otherwise authorized by Transport Canada.

Passenger Convenience Items: means those items related to passenger convenience, comfort or entertainment such as, but not limited to, galley equipment, lavatory, movie equipment, ash trays, stereo equipment, overhead reading lamps, etc.

Placard: Each MMEL item, if inoperative, must be placarded to inform and remind the crew members and maintenance personnel of the equipment condition.

Note: To the extent practical, placards should be located adjacent to the control or indicator for the item affected; however, unless otherwise specified, placard wording and location will be determined by the operator.

Remarks or Exceptions: (Column 4) includes a statement either prohibiting or permitting operation with a specific number of items inoperative, provisos (conditions and limitations) for such operation, and appropriate notes.

A vertical bar (change bar) in the margin indicates a change, addition or deletion in the adjacent text for the current revision of that page only. The change bar is dropped at the next revision of that page.

Note: Where the MMEL shows a variable number installed, the MEL must reflect the actual number installed or an alternate means of configuration control approved by Transport Canada, or Certificating Authority.

Repair Intervals: All users of an MEL must effect repairs on inoperative systems or components, deferred in accordance with the MEL, at or prior to the repair times established by the following letter designators;

Category A: Items in this category shall be repaired within the time interval specified in the remarks column of the operator's approved MEL.

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Category B.: Items in this category shall be repaired within three (3) consecutive calendar days (72 hours), excluding the day the malfunction was recorded in the aircraft maintenance record/logbook. For example, if it were recorded at 10 a.m. on January 26th, the three day interval would begin at midnight the 26th and end at midnight the 29th.

Category C.: Items in this category shall be repaired within ten (10) consecutive calendar days (240 hours), excluding the day the malfunction was recorded in the aircraft maintenance record/logbook. For example, if it were recorded at 10 a.m. on January 26th, the ten day interval would begin at midnight the 26th and end at midnight February 5th.

Category D.: Items in this category shall be repaired within one hundred and twenty (120) consecutive calendar days (2880 hours), excluding the day the malfunction was recorded in the aircraft maintenance log and/or record.

The letter designators are inserted adjacent to Column 2.

Visual Flight Rules (VFR): is as defined in the ANO. This precludes a pilot from filing an Instrument Flight Rules (IFR) flight plan.

Visual Meteorological Conditions (VMC): means the atmospheric environment is such that would allow a flight to proceed under the visual flight rules applicable to the flight. This does not preclude operating under Instrument Flight Rules.

Visible Moisture: means an atmospheric environment containing water in any form that can be seen in natural or artificial light; for example, clouds, fog, rain, sleet, hail or snow.

“*”:** symbol in Column 1 indicates an item which is not required by regulation but which may have been installed on some models of aircraft covered by this MMEL. This item may be included on the operator’s MEL after the approving office has determined that the item has been installed on one or more of the operator’s aircraft. The symbol however, shall not be carried forward into the operator’s MEL. It should be noted that neither this policy nor the use of this symbol provide authority to install or remove an item from an aircraft. The “***” symbol may be considered equivalent to the term “if installed”.

“-”: symbol in column 2 and/or column 3 indicates a variable number (quantity) of the item installed.

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8.3 PROCEDURES (GUIDELINES)

The intent of the procedures is to provide guidance in establishing MMEL candidates, justifying the candidates, providing pertinent operating and maintenance procedures and assigning operating conditions and deferral time constraints.

8.3.1 MMEL Candidate Selection

Objectives of the MMEL include:

- (1) as a minimum, MMEL items, for present series aircraft, be maintained if the system architect is similar.
- (2) systems which are similar to present series aircraft but are not on the MMEL should be enhanced to achieve MMEL relief.
- (3) provide MMEL relief for new systems.

A preliminary MMEL list, based on the above objectives, is provided in Para 8.4. This list shall be used by Suppliers to assist in establishing the scope of their MMEL deliverables.

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When considering dispatch with inoperative equipment the following must be considered:

- (1) The failure of any of the instruments or items of equipment required or installed in the aircraft (i.e., equipment/instruments required for dispatch when other equipment/instruments are inop) must be compensated for by other factors which provide equivalent or an acceptable level of safety no less than the level intended by the FAR's/JAR's.
- (2) Does not conflict with AFM limitations, emergency procedures or Airworthiness Directives unless the AFM or Directive otherwise provide.
- (3) If an item is inoperative, its function must be transferrable to another redundant system, or flight crew, or procedure.
- (4) Must not have an adverse affect on crew workload.
- (5) Must consider the next worst subsequent failure after dispatch - can not put the aircraft in an emergency procedure or situation.
- (6) Must be safe to fly regardless of the time element involved.
- (7) Must consider impact of training and economic issues.
- (8) Item must be certificated. Relief is not granted to future uncertified/uninstalled systems.
- (9) May not be part of an emergency procedure.

The MMEL shall not include any equipment which, if inoperative, is likely to significantly affect the take-off, landing or climb performance of the aircraft or any associated landing speeds presented in the approved AFM (Aircraft Flight Manual) unless the AFM specifies the effect and the MMEL draws attention to this fact.

The MMEL shall not include any part or structural component of the aircraft which is the subject of the aircraft Configuration Deviation List (CDL).

Equipment which is required to be installed and operative under particular circumstances by an Air Navigation Order or Aviation Regulation shall be identified in the required format's remarks column with the words "As required by regulations".

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8.3.2 MMEL Candidate Justification

MMEL justification shall be provided for all MMEL candidates supported by a brief item description including schematics, installation drawings, etc. in sufficient detail to enable the reader to understand the item installation, function and operation. The assessment of an acceptable level of safety for a MMEL item often involves more than one of the following methods of justification:

- (1) the equipment may be considered optional;
- (2) the equipment may be considered redundant;
- (3) a quantitative safety analysis; and/or
- (4) a qualitative analysis.
- (5) FAA MMEL Policy Book, Transport Canada Master Minimum Equipment List Policy and Procedure Manual (TP9155E) and Transport Canada MMEL Guidance Book must be referred to.

8.3.2.1 Optional Equipment

When aircraft are approved with optional equipment on board which is over and above the required equipment (basis of certification), there is no necessity for such equipment to be operative if it is in excess of that required for safe operations for a particular flight condition or route of flight. Inclusion in the MMEL can be accepted on this basis.

8.3.2.2 Redundant Items

If the purpose or function of the considered component/system can be carried out by some other equipment, then it may be accepted on a redundancy basis with the provision that the alternative equipment can be confirmed to be operating normally. Redundancy cannot be claimed as justification for inclusion of an item if the two (or more) sources of the function or information are required by the aircraft type approval basis. In this case, another means of justification such as the safety analysis method must be used.

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8.3.2.3 Quantitative Safety Analysis

If the item cannot be justified by the previous means or criteria, then a safety analysis must be carried out involving a quantitative analysis of the likely risk of the worst effects that can result from additional failures, events and/or environmental conditions occurring during a flight with the particular inoperative item in question. It must be shown that, bearing in mind the reduced exposure time when operating under a MMEL, the probability of a particular hazard has not been increased beyond the levels dictated by the minimum standards specified for the design and operation of the aircraft type.

8.3.2.4 Qualitative Safety Analysis

If an item is to be acceptable for inclusion in a MMEL, a qualitative analysis must be used to consider the impact that the proposed inoperative item has on all other aspects of the aircraft's operation. The qualitative analysis must consider the impact on crew workload, the impact of multiple MMEL items, single worst subsequent system/equipment failure, the complexity of maintenance and/or operational procedures. It may reflect experience with previous MMEL approvals.

Note: A previous MMEL approval of the same item on another aircraft type does not in itself imply that the required level of safety has been met. Factors which must be considered are similarity of system operation and similarity of aircraft operational role.

8.3.2.5 MMEL Conditions

Where applicable, the limitations, procedures and remarks for individual MMEL items should cover at least day, night, VMC, EROPS, icing, rain and IMC flight operating conditions.

8.3.2.6 MMEL Time Constraints

The repair category shall be contained in column 1 of the MMEL. The maximum time between the deferral of an inoperative item and its repair will be specified in the MMEL. Passenger convenience items such as reading lights have no specified repair interval (no category). The category of all other inoperative items will be determined according to the following time intervals:

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- (1) Category A. Items in this category shall be repaired within the time interval specified in the remarks column of the MMEL.
- (2) Category B. Items in this category shall be repaired within three (3) consecutive calendar days (72 hours), excluding the day the malfunction was recorded in the aircraft maintenance record/logbook.
- (3) Category C. Items in this category shall be repaired within ten (10) consecutive calendar days (240 hours), excluding the day the malfunction was recorded in the aircraft maintenance record/logbook.
- (4) Category D. Items in this category shall be repaired within one hundred and twenty (120) consecutive calendar days (2880 hours), excluding the day the malfunction was recorded in the aircraft maintenance record/logbook. To be considered for placement in the D category, an item must be of an optional nature, which an operator may, at his/her discretion, deactivate, remove from or install on an aircraft. To be approved for the D category, the item must meet the following criteria:
 - (a) the absence of the item does not affect crew workload;
 - (b) the pilots do not rely on the function of that item on a routine or continuous basis; and
 - (c) the pilot's training, subsequent habit patterns and procedures do not rely on the use of that item.

The category of each item in the MMEL is to be inserted in column 1 adjacent to column 2.

8.3.2.7 MMEL Maintenance and Operating Procedures

Any item of equipment in the MMEL which when inoperative will require an operational or maintenance procedure to ensure the required level of safety is maintained, and shall be so identified by an appropriate symbol. This will normally be "O" for an operational procedure and "M" for a maintenance procedure. Details of such procedures must be made available for review during the MMEL approval process as they form part of the justification supporting inclusion of an item in the MMEL. However, the approval of the procedures themselves will not be a part of the MMEL approval process.

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8.3.3 Format

Partners/suppliers shall provide MMEL items in a “four column format” where columns 1 to 4 will contain respectively the name of the item, number installed, number required for dispatch and remarks or exceptions.

Each item of equipment listed in the MMEL shall be described and identified in accordance with the Air Transport Association (ATA) specification 100 code system. The number of each item of equipment installed and the number required to be operative for dispatch shall be stated in the appropriate columns. Any condition associated with inoperative equipment, the observance of which is necessary in order to achieve the required level of safety, shall be stated in the remarks column. When practical, the switch, lever, gauge or indicator of a particular item of equipment should be identified.

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DEPARTMENT OF TRANSPORT MASTER MINIMUM EQUIPMENT LIST		MINISTÈRE DES TRANSPORTS LISTE PRINCIPALE D'ÉQUIPEMENT MINIMAL	
Aircraft - Aéronef		Revision	Page
De HAVILLAND DHC - 8		Date	
System & Nos de Sequence système et Numbers de série	Item - Article	1. 2. Number install - Nombre d'articles installés	
		3. Number require for dispatch - Nombre d'articles à expédier	
		4. Remarks of Exceptions - Remarques ou exceptions	

JUSTIFICATION

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DEPARTMENT OF TRANSPORT MASTER MINIMUM EQUIPMENT LIST		MINISTÈRE DES TRANSPORTS LISTE PRINCIPALE D'ÉQUIPEMENT MINIMAL	
Aircraft - Aéronef		Revision	Page
De HAVILLAND DHC - 8		Revision	
Date			

System & Nos de Sequence système et Numbers de série	Item - Article	1.	2. Number install - Nombre d'articles installés
			3. Number require for dispatch - Nombre d'articles à expédier
			4. Remarks of Exceptions - Remarques ou exceptions

Placard

Operating Procedures

Maintenance Procedures

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8.4 APPENDIX A: MMEL PRELIMINARY LIST

8.4.1 ATA 21 AIR CONDITIONING

- (1) Cabin Pressure Control
- (2) Cabin Pressure Control System
 - Automatic and/or Manual modes
- (3) Differential Pressure Indicator
- (4) Cabin Altitude Indicator
- (5) Cabin Rate of Climb Indicator
- (6) Cabin Pressure Caution Light
- (7) Environmental Control
- (8) Cabin Temperature Control
 - Automatic or Manual
- (9) Flight Compartment Temperature Control
 - Automatic or Manual
- (10) Cabin Duct Temperature Indicator
- (11) Temperature Bulb for Temperature Controller
- (12) Recirculation Fan(s)
- (13) Avionics Cooling Fan(s)
- (14) Air Cycle Machines
- (15) Advisory Display Cooling Fans
- (16) Gasper Fan
- (17) Temperature Trim Valve
- (18) Equipment Cooling Fan
- (19) Pack Temperature Control Valves

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8.4.2 ATA 22 AUTO FLIGHT

- (1) Autopilot
- (2) Control Wheel Disengage Switches
- (3) Autopilot Disengage Lights
- (4) Yaw Damper Channels
- (5) Flight Guidance Computers

8.4.3 ATA 23 COMMUNICATIONS

- (1) Flight Compartment Speakers
- (2) Passenger Address System
- (3) Cabin Attendant's Interphone System
- (4) Service Interphone System
- (5) Passenger to Flight Attendant Call System
- (6) Cabin Chimes System
- (7) Prerecorded Passenger Announcement System
- (8) Static Dischargers
- (9) Cockpit Voice Recorder System
- (10) Boom Microphones
- (11) Boom Microphone Push to Talk Switches

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8.4.4 ATA 24 ELECTRICAL POWER

- (1) Transformer Rectifiers
- (2) Inverter Fail Caution Lights
- (3) AC Voltmeter (Variable Frequency)
- (4) AC Loadmeter (Variable Frequency)
- (5) AC GEN Fail Caution Lights
- (6) DC Loadmeter
- (7) Inverter Voltmeter
- (8) Inverters
- (9) Inverter Loadmeter
- (10) DC Generator Control System (GCU and Generator)
- (11) Battery Temperature Monitors (Auxiliary and Main)
- (12) AC External Power System
- (13) DC External Power System
- (14) DC Generator Control Unit
 - Start Terminate Function

8.4.5 ATA 25 EQUIPMENT / FURNISHINGS

- (1) Pilot's Seat Adjustment
 - Vertical Mode
 - Horizontal Mode
- (2) Flight Attendant Seat Assembly
- (3) Passenger Seats
- (4) Emergency Locator Transmitter (ELT)
- (5) Passenger Convenience Items
- (6) Forward Observer Seat

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-Forward Observer's Audio Selector Panel

- (7) Type III Exit Ditching Dams
- (8) Overhead Stowage Bin Latches

8.4.6 ATA 26 FIRE PROTECTION

- (1) Power Plant Fire Detection System (Dual Loop Configuration)
- (2) Fire Extinguish Thermal & Discharge Discs
- (3) Lavatory Smoke Detection Systems
- (4) Lavatory Fire Extinguisher Systems
- (5) APU Fire Detection System
- (6) APU Fire Extinguishing System
- (7) Baggage Compartment Smoke Detectors

8.4.7 ATA 27 FLIGHT CONTROLS

- (1) Aileron Trim Indicator
- (2) Stall Warning System
 - Stick Pusher System
- (3) Rudder Pedal Adjustment
- (4) Rudder Trim Indicator
- (5) RUD PRESS Caution Light
- (6) Roll Spoilers (Ground Mode)
- (7) Spoiler Advisory Lights
- (8) Roll Spoiler Caution Lights
- (9) FLAP POWER Caution Light System
- (10) Rudder Pressure Regulator System
- (11) Rudder Trim Switch
- (12) PFCS Indication

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8.4.8 ATA 28 FUEL

- (1) TANK FUEL LOW Caution Lights
- (2) Fuel Quantity Indication (Flight Compt.)
- (3) Fuel Quantity Indication (External Refuel/Defuel Panel)
- (4) Magnetic Dipsticks
- (5) Pressure Refuelling System
- (6) Pressure Refuelling Automatic Shutoff
- (7) FUELING ON Caution Light
- (8) AUX PUMP Advisory Lights
- (9) Fuel Tank Temperature Indicator

8.4.9 ATA 29 HYDRAULIC POWER

- (1) Main Hydraulic Pressure Indication
- (2) Standby Hydraulic Pressure Indication
- (3) ENG HYD PUMP Caution Lights
- (4) HYD FLUID HOT Caution Lights
- (5) Nacelle Hydraulic Quantity Indicators

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8.4.10 ATA 30 ICE AND RAIN PROTECTION

- (1) Airframe De-Icing System
- (2) De-ice Timer (Automatic)
- (3) Propeller De-Icing System
- (4) Windshield Wipers
- (5) Pitot/Static Heaters
- (6) PITOT HEAT Caution Lights
- (7) Tail De-Ice Boot Advisory Lights
- (8) DE-ICE PRESS Indicator
- (9) DE-ICE PRESS Caution Light
- (10) Windshield Heater Systems
- (11) Propeller Heat Timers
- (12) Engine Intake Heaters
- (13) Engine Intake Heater Indicators
- (14) Wing Deicer Boot Advisory Lights
- (15) Propeller Heat Advisory Lights
- (16) Ice Detector Lights
- (17) Ice Detector Probe(s)
- (18) Low Pressure Switch (manifold)
- (19) De-ice Boot Sensor

8.4.11 ATA 31 INDICATING / RECORDING

- (1) Flight Data Recorder (FDR)
- (2) Clocks

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8.4.12 ATA 32 LANDING GEAR

- (1) Parking Brake Pressure Indicators
- (2) Anti-Skid System (Performance Restrictions)
- (3) Nosewheel Steering System
- (4) Touched Runway Indication System

8.4.13 ATA 33 LIGHTS

- (1) Flight Deck and Instr. Panel Lighting Systems
- (2) Cabin Interior Normal Lighting System
- (3) Passenger Notice System ("No Smoking/Fasten Belt" Sign)
- (4) Landing Lights
- (5) Taxi Light
- (6) Wing Inspection Lights
- (7) Position Lights
- (8) Anti-collision Lights (White)
- (9) Anti-collision Lights (Red) - Ramp Light
- (10) Logo Lights
- (11) Interior Emergency Lighting System
 - Cargo Configuration
- (12) Overhead Emergency Dome Light(s)
- (13) Exterior Emergency Lighting System
- (14) Floor Proximity Emergency Escape Path Marking System
 - Floor Mounted Light Track
 - "Exit" Identifiers
- (15) Cargo Compartment Lights
- (16) Passenger Door Step Lights
- (17) Boarding Lights
- (18) Advisory Lights System

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-
- Dimming Function
 - (19) Caution Lights System
 - Dimming Function
 - (20) Warning Lights System
 - Dimming Function

8.4.14 ATA 34 NAVIGATION

- (1) Static Air Temperatures
- (2) Radio Altimeter System
- (3) RAD ALT Height Display
- (4) Radio Magnetic Indicators
- (5) Non-Stabilized Magnetic (Stdby) Compass
- (6) Turn Indication
- (7) Slip Indicator/Inclinometer
- (8) Attitude/Heading Reference System (in combination with IRS/INS installation)
- (9) OAT/SAT Indication
- (10) Ground Proximity Warning System (GPWS)
 - Modes 1-4
 - Test Mode
 - Glideslope Deviation Lights (Mode 5)
 - Advisory Callouts

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-Windshear Mode

- (11) Altitude Alerter/Preselector System
- (12) Flight Director Systems
- (13) Microwave Landing System (MLS)
- (14) RNAV System
- (15) Weather Radar
- (16) Radar Graphics System
- (17) Weather Radar Stabilization
- (18) Traffic Alert Collision Avoidance System

-Combined Traffic Alert and Resolution

- (19) Advisory Dual Display

-Resolution Advisory Display System(s)

-Traffic Alert Display System

- (20) Windshear System
- (21) Marker Beacon System
- (22) EFIS Display(s) (including Dimming Function)
- (23) Standby Attitude Indicator
- (24) Maximum Operating Speed (Vmo) Pointer
- (25) Inertial Reference System
- (26) Inertial Vertical Speed Indicator
- (27) HSI Bearing Pointers
- (28) Flight Management System
- (29) Long Range Navigation Systems (INS, LORAN, GPS, etc.)
- (30) Head-Up Display System

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8.4.15 ATA 35 OXYGEN

- (1) Crew Fixed Oxygen System Pressure Gauges
- (2) Crew Fixed Oxygen System Overboard
- (3) Discharge Indicator

8.4.16 ATA 49 AUXILIARY POWER

- (1) Auxiliary Power Unit
- (2) APU Caution Light/Advisories
- (3) APU Generator
- (4) APU Bleed Air
- (5) Hourmeter and/or Cycle Counter

8.4.17 ATA 52 DOORS

- (1) Baggage Door Indication System
- (2) Forward Entry Door Indication System
- (3) Rear Entry Door Indication System
- (4) Entry Door Inflatable Seal
- (5) Type I Emerg. Exit Door Inflatable Seal
- (6) Baggage Door Counterbalance System
- (7) Service Door
- (8) Service Door Indication System

8.4.18 ATA 61 PROPELLER

- (1) Synchrophasing System
- (2) Autofeather System (Performance Restrictions)
- (3) Propeller Brake

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8.4.19 ATA 71 POWERPLANT

- (1) Engine Intake Bypass Doors
- (2) Engine Intake Bypass Door Indicators
- (3) Engine Condition Panel

8.4.20 ATA 73 ENGINE FUEL & CONTROL

- (1) Fuel Flow Meters
- (2) Low Fuel Pressure Indicator
- (3) Fuel Temperature Sensor
- (4) Quiet Taxi Systems
- (5) Full Authority Digital Engine Control (FADEC)
- (6) Engine Management System (EMS)

8.4.21 ATA 75 BLEED AIR

- (1) Handling Bleed Shut-Off Valves

8.4.22 ATA 77 ENGINE INDICATING

- (1) NH Indication
- (2) NL Indication
- (3) Torque Indication
- (4) EGT Indication
- (5) ESIDS Display(s) (including Dimming Function)
- (6) Engine overtemp warning lights

8.4.23 ATA 79 ENGINE OIL

- (1) Low Oil Pressure Indicator
- (2) High Oil Temperature Indicator

Note: The above list is subject to revision as systems continue to be added, deleted or modified as the program evolves.

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Chapter 9

DIRECT MAINTENANCE COST ANALYSIS

1996-07-05

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RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES

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9 DIRECT MAINTENANCE COST ANALYSIS

9.1 INTRODUCTION

This document provides guidelines for preparing a Direct Maintenance Cost (DMC) Analysis.

Supplier DMC analyses shall be incorporated by DHI into an aircraft DMC analysis which shall determine an aggregate cost per flight hour.

Direct Maintenance Costs shall comprise of all mature scheduled and unscheduled labour and material costs expressed in 1995 U.S. dollars, associated with aircraft maintenance, and no fault found costs (including labour) incurred during fault verification and testing.

9.2 APPLICABLE DOCUMENTS

EPS 1-18 R&M Specification Requirements

ESP 91 R&M Control Plan - DHC-8-400

9.3 DEFINITIONS & ABBREVIATIONS / ACRONYMS

DHI	de Havilland Inc.
DMC	Direct Maintenance Cost
FC	Flight Cycle
FH	Flight Hour
LRU	Line Replacement Unit
MHR	Manhours
MTF	Maintenance Task Frequency
QPA	Quantity Per Aircraft
RATE	Labour rate in US dollar
UR	Unscheduled Removal
URR	Unscheduled Removal Rate

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9.4 PROCEDURES

The following procedures detail the steps required for producing a Direct Maintenance Cost analysis (i.e. unscheduled and scheduled maintenance costs associated with operating the aircraft).

For each LRU, total maintenance costs shall be calculated and tabulated using the table format presented in EPS 1-18. DMC shall be determined by means of manhours and material costs expensed at airline facilities and overhaul/repair facilities and expressed as current year (1995) \$US per flight hour (FH) or flight cycle (FC). Note that the procedures below are expressed in terms of flight hours; however, if more appropriate, flight cycles or a combination of cycles and hours should be used. All LRU DMC's shall be summed to provide a total System DMC.

To demonstrate the effect of duty cycle on DMC, an estimate of the total maintenance cost for the equipment shall be provided in both an equation form and graphical representation. The range of flight times shall be 25 minutes to 3.0 hours duration. The equation form estimate shall be in the following format.

Sum total = \$/flight hour + \$/flight cycle

9.4.1 Unscheduled Maintenance Costs (per LRU)

9.4.1.1 Labour

(1) Line Maintenance

- a) determine unscheduled removals (UR) for LRU's using historical data or predictions.
- b) determine manhours (MHR) to remove and replace LRU's.
- c) determine line labour costs/hour (RATE); assume \$20 1995 U.S.
- d) calculate unscheduled maintenance line labour costs per flight hour as follows:

$$MC_{(ULM)} = \frac{(UR) \times (RATE) MHR}{FH}$$

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(2) Shop Repairs

- a) determine unscheduled removals (UR/FHxQPA) for LRU's using historical data or predictions.
- b) determine average shop manhours per unscheduled removal (MHR/UR).
- c) determine shop labour cost/hour (RATE).
- d) calculate unscheduled maintenance shop labour costs per flight hour as follows:

$$MC_{(USR)} = \frac{(UR) \times (RATE)MHR}{FH}$$

9.4.1.2 Material**(1) Line Maintenance**

- a) determine unscheduled removal rates (UR/FH) for LRU's using historical data or predictions.
- b) determine average material costs required in accomplishing anticipated unscheduled maintenance of a LRU. Note, material cost does not include cost of a replacement LRU (\$/MAT'RL).
- c) calculate unscheduled maintenance line material cost per flight hour as follows:

$$MC_{(ULMAT)} = \frac{MAT'RL}{FH} \times UR$$

(2) Shop Repairs

- a) determine unscheduled removals (UR) for LRU's using historical data or predictions.
- b) determine average shop material costs required in accomplishing anticipated repairs (\$MAT'RL). If the LRU is not economically feasible to repair then use replacement cost in the formula.
- c) calculate unscheduled maintenance shop material cost per flight hour as follows:

$$MC_{(USMAT)} = \frac{MAT'RL}{FH} \times UR$$

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9.4.2 Scheduled Maintenance Costs (per LRU)**9.4.2.1 Labour****(1) On Aircraft**

- a) determine manhours required per scheduled maintenance task (MHR). Includes labour associated with accomplishing task on aircraft (i.e. operational checks, lubrication, component removal for overhaul, etc.) and labour required with component repair/overhauls.
- b) determine line labour costs (RATE); assume \$20 1995 U.S.
- c) determine maintenance task frequency--MTF (hours).
- d) calculate scheduled maintenance labour costs per flight hour as follows:

$$MC_{(SL)} = (MHR) * (RATE) * (1/MTF)$$

(2) Shop Repairs

- a) determine shop manhours required per scheduled maintenance task (MHR).
- b) determine shop labour costs (RATE); assume \$20 1995 US.
- c) determine maintenance task frequency--MTF (hours).
- d) calculate shop scheduled maintenance labour costs per flight hour as follows:

$$MC_{(SR)} = (MHR) * (RATE) * (1/MTF)$$

9.4.2.2 Material**(1) On Aircraft**

- a) determine maintenance task frequency--MTF (hours).
- b) determine material costs for scheduled maintenance task (\$).

$$MC_{(SSMAT)} = (1/MTF) * (MAT'RL)$$

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(2) Shop Repairs

- a) determine maintenance task frequency--MTF (hours).
- b) determine shop material costs for scheduled maintenance task (\$).

$$MC_{(SSRMAT)} = (1/MTF) * (MAT'RL)$$

9.5 FORMAT

Format as per EPS 1-18 (Table 1 - Maintenance Cost Table)

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Chapter 10

MAINTENANCE ANALYSIS

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CHAPTER 10

10 MAINTENANCE ANALYSIS

10.1 INTRODUCTION

This section outlines DHI's maintainability objectives, detailing guidelines for assessing aircraft maintainability. Ensuring that maintainability requirements objectives are properly addressed in the design of an aircraft will result in both safety and economic benefits. These objectives include:

- (1) minimize maintenance requirements
- (2) allow for efficient maintenance
- (3) minimize the deterioration of inherent reliability and safety
- (4) minimize on-aircraft failures through preventative maintenance
- (5) provide a safe working environment for maintenance

This Maintainability Requirements document looks for answers to questions regarding:

- (1) removal & replacement
- (2) accessibility
- (3) servicing
- (4) human engineering
- (5) scheduled and unscheduled maintenance

The answers to these questions will aid in the determination of the maintainability of the design.

10.2 DEFINITIONS & ABBREVIATIONS / ACRONYMS

AC	Aircraft
ATA	Air Transport Association
BAGNA	Bombardier Aerospace Group North America
CDL	Configuration Deviation List
CDR	Critical Design Review
DHI	de Havilland Inc.
E.T.	Elapsed Time

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FT	Functional Test
LRU	Line Replaceable Unit
MDS	Maintenance Data Sheet
MH	Man Hours
MMEL	Master Minimum Equipment List
MRB	Maintenance Review Board
MSG	Maintenance Steering Group
MSI	Maintenance Significant Item
MTTR	Mean Time to Removal
OPC	Operational Check
PDR	Preliminary Design Review
PSE	Principle Structural Element
SSI	Structurally Significant Items
TC	Transport Canada
WATOG	World Airlines Technical Operations Glossary

10.3 MAINTAINABILITY STEPS

The following steps shall be adhered to where feasible and practical. Since this document is meant to be generic, not all steps will apply to all Suppliers. Any questions regarding maintainability requirements should be addressed to de Havilland's R&M Engineering department.

- (1) Define maintainability requirements
- (2) Review all applicable documents
- (3) Create preliminary list of all Maintenance Significant Items (MSI) and Structural Significant Items (which include all Principal Significant Items).
- (4) Identify all possible Master Minimum Equipment List (MMEL) candidates
- (5) Create schedule for deliverables to meet PDR and CDR dates
- (6) Participate in identification of Interchangeable / Replaceable parts

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- (7) Assess access panels and identify accessibility requirements
 - (8) Review drawings and mock-up while completing maintainability check list and identify any potential maintainability problems.
 - (9) Complete preliminary Maintenance Data Sheets (MDS), for all MSIs identified earlier, to evaluate maintainability in terms of accessibility, installation, maintenance procedures and times.
 - (10) Propose scheduled maintenance tasks with substantiation
 - (11) Prepare preliminary Configuration Deviation List (CDL) candidates
 - (12) Circulate CDL candidates to all relevant departments and coordinate responses to determine any performance decrements or flight test requirements
 - (13) Participate in PDR
 - (14) Revise preliminary MDS and scheduled maintenance tasks to reflect any modifications
 - (15) Prepare preliminary inspection procedures for unscheduled tasks (Maintenance Manual, Chapter 5 inspections, e.g. lightning strike, bird strike, hard landing, volcanic ash ingestion, etc.)
 - (16) Update preliminary MMEL and prepare preliminary procedures
 - (17) Prepare preliminary MSG 3 sheets and procedures
 - (18) Update preliminary SSI list and complete preliminary MDS for all SSIs stating the inspection method
 - (19) Prepare final CDL candidates
 - (20) Circulate CDL candidates to all relevant departments and coordinate responses to determine any performance decrements or flight test requirements
 - (21) Participate in CDR
 - (22) One year prior to certification, complete the final version of:
 - (23) Maintenance Steering Group (MSG) 3 sheets
 - (24) Inspection procedures for unscheduled tasks (Maintenance Manual, Chapter 5)
 - (25) Maintenance Data Sheets
-

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- (26) MMEL and procedures
- (27) Prepare unscheduled line maintenance analysis for relevant failure modes identified as per equipment/system FMECA (refer to EPS 1-18)
- (28) Participate in Maintenance Review Board (MRB) process for development of maintenance program
- (29) Finalize CDL for submittal to Transport Canada (TC) for approval and subsequent incorporation into the flight manual.

10.4 MAINTAINABILITY CHECK LISTS

For the following check list sheets, any response which is not affirmative must be explained in the remarks column. This checklist is performed on a per aircraft structure section or system/subsystem (e.g. forward fuse, centre fuse, nacelle, nose landing gear etc.). The checklist is meant as a guide to evaluate the maintainability of the design and an electronic copy is available upon request.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 10***TABLE 10.1: MAINTAINABILITY CHECK LIST - REMOVAL &
REPLACEMENT**

MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
GENERAL			
Are modularized components used for most rapid exchange and restoration of operation and to enable replacement by hand without tools?			
Are service-proven components and parts common to other airplanes, used wherever possible?			
Are multi-use components, assemblies and installations, used wherever possible to reduce procurement cost and customer spares inventories?			
Has the size and weight of interchangeable components been limited to a maximum of 40 pounds?			
If components are heavier than 40 lbs, are structurally-mounted hoisting and positioning provisions provided?			
Are guide pins or rails for installation alignment and positioning of heavy or non-symmetrical units provided?			
Are fluid quantity and pressure transducers and sight gauges made replaceable without having to drain the fluid reservoir?			
Does replacement of the panel-mounted instruments not require prior removal of other equipment, glare shields, etc.?			
Are large hydraulic units designed to facilitate replacement of external packings, ring seals, filters, etc., without removing the unit from the airplane?			
Are airframe deflection and tolerance build-up considered in determining clearances for component installations?			
Are components and/or structure compatible with their expected operating environment (i.e. corrosion, heat, high voltage, wear, fluid spillage, etc.)?			
Are components and assemblies designed as replaceable units to permit bench assembly, alignment, calibration, test, repair and overhaul?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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REPLACEMENT (Cont'd)**

MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
Have system components and /or structures been designed for maximum interchangeability?			
Have magnesium castings and forgings for components/parts been avoided except as verified by previous satisfactory experience?			
Have sealed components been limited to applications where sealing is essential or where replacement cost is no greater than repair cost?			
Where opposite (left-right, etc.) parts are physically symmetrical, has mechanical indexing or other means been provided to prevent installation error?			
Where two or more components are identical in appearance, but different in function, has mechanical indexing or other means been provided to prevent installation error?			
Has the quantity of parasite items/components, mounted on frequently removed equipment, been minimized?			
Where component location or position depends upon attaching parts such as hangers, brackets or clips, have the attaching parts been designed with indexing tabs or other means to mechanically prevent improper installation?			
Have mechanical parts, subject to maintenance disassembly, been indexed to ensure proper relative position on reassembly?			
Has the least complex test and ground support equipment, capable of fulfilling technical requirements, been utilized?			
Have GOOD-BAD meters and/or appropriate indicators to display circuit or equipment condition been utilized?			
Have easily accessible test connections for attachment of monitoring equipment been provided?			
Has self-test or built in test equipment (BITE) for rapid problem identification been utilized?			
Has sufficient clearance around component installations and hardware been provided to allow use of standard tools and wrenches?			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 10***TABLE 10.1: MAINTAINABILITY CHECK LIST - REMOVAL &
REPLACEMENT (Cont'd)**

MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
Have components and parts been selected/designed which do not require specialized or system peculiar support equipment and tools?			
Is equipment identified with visible labels and adjacent maintenance instructions (i.e. adjustment and/or test instructions)?			
Have all exposed structural and wing spar stations been labeled for ease in locating equipment and to identify specific locations when inspection, modification or rework is required?			
Have all walkways and "No Step" areas been labeled to prevent inadvertent damage?			
Are all removable trim panels, grilles, floor and ceiling panels part numbered to avoid mixing and to assure proper reinstallation?			
Are permanent nameplates stating fluid type and grade provided at fluid servicing points?			
Are all static pressure ports or sensors externally identified to prevent them being obstructed or plugged?			
Are rotating parts externally marked to show normal direction or rotation wherever of importance?			
Do Limit or sequencing switches, which are not attached to components, have their function and electrical item numbers permanently marked adjacent to the switch?			
Is electrical wiring identified in accord with ATA specification and code wiring bundles by circuit function?			
In addition to normal number coding, are all essential flight control electrical bundles colour coded?			
Are all modules, relays and switches labeled by wiring diagram item number, where space permits, for ease of identification and troubleshooting? Are ink stamping and other non-permanent surface markings coated with a clear protective finish?			
Are permanently affixed metal nameplates being utilized in lieu of foil metal-cals or decals?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 10***TABLE 10.1: MAINTAINABILITY CHECK LIST - REMOVAL &
REPLACEMENT (Cont'd)**

MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
Are torquing instructions for bolts or nuts in critical areas or that differ from standard, stated on adjacent nameplates?			
If nameplates are impractical because of design, size or material, is acid etching, electro-chemical marking, vibro-etching, etc. being used?			
Are components and special hardware items serialized, as specified in the serialization plan and for tabulation in the appropriate aircraft log?			
Are airframe strong points that are usable in moving a crippled airplane identified? Is access to these points through removable panels or on the exterior?			
Are cable identification placards and/or coding installed on fairleads or bulkheads in areas of cable congestion, and at all pressure bulkheads or pressure seals?			
Are high-strength steel parts permanently identified with an approved marking method?			
Do all Maintenance Significant Items have nameplates providing functional and part number identification?			
For components installed so that identification is obscured and function is not readily apparent, have a placard installed adjacent to the item?			
Has steel stamping or other permanent type part numbering been utilized for components where structural integrity is not reduced?			
Has colour or number coding, sizing or indexing been used to prevent maintenance errors?			
Has a controlled path for fluid leakage / spillage / drainage been provided to prevent ingress into or contamination of other areas or airplane exterior? (Controlled path should allow flushing or wet-washing).			
Have visible external differential pressure indicators, been utilized wherever possible, to identify clogged filter elements?			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 10***TABLE 10.1: MAINTAINABILITY CHECK LIST - REMOVAL &
REPLACEMENT (Cont'd)**

MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
Are fluid filters and screens made removable for cleaning or replacement by hand tightening or using standard hand tools only?			
Do all fluid system components requiring removal for cleaning or replacement have fluid shut-off provisions to prevent fluid loss?			
Do components, which require bleeding after replacement, have bleed valves easily accessible?			
Has snap-in design been used for air grilles, screens and filters requiring removal for servicing?			
Have sufficient electrical outlets been provided for interior vacuuming convenience?			
Have provisions been made for external washing of pilot's windshields through an adjacent sliding window?			
Has the quantity, frequency and complexity of preventative maintenance been minimized?			
Have the training and skill requirements for maintenance personnel been minimized?			
Have all drain openings been made 3/8 of an inch diameter and located at lowest possible point?			
Do stringers have drain holes at lowest possible point?			
Do all structures comply with DHI standard corrosion protection/prevention procedures?			
Has the use of sealant as a filler to create flow paths to the drain been avoided? (Do not want to use sealant as filler).			
Can components required for immediate dispatch be replaced within the turn around time of 15 minutes to avoid a flight delay?			
Do calendar lifed components (i.e. oxygen bottles, firex bottles, cartridges, etc.) have expiry dates clearly marked and readily visible?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
1.1.4.2 ACCESSIBILITY			
Are removable fairings designed to be replaced by one person? (Sectionalize, if strength and durability are not affected).			
Is the fairing designed so that it is not flimsy? (i.e. reinforced; otherwise fairing will distort when removed)			
Have components and accesses been located so that it is unnecessary to remove other components, wires, cables, etc., to reach the item requiring maintenance?			
Have components been located by functional groupings, where possible, to avoid maintenance activity congestion by those working on other systems?			
Have small components and parts been located so they are not blocked by large or heavy components or parts?			
Have critical or delicate components been located or mounted in areas protected from environmental and/or maintenance damage? If not possible, have protective guards or covers been provided?			
Have door latches, hinges and locks been installed with screws and units made replaceable without prior removal of trim, seals, etc.?			
Has maximum access been provided to all points, units, components and installations which may require inspecting, servicing, testing, adjusting, replacing, rigging or repairing?			
Have components been located outside of the cargo compartment so that their removal does not require unloading baggage?			
When access must be located over dangerous mechanical or electrical components, has a highly visible warning placard been provided on the access?			
Have edges of access openings been protected with internal fillets or other suitable coverings wherever sharp edges might cause personnel injury, damage hoses, etc.?			
Have safety interlocks been provided for accessing high voltage equipment?			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
If circuitry must be "On" during maintenance, has a "cheater" switch, which automatically resets when the access is closed, been provided?			
Have pull-out drawers or racks been provided wherever practical?			
Have access panels/covers been designed for maximum interchangeability and commonality?			
Have unstressed panels/covers been provided wherever frequent access may be necessary?			
If large stressed panels cannot be avoided, has a smaller access plate/door within the stressed panel been provided?			
Have exterior access panels/covers been hinged at the forward edge?			
Have aluminum piano-wire hinges been avoided wherever frequent use or vibration would cause excessive wear?			
Have hold-open devices using locks, catches or fasteners been provided to prevent dislodgment, of large or heavy access doors/panels?			
Have service access panels been designed to prevent their closure with servicing valves or caps removed or not properly secured?			
Has the use of large trim panels made of porous material been avoided, except for acoustic reasons? (They are difficult to handle and clean).			
Do major components and assemblies have removable coverings to allow for internal inspection?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
Is access location, type, size, shape, and method of attachment based upon: - Component location, orientation, and operational environment? - Access frequency? - Time required to perform the maintenance actions? - Types of tools and equipment needed for maintenance? - Work clearances required to perform the maintenance (i.e. types of clothing likely to be worn)? - Visual requirements and distance the mechanic must reach to perform structural and system maintenance? - Packaging of equipment, mounting of items, units, etc., behind the access? - Away from high voltage or dangerous mechanical equipment or insulate, shield, etc., such parts to prevent personnel injury? - So that heavy units can be pulled out rather than lifted out? - So that the bottom edge of a limited access is not lower than 24 inches or the top edge not higher than 60 inches from the floor or work platform? - To conform to heights of existing work stands and carts used for access where possible?			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
ATTACHMENTS			
Have mounting bolts been minimized and a standard type, same diameter and length, for panels and components?			
Where fasteners of different lengths cannot be avoided, are different diameters used to avoid installation error? (Use DHI Standards Parts List wherever possible; special parts create problems).			
Are self-locking fasteners used instead of safety-wired or cottered retainers for component mounting?			
Is mounting hardware of removable components visible? (Blind mounting hardware should be captive).			
Where possible, are units mounted on airplane structure being retained by nutplates?			
Are anchor nuts or flanged channel fasteners provided in inaccessible areas?			
Do nutplates, used for fastening, allow for replacement without using blind fasteners?			
Have exterior steel and titanium fasteners in aluminum structure been protected against corrosion?			
Are hexagonal socket-head bolts used rather than recessed-head bolts to minimize damage and allow fast removal?			
Where frequent removal of a clamped item is anticipated, does the use of clamp design permit the clamp to be securely fastened to its mount while still allowing release of the clamped item?			
Are clamp locations on hoses marked by painting a band or stripe of hydraulic fluid resistant paint on the hose to enable maintenance personnel to quickly determine whether all clamps are installed at proper locations?			
Are fasteners greater than 8/32 reduced head used for access panels?			
Do fasteners on hinged panels visibly indicate a "no-lock" condition?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
Are larger size fasteners used to reduce the number of fasteners required?			
Are quick release fasteners or latches used over screws for access panels where access is frequent?			
Are access panel fasteners requiring the least number of turns to unlock or remove being used?			
Are fastening devices operable by fingers and/or gloved hands or using standard tools?			
Has the use of special-head fasteners (Hi-Torque, etc.) been limited to panels/covers estimated to be removed only two or three times during airplane design life?			
Has the use of metric hardware been avoided? (Only imperial standard hardware is to be used).			
Do bolts and or pins on major structural joints have chrome plating or other corrosion protection?			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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CALIBRATIONS**

MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
ADJUSTMENTS AND CALIBRATIONS			
Has self-compensating and/or self-aligning equipment been used to minimize adjustments and calibration?			
Have equipment and parts with broad tolerances been used in order to eliminate matching of replacement items, except where close tolerances permit item replacement without re-rigging adjustments?			
Have components been provided which can be readily adjusted to compensate for wear?			
Where adjustments are necessary, has the design allowed for independent adjustments to avoid mandatory sequential adjustments?			
Have adjustment points been made accessible and adequately labeled?			
Are knobs, rather than screwdriver slots, used for adjustments wherever possible?			
Has the adjustment been designed so that clockwise rotation produces an increasing value, and vice versa?			
Are fine adjustments made through large movements to avoid critical adjustment?			
Have shims for parts or equipment adjustment/alignment been avoided?			
Have safety devices (e.g. adjustment locking devices), been provided to prevent inadvertent decalibration on disassembly or removal?			
Have serrated plates been used for position adjustment of electrical switches (e.g. door warning)?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
CONTROLS AND CABLES			
Have cable systems been designed to prevent reverse installation or connection?			
Do cables passing through removable structure or components have mechanical breaks to allow item replacement without cable removal and re-rigging?			
Are cable guards easily removable to permit cable replacement without pulley bracket removal?			
Are cables routed to avoid their being stepped on or used as hand-holds?			
Do shrouded control cables use transparent conduit for ease of cable inspection?			
Are cable seals replaceable without disrupting cable rigging?			
Are cable fairleads split type and attached with removable fasteners?			
Is constant or automatic cable tensioning used wherever possible?			
Are close-tolerance rig pins used to avoid rigging sloppiness at cable interfaces?			
On rigging drawings, are the required rig pin length in addition to its diameter listed?			
Have light structural members been avoided for alignment of system rig pins?			
Have stainless steel cables been used in corrosion prone areas (MLG emergency extension cable)?			
Are cable rigging pins stowed in a kit to show if any are missing and still installed?			
Is control system rigging performed in linear measurement and measurable without special tools?			
Are easily replaced lubricated bushings used on all structural pin joints?			
Has ample allowance in joint design been provided to allow installation of oversize bushings when necessary?			

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TABLE 10.6: MAINTAINABILITY CHECK LIST - WIRING & SWITCHES

MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
WIRING (AND SWITCHES)			
Have potting compounds been avoided for electrical switches and connectors?			
Are electrical wiring disconnects provided for all instruments, switches, modules, light assemblies, etc., mounted in instrument and electrical panels?.			
Are wiring splices avoided, wherever possible?			
Is sufficient wiring length provided to permit component removal after at least three wire bundle repairs have been made?			
Do electrical cables run below fuel lines? (Electrical cables must not run above fuel lines unless adequately protected).			
Are electrical cables routed to avoid being stepped on or used as hand hold?			
Where electrical wires or jumpers require attachment to rotating or translating surfaces, does the orientation of attachments minimize bend angle of wires?			
Are electrical/electronic equipment bays protected against fluid seeping or dripping?			
Are dissimilar electrical connections provided for units which are physically, but not functionally interchangeable?			
Does antenna cable routing provide a minimum bend radius of ten times the cable diameter?			
Are spare wires provided in selected wiring bundles which are routed in areas of difficult accessibility?			
Are quick-release captive dust caps used to protect exposed electrical test receptacles?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
PIPES AND TUBES			
Is sufficient flexibility provided in tubing runs to prevent installation preloading?			
Is Teflon tape used where chaffing is possible?			
Is there a one (1) inch minimum space between tube runs to allow for tool access?			
Is there a four (4) inch minimum space between flammable fluid lines and electrical cables or hot air ducts?			
For flexible connections, have coiled tubing, hose or swivel joints been utilized, in that order of preference?			
Are flexible hoses for panel-mounted instruments of sufficient length to permit front removal?			
Have connections been oriented, indexed, sized or labeled to prevent erroneous installations and/or connection?			
Have quick-disconnect, self-sealing connections used whenever possible?			
Are hoses instead of rigid tubing being utilized at component connections to enhance replaceability?			
Are enclosed areas, which contain hot air bleed ducts, ventilated or have blowout panels or plugs?			
Are connectors that are repairable with standard connector tools being used?			
Are tubing runs colour coded and identified as to fluid type, function and direction of flow?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
SERVICING			
Have servicing areas been separated to permit simultaneous use without congestion of personnel, ground equipment and servicing vehicles?			
Does the design allow use of existing Ground Servicing Equipment (GSE)?			
Do servicing frequencies match scheduled maintenance intervals?			
Are all servicing points visible and easily accessible with adequate servicing instructions at system servicing locations?			
Are servicing points located at heights which are the most convenient for maintenance personnel?			
Are components and equipment protected from damage during servicing with replaceable wear surfaces?			
Are all maintenance and servicing areas painted a light colour and provide a durable protective finish where necessary?			
Are servicing caps, etc., large enough to be easily removed with gloved hands?			
Can servicing tasks be completed in less than 10 minutes elapsed time by one person without the need for hand tools (i.e. screw driver, flashlight, pliers, etc.)?			
Are servicing tasks capable of being conducted in adverse weather conditions such as: - Maximum Arctic Environmental conditions? - Maximum Tropical Environmental conditions? - Air temperatures from -65C to +40C? - Winds up to 60 MPH? - Blowing sand & dust? - Snow and rain storms?			
Are all categories of consumable items, required for servicing and maintenance, kept to the minimum type(s) and where possible common with other airline equipment?			
Can servicing tasks be conducted without the need for work stands?			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
Has the need to step on the aircraft external surfaces to service the aircraft been avoided?			
Where external surfaces are stepped on for maintenance, has the aircraft structure been reinforced to handle the increased loads?			
Are sight gauges, blow out discs, running time meters, etc. requiring inspection, visible from the ground?			
Are permanent nameplates stating fluid type and grade at fluid servicing points?			
Have fluid level indicating or automatic shut-off devices been used? (Avoid overflow gauging).			
Do fluid level dipsticks and sight gauges indicate quantity to be added, not the amount remaining?			
Are fluid level sight gauges visible from the service connections and inspection accesses without obstruction by hoses, tubing and/or structural impediments?			
Are easily operated bleed-off methods provided for servicing pressurized reservoirs?			
Is single-point service filling used (except where mechanisms and rotating machinery are designed for opposite installation and should have dual fluid servicing points and fluid level indicating devices)?			
Are provisions for pressure and gravity filling, provided for component fluid servicing?			
Have fluid servicing points been designed for vertical filling to avoid the necessity of using special filler spouts?			
Has sufficient access been provided for the maximum size container used for refilling/topping-off during reservoir servicing, (e.g. quart, imperial quart, etc.)?			
Do fluid reservoirs have drain provisions to permit complete fluid drainage and purging?			
Are removable filler caps at servicing points made captive?			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTAINABILITY CHECK LIST	YES	NO	REMARKS
Have standard and/or permanent types of lubricant been used? (Avoid specialty lubricants).			
Have single size and type of lubrication fitting been used for servicing convenience?			
Are non-standard fittings used where special lubricant is required?			
Are protruding lubrication fittings (MS 15000) used? (Protruding fittings are preferred over flush-type fittings).			
Are components, controls, etc., able to be lubricated without item disassembly, removal, or de-rigging?			
Is there provision for lubrication on heavy rotating parts? Linear actuators, requiring fluid lubricant, have an integral reservoir for self-lubrication?			

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10.5 STRUCTURAL INSPECTABILITY

Reference ESP 79, Aircraft Structure Inspectability

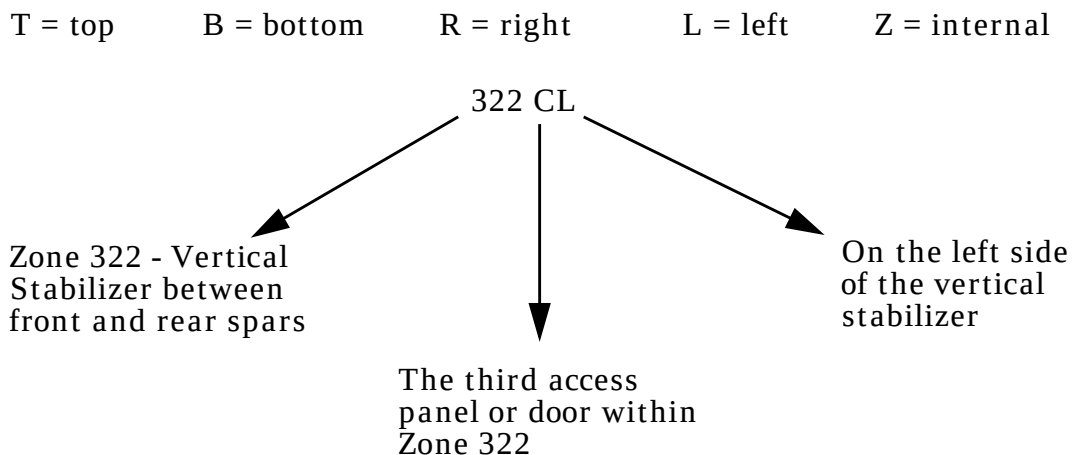
10.6 ACCESS PANEL DEFINITION

This section is intended to give a brief description on how to identify access panels and doors for de Havilland aircraft. Also The zone numbers can be obtained from de Havilland.

A sample of access panel identification is attached. A similar tabular format will be required, on column identifying the access panel/door and the next column describing the systems and components accessed through this particular panel/door.

10.6.1 Identification

Each access panel is identified in relation to the aircraft zone in which the panel or door is located. The identification consists of a three digit zone number followed by two letters. Within each zone, the panels and doors are identified by the first letter (allocated in a logical sequence), and the second letter indicates the location of the access, as follows:



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10.6.2 Sample Access Panel Descriptions

The following is the listing of access panels and doors located in front of the airplane (Ref to Figure 10.1)

- (1) 111AT: Weather radar antenna, VOR/Localizer antenna, glide slope antenna
- (2) 112AR: Crew oxygen bottle, oxygen lines, nose wheel steering electronic control unit, hydraulic lines
- (3) 112BR: Steering manifold, nose gear doors solenoid sequence valve, emergency reservoir (main gear extend)
- (4) 113AL: Battery
- (5) 121AL: Brake linkage, rudder control interconnect pushrod, rudder input quadrant, rudder pedal adjustment mechanism, rudder control cables
- (6) 121BL: Roll spoiler quadrant, roll spoiler control cables, roll interconnect rod, pitch interconnect torque tube, elevator output quadrant, pitch disconnect clutch, pitch disconnect cable, gust lock quadrant, gust lock control cables, power lever layshaft, power lever limit switches, condition lever layshaft, condition lever limit switches, engine control cables, engine intake adapter heater and elevator horn heater thermostats, electrical wiring
- (7) 122AR: Brake linkage, rudder input quadrant, rudder pedal adjustment mechanism, rudder control cables, rudder restrictor mechanism

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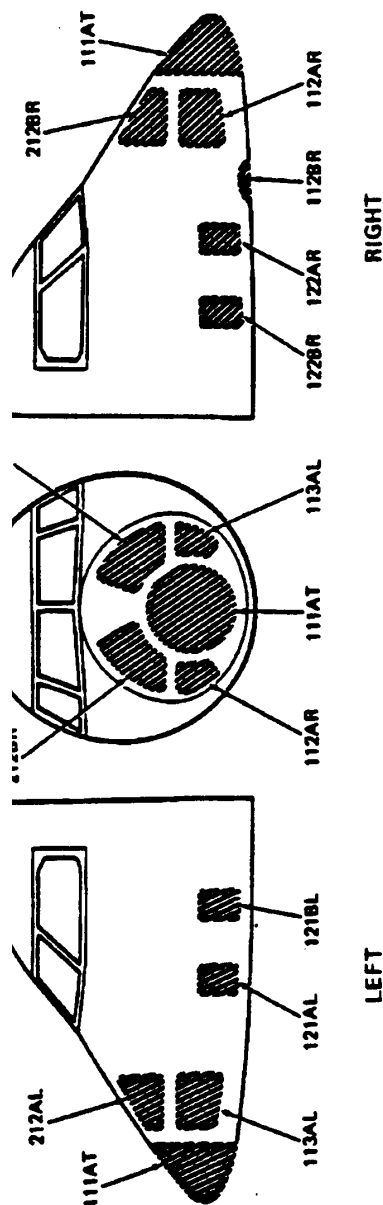


FIGURE 10.1 ACCESS PANELS AND DOORS - FRONT FUSELAGE

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- (8) 122BR: Aileron quadrant, aileron servo, aileron control cables, roll disconnect clutch, roll disconnect cables, elevator output quadrant, elevator trim chain and cable assembly, power lever layshaft, power lever limit switches, condition lever layshaft, condition lever limit switches, engine control cables, electrical wiring
- (9) 212AL: Transformer/rectifier units, pilot's wiper motor, D.C. contactor box
- (10) 212BR: Copilot's wiper motor, flight compartment fan, nose landing light, windshield washer reservoir (SOO 8008)

10.7 MAINTENANCE DATA SHEETS

Microsoft Word (version 6.0 for windows) is to be used to complete the following maintenance data sheets.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***CHAPTER 10***TABLE 10.9: MAINTENANCE DATA SHEET**

MAINTENANCE DATA SHEET		Page 1
Date: _____	A/C Type: _____	ATA No.: _____
		Prepared By: _____
Item: _____	Part No.: _____	
MANUFACTURER: _____		QTY PER A/C: _____
FUNCTION: _____		
LOCATION (ZONE): _____		REF (DWG NO., MANUAL): _____
A. ACCESSIBILITY:		
1. Access Location (Panel): _____ Type: _____		
Ident: _____		
2. Fastener Type: _____ No. of Fasteners: _____		
3. Is working access adequate for human appendages, tools, equipment, etc.? _____		
4. Work stand required: _____ If yes, state type: _____		
B. SYSTEM / STRUCTURAL INSTALLATION AND ARRANGEMENT:		
1. Are part and serial number required for identification easily read? _____		
If no, explain: _____		
2. Is work area space sufficient to inspect, test, service or repair without prior removal? _____		
If no for any item, explain: _____		
3. For access or removal, are other systems or structures removal required? _____		
If yes, explain: _____		
4. Is item or structure located in an area subject to excessive heat, high voltage, vibration, fluid spillage, environmental or accidental damage, or other condition? _____		
If yes, list each one and explain what precautions have been taken to counteract these conditions (e.g. corrosion protection, shielding, guards, sealing, drains, etc.): _____		
5. Is there a similar item in the vicinity that could cause wrong identification? _____		
If yes, is it interchangeable? Explain: _____		
6. Can item or subassemblies, connectors, lines, cables, be installed incorrectly? _____		
If yes, state reason: _____		
7. Is instruction plate required? _____		
If yes, is plate concise? _____ visible? _____ durable? _____		

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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MAINTENANCE DATA SHEET		Page
Date: _____	A/C Type: _____	ATA No.: _____
		Prepared By: _____
Item: _____	Part No.: _____	
C. <u>SYSTEM / STRUCTURE MAINTENANCE:</u>		
1. Are precautions to be taken before removal/repair for personal safety/system integrity? _____ If yes, explain (e.g. installing safety pins, clipping circuit breakers, discharging equipment, special handling, etc.): _____ _____		
2. Are special preparations required before installation/repair? _____ If yes, explain: _____ _____		
3. Method of attachment (e.g. bolt, clamp, permanent, etc.): _____ Supply part number where applicable. _____		
4. Fastener locking: Self Locking _____ Lockwire _____ Lock Washer _____ Tab washer _____ Other _____		
5. Do fasteners require special treatment before/after installation? _____ If yes, explain: _____ _____		
6. Is torquing required? _____ If yes, state torque: _____		
7. Is servicing required? _____ If no, go on to question 8.		
a. Type of servicing required: _____		
b. Type of fluid, lubricant, or cleaning agent used: _____ Is this a common type? _____		
c. Are servicing point marked and accessible?: _____ If no, explain: _____ _____ _____		
8. Can o-rings and seals be replaced without removing unit? _____ If no, explain: _____ _____		
9. Can some form of operation be provided if the component is physically isolated from the system or locked for single mode operation?: _____		
a. Explain: _____ _____ _____		
b. Is there an indication to prove the above? _____		

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TABLE 10.9: MAINTENANCE DATA SHEET (Cont'd)

MAINTENANCE DATA SHEET		Page 3
Date: _____	A/C Type: _____	ATA No.: _____
		Prepared By: _____
Item: _____	Part No.: _____	
C. SYSTEM / STRUCTURE MAINTENANCE (CONTINUED):		
10. What method is required to detect an incipient failure/crack (e.g. by inspection, noise during operation, manual movement, etc.)? _____ If yes, explain:		
11. For crack suspected structure, are there any unsatisfactory conditions or arrangements hampering and complicating direct visual inspection? _____ State detectable crack size as well as Non Destructive Inspection (NDI) method:		
12. After replacement, does the component require: Alignment _____ Calibration _____ Clearance _____ Adjustment _____ Bleeding _____ Servicing _____ Pressure Test _____ Sealing _____ Surface Protection _____ Operational Test _____ Functional Test _____ Engine Run _____		
13. Where alignment is of major importance, is the method of aligning obvious? _____ If no, explain:		
14. Is the component capable of overhaul/restoration at the level of the end user? _____ If yes, are overhaul/restoration instructions available and adequate, and do they describe all necessary testing equipment?:		
15. Are special tools required? _____ If so, list:		

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TABLE 10.9: MAINTENANCE DATA SHEET (Cont'd)

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MAINTENANCE DATA SHEET					Page 4
Date: _____ A/C Type: _____ ATA No.: _____ Prepared By: _____					
Item: _____ Part No.: _____					
D. TASK PROCEDURES AND TIMES:					
Identify task as either inspection, servicing, functional check, operational check, safe life, overhaul/restoration, unscheduled removal, repair, or other: _____					
If scheduled task, give MSI/SSI number: _____					
Interval (flight hours/cycles): _____					
No.	Procedure	Men	M.H	E.T.	
DISCREPANCIES IDENTIFIED / ACTION TAKEN:					
TASK TIME SUMMARY:					
1. MH and clock hours for fault analysis (identify access time): _____					
2. MH and clock hours to remove and replace (identify access time): _____					
3. MH and clock hours to FT/OPC after replace: _____					

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10.8 MAINTENANCE ANALYSIS

10.8.1 Scheduled Maintenance Analysis (MSG-3)

The format and software to be used when completing the MSG-3 sheets can be obtained from Bombardier Regional Aircraft Division (BRAD). It is R&M Engineering's responsibility to review these documents prior to design freeze.

10.8.2 Unscheduled Maintenance Analysis

In addition to the Unscheduled Maintenance Analysis outlined in EPS 1-18, inspection checks are required for the items listed in Chapter 5 of Maintenance Manual.

Listed are examples of typical inspection checks required as a result of unforeseen incidents. Procedures need to be written for those systems and/or structures which are your particular design responsibility.

- (1) Hard Landing Inspection
- (2) Inspection After Illumination of Touched Runway Warning Light
- (3) Inspection After Severe Turbulence or Buffeting
- (4) Inspection After Bird Strike Condition
- (5) Inspection After Lightning Strike
- (6) Inspection of Engine Driven Pump (EDP) After Hydraulic Fluid Loss
- (7) Inspection of AC Generator After an Overheat Condition
- (8) Inspection After Excessive Air Maneuvers
- (9) Inspection After Gear Operation Above Maximum Gear Operation Speed
- (10) Inspection After Exceeding Wing Flaps Down Speeds
- (11) Inspection After Exposure to High Wind/Wind gust-Parked
- (12) Inspection After Excessive Ground Deicing
- (13) Inspection After Autofeather at High Power or After Power Loss with Autofeather Armed
- (14) Inspection After Rough Towing Condition
- (15) Inspection After Volcanic Ash Condition

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(16) Inspection After Tire Burst or Tread Shedding

(17) Inspection After Excessive Braking

10.9 CONFIGURATION DEVIATION LIST (CDL)

A CDL, as defined in the World Airlines Technical Operation Glossary (WATOG), is an item, such as access panels, caps, fairings, etc., normally forming part of the exterior profile of the aircraft, the absence of which do not prevent dispatch. Each structural supplier is to provide a list of potential CDL candidates. The design of the aircraft should attempt to emulate but not to be limited to the following list

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TABLE 10.10: CONFIGURATION DEVIATION LIST (CDL)

ATA SUB-SYSTEMS	PART DESCRIPTION	REMARKS AND/OR EXCEPTIONS
30-1	WING ROOT COLD BONDED LEADING EDGE DEICE BOOT	One may be missing with no performance penalty for a maximum of three (3) calendar days provided: a) associated leading edge surface is cleaned; b) associated boot supply/vacuum manifold hoses are capped; c) leading edge holes from manifold are covered; and d) the airplane is not operated in known or forecast icing and/or heavy precipitation conditions.
30-2	ENGINE INTAKE DEICE BOOT	One may be missing with no performance penalty for a maximum of three (3) days provided: a) associated engine intake leading edge is cleaned; b) the airplane is not operated in known or forecast icing and/or heavy precipitation conditions.
32-1 32-2	MLG DRAG STRUT FAIRINGS MLG SHOCK STRUT FAIRINGS	Any or all MLG fairings may be missing provided performance limited weights obtained from the DOT approved flight manual are reduced by 190 kg (420 lbs).

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ATA SUB-SYSTEMS	PART DESCRIPTION	REMARKS AND/OR EXCEPTIONS
32-3	NOSE LANDING GEAR AFT DOORS	One may be missing provided airspeed is limited to a maximum of 190 KIAS and operable headsets are made available to each pilot.
52-1	GROUND INTERPHONE COVER	May be missing with no performance penalty.
52-2	EXTERNAL D.C. POWER RECEPTACLE DOOR	May be missing with no performance penalty.
52-3	ACCESS PANEL (121AL,121BL, 122AR, 122BR) HANDLE DOOR	Any number of these doors may be missing with no performance penalty.
52-4	TOILET SERVICING DOOR	May be missing with no performance penalty.
52-5	HYD. GROUND SERVICE DOOR, #1 SYSTEM	May be missing with no performance penalty.

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ATA SUB-SYSTEMS	PART DESCRIPTION	REMARKS AND/OR EXCEPTIONS
52-6	HYD. GROUND SERVICE DOOR, #2 SYSTEM	May be missing with no performance penalty.
52-7	EXTERNAL AC POWER RECEPTACLE DOOR	May be missing with no performance penalty.
52-8	REFUELING PANEL DOOR	May be missing with no performance penalty.
52-9	GROUND AIR INLET DOOR	May be missing with no performance penalty.
57-1	INBOARD FLAP CLOSURE FAIRINGS	Any number of fairings may be missing with no performance penalty.
57-2	OUTBOARD FLAP CLOSURE FAIRINGS	One or both fairings may be missing with no performance penalty.
57-3	GLARESHIELD, WING TIP	One or both fairings may be missing with no performance penalty.

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ATA SUB-SYSTEMS	PART DESCRIPTION	REMARKS AND/OR EXCEPTIONS
71-1	COWL LATCH COVERS	May be missing with no performance penalty.
78-1	FLOATING HEAT SHIELD ABOVE EXHAUST FINGERNAIL (POST-MOD 8/0484 AND PRE-MOD 8/1664)	One or both may be missing with no performance penalty. The base exhaust fingernail must be verified free of damage. Do not operate the aircraft in ambient temperatures greater than 30 . The structure surrounding the floating heat shield above the fingernail must be inspected every 50 flying hours.
79-1	OIL COOLER DOOR	One may be missing with no performance penalty.

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SSIs are derived using MSG-3 analysis to derive structural maintenance tasks as a result of fatigue damage, environmental damage and accidental damage.

For fatigue damage items, now being referred to as Principal Structural Elements (PSE), will need to identify detectable crack size, initial inspection and repeat intervals and inspection method.

All structural maintenance tasks require inspection procedures to be completed. These procedures are to be written on the Maintenance Data Sheets.

The following PSE lists are examples of typical fatigue damage items to be inspected on the aircraft.

TABLE 10.11: WING BOX, AILERONS

PSE CHECK LIST	Yes	No	N/A	Remarks
Wing centre dsection skin panel (with inter-stringer straps)				
Wing centre section skin panel (no inter-stringer straps)				
Wing center section skin panel at fuselage drag angle				
Wing centre section rear spar at fuselage drag angle				
Wing center section rear spar at critical location				
Wing centre section skin panel at nacelle drag angle				
Wing lower skin joint at STN YW172				
Outer wing skin panel (with inter-stringer straps)				
Outer wing skin panel (no inter-stringer straps)				
Outer wing rear spar at critical location				
Outer wing, fuel pump access hole				
Wing lower rear spar cap joint at STN YW172				
Wing stringer run out at critical location				
Aileron outboard hinge, wing portion				

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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PSE CHECK LIST	Yes	No	N/A	Remarks
Aileron outboard hinge, aileron portion				
Aileron basic structure at critical location				
Aileron structure at outboard hinge				
Aileron geared tab critical hinge, aileron portion				
Aileron geared tab critical hinge, tab portion				
Aileron trim tab balance support				
Wing/fuselage joint at rear spar				
Wing/fuselage R/S bathtub fitting, wing portion				
Wing/fuselage F/S bathtub fitting, wing portion				
Aileron Trim tab critical hinge, aileron portion				
Aileron trim tab critical hinge, tab portion				
Wing box upper skin panel				

**TABLE 10.12: FUSELAGE PRESSURE SHELL & WING/FUSELAGE
JOINTS**

PSE CHECK LIST	Yes	No	N/A	Remarks
Longitudinal crack in basic fuselage shell structure Stns X129 to X387, Strs 11P to 11S				
Longitudinal crack in basic fuselage shell structure Stns X129 to X387, Strs 11 to 32				
Longitudinal crack in basic fuselage shell structure Stns X129 to X387, STRS 22 to 23 & 32P to 32S				
Longitudinal crack in basic fuselage shell structure Stns X387 to X424, Strs 22 to 23 & 32P to 32S				
Longitudinal crack in basic fuselage shell structure Stns X387 to X424, Strs 10 to 22				
Longitudinal crack in basic fuselage shell structure Stns X424 to X593, Strs 2 to 11				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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JOINTS (Cont'd)**

PSE CHECK LIST	Yes	No	N/A	Remarks
Longitudinal crack in basic fuselage shell structure Stns X424 to X593, Strs 11 o 33				
Longitudinal crack in basic fuselage shell structure Stns X424 to X488, Strs 22 to 23 & 32P to 32S				
Longitudinal crack in basic fuselage shell structure Stns X593 to X 680, Strs 2P to 7P				
Longitudinal crack in basic fuselage shell structure Stns X593 to X680				
Longitudinal crack in basic fuselage shell structure Stns X593 to X680, Strs 2S to 28S				
Pressure shell circumferential crack Stns X129 to X387				
Pressure shell circumferential crack Stns X424 to X593				
Pressure shell circumferential crack Stns X593 to pressure dome				
Pressure shell skin joint, Stns X129 to pressure dome				
Rear pressure dome basic structure				
Baggage door cut-out top sill				
Baggage door cut-out edge frame				
Type 3 exit cut-out top sill				
Type 3 exit cut-out edge frame				
Airstair door cut-out top sill				
Airstair door cut-out edge frame				
Cabin windows forward of Stn X387 & aft of Stn X445				
Cabin windows between Stns X387 & X445				
Fuselage frames near floor level				
Longitudinal crack in flight compartment basic structure				
Flight compartment circumferential crack				
Flight compartment longitudinal skin joint (portion without external strap)				
Flight compartment access hole				

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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JOINTS (Cont'd)**

PSE CHECK LIST	Yes	No	N/A	Remarks
Windscreen side post				
Windscreen centre post				
Front pressure bulkhead basic structure				
Front pressure bulkhead penetrations				
Longeron at Str 8 below wing box				
Wing/fuselage joint at rear spar - steel strut				
Wing/fuselage joint at rear spar - fuselage frame				
Longitudinal crack in basic fuselage shell structure Stn X680 to pressure dome				
Flight compartment windscreen lower sill				
Flight compartment side window lower sill				
Flight compartment escape hatch surround				
Wing/fuselage drag angle, Stns X387 to X424				
Wing/fuselage joint at R/S & Str 3, fuselage portion				
Wing/fuselage fairing edge member				
Wing/fuselage fairing, Stn X387 to X424				
Door stops, type 1 exit				
Door stops, type 3 exit				
Airstair door stops & attachments, door portion				
Flight compartment roof hatch spigots				
Windscreen lower sill tie beam at Stn X50 and beam-to-sill joint				
Windscreen transparency				
Flight compartment side window transparency				
Cabin window transparencies				
Baggage door stops				
Longitudinal crack in basic fuselage shell structure Stns X270 to X424, Str 21P to 29P				

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JOINTS (Cont'd)**

PSE CHECK LIST	Yes	No	N/A	Remarks
Flight compartment windscreen lower sill joint				
Flight compartment windscreen upper sill				
Flight compartment side window attachment screws				
Airstair door cross-beams 1 & 5 and airstair door structure other than beams 1 & 5				
Joint at Str 7P in airstair door cut-out edge frames				
Wing/fuselage steel strut-to-frame joint bolts				
Front pressur bulkhead beam tension fittings				
Frame joint at Stn X64, Str 15A				
Frame attachments to sidewindow lower sill				
Wing/fuselage joint at F/S & Str 3, fuselage portion				
Airstair door stops, fuselage portion				
Winsscreen retention frame				
Service door cut-out, edge frames				
Service door cut-out, sill member				
Type 1 exit cut-out, edge frames				
Type 1 exit cut-out, sill member				
Service door stops				
Ice shield installation				
TCAS Installation - Aft direction antenna				
TCAS Installation - Forward directional antenna				
TCAS Installation - VHF antenna				
TCAS Installation - L-Band antenna				
Closing angles, wing spar-to-fuselage shell				
NLG Drag link trunnion fitting				

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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PSE CHECK LIST	Yes	No	N/A	Remarks
Horizontal/vertical stabilizer joint, front spar, vertical stabilizer portion				
Horizontal/vertical stabilizer joint, front spar, horizontal stabilizer portion				
Horizontal/vertical stabilizer joint, mid spar, vertical stabilizer portion				
Horizontal/vertical stabilizer joint, mid spar, horizontal stabilizer portion				
Horizontal/vertical stabilizer joint, rear spar, vertical stabilizer portion				
Horizontal/vertical stabilizer joint, rear spar, horizontal stabilizer portion				
Vertical stabilizer/fuselage leading edge spar joint				
Vertical stabilizer/fuselage front spar joint				
Vertical stabilizer/fuselage mid spar joint				
Vertical stabilizer/fuselage rear spar joint				
Fuselage frame at vertical stabilizer front spar				
Fuselage frame at vertical stabilizer mid spar				
Fuselage frame at vertical stabilizer rear spar				
Horizontal stabilizer skin joint at Stn YH6.15				
Horizontal stabilizer stringer runout				
Vertical stabilizer/rudder mid hinge, stabilizer portion				
Vertical stabilizer/rudder mid hinge, rudder portion				
Vertical stabilizer/rudder upper & lower hinge, vertical stabilizer portion				
Vertical Stabilizer/rudder upper & lower hinge, rudder portion				
Rudder/rudder lower hinge, fore rudder portion				
Rudder/rudder lower hinge, aft rudder portion				
Rudder/rudder mid hinge, fore rudder portion				
Rudder/rudder mid hinge, aft rudder portion				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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PSE CHECK LIST	Yes	No	N/A	Remarks
Aft rudder basic structure				
Fore rudder basic structure				
Elevator inboard hinge, horizontal stabilizer portion				
Elevator inboard hinge, elevator portion				
Elevator mid/outer hinge, horizontal stabilizer portion				
Elevator mid/outer hinge, elevator portion				
Elevator basic structure				
Elevator structure at horn balance				
Elevator spring tab balance, elevator portion				
Elevator spring tab balance, tab portion				
Elevator trim tab hinge, elevator portion				
Elevator trim tab hinge, tab portion				
Tailplane mid spar run-out				
Elevator spring tab mass balance arm				
APU Installation				

TABLE 10.14: NACELLE STRUCTURE

PSE CHECK LIST	Yes	No	N/A	Remarks
Lower cowl to horsecollar latch				
Nacelle roof structure at critical location				
Engine mounting top tube				
Engine mounting bottom tube				
Torque tube and fittings				
Horsecollar critical location				
Lower longeron				
Nacelle sidewall				
Nacelle upper attachment to wing box				

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 10***TABLE 10.14: NACELLE STRUCTURE (Cont'd)**

PSE CHECK LIST	Yes	No	N/A	Remarks
Engine mounting, front centre				
Engine mounting, front side				
Engien mounting, rear				
Sidewall skin attachment member				

TABLE 10.15: FLAP & FLAP TRACK STRUCTURE

PSE CHECK LIST	Yes	No	N/A	Remarks
Track 1 to wing lower joint - wing portion				
Track 1 to wing lower joint - track portion				
Track 1 beam				
Track 2 aft roller fail-safe catcher				
Basic flap track (longitudinal cracking)				
Track 2 beam to wing joint, wing portion				
Track 2 beam to wing joint, beam portion				
Track 2 beam to wing joint, nacelle portion				
Track 2 beam to nacelle joint, beam portion				
Track 2 beam				
Track 4 to wing joint, forward, wing portion				
Track 4 to wing joint, forward, track portion				
Track 4 to wing joint, aft (complete joint)				
Track 4 beam				
Track 4, roller carriage to flap joint front, flap portion				
Track 4, roller carriage to flap joint front, carriage portion				
Track 4, roller carriage to flap joint, rear, flap portion				
Track 4, roller carriage to flap joint, rear, carriage portion				
Track 4, roller carriage side plates				
Track 4, aft roller and attachment to carriage				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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PSE CHECK LIST	Yes	No	N/A	Remarks
Track 4, hook roller and attachment to carriage				
Track 5, roller carriage to flap joint, front, flap portion				
Track 5, roller carriage to flap joint, front, carriage portion				
Track 5, roller carriage to flap joint, rear, flap portion				
Track 5, roller carriage to flap joint, rear, carriage portion				
Flap actuator attachment				
Outer flap basic structure				
Track 2 forward roller attachment to structure				
Track 3, upper roller track at critical location				
Inner flap basic structure				
Tracks 1, 2 & 3; track to beam attachment				

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Chapter 11

RELIABILITY DESIGN CHECK LIST

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Are standard circuits employed to the greatest possible extent?				
Is simplification by the reduction of components, explored?				
Is the use of mechanical adjustments, avoided?				
Is the number of parts that may cause catastrophic failures, minimized?				
Are adequate provisions made for transient suppression?				
Is reliability stress analysis completed?				
Are the effects of the input variables analyzed?				
Is stability / drift defined as a design parameter?				
Are all parts qualified products: MIL Spec.?				
If unqualified parts are employed, are provisions made for:				
Qualification?				
Reliability (MTBF) demonstration?				
Is the dielectric breakdown rating, adequate for the most severe environments?				
Is the insulation resistance rating adequate for the most severe environment?				
Are the corona effects considered?				
Is encapsulation considered to improve reliability?				
Is hermetic sealing considered to improve reliability?				
Are printed circuits considered to improve reliability?				
Are microelectronics considered to improve reliability?				
Is the moisture proofing adequate?				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Are part parameters considered over the intended temperature range?				
Is redundancy considered for critical functions where practical?				
Where redundancy is used, is consideration given to avoid common mode failure situations which could disable all redundant circuits?				
Is reliability considered as a factor in all trade-off studies affecting equipment reliability?				
Are design practices applied to obtain RFI suppression such as:				
Use alternating current non-commutating machinery rather than direct current machinery when feasible?				
Provide optimum interference suppression with two twisted wires in a common shield whenever wire pairs can be used?				
Use short wires in preference to long wires?				
Filter power lines to remove harmonics and other types of inherent interference?				
Mount filters as close as possible to interference sources without altering the effectiveness of the filter?				
Use bonding techniques to ensure that good electrical contact is made between chassis, conduit, shielding, connectors, structural and housing metal parts?				
Remove non-conducting coatings from bolts, nuts, and tapped holes?				
Internally, shield individual sections of equipment which are either highly susceptible to interference or which generate interference. For example, the r-f input stages and local oscillators should be shielded individually?				
Use direct current filament sources where practicable?				
Ground center tap of filament transformer secondary winding to reduce hum?				

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Avoid the use of gaseous lighting devices in the vicinity of sensitive wiring or electronic equipment				
Do not cable noisy and clean leads together?				
Never route cables near known interference sources?				
Do not use shields or metal structures for return current paths?				
Avoid the use of corrosion preventive compounds with high insulating qualities at bond joints				
Capacitors:				
Is the temperature derating adequate?				
Is the voltage derating at least 75%?				
Are the containers designed for changing atmospheric pressure so that no change of capacitance, or damage shall result when exposed to this condition?				
Are all paper capacitors hermetically sealed?				
Are all ceramic capacitors in AC or pulsating DC circuits operated below corona starting voltage?				
Are factors, that may cause long term dielectric constant changes, such as: aging, temperature, voltage, frequency, humidity, etc., considered?				
Is derating of electrolytic capacitors, to the point that reforming is required, avoided?				
Motors:				
Is the rotational speed held to a minimum, compatible with functional and reliability requirements?				
Are the type of bearings, and the lubricants adequate for the rotational speed and the intended environment?				
Is the torque envelope specified for the intended application?				
Is the power derating compatible with functional and life requirements?				
Is efficiency considered?				
Is maximum allowable case temperature specified?				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Is the insulation adequate for the intended environment and temperature rise?				
Is thermal cut-out protection provided?				
Potentiometers:				
Is the power capability derated at least by 50%?				
Is the minimum life compatible with functional and reliability requirements?				
Are the anticipated environmental (e.g. vibration, temperature, humidity, etc) effects ascertained?				
Relays:				
Are the contacts protected against arcing?				
Are the contacts derated?				
Is hermetic construction considered to improve reliability?				
Is make before break or the reverse, specified for the intended application?				
Are the coils protected against damaging transients?				
Is the allowable contact chatter considered for the intended application?				
Is mounting attitude considered to minimize contact movements in the anticipated shock and vibration environment?				
Is the switching accomplished at the ground side so that leakage and safety hazards are minimized?				
Are the presence of explosive atmosphere and the associated hazard, considered when the contacts are exposed?				
Are all the available contacts on the relay utilized? (Paralleling of contacts will increase the reliability provided that such paralleling is not done to increase the current rating, since different contacts of the same relay do not make and break simultaneously).				
Are the make and break times considered?				
Is the contact resistance considered?				
Are dielectric break down and insulation resistances considered?				

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Resistors:				
Is consideration given to wire-size of wire wound resistors? (Wire sizes less than 1.2 mils are not recommended.)				
Are precautions taken not to exceed the maximum rated voltage?				
Is the power derating at least 50%?				
Is the temperature coefficient considered for the intended application?				
Semiconductors:				
Is application of germanium semiconductor avoided when the junction temperature exceeds 90°C?				
Is application of silicon semiconductors avoided when the junction temperature exceeds 180°C?				
Are the semiconductors derated for 50% power?				
Is the safety margin sufficient to prevent damage or faulty circuit performance due to exposed to peak AC voltages, ripple riding on DC, or transient spikes?				
Are provisions for current suppression provided to protect semiconductors in applications where current surges are anticipated?				
Is internally generated heat or heat from adjacent parts, considered in the placement of semiconductors?				
Switches:				
Is adequate protection against arcing provided?				
Are the contacts derated?				
Are the contacts protected against the environmental effects in the intended application?				
Are precautions taken to prevent over travel of motor actuated switches?				
Are the dielectric properties adequate to withstand the highest voltage in the most severe environment of the intended application?				
Transformers:				
Can the insulation withstand the combined effect of the internally generated heat and temperature rise?				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
If the transformer is exposed to high level vibration, is encapsulation considered?				
Is efficiency considered?				
Is the transformer designed for the frequency of the intended application?				
Printed Wiring Boards:				
Are the PWB's designed for the following considerations:				
Is PWB material compatible with storage and operating temperature (plus operating temperature rises) with respect to:				
PWB material?				
Metal cladding / bonding strengths?				
Board warping?				
Is PWB resistivity sufficiently high, to meet circuit leakage current requirements, even under high humidity?				
Is PWB arc resistance sufficiently high, where high voltages are present?				
Is PWB dielectric constant sufficiently low, to prevent building up of unwanted capacitances?				
Is PWB flexural strength (function of board material and dimensions) sufficient to meet structural and vibration requirements?				
Is PWB conductors width sufficient to handle maximum current flow without harmful heat generation or resistance drop?				
Does PWB have plated through holes to aid in soldering of lead electrical connections?				
Do PWB conductors have a minimum spacing based upon voltage between conductors (e.g., .025" per 150 volts peak)?				
Are PWB conductor paths spaced and designed to keep capacitance between conductors to a minimum?				
Is PWB conformally coated?				
Where encapsulation, imbedding and potting are used; does the material:				

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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Have good thermal conductivity for heat transfer?				
Have good electrical isolation / dielectric?				
Provide dampening for shock and vibration?				
Have thermal expansion coefficients which match those of items encapsulated?				
Have strength to resist crack or shatter under vibration and mechanical / thermal shock?				
Have good chemical stability under anticipated use environments?				
Miscellaneous Equipment Parts:				
Are operating and maintenance personnel protected against electric shock, excessive temperature, and mechanical hazards?				
Are adjoining surface of dissimilar metals eliminated or suitably protected against galvanic corrosion?				
Are heat generating parts provided with efficient heat dissipation devices?				
Is placement of temperature sensitive parts, in close proximity to heat generating parts, avoided?				
Are internal controls, such as switches and adjustment screws located close to dangerous voltages? Are safety guides provided if blind screw adjustments must be made?				
Are precautions taken to minimize danger to personnel and equipment from explosion of electrolytic capacitors?				
Are barrier strips employed to prevent shorts between adjacent terminals?				
Are the terminals rated for the currents and voltages of the intended application?				
Are the terminals marked and covered when high voltages are involved?				
Is adequate consideration given to packaging to eliminate the effect of harmful environments?				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Are all relays mounted so that the direction of armature motion does not coincide with the direction of shocks anticipated?				
Are over-voltage and under-voltage characteristics satisfactory for the intended application?				
Are starting current transient characteristics compatible with the electrical system and the individual equipment, involved?				
Are the possible adverse effects of wave shape distortion or changes in power factor, considered?				
Are the adjacent connectors physically different or polarized to prevent incorrect mating?				
Is the use of riveted joints as electrical conductors avoided?				
Requirement 1 of MIL-STD--454G: The Checklist establishes the objectives for the design and development of electronic equipment to promote maximum safety for personnel and equipment during its life cycle. Refer to MIL-STD-454G.				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Does contractor have a Parts Control Board (PCB) to promote proper selection and application of parts used in the design?				
Does contractor have a maintained and an up-to-date Preferred Parts List (PPL) to be used by designers?				
Does contractor have an established derating guideline for electrical/electronic parts electrical stresses?				
Do derating guidelines correspond to specification requirements and / or Navy proposed derating levels?				
Does contractor have a part application guideline for proper selection of part types for circuit use?				
Are military grade parts used in the design?				
Are non-standard parts used only when a military equivalent part cannot be obtained?				
Where non-standard parts are used, do they have adequate qualification / test data and a history of high reliability?				
Where non-standard parts are used, are they procured via specification control drawing which specifies:				
Reliability requirements?				
Environmental requirements?				
Test requirements?				
Does contractor submit non-standard part data for approval per applicable specification (e.g. MIL-STD-749/965)?				
Are parts reviewed for proper application and are part stresses calculated or measured? Do they meet:				
Derating guidelines?				
Application guidelines?				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 11***TABLE 11.2: RELIABILITY DESIGN GUIDELINES CHECK LIST (Cont'd)**

RELIABILITY CHECK LIST	Yes	No	N/A	Remarks
Are established reliability (ER) components and JAN semiconductors and microcircuit devices used in the design?				
Do all parts selected meet the life requirements of the equipment?				
Have dominant failure modes of a particular part type been considered in the selection of that part?				
Are fixed rather than variable components (such as resistors, capacitors, inductors, etc.) used in the design wherever possible?				
Are all relays, motors, dynamotors, rotary power converters, etc. suppressed so as not to produce excessive spikes or transients during operation?				
Are all semiconductor devices silicon rather than Germanium?				
Are plastic coated and / or encapsulated semiconductor devices not used?				
Do all microcircuits have hermetically sealed ceramic cases rather than plastic cases?				
Do all microcircuits used have at least two potential suppliers?				
Do all unused gates of a digital microcircuit have inputs grounded?				
Are the number of expandable gates limited to no more than 76% of allowable number of expandables?				
Where humidity is not controlled, are hermetically sealed resistors, capacitors, relays, etc., used?				
Are parts, even MIL-M-38510, JANTX, Established, Reliability (ER) parts screened at incoming inspection:				
100%				
Sampling per _____?				
Environmentally _____?				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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SAFETY CHECK LIST	Yes	No	N/A	Remarks
Instrument and Display System				
Is the instrument grouping such that scanning may be performed with a minimum of eye movement?				
Is the instrument configuration and location such that parallax is minimized?				
Can the instruments be read to the accuracy required by the flight crew?				
Is the display system free of features which might produce ambiguity or invite gross reading error?				
Are changes in readings easily detected?				
Are multiple monitoring instruments arranged so that normal positions are in line and abnormal conditions are readily detected?				
Is the probability of mental translation from one indicator to another eliminated?				
Are unsafe ranges of operation marked conspicuously on the indicator?				
Is the relationship of the required control movement natural to the expected instrument movement?				
Are the instruments readily distinguishable from each other?				
Will the flight crew be aware of an inoperative condition?				
Is the illumination satisfactory under all conditions of the expected operation?				
Is adequate protection provided against glare from sunlight?				
Is general illumination adequate for retention of depth perception?				
Consoles and Controls				

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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SAFETY CHECK LIST	Yes	No	N/A	Remarks
Are all controls provided with detents or other positive "feel" to prevent inadvertent partial operation?				
Are control handles designed to prevent inadvertent motion (complete or partial) during operation?				
Are stops provided to withstand maximum loads imposed by the flight crew?				
Are distinctive shapes provided for control knobs or handles, switch levers where they must be operated by feel?				
Are controls clearly identified and appropriate position markings shown?				
Are knobs and handles designed consistent with the operating force?				
Are control forces within allowable limits?				

1996-07-05

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CAGE CODE 71867

Chapter 12

RELIABILITY APPORTIONMENT PROCEDURE

1996-07-05

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12 RELIABILITY APPORTIONMENT PROCEDURE

12.1 GENERAL

Reliability requirements and objectives are established by de Havilland Inc. (i.e. by DTRD-8-010) to ensure a successful Aircraft design, and in-service operation by proper consideration of all aspects of Reliability, Safety, and Maintainability throughout all phases of the program.

Reliability requirements, whether imposed or created, are not absolute and should be challenged periodically. Removal of an unnecessary, unrealistic requirement during the early stages of the program can save substantial time, effort, and money as well as increase the resources which can be concentrated on solution of other design problems.

In a complex design/program, it is necessary to break down the overall reliability requirement into separate requirements for the numerous items that make up the system.

The **first step** in the design process shall be to translate the overall system/airplane reliability requirement into reliability requirements for each of the subsystems

*The process of assigning reliability requirements to individual items to attain a desired airplane/system reliability is **reliability apportionment (or allocation)**.*

There is more involved, however, than a simple mathematical relationship. The reliability of an individual item varies with the type of function to be performed, its complexity, and the method of accomplishing the function. The various factors influencing the reliability of each item must be considered during allocation if the most economical and realistic requirements are to be specified.

The allocation of requirements should result in the most economical use of available resources. The allocation process, however, is approximate and usually results from a trade-off between the reliabilities of individual items.

The allocated reliability requirements shall be used to establish **baseline** requirements for designers.

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If the reliability for a specific item/subsystem **can not** be achieved at the current state of technology, then the system design must be modified and the allocation reassigned.

This **procedure is repeated** until one allocation is achieved that satisfies the system level requirement, and results in items that can be designed economically, and within the state-of-the-art.

12.2 SCOPE

Reliability apportionment/allocation represents the assignment of **De Havilland Inc.** reliability goals and requirements to subsystems in such a manner that the system reliability goals and requirements shall be satisfied.

Whereas prediction utilized the reliability model/reliability block diagram (RBD) to obtain system reliability from subsystem reliability values, apportionment makes use of the same models by proceeding from system reliability goals to compatible subsystem goals.

Apportioned reliability requirements shall prove useful for directing reliability effort along profitable channels and keeping the development effort compatible.

A few important uses of **reliability apportionment** are listed:

- (1) During the conceptual phase, apportionment of specified reliability requirements shall provide an aid in determination of feasibility,
- (2) When various subsystems are being developed by different contractors, apportionment shall provide compatible contractual reliability requirements.
- (3) Apportionment shall provide the buyer, De Havilland Inc., with a means of evaluating reliability achievements.
- (4) Apportioned reliability requirements shall be used as developmental goals for parts and subsystems. Consequently, reliability growth progress shall be monitored for subsystems with the result that problem areas may be discovered and such problems alleviated by reallocation of resources and efforts or initiating appropriate reliability trade-offs.

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12.2.1 Considerations for Reliability Apportionment

The ideal apportionment would be the allocation of reliability requirements resulting in the most economical use of resources, including time and cost.

Apportionment of reliability is a trade-off between the reliabilities of units to achieve the specified system reliability.

By imposing high requirements on those units which high reliability is easier to attain, and lower requirements on those in which high reliability is more difficult and more costly, the overall cost of the system development may be reduced.

A few **important factors** for consideration follow:

- (1) The **Complexity** of the system will have an effect on the achievable reliability.

The more complex the system, the greater the number of subassemblies and modules, the more difficult and costly it is to achieve a high reliability.

Imposing an unrealistically high reliability on the more complex subsystem increases the cost disproportionately when compared with the effect of increasing the reliability requirement for simpler subsystems.

- (2) The amount of development and research required to produce the system will greatly influence the time and cost of development.

Imposition of a high reliability requirement on a system under development will increase the development time, number of tests required to obtain the reliability, and the cost.

- (3) The intended operational environment will have an effect on the achievable reliability. A system to be used in a rugged environment will tend to cost more to develop than the one to be used under less severe conditions, for the same reliability level.

- (4) The length of time the equipment is required to perform will influence the achievable reliability. It will require more development effort and cost to produce a system capable of operating for a long period of time without failure than to develop one for shorter period of use.

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- (5) The need for high reliability in a subsystem is based on the importance of its operation. A subsystem whose failure would not jeopardize the accomplishment of the mission need not be highly reliable.

To the extent that failures can be tolerated, lower reliability requirements should be imposed.

12.3 APPLICABLE DOCUMENTS

Unless otherwise specified, latest issue of referenced document applies. Buyer shall be responsible for supplying Buyer's documents only to potential subcontractors.

12.3.1 Government Documents

MIL-STD-785B, Task 202	-	Reliability Program for Systems & Equipment Development & Production
MIL-STD-721C	-	Definition of Terms for R&M

12.3.2 De Havilland Inc. Documents

EPS-1-18	-	De Havilland Engineering Procurement Specification
DTRD-8-010	-	De Havilland Technical Requirement Document- General DHC-8 Series 400 Aircraft

12.4 ABBREVIATIONS AND ACRONYMS

DFM	-	Design For Manufacturing
DHI	-	De Havilland Inc.
DHC	-	De Havilland Canada
EPS	-	Engineering Procurement Specification
FBD	-	Functional Block Diagram
MTBF	-	Mean Time Between Failures
RBD	-	Reliability Block Diagram

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RFP	-	Request For Proposal
RFQ	-	Request For Quotation
R&M	-	Reliability and Maintainability

12.5 RELIABILITY ALLOCATION PROCESS

Reliability allocation is the assignment of reliability requirements to lower item levels in such a manner that the system reliability requirements will be satisfied.

The allocated requirements shall be based on the reliability requirement, the relative complexity of the items, and the relative importance of the functions performed by the individual items.

Allocation of the system reliability to the lower level subassemblies involves solving the basic inequality:

$$R(\text{sys}) \leq f(R_1, R_2, R_3, \dots, R_n)$$

where;

R_n = Allocated reliability for the n th item,

$R(\text{sys})$ = System reliability requirement, (i.e. $R=0.99$)

f = Functional relationship between item and system reliability.

This inequality theoretically has an infinite number of solutions if no restrictions are placed on the allocation.

The problem is to establish a procedure that yields a unique or limited number of solutions by which consistent and reasonable reliabilities may be allocated, and are achievable.

The allocation process is approximate.

The reliability parameters apportioned to the subsystems shall be used as guidelines to determine design feasibility.

If the allocated reliability for a specific subsystem **cannot** be achieved at the current state of technology, then the system design must be modified and the allocations reassigned.

This procedure is repeated until an allocation is achieved that satisfies the **de Havilland Inc.** system/aircraft level requirements and all constraints and results in subsystems that can be designed within the state-of-the-art.

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In the event that even with re-allocation some of the individual subsystem, requirements cannot be met within the current state of the art, then the designer must use one or any number of the following approaches (assuming that they are not mutually exclusive) in order to achieve the required reliability:

- (1) Find more reliable component parts to use,
- (2) Simplify the design by using fewer component parts, (using DFM techniques), if this is possible without degrading performance,
- (3) Apply component derating techniques to reduce the stresses (electrical, thermal, mechanical, etc.), and the part failure rates,
- (4) Use redundancy and/or maintenance policies to optimize the subsystem MTBF for those cases where (1), (2), and (3) do not apply.

It should be noted that the allocation process can, in turn, be performed at each of the lower levels of the system hierarchy, if necessary, e.g., equipment, module, component.

12.6 RELIABILITY BLOCK DIAGRAMS (RBD)

The **first step** in the allocation process is the construction of a **reliability block diagram**, (RBD). For a complex system, (i.e. DHC Aircraft), it is convenient to have several block diagrams.

The first would be a simple diagram showing the first-order breakdown of the system. Separate block diagrams are then constructed for each of the first order breakdowns of the system.

Figure 12.1 shows the evolution of a block diagram from the major system level down to the part level as a function of design evolution.

Level I and II diagrams represent the first order breakdown of the system and usually are producible from information available in the system planning stage.

These diagrams are considered adequate for making preliminary reliability allocations and feasibility estimates.

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The level III and level IV diagrams are produced as the design information becomes available to show the specific configuration at the subsystem and unit levels. The level V diagram represents the failure mode diagram at the part level where stress analysis and failure mode studies are performed on individual parts within the system

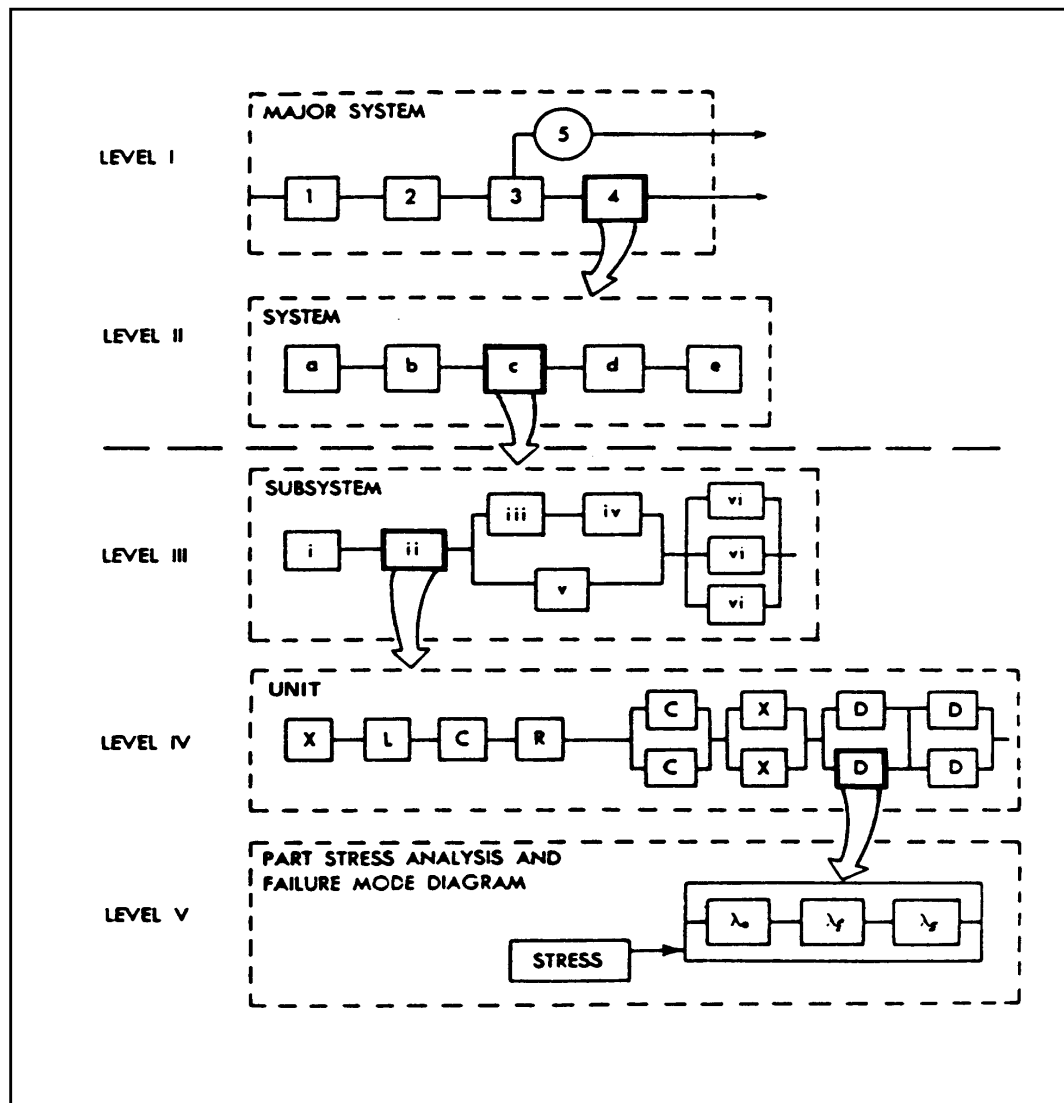


FIGURE 12.1: PROGRESSIVE EXPANSION OF THE RELIABILITY BLOCK DIAGRAM

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A **preliminary Reliability Block Diagram (RBD)** shall be constructed to show the manner in which system element functions must combine to perform the events defined for success.

In order to develop the diagram, it is necessary to have a definition of what is required for mission success. The diagram shall be developed through analysis of the functional relationships of equipment as shown by the functional block diagrams (FBD), system boundaries, and mission profiles.

The reliability block diagram should show the series-parallel relationships of subsystems and equipment required for performance of individual system functions.

The RBD shall be considered a logic chart which depicts the effect of item failure on a system. An item whose failure will cause system failure is shown in series with other items.

It is possible to convey all of the pertinent information merely by the arrangement of blocks and interconnecting lines, therefore, appropriate notation should be included on the diagram or in accompanying description, (i.e. maintenance concept)

RBDs are started at the top level of the system and extended downward to the level at which planning information is firm.

Separate block diagrams or sets of diagrams should be developed for each phase defined in each mission profile for the mission time interval for which the configuration is constant.

Figure 12.2 is an example applied to an aircraft system. In this example, the aircraft is dependent upon twenty-seven (27) items (series dependency) to operate.

Each of the items in this diagram is required to function for aircraft mission success.

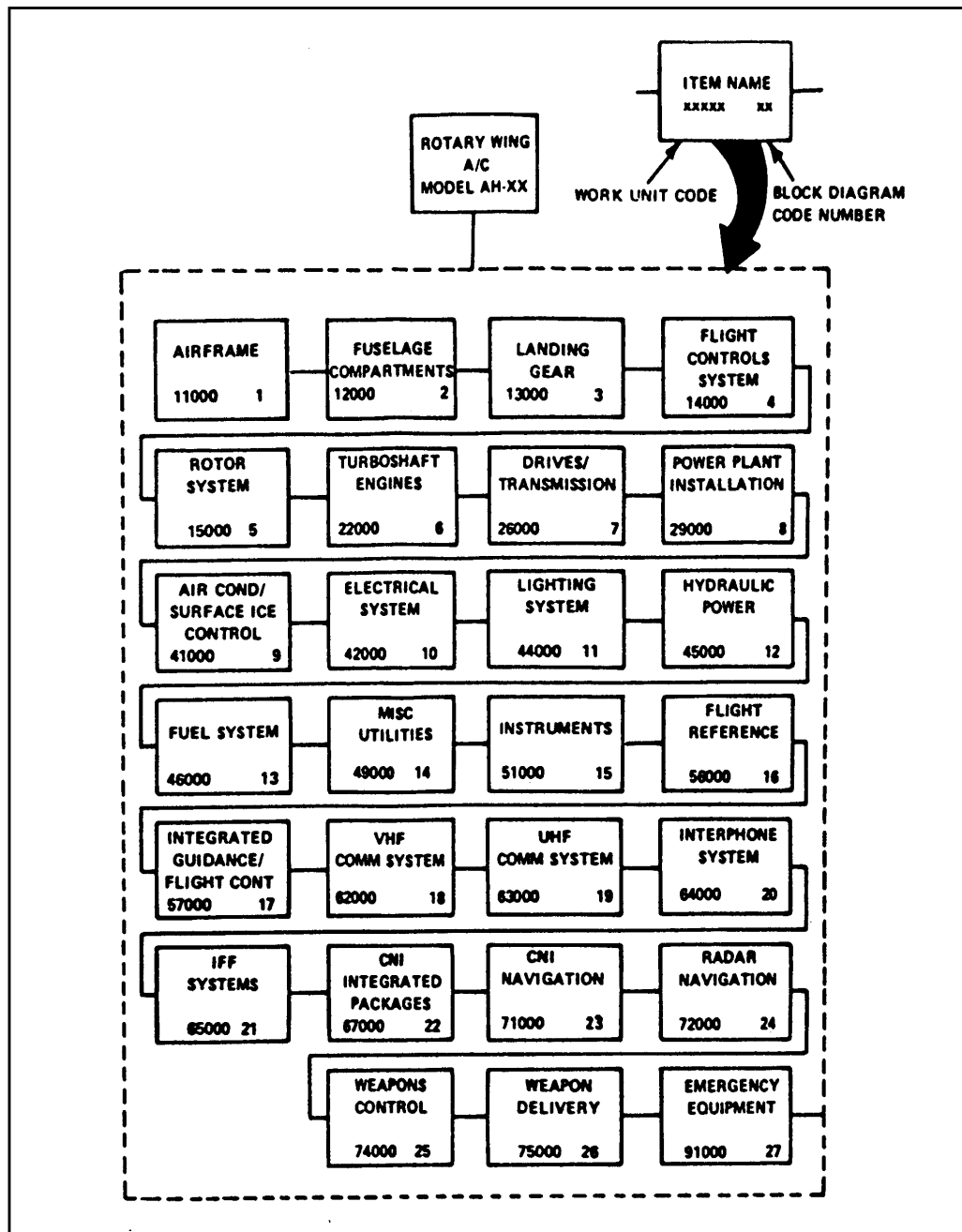
Each of the 27 items, in turn, also has its own reliability block diagram. For example Figure 12.3 is a reliability block diagram of the aircraft airframe, which is block diagram code number 1 of Figure 12.2.

Several levels of breakdown are included. The airframe is functionally dependent upon the fuselage and wings. In turn, the fuselage is dependent upon five (5) items, one of which (Fwd Fuselage) is functionally dependent upon eleven (11) items.

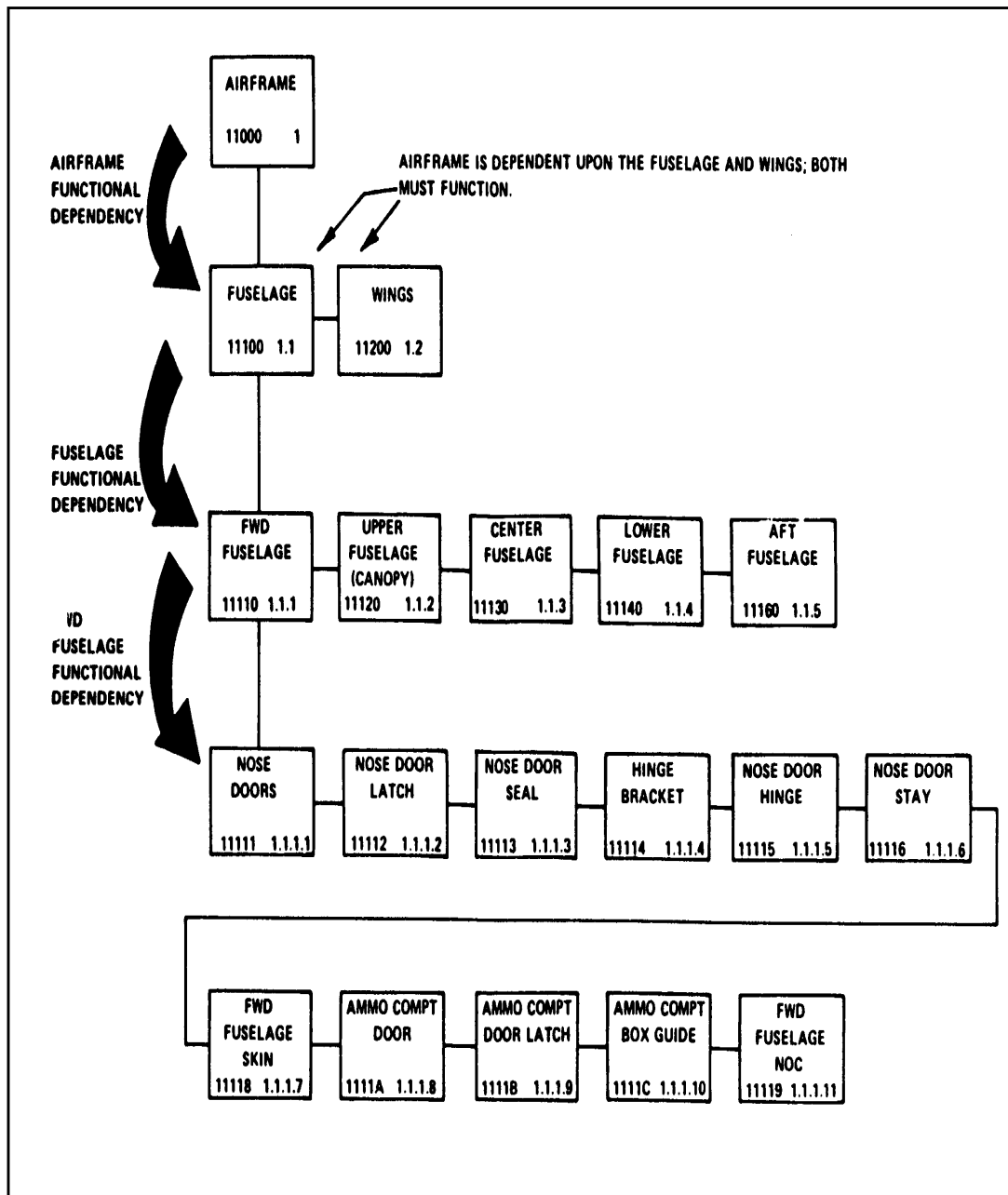
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**FIGURE 12.2: RELIABILITY BLOCK DIAGRAM OF AN
AIRCRAFT SYSTEM**

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***CHAPTER 12***FIGURE 12.3: RELIABILITY BLOCK DIAGRAM OF AN AIRCRAFT SYSTEM ITEM**

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Only the Fuselage and Fwd Fuselage have been expanded for further detail in this illustration.

If it is determined that the reliability requirement dictated by the operational specification requirement exceeds that attainable by state-of-the-art design; redundant design techniques or "on-line" maintenance, periodic inspection/maintenance policies/provisions may be necessary.

The anticipated design requirement then must be included as part of the system description to guide program planning and prospective design activities in the study of design feasibility and reliability allocation.

12.7 RELIABILITY APPORTIONMENT TECHNIQUES

This document will discuss six (6) different techniques to reliability allocation.

These approaches differ in complexity, depending upon the amount of subsystem definition available, and the degree of rigor desired to be employed.

The method to be used shall be defined by D.H.I. R&M engineer.

Procedure and definition of six (6) methods are as follows:

12.7.1 Equal Apportionment Technique

12.7.1.1 General

In the absence of definitive information on the system, other than the fact that (n) subsystems are to be used in series, equal apportionment to each subsystem would seem reasonable.

In this case, the nth root of the system reliability requirement shall be apportioned to each of the (n) subsystems.

12.7.1.2 Detailed Explanation

In the absence of definitive information on the system, other than the fact that (n) subsystems are to be used in series, equal apportionment to each subsystem would seem reasonable, (RFQ phase, conceptual design phase, etc.)

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- a) A prime weakness of the method is that the subsystem goals are not assigned in accordance with the degree of difficulty associated with achievement of these goals.

For this technique, the model is:

$$R(\text{sys}) = \prod_{i=1}^n R_i \quad \text{or}$$

$$R_i = (R_{\text{sys}})^{1/n} \quad \text{for } i = 1, 2, \dots, n$$

where,

$R(\text{sys})$ = is the required system reliability,

R_i = is the reliability requirement apportioned to subsystem (i).

- b) To exemplify this technique, consider a proposed communication system which consists of 3 subsystems (transmitter, receiver, and coder) each of which must function if the system is to function.

Each of the subsystems is to be developed independently. Assuming each to be equally expensive to develop, what reliability requirement should be assigned to each subsystem in order to meet a system reliability requirement of 0.729.

- c) The apportioned subsystem requirements are found as;

$$\begin{aligned} R(\text{transmitter}) &= R(\text{receiver}) = R(\text{coder}) = R(R_{\text{sys}})^{1/n} \\ &= (0.729)^{1/3} = 0.90 \end{aligned}$$

Then a reliability requirement of 0.90 should be assigned to each subsystem.

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12.7.2 Agree Apportionment Technique**12.7.2.1 General**

This technique shall take into consideration both the complexity and importance of subsystem.

It assumes a series of (n) subsystems, each with exponential failure distributions.

The apportioned reliability goal is expressed in terms of MTBF.

12.7.2.2 Detailed Explanation

This technique takes into consideration both the complexity and importance of each subsystem. It assumes a series of (k) subsystems each with exponential failure distributions.

Then the minimum acceptable mean life of the i the subsystem is defined as;

$$\theta_i = \frac{N \cdot w_i \cdot t_i}{n_i[-\ln R_{\text{sys}}(t)]}$$

and the corresponding i the subsystem reliability requirement becomes;

$$R_i(t_i) = \exp\left(-\frac{t_i}{\theta_i}\right)$$

where,

i = 1, 2, 3,..., k number of subsystems,

t = required mission time of the system,

t_i = required mission time of the ith subsystem,

w_i = importance factor expressed as the conditional probability that failure of the ith subsystem (i.e., level II in RBD of Figure 12.1) will result in system failure.

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n_i = number of modules in the i th subsystem (i.e., level III in the RBD, Figure 12.1),

$$N = \sum_{i=1}^k n_i = \text{total number of modules in the system,}$$

$R(t)$ = the required system (aircraft) reliability for system mission time (i.e. 0.99),

$R_i(t_i)$ = the reliability apportioned to the i th subsystem for its mission time,

θ_i = apportioned mean time to failure for i th subsystem.

A concept of module is used in this technique for three purposes:

- (1) the relative complexity inherently required can be taken into account;
- (2) the minimum acceptable reliability figures will not be grossly inconsistent; and,
- (3) reliability requirements will be dynamic and state of the art changes can be incorporated as they occur.

To illustrate the AGREE apportionment method, consider a system composed of four (4) subsystems, (level II).

The system has a mission time of 4 hours and required reliability of 0.9.

Table 12.4: shows the number of modules/units, importance factor and mission time for each subsystem.

TABLE 12.4: AGREE APPORTIONMENT TECHNIQUE EXAMPLE

Subsystem	No. Modules (n_i)	Importance Factor (w_i)	Mission Time (t_i)
1	20	0.7	4
2	30	0.5	4
3	200	0.8	4
4	50	0.2	4
Total	300		

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Note: The w_i factor is applicable for level III and lower levels of the RBD in Figure 12.1.

For level II, $w_i = 1$ by definition.

The apportionment to each subsystem shall be found as follows:

$$\theta_i = \frac{N \cdot w_i \cdot t_i}{n_i[-\ln R_{\text{sys}}(t)]}$$

and

$$R_i(t_i) = \exp\left(-\frac{t_i}{\theta_i}\right)$$

where $R_{\text{sys}}(4) = 0.90$

$$\theta_1 = \frac{300 \cdot (0.7) \cdot (4)}{20 \cdot (-\ln 0.90)} = 398 \text{ hours}$$

$$R_1(4) = \exp(-4/398) = 0.990$$

$$\theta_2 = \frac{300 \cdot (0.5) \cdot (4)}{30 \cdot (-\ln 0.90)} = 189 \text{ hours}$$

$$R_2(4) = \exp(-4/189) = 0.979$$

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$$\theta_3 = \frac{300 \cdot (0.8) \cdot (4)}{200 \cdot (-\ln 0.90)} = 45 \text{ hours}$$

$$R_3(4) = \exp(-4 / 45) = 0.911$$

$$\theta_4 = \frac{300 \cdot (0.2) \cdot (4)}{50 \cdot (-\ln 0.90)} = 45 \text{ hours}$$

$$R_4(4) = \exp(-4 / 45) = 0.911$$

12.7.3 Arinc Apportionment Technique**12.7.3.1 General**

This method assumes series subsystems with constant failure rates such that any subsystem failure causes system failure and that subsystem mission time is equal to system mission time.

This apportionment technique requires expression of reliability requirement in terms of failure rate.

12.7.3.2 Detailed Explanation

This method assumes series subsystems with constant failure rates such that any subsystem failure causes system failure and that subsystem mission time is equal to system mission time.

The apportionment technique requires expression of reliability requirements in terms of failure rate.

The following steps apply:

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-
- (1) The objective is to choose λ_i such that

$$\sum_{i=1}^n \lambda_i \leq \lambda(\text{sys})$$

where,

λ_i = is the failure rate allocated to subsystem i,

$\lambda(\text{sys})$ = is the required system failure rate.

- (2) Determine the subsystem failure rates (λ_i) from past observation, estimation, historical data, or engineering experience/judgment.
- (3) Assign a weighting factor (w_i) to each subsystem according to the failure rates determined in Step 2.

$$w_i = \frac{\lambda_i}{\sum_{i=1}^n \lambda_i}$$

- (4) Allocate subsystem failure rate requirements.

$$\lambda_i = w_i \times \lambda(\text{sys})$$

To illustrate this method, consider an aircraft system composed of the three subsystems (detection equipment, tracking equipment, and firing equipment) with predicted failure rates of $\lambda_1 = 0.003$, $\lambda_2 = 0.001$, and $\lambda_3 = 0.004$ failures per hour respectively. The system has a mission time of 20 hours and 0.90 reliability is required.

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Find the subsystem apportionment requirements:

The apportioned failure rates and reliability goals shall be found as follows:

(1) $R_{\text{sys}}(20) = \exp[-\lambda_{\text{sys}}(20)] = 0.90$

Then,

$\lambda_{\text{sys}} = 0.005$ failures per hour.

(2) $\lambda_1 = 0.003, \quad \lambda_2 = 0.001, \quad \lambda_3 = 0.004$

$$w_1 = \frac{0.003}{0.003 + 0.001 + 0.004} = 0.375$$

$$w_2 = \frac{0.001}{0.003 + 0.001 + 0.004} = 0.125$$

$$w_3 = \frac{0.004}{0.003 + 0.001 + 0.004} = 0.500$$

(3) $\lambda_1 = 0.375 \times (0.005) = 0.001875$

$\lambda_2 = 0.125 \times (0.005) = 0.000625$

$\lambda_3 = 0.5 \times (0.005) = 0.0025$

(4) The corresponding apportioned subsystem reliability requirements are:

$R_1(20) = \exp[-20(0.001875)] = 0.96$

$R_2(20) = \exp[-20(0.000625)] = 0.99$

$R_3(20) = \exp[-20(0.0025)] = 0.95$

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12.7.4 Feasibility-of-Objectives Technique

12.7.4.1 General

This technique was developed primarily as a method of allocating reliability for mechanical and electrical systems. (This method is highly recommended for reliability allocation process).

In this method, subsystem allocation factors are computed as a function of numerical ratings of system complexity, state-of-the-art, performance time, and environmental conditions.

These ratings shall be estimated by the R&M engineering group (Vendor and/or DHI) based on experience, engineering judgment, and historical data.

12.7.4.2 Detailed Explanation

This technique was developed primarily as a method of allocating reliability requirement for mechanical, electro-mechanical, and electrical systems.

In this method, subsystem allocation factors are computed as a function of numerical ratings of system complexity, state of the art, performance time (operating time), and environmental conditions, (mission criticality factor also may be taken into account if necessary).

These ratings are estimated by the R&M engineers (vendor and/or buyer) on the basis of his experience.

Each rating is on a scale from 1 to 10, with values assigned as discussed:

In most cases this method shall be used for reliability requirement apportionment.

(1) System Complexity

Complexity is evaluated by considering the probable number of parts or components making up the system and also is judged by the assembled complexity of these parts or components.

The least complex system is rated at 1, and a highly complex system is rated at 10.

(2) State of the Art

The state of present engineering progress in all fields is considered.

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The least developed design or method is a value of 10, and the most highly developed is assigned a value of 1.

(3) Performance Time

The element that operates for the entire mission time is rated 10, and the element that operates the least time during the mission is rated at 1.

(4) Environment

Environmental conditions are also rated from 10 through 1.

Elements expected to experience harsh and very severe environments during their operation are rated as 10, and those expected to encounter the least severe environments are rated as 1.

(5) Mission Criticality

The element that is the most mission critical is rated as 10, and the least mission critical is rated as 1.

The ratings shall be assigned by a team of engineers (i.e., R&M engineer, design engineer, etc.), based upon their engineering know-how and experience.

An estimate is made of the types of parts and components likely to be used in the new system and what effect their expected use has on their reliability.

If particular components had proven to be unreliable in a particular environment, the environmental rating is raised.

The ratings for each subsystem are multiplied together to give a rating for the subsystem.

The subsystem ratings are then normalized so that their sum is 1

12.7.4.3 Basic Equations

$$\lambda(\text{sys}) \cdot t = \sum \bar{\lambda}(k) \cdot t$$

$$\bar{\lambda}(k) = C_k \cdot \lambda(\text{sys})$$

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where,

C_k = complexity of subsystem k

$C_k = w_k / W$

$w_k = r(1k) \cdot r(2k) \cdot r(3k) \cdot r(4k)$

$$W = \sum_{k=1}^N w(k)$$

where,

$\lambda(\text{sys})$ = system failure rate,

t = mission duration,

$\bar{\lambda}(k)$ = failure rate allocated to each subsystem,

N = number of subsystems

$w(k)$ = rating for subsystem k

$r(ik)$ = rating for each of the factors for each subsystem.

Example 1

A mechanical-electrical system consists of the following subsystems:

Propulsion, flight control, airframe, auxiliary power, landing gear, and fuel system.

A system reliability of 0.90 in 120 hours is required.

Engineering estimates of complexity (here combined with the criticality factor), state of the art, performance time, and environments can be made.

The subsystems and their ratings are described in Table 12.5, columns 1-5

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Subsystem	Complex- ity r'_1	State-of- the-art r'_2	Perfor- mance time r'_3	Environ- ment r'_4	Overall rating w'_k	Complex- ity factor C'_k	Allocated failure rate per (10^6 hrs)
1. Propulsion	5	6	5	5	750	.097	85
2. Airframe	7	6	10	2	840	.109	96
3. Landing Gear	10	10	5	5	2500	.324	284
4. Flight Control	8	8	5	7	2240	.290	265
5. Fuel System	4	2	10	8	640	.083	73
6. Aux. Power	6	5	5	5	750	.097	85
Total					W=7720	1.000	878

System s-reliability = 0.90

Mission Time = 120 Hours

 $\lambda_s = 878$ per 10^6 hours

Compute the allocated failure rate for each subsystem.

Step 1 Compute the product of the rating $r(i)$ for each subsystem and their sums, i.e., fill in column 6, Table 12.5, by equations given in .

$$w(1) = 5 \times 6 \times 5 \times 5 = 750$$

-

-

-

$$w(6) = 6 \times 5 \times 5 \times 5 = 750$$

$$W = 750 + 840 + 2500 + 2240 + 640 + 750$$

$$W = 7720$$

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Step 2 Compute the complexity factors $C(k)$ for each subsystem, i.e., fill in column 7, Table 12.5, by equations given in .

$$C(1) = 750: 7720 = 0.097$$

-

-

-

$$C(6) = 750: 7720 = 0.097$$

Step 3 Compute system average failure rate $\bar{\lambda}(\text{sys})$ from system specifications;

$$R(\text{sys}) = 0.90 \text{ and } t = 120 \text{ hours}$$

$$\bar{\lambda}(\text{sys}) = -\ln 0.90 / 120$$

$$\bar{\lambda}(\text{sys}) = 878 \text{ failures per } 10^{**}6 \text{ hours.}$$

Step 4 Compute the allocated subsystem average failure rate $\bar{\lambda}(k)$, i.e., fill in column 8, Table 12.5, by equations given in 6.4.2.

$$\bar{\lambda}(1) = 0.097 \times 878.0$$

$$\bar{\lambda}(1) = 85.17 \text{ failures / } 10^{**}6 \text{ hours}$$

-

-

$$\bar{\lambda}(6) = 0.097 \times 878.0$$

$$\bar{\lambda}(6) = 85.17 \text{ failures / } 10^{**}6 \text{ hours}$$

Step 5 Round off failure rates $\bar{\lambda}(k)$ to 2 significant figures, so that too much accuracy will not be implied;

Sum, and compare with $\lambda(\text{sys})$, Step (3).

$$85 + 96 + 284 + 255 + 73 + 85 = 878 \leq 878$$

$$\sum \bar{\lambda}(k) \leq \lambda(\text{sys})$$

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Example 2

This example, in Table 12.6, shows a spreadsheet that may be used for this method.

Note that here we have 5 ratings; Complexity, State of the art, Operating time, Environment, and Mission Criticality.

Specified system failure rate is 400 per 10^6 hours (based on 2500 hours goal MTBF)

Last column shows the estimated failure rates.

- Compare and evaluate the allocated and estimated values.
- Wherever we see a significant difference, it has to be explained, and corrective action has to be taken if necessary.

12.7.5 Minimization of Effort Algorithm Technique

12.7.5.1 General

This algorithm considers minimization of total effort expended to meet system reliability requirements.

It assumes a system comprised of (n) subsystem in series. Certain assumptions are made concerning the effort function.

It assumes that the reliability of each subsystem is measured at the present stage of development or is estimated, and apportions reliability such that greater reliability improvement is demanded of the lower reliability subsystems.

12.7.5.2 Detailed Explanation

This apportionment technique considers minimization of total effort expended to meet the system reliability requirements.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES****CHAPTER 12****TABLE 12.6: FAILURE RATE APPORTIONMENT WORKSHEET**

END ITEM: 14SF-7 PROP SYSTEM							SPECIFIED FAILURE RATE (SFR) = 400 (Based on a 2,500 Hr. Goal)			
* C = Complexity S = State of the Art							T = Operational Time E = Environment		M = Mission Criticality	
ID	HS NOMENCLATURE	WEIGHT FACTORS *					SUM	(A)/(B)	(D) x SFR	ESTIMATED OPERATIONAL FAILURE RATE
		C	S	T	E	M	(A)	(D)	APPORTIONED SFR	
1.0	Propeller Control Unit									
1.1	-Main Governor Assembly	6	7	8	6	6	33	0.0611	24.4444	13.036
1.2	-Reverse Valve	4	4	7	6	3	24	0.0444	17.7778	6.048
1.3	-Beta Valve	5	5	2	6	3	21	0.0389	15.5556	4.938
1.4	-Feather Solenoid Valve	5	8	4	6	5	28	0.0519	20.7407	13.898
1.5	-Low Pitch Switch	5	8	2	6	3	24	0.0444	17.7778	5.853
1.6	-Not Applicable									
1.7	-Servo	6	4	10	6	6	32	0.0593	23.7037	37.539
1.8	-Synchrophaser Torque Motor	3	3	4	6	6	22	0.0407	16.2963	11.589
1.9	-Least Selector Valve	2	4	2	6	3	17	0.0315	12.5926	4.641
1.10	-Miscellaneous	5	3	8	6	5	27	0.0500	20.0000	10.455
2.0	Prop Assembly									
2.1	-Blades	7	8	10	10	1	36	0.0667	26.6667	72.648
2.2	-Spinner	4	4	10	8	5	31	0.0574	22.9630	18.456
	Bulkhead & Slip Flange									
2.3	-Actuator	8	8	10	7	1	36	0.0667	26.6667	15.519
2.4	-Barrel Assembly	4	5	10	7	1	27	0.0500	20.0000	15.510
3.0	Accessories									
3.1	-Brushblock Assembly	3	4	4	8	7	26	0.0481	19.2593	22.696
3.2	-Transfer Tube Assembly	5	9	10	8	3	35	0.0648	25.9259	9.954
3.3	-Deicer Timer	4	4	4	6	7	25	0.0463	18.5185	27.000
3.4	-Synchrophaser Pulse Pickup	3	3	10	5	4	25	0.0463	18.5185	1.386
3.5	-Synchrophaser	6	5	4	4	4	23	0.0426	17.0370	26.520
3.6	-Aux. Pump & Motor	4	4	2	6	5	21	0.0389	15.5556	6.900
		SUM OF WEIGHTS (B) =					540	TOTALS:	400	337

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A system is considered where (n) subsystems are arranged in series.

Let $R_1, R_2, \dots, R_n$ denote subsystem reliabilities and the system reliability $R(\text{sys})$ would be given by;

$$R(\text{sys}) = \prod_{i=1}^n R_i$$

Let $R(\text{req})$ be the required reliability of the system, where $R(\text{req}) > R(\text{sys})$.

It is then required to increase at least one of the subsystem values of the R_i to the point that the required reliability $R(\text{req})$ will be met.

To accomplish such an increase takes a certain effort, which is to be apportioned in some way among the subsystems. The amount of effort would be some function of number of tests, amount of engineering manpower applied to the task, etc.

The algorithm assumes that each subsystem has associated with it the same effort function, which measures the amount of effort needed to increase the reliability of the i th subsystem from R_i to $R(\text{req})$.

As an **Example**; consider a system that consists of three subsystems (A, B, and C), all of which must function without failure in order to achieve system success.

The system reliability requirement has been set at 0.70.

We have predicted subsystem reliabilities as $R(A) = 0.90$, $R(B) = 0.80$, and $R(C) = 0.85$.

How should we apportion the system required reliability, to the subsystems, in order that total effort be minimized, and that the system reliability be satisfied?

Step 1 Assume identical effort functions for the three subsystems.

The resulting minimum effort apportionment goals are found as follows;

Step 2 Arrange subsystem reliability values in ascending order:

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$$R_1 \leq R_2 \leq \dots \leq R_n$$

$$R_1 = R(B) = 0.80,$$

$$R_2 = R(C) = 0.85, \text{ and}$$

$$R_3 = R(A) = 0.90$$

Step 3 Determine K_o = the maximum value of j , such that

$$R_j < \left[\frac{R_{\text{req}}}{\prod_{i=j+1}^{n+1} R_i} \right]^{1/j} = r_j$$

where $R_{(n+1)} = 1$ by definition.

Step 4 When $j = 1$

$$R_1 = 0.80 < r_1 = \left[\frac{0.7}{R_2 \cdot R_3 \cdot 1} \right]^1 = \frac{0.7}{0.85 \cdot 0.90 \cdot 1.0}$$

$$r_1 = 0.915$$

when $j = 2$

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$$R_2 = 0.85 < r_2 = \left[\frac{0.7}{R_3 \cdot 1.0} \right]^{1/2} = \left[\frac{0.7}{0.90 \cdot 1.0} \right]^{1/2}$$

$$r_2 = 0.882$$

when $j = 3$

$$R_3 = 0.9 > r_3 = \frac{0.7}{1.0} = (0.70)$$

$$r_3 = 0.888$$

Step 5 Since $R_1 < r_1$, $R_2 < r_2$, but $R_3 > r_3$, then
 $k_0 = 2$ because 2 is the largest subscript j such that $R_j < r_j$.
 Thus,

$$R_0 = \left[\frac{R}{\prod_{j=k_0+1}^{n+1} R_j} \right]^{1/k_0} = \left[\frac{0.7}{R_3} \right]^{1/2} = 0.882$$

Step 6 That means that the effort is to be allotted so that;

- subsystem B increases in reliability from 0.80 to 0.882.
- subsystem C increases in reliability from 0.85 to 0.882,
- whereas subsystem A is left alone with a reliability of 0.90.

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Step 7 The resulting reliability of the entire system is, as required
 $0.70 = (0.882)^2 \times (0.90).$

This means that effort should be expended on subsystems C and B to raise their respective reliabilities to 0.882 with no developmental effort spent on subsystem A.

This policy would minimize the total expended effort required to meet system reliability requirements.

The minimization, however, is dependent upon the effort function meeting the initial assumptions, which may not be possible.

Note that the math behind these equations is not developed in this document.

12.7.6 Dynamic Programming Technique

12.7.6.1 General

If all subsystems are not equally difficult to develop, dynamic programming provides an approach to reliability apportionment with minimum effort expenditure when the subsystems are subject to different but identifiable effort functions.

The preceding minimization of effort algorithm requires that all subsystem be subject to the same effort function.

The dynamic programming approach can be most useful because it can be implemented with a simple algorithm that consists of only arithmetic operations.

This method requires a computer program for complex systems to be solved.

Not recommended at this point of time for reliability requirement apportionment.

12.7.6.2 Detailed Explanation

No detailed explanation is provided in this document. However, information on this topic is available upon request.

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Chapter 13

RELIABILITY MODELING, PREDICTIONS, METHODS AND PROCEDURES

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13 RELIABILITY MODELING, PREDICTIONS, METHODS AND PROCEDURES

13.1 SCOPE

13.1.1 Introduction

Any Reliability Model or Method which is not addressed in this document will be added if becomes relevant or requirement.

This procedure establishes uniform methods and ground rules for the preparation of Mission/Flight Reliability and Basic Reliability models and estimates for electronic, electrical, electromechanical, and mechanical systems and equipments.

Item complexity may range from a complete aircraft to the simplest subsystem of the aircraft.

The primary value of Reliability Model/Estimates is as a design tool to provide relative measures of system reliability to design decisions, inputs for other R&M and Safety activities/evaluations.

13.1.2 Application

The procedures and methods established by this document shall be applied to any de Havilland Inc. procured and in-house designs for system development and production.

It is not intended that all the methods herein will need to be applied to every item or program phase. De Havilland and Vendor R&M engineering shall tailor the methods of these procedure to the optimum needs of each procurement and in-house designs.

13.1.3 Purpose

Reliability modeling and estimation is a methodology for estimating an item's ability to meet specified RMS (Reliability, Maintainability, and Safety) requirements.

The Mission/Flight Reliability estimates the probability that the system will perform its required functions during the mission/flight.

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The Basic Reliability estimates the demand for maintenance and logistic support caused by the item's unreliability.

When used in combination, the two estimates provide a basis for identifying areas wherein special emphasis or attention is needed, and for comparing the ownership cost effectiveness of various design configurations.

The two estimates shall also be used as a basis for the **apportionment** (allocation) of ownership cost, operational effectiveness and RMS requirements to various subsystems.

13.1.4 Reliability Mathematical Model

A Reliability Mathematical Model; based on system/subsystem/equipment functions shall be developed and maintained. As the design evolves, a reliability block diagram (RBD), shall be developed and maintained for the system/subsystem with associated allocations and estimations for all items in each reliability block.

The reliability block diagram shall be keyed and traceable to the functional block diagram, schematics, and drawings, and shall provide the basis for accurate **mathematical** representation of reliability

Nomenclature of items used in reliability block diagrams shall be consistent with that used in functional block diagrams (FBD), drawings, and schematics, weight statements, power budgets, and specifications.

The model outputs shall be expressed in terms of contractual reliability requirements, and other reliability terms as specified.

When required for the production phase, the model shall be updated to include hardware design changes.

The reliability mathematical model shall be updated with information resulting from reliability and other relevant tests as well as changes in item configuration, mission parameters and operational constraints.

Inputs and outputs of the reliability mathematical model shall be compatible with the input and output requirements of the system and subsystem level analysis models.

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13.2 APPLICABLE DOCUMENTS

Unless otherwise specified, latest issue of referenced document applies. Buyer shall be responsible for supplying Buyer's documents only to potential subcontractors.

13.2.1 Military Documents

MIL-STD-785B	Reliability Program for Systems and Equipment Development and Production
MIL-STD-72	Definitions of Terms for R&M
MIL-STD-881	Work Breakdown Structures for
MIL-STD-780	Work Unit Codes for Aeronautical Equipment
MIL-STD-280	Definitions of Item Levels
GIDEP	Government Industry Data Exchange Program
NPRD	Nonelectronic Parts Reliability Data
MIL-HDBK-217F	Reliability Prediction of Electronic Equipment
MIL-HDBK-251	Reliability/Design Thermal Applications

13.2.2 De Havilland Inc. Documents

EPS-1-18	De Havilland Engineering Procurement Specification
DTRD-8-010	De Havilland Technical Requirement Document General DHC-8 Series 400 Aircraft

13.3 DEFINITIONS, ABBREVIATIONS, ACRONYMS

BTT	Boolean Truth Table
c.d.f	Cumulative density function
CTE	Coefficient of Thermal Expansion
DHI	De Havilland Inc
EPS	Engineering Procurement Specification
ESS	Environmental Stress Screening

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H/W	Hardware
FBD	Functional Block Diagram
FMECA	Failure Modes, Effect, and Criticality Analysis
FTA	Fault Tree Analysis
LR	Loading Roughness
LCC	Leadless Chip Carrier
MTBF	Mean Time Between Failures
MTTFF	Mean Time To First Failure
p.d.f	Probability density function
PWB	Printed Wiring Board
PTH	Plated Through Holes
RADC	Rome Air Development Center
RBD	Reliability Block Diagram
R&M	Reliability and Maintainability
SM	Safety Margin
SMT	Surface Mount Technology
SMD	Surface Mounted Device
S/W	Software

**13.4 RELIABILITY MODELING, PREDICTION PROCEDURE AND
METHODOLOGY****13.4.1 General**

Reliability modeling and prediction shall be planned and performed in accordance with the general requirements of this document, and method(s) specified by the Buyer (procuring activity).

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13.4.2 Implementation

Reliability modeling and prediction shall be initiated early in the configuration definition stage to aid in the evaluation of the design and to provide a basis for item reliability apportionment and establishing corrective action priorities.

Reliability models and predictions shall be updated when there is a significant change in the item design, availability of design details, environmental requirements, stress data, failure rate data, or service use profile.

13.4.3 Ground rules and assumptions

The Buyer shall develop ground rules and analysis assumptions, (R&M Control Plan Document ESP 91).

The ground rules shall identify the reliability modeling and prediction approach, the lowest indenture level to be analyzed, and include a definition of mission success/profile for the item in terms of performance criteria and allowable limits.

Ground rules and analysis assumptions are not inflexible and may be added, modified, or deleted if requirements change.

Ground rules and analysis assumptions shall be documented and included in the reliability modeling and prediction report.

13.4.4 Coding System

For consistent identification of item functions and hardware elements, the Buyer/Seller shall adhere to a coding system based upon the hardware breakdown structure, work unit code numbering system of MIL-STD-780, or other similar uniform numbering system.

The coding shall be consistent with the **FMECA**, and functional block diagram numbering system to provide complete visibility of each modeled element and its relationship to the item.

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13.4.5 Mission success definition

The Buyer and/or Seller shall develop general statements of item mission success in terms of performance, safety, R&M, and allowable limits for each specified output.

Mission success definitions shall be included in the ground rules.

13.4.6 General procedure

The steps set forth below define the procedure for developing a **reliability model** and performing a reliability prediction.

Effort to develop the information for the steps below shall be closely coordinated with related program activities as a concurrent engineering team, (such as design engineering, system engineering, maintainability, and logistics) to minimize duplications and to assure consistency and correctness.

Define the item for which the prediction is applicable, (see 13.4.7).

Define the service use (life cycle) for which item reliability will be modeled and predicted, (see 13.4.8).

Define the item reliability block diagrams.

Define the mathematical models for computing item reliability.

Define the parts of the item.

Define the environmental data/requirements including the mission profile.

Define the stress data (i.e. electrical, mechanical, thermal, etc.).

Define the failure distributions, (probability density functions, p.d.f.).

Define the maintenance concept.

Define the failure rates.

Compute the item reliability, (Basic, and Mission).

13.4.7 Item definition

Item definition shall include performance requirements and hardware concept to the extent known at the time model and prediction are prepared.

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Characteristics of the item shall be stated in terms of range, altitude, speed, environmental conditions, power, or such other parameters as may be applicable.

The manner in which the item and its subdivision operate is usually expressed by means of functional diagrams which can become the basis for the reliability block diagrams.

Normally, the initial item definition used for the feasibility prediction will be lacking several details and will require certain assumptions as to environmental conditions, design configuration, etc.

The item definition shall be refined and updated as more information becomes available to support the preliminary design prediction, and subsequently, the detailed design prediction.

As the item description is progressively updated, higher levels of accuracy will be attained for prediction results.

13.4.8 Service use profile

The service use (life cycle) profile or portion thereof to be used for reliability modeling and prediction shall either be provided by the Buyer or specified for Seller preparation.

The service use profile is a thorough description of all events and environments associated with an item from final factory acceptance through its terminal expenditure or removal from inventory.

Each significant service use event, such as transportation, storage, test and checkout, operational deployment, etc., is addressed.

The profile depicts expected time spans, environments, operating modes (including standby and ready modes), etc., for each event.

Information from logistic cycles, operational cycles, mission profiles, and environmental profiles is used to develop the service use profile.

13.4.9 Reliability modeling and prediction report

The reliability models and reliability predictions shall be documented in a report that identifies the level of analysis, summarizes the results, documents the data sources and techniques/methods used in performing the

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analysis, and includes the item definition, resultant analysis data, worksheets, ground rules and assumptions.

Interim reports shall be available at each design review to provide comparisons of alternative designs and to highlight high failure rate elements of the item design, potential mission/flight reliability, single failure points, and proposed design corrections or improvements.

The final report shall reflect the final design and provide identification of high failure rate elements, overstressed parts, and mission/flight reliability single failure points which could not be eliminated from design.

13.4.9.1 Report Summary

The report shall contain a summary which provides the conclusions and recommendations based upon the analysis.

Interpretation and comments concerning the analysis and the initiated as recommended actions for the elimination or reduction of failure risks shall be included.

A design evaluation summary of major problems detected during the analysis shall be provided in the final report.

A list of hardware or functional elements of the item omitted from the reliability models and reliability predictions shall be included with rational for each element's exclusion.

13.5 RELIABILITY MODELING AND PREDICTION METHODOLOGY

13.5.1 Reliability Modeling

13.5.1.1 Reliability Block Diagrams

Reliability block diagram shall be prepared to show interdependencies among all elements (subsystems, equipments, etc.) or functional groups of the item for item success in each service use event.

The purpose of the reliability block diagram is to show by concise visual shorthand the various block combinations (paths) that result in item success. A complete understanding of the item's mission definition, and service use profile is required to produce the reliability diagram.

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Each RBD shall have a title including identification of the item, the mission identification or portion of the service use profile addressed, and a description of the mode of operation for which the prediction is to be performed.

All blocks of the RBD shall be configured in series, parallel, standby, or combinations thereof as appropriate.

The following general assumptions shall apply to reliability block diagrams:

- (1) The blocks denote elements or functions of the items that are considered when evaluating reliability and which have reliability values associated with them.
- (2) All lines connecting blocks have no reliability values. The lines serve only to give order and direction to the diagram and do not represent the wiring cables and connectors associated with the item.
- (3) Cabling and connectors are incorporated into a single block or included as part of the block for an element or function.
- (4) All inputs to the item are within specification limits.
- (5) Failure of any element or function denoted by a block in the diagram will cause failure of the entire item, except where alternative paths of operation may be present.
- (6) Each element or function denoted by a block in the diagram is independent, with regard to probability of failure, from all other blocks.

Software reliability assumptions.

The assumptions that all software is completely reliable shall be stated in instances when software reliability is not incorporated in the item reliability prediction.

Human reliability assumptions.

The assumptions that all human elements are completely reliable and that no interface problems occur between human elements and the item, shall be stated in instances when human reliability is not incorporated in the item reliability prediction.

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13.5.1.2 Reliability Mathematical Models

Models shall be derived to mathematically relate reliability block diagrams to time-event relationships and failure rate data (time to failure distributions).

The solution of the models will be the item estimated reliability. The mathematical model shall be capable of being readily updated with information resulting from reliability and other relevant tests as well as changes in the item configuration, mission parameters, and operational constraints.

13.5.2 Basic Reliability Model

A Basic Reliability model is a **series** model used for estimating the demand for maintenance and **logistic support** caused by an item and its component parts.

Accordingly, all elements of the item provided for redundancy or alternate paths of operation are modeled in series.

Except for those instances in which there is neither redundancy nor alternate paths of operation provided for the item, the Basic Reliability model cannot be used to estimate Mission Reliability.

However, both the Basic Reliability model and the Mission Reliability model are used in combination to compare the ownership cost-effectiveness of various design configurations and as a basis for apportionment of ownership cost and operational effectiveness requirements to various subdivisions of an item.

The basic information for the Basic Reliability model is derived from documentation identifying all equipments and associated quantities that comprise the item.

As the proposed item design is firmed and comes under configuration control, the established configuration baseline should be the basis for the Basic Reliability model.

The Supplier shall develop and maintain a Basic Reliability model based upon a defined item configuration.

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The Basic Reliability block diagram shall be keyed and traceable to the Mission Reliability model, functional block diagrams (FBD), schematics, and drawing, and shall provide the basis for accurate mathematical representation of Basic Reliability.

Nomenclature of elements of the item used in the Basic Reliability block diagrams shall be consistent with that used in the Mission Reliability model, functional block diagrams, drawings, schematics, and specifications.

13.5.3 Mission Reliability Model

A Mission Reliability model shall be used for evaluating complex equipment arrangements which exist in aircraft systems.

Item reliability is defined as the probability of performing a specified function or mission under specified conditions for a specified time.

Therefore, a reliability requirement for function or mission success must include:

- (1) A definition of item performance such that every condition is defined as acceptable (success) or unacceptable (failure).
- (2) A definition of the conditions. This involves defining the environmental conditions which prevail on the various equipments of the item throughout the mission.

In addition, duty cycles or periods of operation for the various equipments must be defined.

- (3) A definition of mission time. A careful quantitative statement of the time during which the item must function is important.

In complex items which operate in different functional modes at different stages of the mission or which use certain subsystems only if conditions require, the functioning-time requirements for each subordinate group shall be established.

- (4) A definition of the reliability variable of the item elements.

The reliability variable is a number (time, cycles, events, etc.) used to describe the duration required by each item element (and included in the Mission Reliability block diagram) to perform its stated function.

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13.5.3.1 Developing the Item Definition

A complete definition of the item covers the use, performance, restraints, and failure definitions.

Thus, it is necessary to define:

Step 1 Define the purpose, intended use or mission of the item.

Before a model can be developed, requirements must be formulated. A word statement of what is required for mission success or a Mission Reliability block diagram must be generated.

The Mission Reliability block diagram is a pictorial form of a statement of what is required for mission/flight success.

Step 2 Establish and specify the item and subsystem performance parameters and allowable limits. It is desirable to construct a list or chart which illustrates a list of performance parameters and allowable upper and lower limits, and failure criteria as in Table 13.1.

TABLE 13.1: PERFORMANCE PARAMETERS

Performance Parameter	Units of Measure	Specified Requirements	Failure Classification in terms of Performance Units
1. Power	HP, KW	PO=500+/-20%	Major 200<PO<400
Output (PO)	etc.		Critical: PO<200

Step 3 Determine the physical and functional boundaries of the item.

Step 4 Determine the conditions which constitute mission failure.

A failure is an inability to complete a stated mission/flight within specific limits.

Using the previous steps, identify and list the conditions that would constitute mission failure.

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For example, one condition of successful mission completion may be a requirement of a minimum 200 KW for the power output of a transmitter.

Hence, any single or combination of item hardware and software failure that would result in less than 200 KW of transmitter power output would constitute a mission failure.

Step 5 Define the service use profile.

Although the Mission Reliability model consider the complete logistic and operational cycles associated with the service use profile it is the mission profile and environmental profile that receives the most attention.

The mission profile(s) needs to address the item duty cycles or periods of operation.

Duty cycle is the ratio of operating time to total time. The method to handle duty cycle in calculation is as follows:

- (1) If the component is considered to have a negligible failure rate during a non operating period, the failure rate can be modified by a duty cycle factor.

For example the equation;

$P(\text{sys}) = e^{-\lambda t d}$ can be used for a constant failure rate component where d, the duty cycle factor, is the ratio of operating time to total mission time, t.

- (2) When a component has a failure rate during non-operating periods different from that experienced during operating periods, the following equation shall be used;

$P_s = P_s(\text{operating}) \cdot P_s(\text{nonoperating})$

For the constant failure rate component, this equation yields;

$P_s = \exp - \{\lambda_1 \cdot t \cdot d + \lambda_2 \cdot t \cdot (1-d)\}$

where,

λ_1 = failure rate during operation

λ_2 = failure rate during non-operation.

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13.5.3.2 Procedure for developing item models

Step 1 Define what is required for mission success and translate this into a mission success diagram.

Step 2 Write the probability of success, P_s , equation for the item.

Step 3 Calculate P_s for each of the equipments of the item. This is done by utilizing one of the various reliability prediction techniques.

Step 4 The probability of success numbers for the various equipments derived in Step 3 are inserted in the formula derived in Step 2 for the item probability of success.

Step 5 A probability of success curve versus time can be plotted by taking several values of time for mission time, and evaluating the probability of item success by the above procedure for the several values of time chosen.

Step 6 Additional steps in the analysis will depend upon the decisions that the analysis is intended to optimize.

Defining mission success is to write a word statement which describes what equipments or combination of equipments are required for mission success and drawing a Reliability Block Diagram for the statement.

Several methods of going from a RBD to a probability of survival formula are given in this document, (Section 13.6).

13.6 RELIABILITY MODELING AND ESTIMATION METHODS

The purpose of these methods is to prepare a reliability mathematical models from a reliability block diagram, by means of probabilistic methods applicable to single functioned and multifunctioned system.

13.6.1 Conventional Methods

The conventional probability methods make use of the equations developed to handle redundant, series, parallel, series-parallel, non series-parallel, or complex configurations.

Equations for probability of success, P_s , for various system configurations are derived as follows for various success diagrams evaluation.

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13.6.1.1 Series Arrangement Model

The system is composed of n subsystems $S_1, S_2, \dots, S_n$ which all are arranged in series (see Figure 13.1, Mission Reliability diagram).

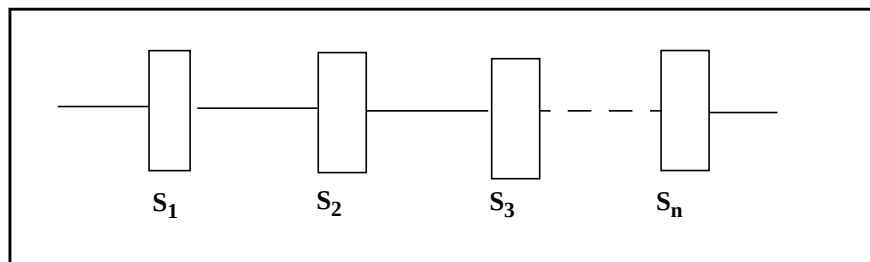


FIGURE 13.1: MISSION RELIABILITY DIAGRAM - SERIES SYSTEM

It is assumed that the (S_i) fail independently and must all operate successfully if the system S is to operate successfully.

The **c.d.f.** of system failure time is;

$$G(s)(t) = 1 - P(T > t) = 1 - \prod_{i=1}^n (1 - F_i(t))$$

where, T = time to failure of the system.

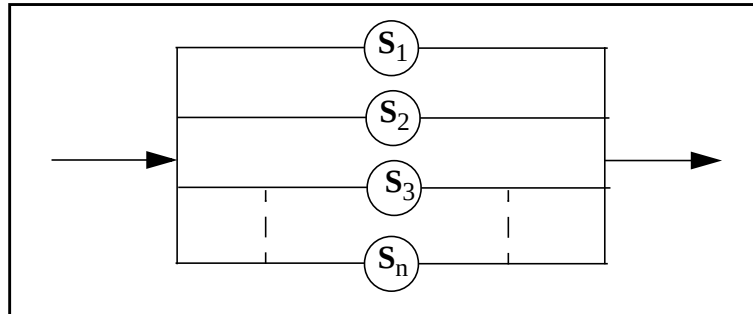
Hence, the probability of success (reliability) of the system for the time interval $(0, t]$ is defined as the probability that the system survives for a length of time t and can be written as;

$$R_{sys}(t) = \prod_{i=1}^n R_i(t)$$

13.6.1.2 Parallel Arrangement Model

The system is composed of n subsystem $S_1, S_2, \dots, S_n$ which are arranged in parallel redundancy, i.e., are all operating simultaneously, (see Figure 13.2).

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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SYSTEM**

It is assumed that the (S_j) fail independently of each other and that the system operates successfully if at least one of the (S_j) , $j = 1, 2, \dots, n$ operates successfully.

The **c.d.f.** of the system failure time is;

$$G_p(t) = \prod_{j=1}^n F_j(t),$$

and the probability of success (reliability) of the system for the time interval $(0, t]$ becomes;

$$R_p(t) = 1 - G_p(t) = 1 - \prod_{j=1}^n F_j(t),$$

13.6.1.3 k-out-of-n Arrangement Model.

A generalization, which includes both the series and parallel system arrangement, is the so called k out of n system.

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13.6.1.3.1 Active (On-Line) Standby System (all n units Identical)

It is assumed that the system is composed of n units, each of which has the same failure time **c.d.f.** $F(t)$, and where the units are assumed to fail independently of each other.

The system is said to operate successfully over the time interval $(0,t]$ if at least k out of the n units operate successfully over $(0,t]$.

The easiest way to find $R_{k,n}(t)$, the reliability of a k out of n system is to use the binomial distribution.

Over the interval $(0,t]$ there are two possible outcomes for each unit:

- Survival, with associated probability $1-F(t)$, and
- Failure, with associated probability $F(t)$.

Because of the assumed independence of the n units we have n Bernoulli trials and

$R_{k,n}(t)$ is the probability that at least k out of n units survive.

Hence, we have:

$$R_{k,n}(t) = \sum_{j=k}^n \binom{n}{j} [1-F(t)]^j [F(t)]^{n-j}$$

13.6.1.3.2 Active (On-Line) Standby System (all n units Different)

If all the n subsystems are not identical, (failure time c.d.f. are different), $R_{k,n}(t)$ equation in 13.6.1.3.1 is no longer valid.

- (1) To compute the system reliability, we have to enumerate the system's success paths.

This is aided by a reliability signal flow graph and application of set theory.

- (2) The graph will have $\binom{n}{k}$ parallel paths. Each path, containing k elements, corresponds to one of the n events taken k at a time.

The success of each path depends on the success of all the k elements.

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Therefore, by set theory, the reliability is given as:

$$R(t) = P(X_1 \cup X_2 \cup X_3 \cup \dots \cup X_n) \quad (1)$$

where,

$X_1, X_2, \dots, X_n$ are sets of path elements.

This can be solved as in equation below;

$$R = P(X_1 \cup X_2 \cup X_3 \cup \dots \cup X_n) \quad (2)$$

Expansion of equation (2) by Boolean Algebra gives;

$$R = P(X_1) + P(X_2) + P(X_3) + \dots + P(X_n) - [P(X_1X_2) + \dots + P_{i=j}(X_iX_j)] + \dots + (-1)^{n-i} P(X_1X_2X_3 \dots X_n) \quad (3)$$

Example:

For a **3-out-of-4** configuration, the reliability graph is shown as in Figure 13.3.

The probability of success is given by the probability of success of the path $X_1X_2X_3$ or $X_1X_2X_4$ or $X_1X_3X_4$ or $X_2X_3X_4$

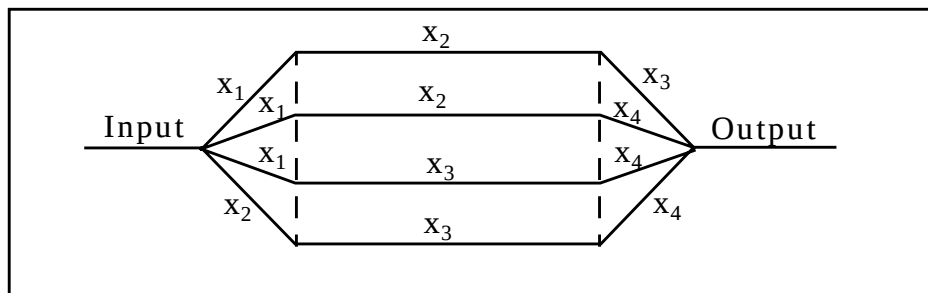


FIGURE 13.3: RELIABILITY DIAGRAM FOR A 3-OUT -OF-4 CONFIGURATION

This is given as:

$$R_{sys} = P(A_1 \cup A_2 \cup A_3 \cup A_4)$$

where,

$$A_1 = X_1X_2X_3,$$

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$$A2 = X1X2X4$$

$$A3 = X1X3X4 \text{ and}$$

$$A4 = X2X3X4$$

Similarly as for equation (3),

$$R_{sys} = P(A1) + P(A2) + P(A3) + P(A4) \quad (4)$$

$$- \sum_i \sum_j P(A1) + \sum_i \sum_j \sum_k P(A1) - \sum_i \sum_j \sum_k \sum_l P(A1)$$

All redundant terms are ignored, for example,

$P(A1A2) = P(X1X2X3) P(X1X2X4)$ becomes $P(X1X2X3X4)$.

The redundant X's are dropped

13.6.1.3.3 Cold (off-line) Standby System

- (1) A system consisting of (n) identical, statistically independent subsystems is said to be a k-out-of-n Cold (off-line) Standby System provided the system works in the following manner.

Initially all the n subsystems are good, in which only k are on line. The other n-k are on standby.

The failed subsystem is instantaneously replaced by the cold standby subsystems, requiring negligible time.

The probability that at least (k) subsystems out of the (n) subsystems will be successful is given below:

$$R(k,n,p) = \sum_{i=0}^{n-k} \frac{p^k}{i!} (-k \ln p)^i$$

- (2) Consider n+1 identical elements where only one is functioning when the system is initiated and the remaining (n) elements are standing by until preceding elements fail.

Assuming a perfect sensory and switching procedure, system reliability is the probability of n or less failed elements within the prescribed mission/flight time

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Determination of this probability depends upon the distribution of failure times.

The model which follows depends upon exponential failure times, (p.d.f.).

$$R_{\text{sys}}(t) = \sum_{k=0}^n \frac{(\lambda t)^k \exp(-\lambda t)}{k!}$$

where;

t is a time variable,

λ is the failure rate of the individual elements.

(3) General Model

- a) Consider a system composed of **$n+1$** elements where **n** are standing by and all elements are not identical and may even have different failure time density functions.

The general model for system reliability, assuming independence of the elements and perfect switching procedure, is as follows:

- b) System failure occurs only when the $n+1$ elements fail.

The system failure time density function, i.e., the probability density function (p.d.f.) for the time to failure **$(n+1)$** is:

$$f_s(x) = \int_{t_n=0}^x \int_{t_{n-1}=0}^{t_n} \dots \int_{t_1=0}^{t_2} f_1(t_1) f_2(t_2 - t_1) \dots f_{n+1}(x - t_n) dt_1 dt_2 \dots dt_n$$

where t_i is the time from mission beginning till the i th element will fail.

x is the variable indicating system failure time; i.e., $(n+1)$ element failure, and $f(x)$ is the probability density function of the i th element failure times.

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Then system reliability model is:

$$R_s(x) = \int_x^{\infty} f_s(t) dt$$

- c) As a special case, consider a two element standby system; i.e., one primary and one standby element;

where each element failure time distribution is exponential but with different failure rates.

The (p.d.f.) density functions are;

$$n=1, \quad f_1(x) = \lambda_1 \exp(-\lambda_1 x) \quad \text{and}$$

$$f_2(x) = \lambda_2 \exp(-\lambda_2 x)$$

per equation in (2)

$$f_{sys}(x) = \int_{t_1=0}^x \lambda_1 \cdot \lambda_2 \cdot \{ \exp(-\lambda_1 t_1) \} \{ \exp[-\lambda_2(x - t_1)] \} dt_1$$

then, system p.d.f. becomes;

$$f_{sys}(x) = \frac{\lambda_1 \cdot \lambda_2}{\lambda_2 - \lambda_1} [\exp(-\lambda_1 \cdot x) - \exp(-\lambda_2 \cdot x)]$$

Then system reliability model becomes, as per equation in (2);

$$R_{sys}(x) = \int_x^{\infty} f_{sys}(x) dt$$

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$$R_{\text{sys}}(x) = \frac{\lambda_2 \exp(-\lambda_1 \cdot x) - \lambda_1 \exp(-\lambda_2 \cdot x)}{\lambda_2 - \lambda_1}$$

- d) The same method can be used to expand to any number of elements where the appropriate density function is used for each.

(4) Imperfect Switching Model

Preceding in active redundancy models have assumed a perfect switching procedure.

In practice, however, the probability of switch failure has a significant affect upon system reliability.

A system is said to have units which are reliability wise in standby when these units standby idly until they are called upon to operate by a sensing and switching subsystem, unlike in a parallel system where all units operate simultaneously.

A two-unit standby system succeeds when the functioning unit does not fail or the functioning unit having failed, sometime before the end of the mission/flight, the sensing and switching unit does not fail and the standby unit not having failed already succeeds for the remainder of the mission/flight.

The reliability block diagram of the standby system is as follows:

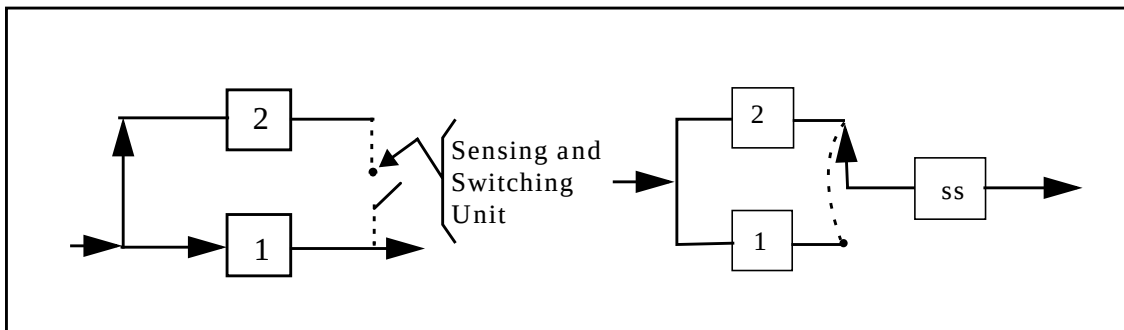


FIGURE 13.4: RELIABILITY BLOCK DIAGRAM IMPERFECT SWITCHING MODEL

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Probabilistically, the reliability of this system is:

- a) the probability that Unit1 succeeds for the whole mission time (t) or,
- b) that Unit 1 fails at same time t1 prior to t, and
- c) the sensing and switching subsystem does not fail by t1, and
- d) the standby unit (Unit 2) does not fail by t1, (quiescent mode), and
- e) that Unit 2 successfully functions for the remainder of the mission/flight, (energized mode).

Mathematically the reliability model of this standby system is given by;

$$R_{sys}(t) = R_1(t) + \int_{t_1=0}^t f_1(t_1) dt_1 \cdot R_{ss}(t_1) \cdot R_{2q}(t_1) \cdot R_{2e}(t-t_1)$$

Example:

If all units have constant failure rates and Unit 1 has an active failure rate of λ_1 , the sensing subsystem has a failure rate of λ_{se} , the switching subsystem has a failure rate of λ_{sw} and operates for one cycle, the standby Unit 2 has a quiescent (idling) failure rate of λ_{2q} and an active functioning failure rate of λ_{2e} .

Then the reliability model shall be as follows;

$$\begin{aligned} R_{sys}(t) &= e^{-\lambda_1 t} + \int_0^t \lambda_1 e^{-\lambda_1 t_1} \cdot e^{-\lambda_{se} t_1} \cdot e^{-\lambda_{sw} t_1} \cdot e^{-\lambda_{2q} t_1} \cdot e^{-\lambda_{2e}(t-t_1)} \cdot dt_1 \\ &= e^{-\lambda_1 t} + \frac{\lambda_1 e^{-\lambda_{sw} t} e^{-\lambda_{2e} t}}{\lambda_1 + \lambda_{se} + \lambda_{2q} - \lambda_{2e}} \cdot [1 - e^{-(\lambda_1 + \lambda_{se} + \lambda_{2q} - \lambda_{2e})t}] \end{aligned}$$

For **Complex Standby** systems a good approach is to prepare a table of the number of system success combinations, units involved in the system, their modes of function, system success function modes and the time domain of function of each unit.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES****CHAPTER 13****(5) Majority Voting Redundancy**

For a three element majority voting redundancy the **Mission Reliability** diagram is:

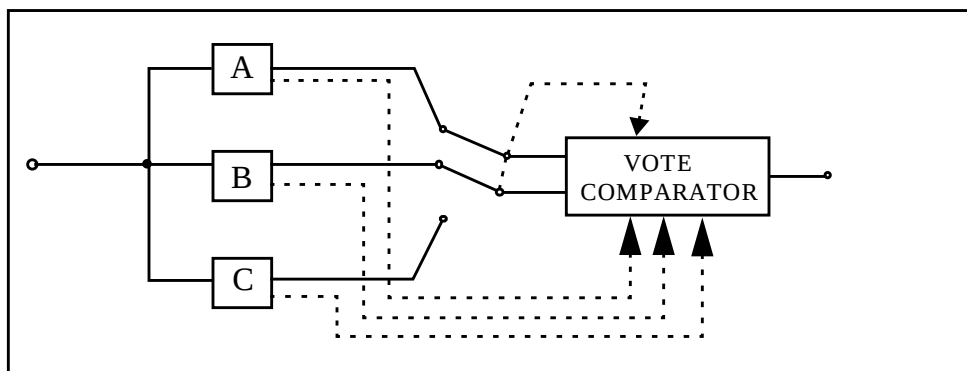


**FIGURE 13.5: MISSION RELIABILITY DIAGRAM
3 ELEMENT MAJORITY VOTING REDUNDANCY**

In majority voting redundancy the proper output of the system is presumed to be the output of the majority of the individual elements which feed the vote comparator.

The output is determined by the vote comparator, which decides what the majority of the elements indicates.

In the three element case, at least two good elements are required for successful operation:

$$P_s = P_v (P_A.P_B + P_A.P_C + P_B.P_C - 2P_A.P_B.P_C)$$

Where, P_v = reliability of the vote comparator.

13.6.1.4 Reliability Models Of Various Arrangements Of Switches

One might get the impression that putting units in parallel always increases reliability. This need not be the case.

Consider a parallel array of mechanical switches (or diodes) and suppose that all of the switches are in the closed position, thus allowing current to pass from some point A to some point B.

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Suppose that the order is given to cut the flow of current from A to B.

In this case the failure of any of the switches to open will result in a failure, since current will continue to flow from A to B.

Clearly, the more switches or diodes that are placed in parallel to control the flow of current between A and B, the greater is the probability that the parallel array of switches will fail short.

Actually, if we wish to protect ourselves against a short circuit type of failure, we would be better off placing the switches in a series arrangements, since now the flow of current from A to B can be cut off, if one or more of the switches obey command to go from a closed to open position.

However, the series arrangement create no panacea either. Suppose that the switches are all in an open position, so that no current flows from A to B.

Suppose we now want current to flow between A and B, and give a command to accomplish this objective.

Clearly, the failure of any of the switches to close when ordered to do so will prevent current flowing from A to B.

A failure of a switch to close when ordered to do so from an open position is called an open circuit failure of the switch.

How should the switches be arranged if we wish to reduce the probability of an open circuit type of failure; the answer is to arrange the switches in parallel, for now current flows from A to B, if one or more of the switches obey the command to go from an open to a closed position.

But, this brings us full circle since, as we saw at the outset, a parallel arrangement of switches increases the probability of short circuit type of failure.

Consequently, if we need protection against both short circuit and open circuit type failures, we need to employ **parallel-series** or **series-parallel** types of arrangements of switches.

Just which arrangement we choose depends on which of the two modes of failures is **dominant** (we assume tacitly that these are the only two ways in which the switch can fail and that these modes are independent and mutually exclusive).

Let us now compute the reliability of series, parallel, series-parallel, and parallel-series arrangements of switches.

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Assuming all switches have a common time to failure **c.d.f.** $F(t)$, and a common conditional probability of failing open, p , and of failing short, $q=1-p$.

If, as is often the case, we are interested in the reliability of various arrangements of switches for a specified length of time t , we define $p_o = p F(t)$ as the probability of a switch failing open in $(0,t]$ and $p_s = (1-p) F(t)$ as the probability of a switch failing short in $(0,t]$.

p_o and p_s are in practice small and, in any case, $p_o + p_s \leq 1$

- (1) Consider n switches $A_1, A_2, \dots, A_n$ are in **series**;

Hence the **Unreliability** of the series array of switches, is given by:

$$\bar{R}_s(t) = p_s^n + [1-(1-p_o)^n]$$

- (2) Suppose that m switches $A_1, A_2, \dots, A_m$ are arranged in **parallel**.

Hence the **Unreliability** of the parallel array of switches, is given by:

$$\bar{R}_p(t) = [1-(1-p_s)^m] + p_o^m$$

- (3) Suppose that mn switches A_{ij} , are in **series-parallel** arrangement.

$i = 1, 2, \dots, n; \quad j = 1, 2, \dots, m$

By this we mean that n black boxes each containing m switches in parallel, are arranged in series.

Hence the Unreliability if the series-parallel array of switches, is given by:

$$\bar{R}_{sp}(t) = [1-(1-p_s)^m]^n + [1-(1-p_o)^m]^n$$

- (4) Suppose that mn switches A_{ji} , are in **parallel-series** arrangement.

$j = 1, 2, \dots, m, \quad i = 1, 2, \dots, n,$

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By this we mean that **m** black boxes, each containing **n** switches in series, are arranged in parallel.

Hence the Unreliability of the parallel-series array of switches, is given by:

$$\bar{R}_{ps}(t) = [1 - (1 - p_s)^n]^m + [1 - (1 - p_o)^n]^m$$

If $p_o = 0$, a switch can only fail short.

In this case the most preferable arrangement of a given number of switches to attain maximum reliability is series arrangement.

If $p_s = 0$, a switch can only fail open.

In this case, the most preferable arrangement of a given number of switches to attain maximum reliability is a parallel arrangement.

For a given p_o and p_s , it is possible to find the n to maximize **$R_s(t)$** or the m to maximize **$R_p(t)$** , or to maximize expected system life for a series or parallel arrangement of switches, all having a common exponential life distribution.

By using paths and cuts it is possible, in principle, to compute exactly the reliability of any arrangement of components given the reliability of the individual components.

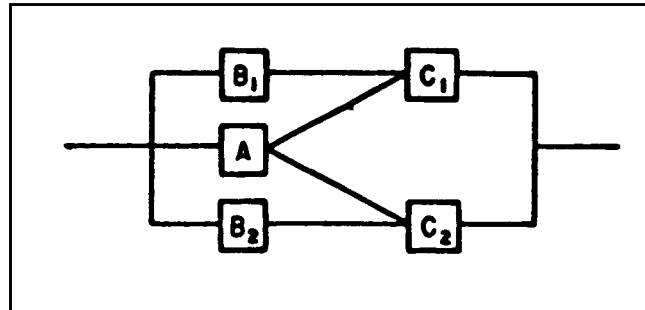
13.6.1.5 Bayes Model for Complex Series-Parallel Configurations

Bayes' model can be applied to all combinations of units in a system; however, if the combination, as given by the reliability block diagram of the system, is that of series, parallel, and standby units, then the procedures discussed previously may be used more expediently.

Nevertheless, if there is any doubt about the reliability combination of the units, then Bayes' theorem shall be used to check it out.

As one example of a complex series-parallel configuration of equipment the Mission Reliability diagram is;

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 13***FIGURE 13.6: MISSION RELIABILITY DIAGRAM - COMPLEX
SERIES - PARALLEL CONFIGURATION.**

The system requirement would be that equipment A and either equipment C1 or C2 work, or that equipments B1 and C1 work, or that B2 and C2 work for success.

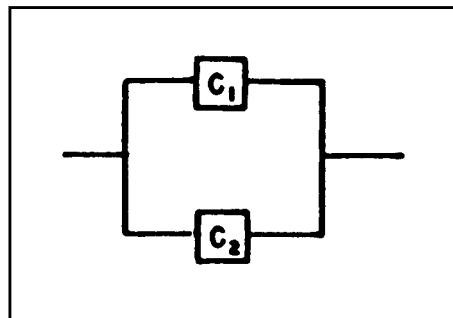
Bayes' model shall be stated as follows:

Unit A shall be used as the critical item in the block diagram,

$R_{sys} = P(\text{mission success with A Good/working}) \times P_A + P(\text{mission success with A Bad/not working}) \times (1 - P_A)$

$R_{sys} = (P_{C1} + P_{C2} - (P_{C1} \cdot P_{C2})) \times P_A + ((P_{B1} \cdot P_{C1}) + (P_{B2} \cdot P_{C2}) - (P_{B1} P_{C1} P_{B2} P_{C2})) (1 - P_A)$

when A is good ($R_A = 1$), the RBD becomes;

**FIGURE 13.7: SIMPLIFIED MISSION RELIABILITY DIAGRAM
(A IS GOOD)**

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when **A** is bad ($R_A=0$), the RBD becomes:

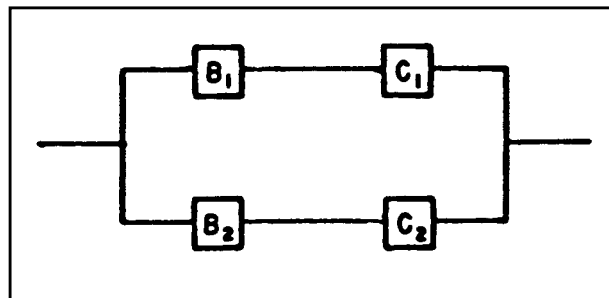


FIGURE 13.8: SIMPLIFIED MISSION RELIABILITY DIAGRAM (A IS BAD)

The same procedure can be followed for any complex Mission Reliability diagram.

As the Mission Reliability diagram becomes increasingly complex it shall be broken down into parts and analyzed in steps.

13.6.1.6 Boolean Truth Table Reliability Model

The purpose of the **Boolean Truth Table** method is to prepare/solve a reliability mathematical model from a complex reliability block diagram by means of Boolean algebra.

The Boolean Truth Table (BTT) method is applicable to single functioned and multifunctioned systems.

This method is more tedious than the conventional probability method and is useful to solve complex reliability configurations.

This method also can easily be computerized to solve complex models and matrices.

13.6.1.6.1 Single Functioned Systems

Single functioned systems consist of equipments considered to have a single function associated with equipment performance.

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The single functioned system Mission Reliability diagram can take the form of equipments connected in series, parallel, series-parallel, or a complex configuration.

Any complex model can be solved with this methodology, and though it is a long process can easily be done by computer aid.

The procedure for the BTT approach is defined by the following example:

The Mission Reliability diagram is given in Figure 13.6

given:

$$\begin{array}{ll}
 PA=0.3 & 1-PA=0.7 \\
 PB1=PB2=0.1 & 1-PB=0.9 \\
 PC1=PC2=0.2 & \text{and therefore } 1-PC=0.8.
 \end{array}$$

- (1) List all equipments in a truth table form as per Boolean Algebra approach, see Table 13.2.
- (2) The truth table has 2^n entries (combinations), where n is the number of equipments/items in the system/reliability block diagram.
- (3) The table has a **1** or **0** entry in each column indicating success or failure respectively on each equipment.
All possible combinations of all equipments working and failing are listed.
- (4) The procedure is to examine each row of the truth table and decide whether the combination of equipments working and failed yields system success (S) or failure (F).
- (5) Insert an S or F respectively in the next column in the table. For each S entry, multiply the respective probabilities for the indicated state of each equipment to yield a P_s for that entry

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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RELIABILITY DIAGRAM**

Entry No:	B ₁	B ₂	C ₁	C ₂	A	Success or Failure	P _s
1	0	0	0	0	0	F	-
2	0	0	0	0	1	F	-
3	0	0	0	1	0	F	-
4	0	0	0	1	1	S	.03888
5	0	0	1	0	0	F	-
6	0	0	1	0	1	S	.03888
7	0	0	1	1	0	F	-
8	0	0	1	1	1	S	.00972
9	0	1	0	0	0	F	-
10	0	1	0	0	1	F	-
11	0	1	0	1	0	S	.01008
12	0	1	0	1	1	S	.00432
13	0	1	1	0	0	F	-
14	0	1	1	0	1	S	.00432
15	0	1	1	1	0	S	.00252
16	0	1	1	1	1	S	.0108
17	1	0	0	0	0	F	-
18	1	0	0	0	1	F	-
19	1	0	0	1	0	F	-
20	1	0	0	1	1	S	.00432
21	1	0	1	0	0	S	.01008
22	1	0	1	0	1	S	.00432
23	1	0	1	1	0	S	.00252
24	1	0	1	1	1	S	.00108
25	1	1	0	0	0	F	-
26	1	1	0	0	1	F	-
27	1	1	0	1	0	S	.00112
28	1	1	0	1	1	S	.00048
29	1	1	1	0	0	S	.00112
30	1	1	1	0	1	S	.00048
31	1	1	1	1	0	S	.00028
32	1	1	1	1	1	S	.00012
Σ All success paths = .13572							

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i.e., Entry number 4 is the entry with a success indicated and $P_4=0.03888$ is obtained by multiplying;

$$P_4=(1-PB_1).(1-PB_2).(1-PC_1).PC_2.PA$$

$$P_4=0.03888.$$

- (6) All figures in the P_s column are then added for a Mission success probability, $P_s=0.13572$ in this example.

(7) **Boolean algebra equation.**

A Mission Reliability equation can be written from the truth table (Table 13.2).

In this case it would look like the following:

$$\begin{aligned} P_s = & \overline{B_1}\overline{B_2}\overline{C_1}C_2A + \overline{B_1}\overline{B_2}C_1\overline{C_2}A + \overline{B_1}\overline{B_2}C_1C_2A \\ & + \overline{B_1}B_2\overline{C_1}C_2\overline{A} + \overline{B_1}B_2\overline{C_1}C_2A + \overline{B_1}B_2C_1\overline{C_2}\overline{A} + \overline{B_1}B_2C_1\overline{C_2}A \\ & + \overline{B_1}B_2C_1C_2\overline{A} + B_1\overline{B_2}\overline{C_1}C_2A + B_1\overline{B_2}C_1\overline{C_2}\overline{A} + B_1\overline{B_2}C_1\overline{C_2}A \\ & + B_1\overline{B_2}C_1C_2\overline{A} + B_1\overline{B_2}C_1C_2A + B_1B_2\overline{C_1}C_2\overline{A} + B_1B_2\overline{C_1}C_2A \\ & + B_1B_2C_1\overline{C_2}\overline{A} + B_1B_2C_1\overline{C_2}A + B_1B_2C_1C_2\overline{A} + B_1B_2C_1C_2A \end{aligned}$$

A bar above a letter indicates the complement or unreliability, e.g., $\overline{A} = (1 - A)$. With the aid of a reduction technique the (19) nineteen terms of equation can be reduced as follows:

- a) Construct a reduction table (Table 13.3) which allows the reduction of the 19 Boolean success terms to a simplified expression for the given Mission Reliability model.

All 19 success paths are first listed in Column 1, of Table 13.3.

All letters represented by a zero (0) in Table 13.2 are indicated with a bar over the letter, which indicates unreliability.

Any letter represented with a one (1) in Table 13.2 will be listed without a bar above it indicating reliability.

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b) By comparative process, product pairs are formed for those terms in Column 1 of Table 13.3 which differ only by a letter inverse, thus forming a new product term which has this letter missing.

For example, if Column 1 the two terms $\overline{B}_1\overline{B}_2\overline{C}_1C_2A$ and $\overline{B}_1\overline{B}_2C_1C_2A$ differ only in the letter C_1 and therefore can be combined to form the product term $\overline{A}\overline{B}_1\overline{B}_2C_2$ entered in Column 2.

c) Again, this process shall be repeated by comparing product terms in Column 2 which differ only by a letter inverse, thus forming a new product term which is then entered in Column 3.

It should be noted that once a term is used in a comparison, it is eliminated from all further comparisons, thus ensuring that all remaining terms are still mutually exclusive.

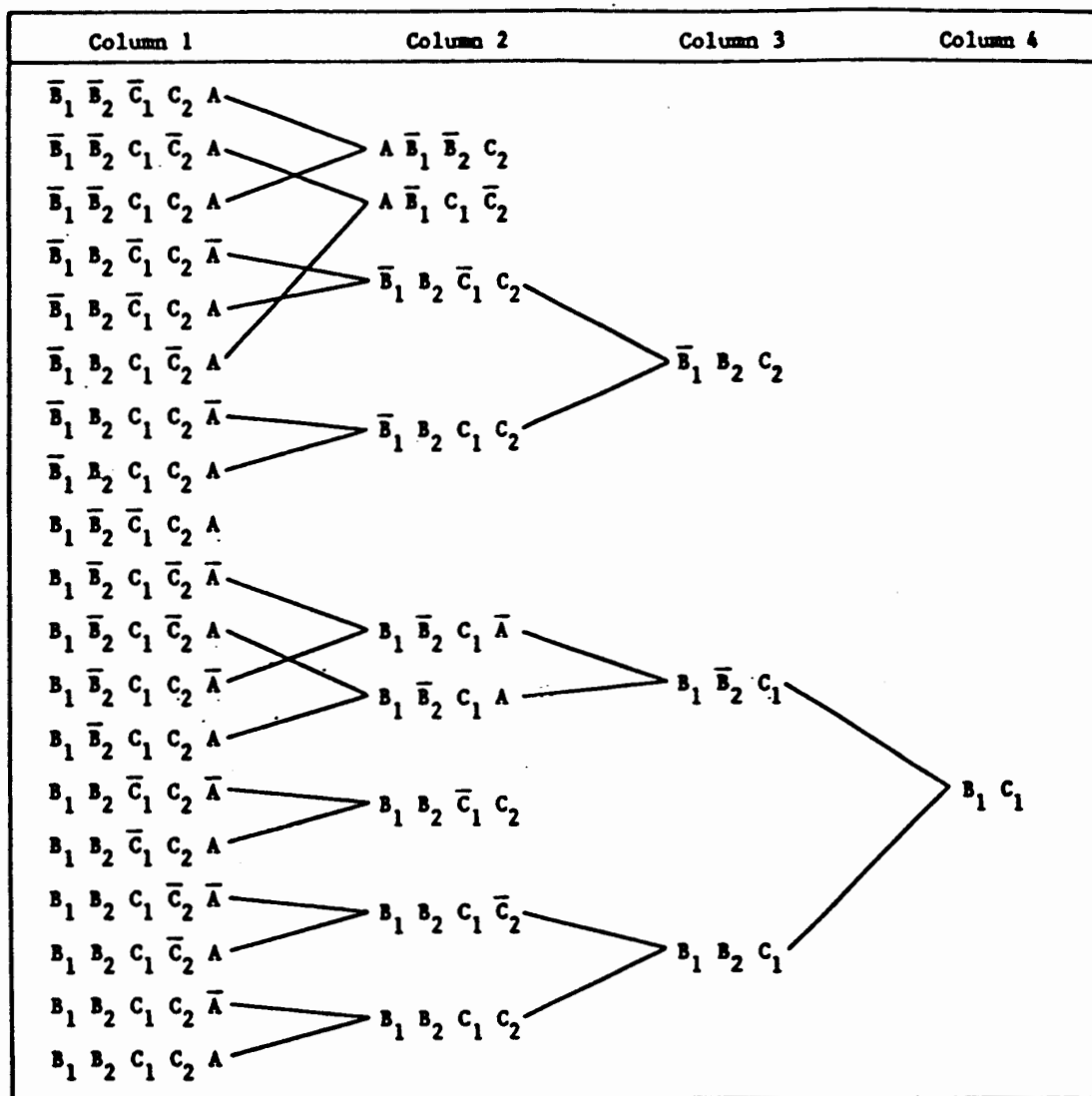
The order of terms selected for the comparison process in Table 13.3 is not a necessary consideration; the resulting disjoint group of Boolean terms can always be interpreted, on a one-for-one basis, as the simplified probability of success (reliability) expression.

For the given model, the probability of mission success (reliability) has been reduced to the following terms:

$$P_s = B_1C_1 + \overline{B}_1B_2C_2 + \overline{A}\overline{B}_1\overline{B}_2C_2 + \overline{A}\overline{B}_1C_1B_1\overline{C}_2 + B_1B_2\overline{C}_1C_2 + \overline{B}_1B_2C_1C_2A$$

d) Substituting the reliability and unreliabilities used previously into (3), we obtain $P_s = 0.13572$ which is the same probability of success shown in the summation for Table 13.2.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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13.6.1.7 Monte Carlo Simulation Reliability Model

13.6.1.7.1 Purpose

The purpose of the Monte Carlo simulation method is to synthesize a system reliability prediction from a reliability block diagram by means of a computer program generated random sampling.

The Monte Carlo simulation method shall be employed in instances where individual equipment probabilities (or equivalent reliability parameter) are known but the mission reliability model is exceedingly complex to derive a general mathematical equation for solution.

The Monte Carlo simulation method does not result in a general probability of success equation but computes the system probability of success from the individual equipment probabilities and the reliability block diagram.

A Monte Carlo simulation shall be performed by computer due to the large number of repetitive trials and calculations required to obtain a significant result.

13.6.1.7.2 Procedure

The Monte Carlo simulation procedure is to determine the distribution of one or more variables from the distribution of the individual variables.

The method involves random sampling from the distributions of all variables and inserting the values so obtained in the equation for the function of interest.

Suppose the function whose probability of success distribution is to be estimated is

$P(X_1, \dots, X_n)$ and that the $X_1, X_2, \dots, X_n$ are independent random variables whose distributions are presumed to be known.

The procedure is to pick a set of x 's randomly from the distributions of the X 's, calculate P for that set, and store that value of P .

The procedure is repeated many times until enough values of P are obtained. From this sample of P values, its distribution and parameters can be estimated.

The Monte Carlo simulation method is based on several principles of probability and on the techniques of probability transformation.

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One of the underlying principles is the law of large numbers, which states that the larger the sample, the more certainly the sample mean will be a good estimate of the population mean.

The procedure for the Monte Carlo simulation method is illustrated by the following example.

The Mission Reliability Block diagram is given as in Figure 13.6.

given:

$PA=0.3$

$PB1=PB2=0.1$

$PC1=PC2=0.2$

Note:

This is simple Direct simulation example, (does not involve any assigned distributions which may need Fortran program to be written to generate probabilities from assigned distributions).

- (1) Select a random number between 0.01 and 1.00 generated by a computer.
- (2) Compare the random number with PA. If the random number is equal to or less than 0.3 then equipment A is a success.
- (3) Once success (S) or failure (F) is determined, it is recorded as in Table 13.4, and the procedure is repeated for equipments B1,B2,C1, and C2.
- (4) A new random number for each equipment is used to compare against that equipment and results are recorded.
- (5) If a success path can be found among the failed and nonfailed equipments then the system function is determined to be a success. Psys is the ratio of system successes to trials.
- (6) Table 13.4 displays the outcome of ten trials of a typical (simplified) Monte Carlo simulation.

In this particular outcome, there was one system success for ten trials (trial 8) resulting in $P_{sys} = 0.10$.

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- (7) Depending upon the random numbers generated, the success/failure array may differ from simulation to simulation and the number of system successes may vary for any fixed number of trials.

However, as the number of trials increase, the ratio of system successes to trials should approach the actual Psys of 0.13572.

- (8) The degree of Monte Carlo precision is determined by the number of trials conducted.

Typically, a minimum of 100 trials is required.

**TABLE 13.4: SUCCESS/FAILURE ARRAY FOR THE MISSION
RELIABILITY DIAGRAM**

Trial No.	A	B₁	B₂	C₁	C₂	System
1	S	F	S	F	F	F
2	F	F	F	F	S	F
3	S	F	F	F	F	F
4	F	F	F	F	F	F
5	S	F	F	F	F	F
6	F	F	F	F	F	F
7	F	F	F	F	S	F
8	S	F	S	F	S	S
9	F	F	F	F	F	F
10	F	S	F	F	F	F
$\hat{P}_S = \frac{1}{10} = 0.10$						
Note: This is only one possible array and one possible outcome among many that can result from a Monte Carlo simulation of ten trials. Additional trials are required to obtain meaningful precision with which the Monte Carlo result will approximate the actual answer.						

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13.6.1.8 Load / Stress - Strength Interference Reliability Model

13.6.1.8.1 Purpose

To day because of the stringent reliability requirement of complex systems or components, the system reliability has to be considered at the design stage to ensure the specified reliability target.

To evaluate electronic component reliability, the concept of constant failure rate is used and failure rate data sources, like MIL-HDBK-217 are available.

However, in the case of mechanical components which follow increasing hazard rate functions, failure rate data sources are limited, i.e., NPRD, GIDEP, RADC documents.

In such cases where, significant failure rate data is not available, it appears that the most appropriate way to predict **new critical mechanical components** reliability is by the application of interference theory.

Therefore, if we design so that strength exceeds stresses, we should not have failure for a specified period of time.

This is the normal approach to design, in which the designer considers the likely extreme values of stress and strength, and ensures that an adequate safety factor is provided.

The main purpose of the Stress-Strength analysis is to improve the reliability of the design. That is to find the optimum comparison of stress and strength that will have an acceptable probability of success and compete favorably with other constraints such as weight, cost, availability of material.

13.6.1.8.2 Procedure / Methodology

a) For mechanical and structural components, such failure rate versus stress data may be obtainable from the manufacturer or the users.

In using a manufacturer's rating and single design stress values, the design engineer / **R&M** engineer must keep in mind that they are really distributions, not single values.

The classical approach to mechanical and structural design is to give every part enough strength to handle the worst stress it will encounter.

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Several references, such as MIL-HDBK-5 (Metallic Materials and Elements for Aerospace Vehicle Structure), are available, providing data on the strength of materials.

Some of these provide limited data on strength degradation with time, resulting from fatigue.

Since failure is not always related to time, the designer / **R&M** engineer needs techniques for comparing stress v.s. strength, and determining the quantitative reliability measure of the design.

b) The concept of stress-strength in design recognizes the reality that loads or stresses and strengths of particular items subjected to these stresses cannot be identified as a specific value but have ranges of values with a probability of occurrence associated with each value in the range.

The ranges of values (variables) shall be described with appropriate statistical distributions for the item.

Stress-Strength design requires knowledge of distributions for the item.

After the strength and stress distributions are determined, a probabilistic approach can be used to calculate the quantitative reliability measure of the design, including confidence limits.

c) The stress and strength curves which can be determined by experiments/tests or analysis (i.e., FEA), Figure 13.10 are combined to illustrate the region of the unreliability given by the shaded area where stress exceeds strength.

Figure 13.10, illustrates normal (Gaussian) stress and strength distributions, where the stress and strength variables are identified as pounds.

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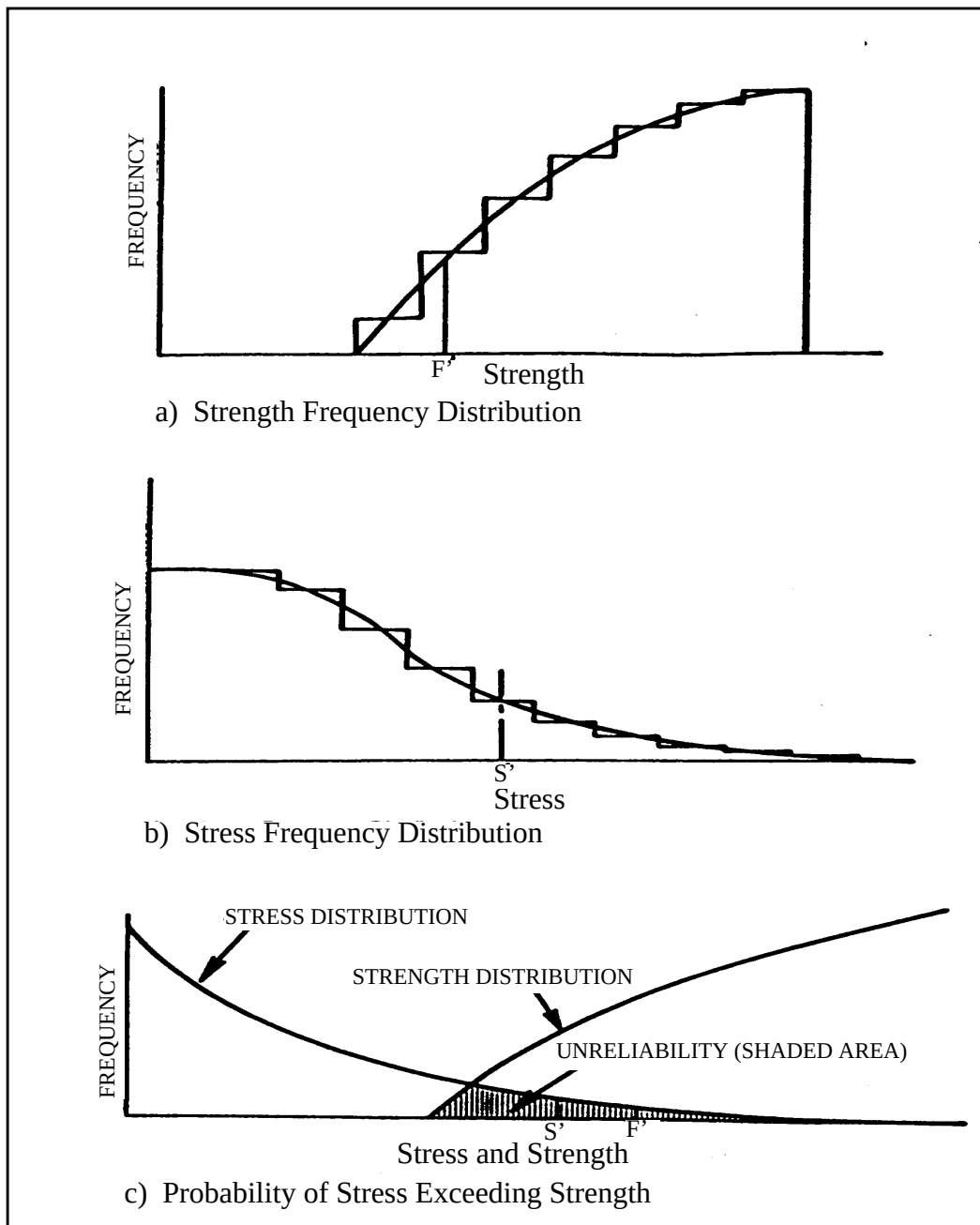


**FIGURE 13.9: STRESS-STRENGTH DISTRIBUTION AND
UNRELIABILITY IN DESIGNS**

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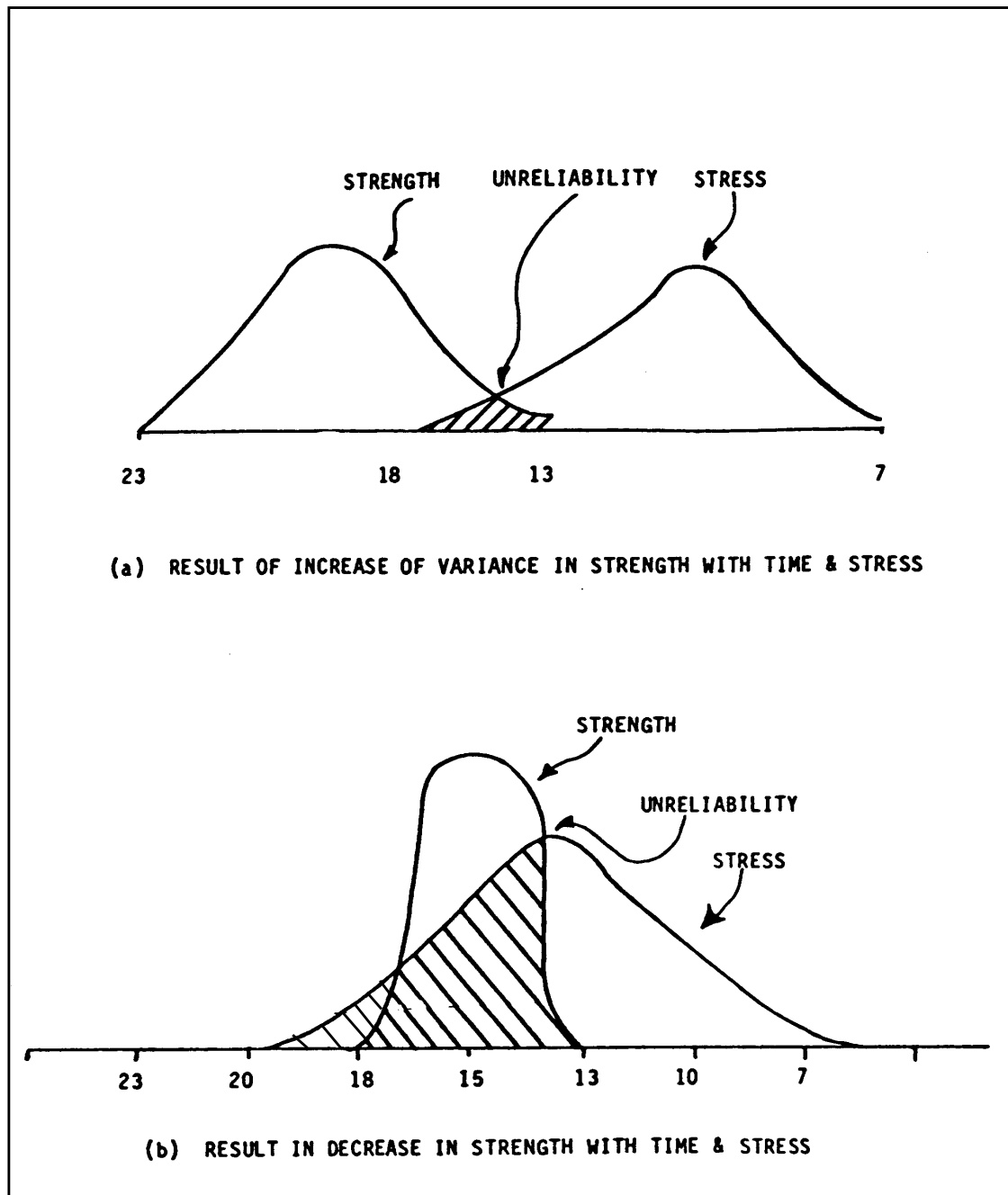


**FIGURE 13.10: UNRELIABILITY - STRESS / STRENGTH
DISTRIBUTION**

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Looking at Figure 13.10, two things may happen with time and repeated stress.

The variance of the strength distribution may change; for example the curve may extend from 13 to 23 Kilo pounds (Kips) rather than the original 16 to 20 Kips.

This would result in an increased unreliability since the shaded area would now extend from 13 to 20 Kips.

The other factor that could change with time and stress is that the mean of the strength distribution might be lowered, to say 15 Kips.

This in turn, would result in a decreased reliability as shown by the shaded area of Figure 13.10.

d) For most products neither stress/load nor strength are fixed, but are distributed statistically.

This is shown in Figure 13.11(a). Each distribution has a mean value, denoted by $\bar{L}$ or $\bar{S}$, and a standard deviation, denoted by σ_L and σ_S .

If an event occurs in which the two distributions overlap, failure will occur.

This situation is shown in Figure 13.11(b).

For distributed load and strength, we define two factors;

(1) The safety margin (SM);

$$SM = \frac{\bar{S} - \bar{L}}{(\sigma_S^2 + \sigma_L^2)^{1/2}}$$

and,

(2) The loading roughness (LR);

$$LR = \frac{\sigma_L}{(\sigma_S^2 + \sigma_L^2)^{1/2}}$$

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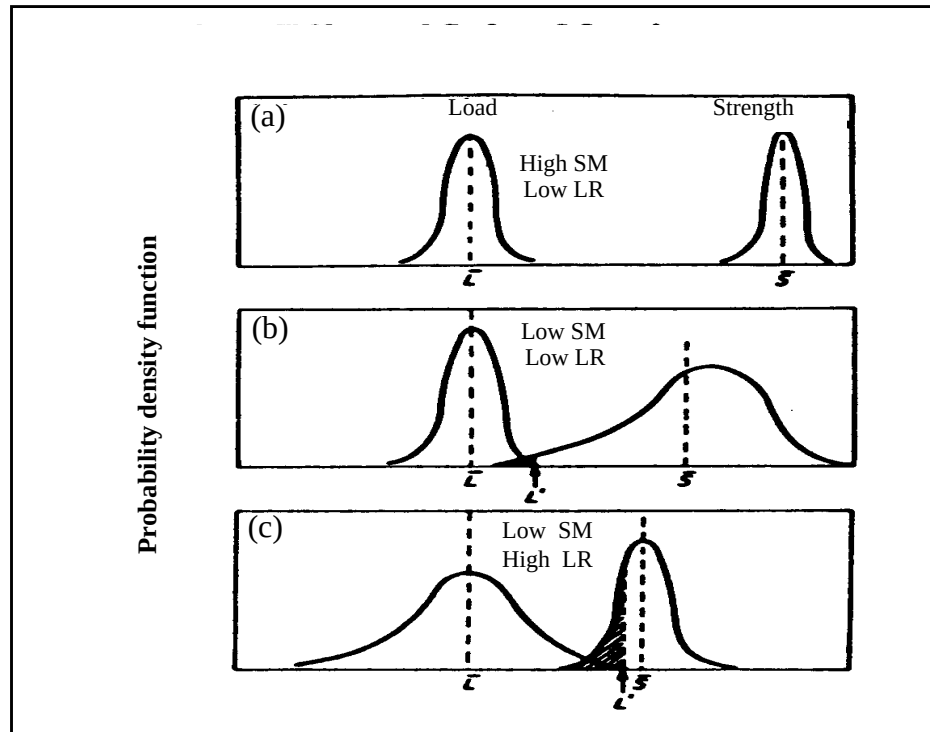
**FIGURE 13.11: EFFECT OF SAFETY MARGIN**

Figure 13.11 (c) shows a low safety margin due to a wide spread of the load distribution.

This is a difficult situation from the reliability point of view, since an extreme stress event will cause a large proportion of the population to fail.

Therefore, it is not economical to improve population reliability by screening out items likely to fail at these stresses.

The options left are to increase the safety margin by increasing the mean strength which might be expensive, or to devise means to curtail the load distribution.

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This is achieved in practice by devices such as current limiters in electronic circuits or pressure relief valves and dampers in pneumatic and hydraulic systems.

13.6.1.8.3 Reliability Analysis Model of Stress-Strength Interference

The reliability of an item may be determined by comparing its strength to the stress to which it will be subjected.

Reliability may be defined as the probability that strength exceeds stress.

Neither item strength nor the stress to which it is subjected are constant values, but both are random variables each with its own probability density function, p.d.f.

If these distributions are known, reliability may be determined analytically.

Since data is generally limited to sample information, the goodness-of-fit (GOF) methods may be used in an attempt to identify the appropriate underlying distributions.

We can obtain the probability of failure of a mechanical part by employing the interference theory.

In other words, when the probability density functions of both stress and strength are known, the part reliability may be determined analytically.

In a mathematical model it can be stated as:

$$R_c = P(S > s)$$

where, R_c = is the reliability of an item,

P = is the probability,

S = is the strength,

s = is the stress.

Equation (1) can be rewritten in the following form:

As in general;

$$R(t) = \int_0^{\infty} f(t) dt$$

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Hence,

$$R_c = \int_0^{\infty} f_{\text{stress}}(s) \cdot \left[\int_s^{\infty} f_{\text{strength}}(S) dS \right] ds$$

where, $f(s)$ = is the p.d.f. of stress,

$f(S)$ = is the p.d.f. of strength

Also, if we define $\mathbf{d}$ as $(S-s)$, $\mathbf{d}$ is a random variable such that,

$$R_c = P(d > 0)$$

(1) Normally distributed strength and stress model

Assuming both the stress and strength distributions to be normal, reliability can be evaluated as follows:

- a) Item strength (S) is a random variable with normal p.d.f

$$f(S) = \frac{1}{\sigma_S \sqrt{2\pi}} \exp \left[-(1/2) \left(\frac{S - \mu_S}{\sigma_S} \right)^2 \right]$$

where,

μ_S = mean strength,

σ_S = strength standard deviation

- b) Stress (s) is a random variable with normal p.d.f.

$$f(s) = \frac{1}{\sigma_s \sqrt{2\pi}} \exp \left[-(1/2) \left(\frac{s - \mu_s}{\sigma_s} \right)^2 \right]$$

where,

μ_s = mean stress level

σ_s = stress standard deviation.

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c) Then, the difference $d=S-s$ is a random variable with normal p.d.f.

$$f(d) = \frac{1}{\sigma_d \sqrt{2\pi}} \exp \left[-(1/2) \left(\frac{d - \mu_d}{\sigma_d} \right)^2 \right]$$

where,

$\mu_d = \mu_S - \mu_s$ = mean difference

$\sigma_d = (\sigma_S^2 + \sigma_s^2)^{1/2}$ = standard deviation of difference

d) Then, **Reliability** shall be defined as;

$$R_c = P(d > 0) = P \left(z > \frac{0 - \mu_d}{\sigma_d} \right) = P \left(z > \frac{-\mu_d}{\sigma_d} \right)$$

Therefore, the **reliability** can be determined by finding the value of the standard cumulative normal variate from the normal distribution tables.

(2) General Stress-Strength Distributions

Determination of reliability based on stress-strength analysis requires that both the stress and strength probability density functions [$f(s)$, and $f(S)$ respectively] be known.

As shown above, analytic determination is quite straightforward if both distributions are Normal.

Although analytic determination is difficult for other distributions, reliability can be determined from equation 2.

For example, we may need to evaluate the reliability of an item whose strength is Weibull distributed, when subjected to loads/stresses that are extreme-value distributed.

These integrals are somewhat complex. Their solution lends itself to numerical methods easily adapted for use by digital computer, (i.e., MathCad).

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(3) Graphical Method

This technique using transformations, provides a graphical reliability determination which may be applied to any distribution.

It may also be applied to sample data when the underlying distribution cannot be identified.

For details (which is not covered in this preliminary document) of this method refer to DHI R&M engineering, if needed.

NOTE:

The main difficulty of this method is that, in attempting to take account of variability, we are introducing assumptions that might not be tenable, e.g., by extrapolating the stress and strength data to the very low probability tails of the assumed population distributions.

We must therefore use engineering knowledge to support the analysis, and use the statistical approach to cater for engineering uncertainty, or when we have good statistical data.

The methods described above are meaningful if applied in predictable stress situations.

However, if the stress is very unpredictable the probability estimates will be very uncertain.

The techniques described above should therefore be used when it is necessary to assess the risk of failure in marginal or critical applications.

13.6.1.9 Reliability Assessment Methodology and Models of Wear Period

13.6.1.9.1 Introduction

Reliability theory and practice differentiates between early wearout, and chance failures for two main reasons.

First, each of these types of failures follows a specific statistical distribution and therefore requires a different mathematical treatment.

Secondly, different methods must be used for their elimination.

- a) **Early** failures shall be eliminated by observing their distribution and determining accordingly the length of the necessary **ESS**, burn-in period and the methods to be followed.

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- b) Further, Reliability Engineering is concerned with preventing **wearout failures** by observing the failure modes/mechanisms which could potentially have an effect on failure rate, the statistical distribution of wearout by designed experiments, determining the maintenance policy for the parts or their design life and develop the failure rate models.
- c) Finally, **chance failures** occur at random intervals unexpectedly which neither good debugging techniques nor the best maintenance practices can eliminate.

These failures are caused by sudden stress accumulations beyond the design strength of the component.

This section is focused on wearout failures, maintenance period effect on MTBF, and the methodology of reliability assessment of life limited items, i.e., actuators, bearings, motors, lamps etc.

13.6.1.9.2 Methodology and Reliability Models

(1) The Derivation of the Reliability Function

The mathematical derivation will result in a general reliability formula which is always valid, regardless of whether the failure rate is constant or variable.

$$\lambda(t) = -\frac{1}{R(t)} \frac{dR}{dt} \quad (5)$$

is the most general expression for the failure rate because it applies to exponential as well as nonexponential reliabilities.

In the general case, (is a function of the operating time t, for both R and dR/dt are functions of t.

By rearrangement and integration of (1), we obtain the general formula for reliability, solving for R and knowing that at t=0, R=1, we obtain;

$$R(t) = \exp \left[-\int_0^t \lambda(t) dt \right] \quad (6)$$

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So far in this derivation we have made no assumptions regarding the failure rate λ , and therefore λ can be any variable and integrable function of the time t .

Consequently, in the equation $R(t)$ mathematically describes reliability in a most general way and applies to all possible kinds of failure distributions.

The failure density function $f(t)$, is;

$$f(t) = -\frac{dR}{dt} \quad (7)$$

The failure rate model in Equation (1) can also be written as;

$$\lambda(t) = -\frac{1}{R(t)} \frac{dR}{dt} = \frac{f(t)}{R(t)} \quad (8)$$

which means the **failure rate model** at any time t equals the $f(t)$ value divided by the reliability function, both taken at the time t .

Equation (4) again applies to all possible distributions and reliabilities, whether or not they are exponential, (electronic and mechanical components).

The important point here is that, the failure rate model is always equals to the ratio of density function $f(t)$, to reliability function $R(t)$.

In the exponential case (electronic components), this ratio is constant.

However, in the case of non-exponential distributions (i.e., motor stepper), the ratio changes with time and therefore the failure rate model is a function of time.

Note: The rate at any given instant, is the hazard rate, $h(t)$, or instantaneous failure rate, which follows the equation (4).

(2) Wearout And Reliability Models

High reliabilities for the aircraft can be achieved for extended period of operation with proper **ESS procedure** to eliminate early failures and with strict methods of component preventive replacement so that the components do not get a chance to fail because of wearout.

Thus, when good preventive maintenance is practiced, reliable aircraft system operation for very long periods becomes possible.

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Although it may still exhibit some chance failure rate, it will in general, be very reliable.

The Normal or Gaussian failure distribution, usually approximates wearout phenomena quite well, and about one-half of the failures occur before the mean life and one-half occur later.

The failures cluster around the mean life **M**. **Failure-free** operation can therefore often be achieved up to a part age relatively close to the mean life of the part, according to how widely the normal curve is spread in the given case.

When **strength deterioration** sets in, the failure rate begins to rise, and **wearout**, which usually follows a normal distribution, is **superimposed** on the exponential failure frequency, see Figure 13.12.

The normal density function is given by:

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(t-M)^2/(2\sigma^2)} \quad (9)$$

Where, **t** is the part age. Thus, the normal distribution depends upon age.

Frequently, the **wearout failure** distribution is sufficiently close to normal that the use of this distribution for predicting or assessing reliability is **valid**.

M is the mean wearout life, **t** is the age or accumulated operating hours since new, and **σ** is the standard deviation of the life times from the mean **M**.

The failure rate of the components increases phenomenally by the time **M+2σ**, as compared to the failure rate at the time **M-3σ**.

Such a dramatic failure rate increase is characteristic of wearout.

a) The increase of the failure rate can be shown in a failure rate graph for the normal distribution of failures.

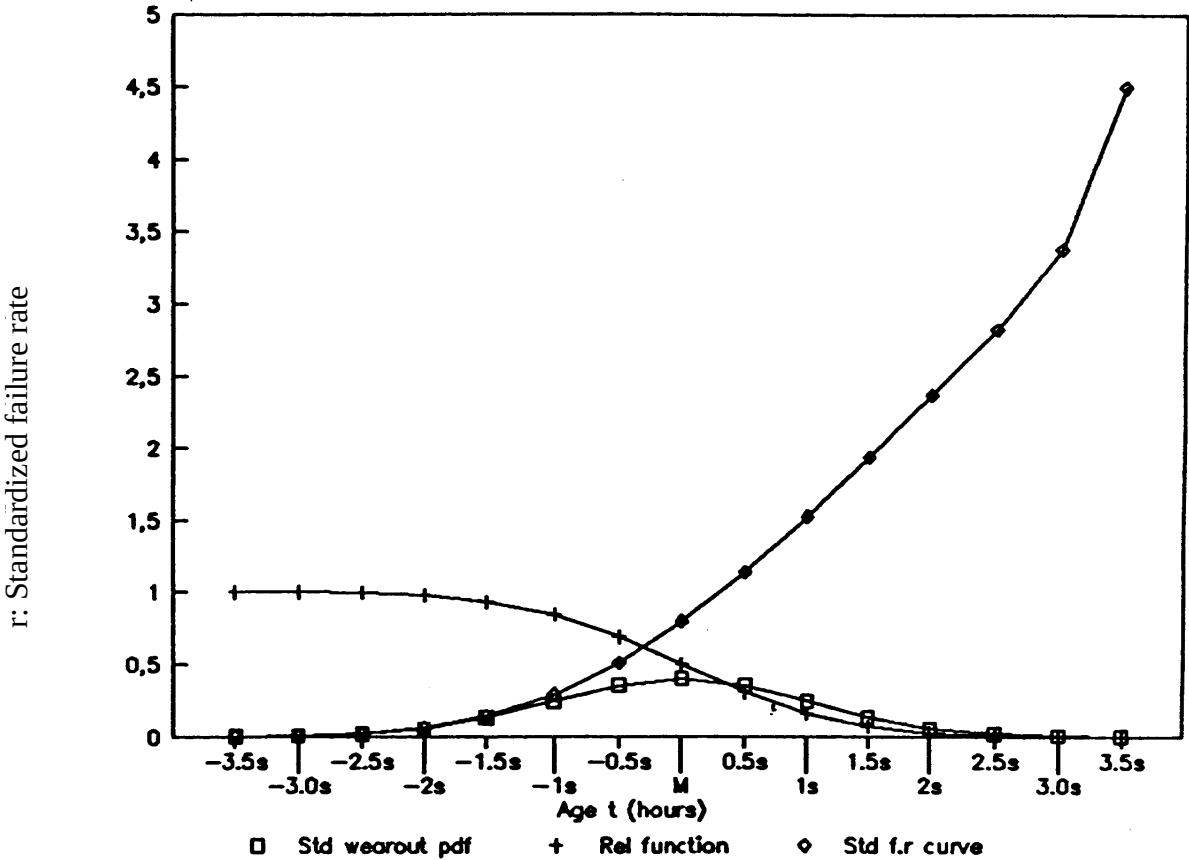
Equation (4) defines the failure rate as.

$$\lambda(t) = \frac{f(t)}{R(t)}$$

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The Gaussian Normal Failure Rate Data

Z	-3.5s	-3.0s	-2.5s	-2s	-1.5s	-1s	-0.5s	0	0.5s	1s	1.5s	2s	2.5s	3.0s	3.5s
f	0,0009	0,0044	0,0175	0,0540	0,1295	0,2420	0,3521	0,3989	0,3521	0,2420	0,1295	0,0540	0,0175	0,0044	0,0009
R	0,9998	0,9987	0,9938	0,9772	0,9332	0,8413	0,6915	0,5000	0,3085	0,1587	0,0668	0,0228	0,0062	0,0013	0,0002
r	0,0009	0,0044	0,0176	0,0553	0,1388	0,2877	0,5092	0,7978	1,1413	1,5249	1,9386	2,3684	2,8226	3,3846	4,5008

FIGURE 13.12: THE GAUSSIAN, STANDARDIZED FAILURE RATE
CURVE

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When we evaluate this ratio from the instantaneous values of the $f(t)$ curve and the $R(t)$ curve of the normal distribution, we obtain the failure rate curve shown in Figure 13.12.

b) For most practical applications we can convert from the normal to standard normal distribution by using transformations;

$$z = \frac{t - M}{\sigma}$$

$$f(t) = \frac{f(z)}{\sigma}$$

Then;

$$f(z) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{z^2}{2}\right)$$

Where,

$$M=0, \sigma^2=1$$

To standardize this curve, the standardized failure density function in units of the standard deviation is used:

$$\phi(t) = \sigma \cdot f(t) = f(z)$$

c) The values of $\phi(t)$ together with $R(t)$ can be obtained directly from normal standard tables.

In this way we obtain the **standardized failure rate/hazard rate curve** as;

$$r(t) = \frac{\phi(t)}{R(t)}$$

The per-hour wearout failure rate model is then;

$$h(t) = \lambda_w(t) = \frac{f(t)}{R(t)} = \frac{\phi(t)}{\sigma R(t)} = \frac{r(t)}{\sigma} \quad (10)$$

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Figure 13.12 shows how the failure rate of a component rapidly increases once the component has ended its useful life.

When the life t is measured in hours, λ_w will be in per hours units.

Note 1:

The normal distribution has difficulty that the area under the density curve becomes 100 percent only if the curve is extended to infinity in both directions.

This is not possible for time dependent events because a new device enters service at $t=0$ and not at $t=-\infty$.

The Gaussian distribution can therefore be regarded only as an approximation.

However, this approximation is very good in most cases, especially when the standard deviation is **small** compared with the mean life m .

In cases where $M < 3\sigma$, we would have to consider a **transformation** of the Gaussian to the **logarithmic normal** distribution of the wearout failures.

Note 2:

When working with the log normal distribution, change values of t to $\log t$, and treat $\log t$ as normally distributed.

From Figure 13.12 obtain answers and transform back to t .

d) Having reviewed the normal distribution approximating wearout, we can now determine the age t_w at which the device has to be **pulled out** of service and replaced to **prevent wearout** failures in operation.

The **replacement time** t_w has to be chosen so as to keep the cumulative probability of wearout failure $Q(t)$ at a **minimum** acceptable level, consistent with the reliability/safety requirements and the maintenance policy of the **program**.

$$Q(t) = 1 - \int_t^{\infty} f(t) dt \quad (11)$$

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For instance, if $t_w = M - 3\sigma$ is chosen as replacement time, the probability of wearout failure for the entire operating life of the component from $t=0$, to $t=t_w = M - 3\sigma$ amounts to $Q = 0.00135$.

$Q_w = 1 - R(t)$, get $R(t)$ for 3σ from the Table in Figure 13.12, and calculate Q_w .

As we have seen from the normal curve and from its failure rate curve, the probability of wearout failure increases with age—extremely slowly at first, but as the age approaches the mean wearout life, this increase becomes very rapid.

Example 1

A Stepper Motor has been observed to follow a **Normal Distribution** with **$M=300$** hours and **$\sigma=40$** hours.

Find the reliability of the motor for an operating time (or time before failure) of 250 hours and the hazard rate at 200 hours.

Step 1

$$R(t=250) = P\left(z > \frac{t - M}{\sigma}\right) = (250 - 300)/40 = P(z > -1.25),$$

from standard tables or Figure 13.12;

$$R(t) = 0.89$$

Step 2

$$h(t) = \frac{f(t)}{R(t)} = \frac{f(z)/\sigma}{R(t)} = \frac{r}{\sigma} \quad (\text{as in Equation 6.})$$

$$f(t = 200) = \frac{f(z = 200 - 300 / 40)}{40} = 1/40 \times f(z = -2.5)$$

$$f(t) = (0.025) \cdot (0.0175) = 0.00044,$$

where $f(z=-2.5)$ from standard normal tables.

$$R(200) = P(Z > 200 - 300/40) = P(z > -2.5) = 0.994, \text{ from tables,}$$

$$h(200) = 0.00044/0.994 = 0.00044 \text{ failures per hour.}$$

Example 2

The failure times of a transmitting tube are found to be **Weibull** distributed with $\beta=2$, and $\eta=1000$ hours (characteristic life).

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Find the reliability of one of these tubes for an operating time of 100 hours, and the hazard rate after a tube has operated successfully for 100 hours.

Step 1

Reliability function is:

$$R(t = 100) = e^{-(t/\eta)^\beta}$$

$$R(t = 100) = e^{-(100/1000)^2} = 0.99$$

Step 2

Hazard rate function is:

$$h(t = 100) = \frac{f(t)}{R(t)} = \left(\frac{\beta}{\eta}\right)\left(\frac{t}{\eta}\right)^{\beta-1}$$

$$h(t = 100) = \left(\frac{2}{1000}\right)\left(\frac{100}{1000}\right)^{2-1}$$

$$h(t=100) = 0.0002 \quad \text{failures/hour.}$$

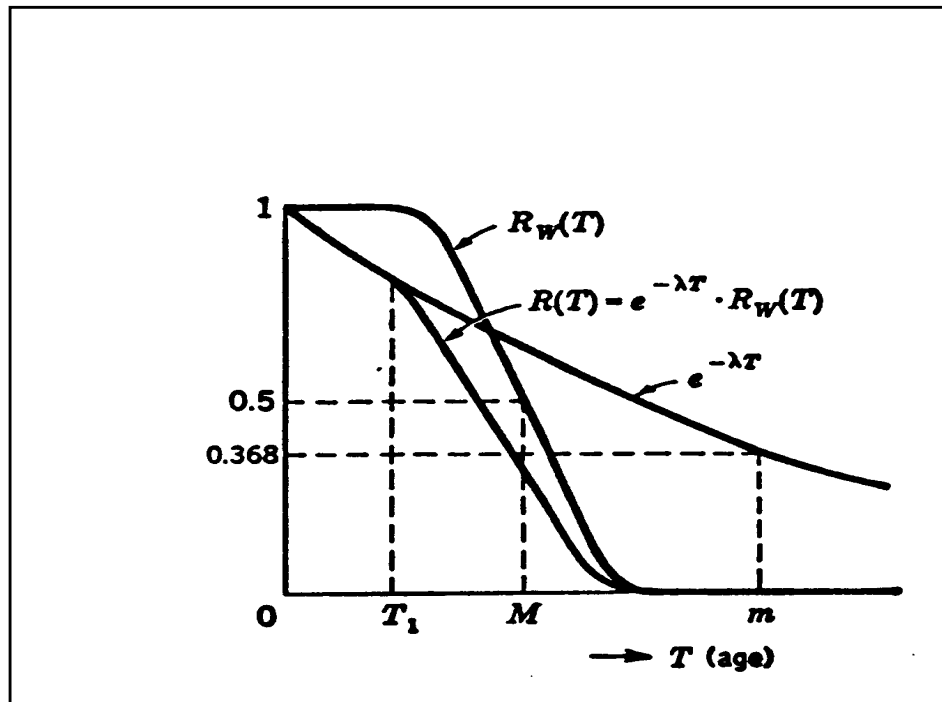
13.6.1.10 MTBF Assessment Methodology and Reliability Models with Maintenance Policy

13.6.1.10.1 Introduction

a) The methods defined previously herein, and traditional methods defined in MIL-STD's provide mathematical/reliability models to calculate **MTBF** under series models and redundancy with no **renewal** repair, or periodic inspection.

This section provides reliability/mathematical models to evaluate system MTBF/Reliability and to optimize the inspection period for systems with redundancy and under maintenance policy.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***CHAPTER 13***FIGURE 13.13: COMBINED RELIABILITY CURVE**

b) These models and evaluation methods shall be also used in Fault Tree Analysis (FTA) and in quantitative FMECA.

Two major maintenance policies are:**(1) Perfect Maintenance Policy**

Means that every unit in the system is checked out after every mission/flight/inspection interval, and is replaced or repaired if it has failed.

No unit is allowed to go into significant wearout before the next flight is completed.

All necessary adjustments are made and all prescribed service actions are taken before the beginning of the next flight.

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(2) Imperfect Maintenance Policy

Means that the system is not maintained as previously after each flight/mission/interval, but is allowed to proceed on its next mission as long as the system is functioning satisfactorily, in other words as long as there is at least one out of all of the system (redundant) units that is still functioning.

Therefore, failed units in the system are not repaired or replaced until the system fails.

13.6.1.10.2 Reliability Model and Evaluation Procedure

(1) Periodically Maintained System

a) Consider the effect of a given/chosen maintenance policy on the reliability, safety, and MTBF of redundant system configuration.

Mean Time Between Failures, (of parallel, stand-by and more complex systems can be calculated by integrating their Reliability function $R(t)$ from $t=0$ to infinity.

$$\theta_{\text{sys}} = \int_0^{\infty} R(t) dt$$

Thus, on the average such redundant system would fail once every θ hours if failed redundant components were not replaced until system failure.

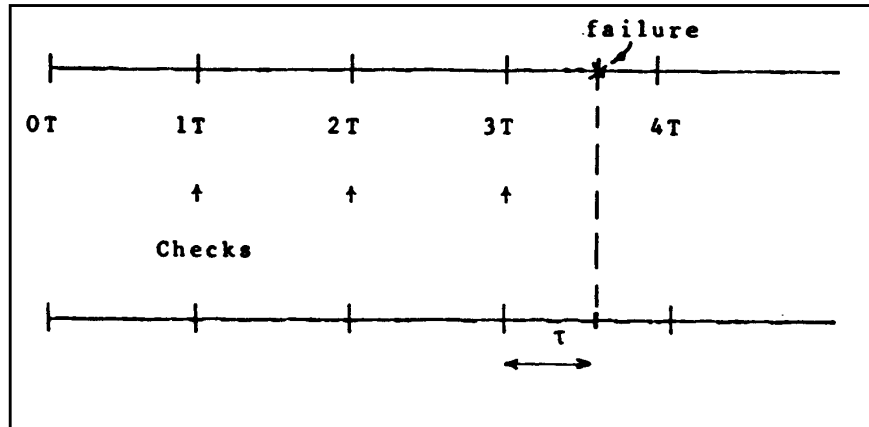
b) However, if a maintenance policy is adopted which allows for the replacement of failed redundant units periodically, system failure can be postponed depending on how often the system is inspected, and maintained, if inspection reveals the presence of failed units.

With this Maintenance Policy the system will fail less frequently than it would without inspections because it is assured that every new interval after an inspection begins with full redundancy restored.

The Mean Time Between System Failures thus becomes longer than θ .

c) To find the correlation between $\mathbf{T}$, by which we denote the operating time between two inspections, and $\theta_{\mathbf{T}}$, which is the Mean Time Between Failures adopted by the system if it is inspected every $\mathbf{T}$ hours.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES****CHAPTER 13****FIGURE 13.14: MAINTENANCE DIAGRAM FOR PERIODICALLY MAINTAINED SYSTEM**

We can mathematically redefine the Mean Time Between Failures of the renewable system in terms of the time T between renewals/checks;

$$\text{i.e., } t = 3T + \tau$$

$$t = jT + \tau, \quad 0 < \tau < T$$

then;

$$R_T(t) = [R(T)]^j \cdot R(\tau)$$

and

$$\theta_T = \int_0^{\infty} R_T(t) dt$$

T indicates that the system is undergoing inspection every T hours of operation.

Since the period T is discrete; $E(t) = E(T1) + E(T2) + \dots$, then,

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$$\theta_T = \sum_{j=0}^{\infty} \int_{jT}^{(j+1)T} R_T(t) dt ,$$

$$\theta_T = \sum_{j=0}^{\infty} \int_0^T [R(T)]^j R(\tau) d\tau ,$$

Rearranging,

$$\theta_T = \sum_{j=0}^{\infty} [R(T)]^j \int_0^T R(\tau) d\tau$$

Since,

$$\sum_{j=0}^{\infty} X^j = \frac{1}{1-x} , \quad \text{for } x < 1$$

then,

$$\theta_T = \frac{1}{1-R(T)} \cdot \int_0^T R(\tau) d\tau$$

$$\theta_T = \frac{\int_0^T R(\tau) d\tau}{1-R(T)} = \frac{0}{F(T)}$$

Where,

$F(T)$ is the c.d.f. (cumulative distribution function)

θ_T **is the Corrective Mean Time Between Failures of the Redundant System**, (or system suffer wearout), which becomes the function of the renewal time **T**.

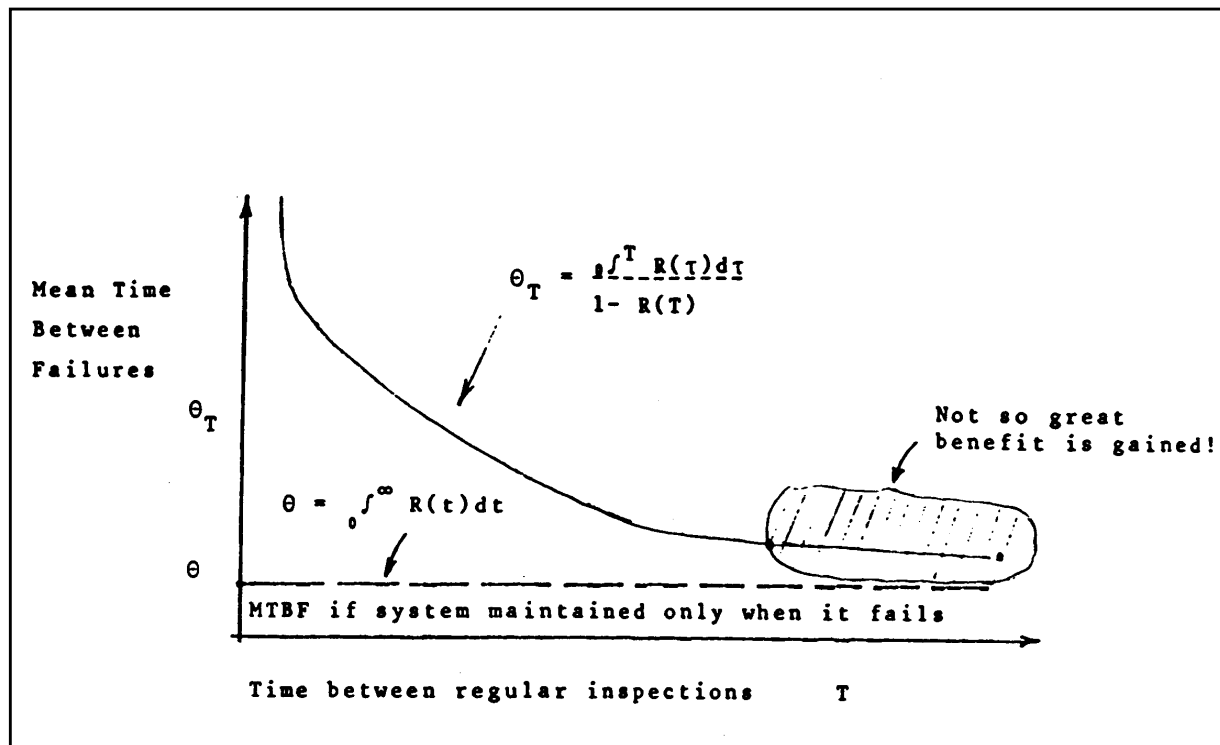
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d) However, if the renewal time T is regular, even a nonexponential system will have the same probability of failure for each interval T , between two scheduled renewals, overhauls, or inspections. This ensures that the system begins each period T in its original good condition, and therefore over long periods of time will fail exponentially with a mean time between failures θ_T given by equation in Para.c., and with an average failure rate given by;

$$\lambda_{\text{avg}} = \frac{1}{\theta_T}$$

which shall be combined with other predicted values or analysis if required, i.e., FTA.

**FIGURE 13.15: MTBF VS. INSPECTION**

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Figure 13.15 shows the mean time between failures θ_T of a regularly inspected redundant system as a function of the inspection interval time T .

The more frequently the system is inspected, that is, the shorter is T , the longer will be the system's mean time between failures.

e) It is also possible to **optimize** the inspection interval/period T knowing the costs and the required system reliability/safety or top event unreliability as in FTA, (it has to be checked that the target reliability is met).

(2) Maintained Redundant System

For maintained system/equipment, Mean Time To First Failure (MTTFF) is a measure of the expected time the system is in an operable state allowing module repair as it fails.

In this maintenance policy; the redundant units are allowed to wear out and replaced only as they fail, within X operating (repair rate) hours or at the first convenient time (i.e., second flight, within 40 hours of operation)

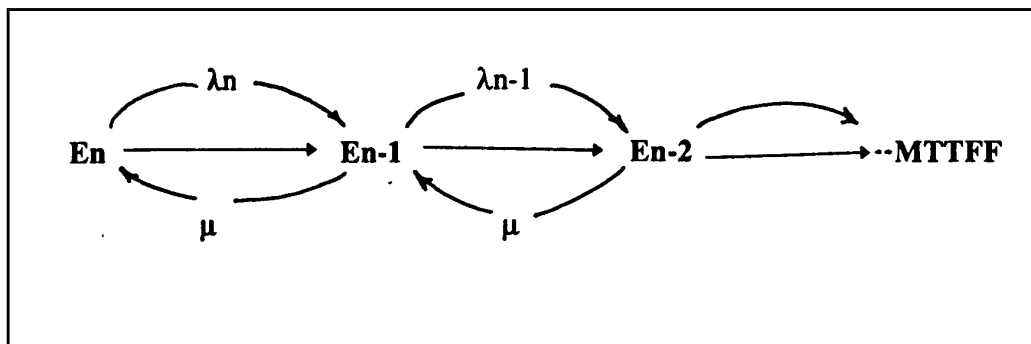


FIGURE 13.16: MTTFF TRANSITION PROBABILITIES

Expected time to failure for maintained system

We have a stochastic process with (conditional) transition probabilities in the time interval in which failed unit shall be repaired, (note that in that time interval the system continue to operate with failed/dormant item)

Solving the linear differential equations (of transition probabilities) using Laplace transforms method, (not shown here), we can get;

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$$MTTFF = l_{n,n-1} + l_{n-1,n-2} + l_{n-2,n-3} + \dots$$

where;

$$l_{n,n-1} = \frac{1}{\lambda_n} \left(1 + \frac{\mu_n}{\lambda_{n+1}} + \frac{\mu_n \mu_{n+1}}{\lambda_{n+1} \lambda_{n+2}} + \dots \right)$$

$$\lambda_n = n \cdot \lambda$$

 $l_{n,n-1}$ = time to failure from one state to the lower state,

 μ = repair rate (i.e., 40 hours/repair)
(3) Redundancy (with repair) Equation Approximation

All units active on-line with equal unit failure rates, (n-q) required for success, with repair (as in 6.1.10.2.2 a).

$$\lambda_{n-q,n} = \frac{n! (\lambda)^{q+1}}{(n-q-1)! (\mu)^q}$$

where,

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

n = number of active on-line items,

 λ = average failure rate of an individual item, failures/hour,

 q = number of on-line active items which are allowed to fail without system failure.
Example 1

a) At least 4 relays out of 6 needed to complete the mission

b) Industry data

Log normal parametric estimators

$$\mu = 8.03$$

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$\sigma = 0.1117$ then,

we may say relays have been observed to follow a normal distribution (as Mean $> 3\sigma$) with

Mean life

$$M = \exp\left(\mu + \frac{\sigma^2}{2}\right)$$

$$M = 3090 \text{ Hours.}$$

Standard deviation

$$\sigma = [\exp(2\mu + 2\sigma^2) - \exp(2\mu + \sigma^2)]^{1/2}$$

$$\sigma = 346 \text{ Hrs.}$$

c) Wearout Failure rate of the relay

When a failure rate of a part must be used in the prediction, R&M analysis, and testability, it must be remembered that only for the special case of the exponential distribution, will the failure rate be constant, with all other values of β (i.e., $\beta \geq 3$ for normal distribution) greater than one, resulting in an increasing failure rate.

In this case an average failure rate over a stated time period shall be calculated and used.

Average failure rate

At time $t = M - 1.5\sigma$,

$$h(t) = \lambda_w(t) = \frac{f(t)}{R(t)} = \frac{\phi(t)}{\sigma R(t)} = \frac{r(t)}{\sigma} \dots \dots \dots \text{Eq. (10) para. 13.6.1.9.2}$$

$$\bar{\lambda}_w(M - 1.5\sigma) = r(-1.5s) / \sigma \text{ per hour}$$

failure rate from Figure 13.12 and Para.13.6.1.9.2,

$$\bar{\lambda}_w = 0.1388 / 346 \times 10^6 = 401 \text{ failures per million hours.}$$

d) Repair Policy

Relays are allowed to wear out and are replaced only as they fail.

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Renewal of the relays shall be performed maximum within 40 operating hours, after the first failure occurred and detected, (time before maintenance).

e) Solution

• **Method 1** per para. 13.6.1.10.2 (3)

Repair rate $\mu = 1/40$

number of relays $n = 6$

average failure rate of one relay $\bar{\lambda}_w = 401 \times 10^{-6}$

number of relays which allowed to fail $q = 2$

Relays unit average failure rate, redundancy with repair (based on above policy)

$$\lambda(\text{relays unit}) = \frac{n!(\lambda)^{q+1}}{(n-q-1)!(\mu)^q}$$

$$= \frac{6!(401 \times 10^{-6})^3}{3!(1/40)^2},$$

$$\lambda_w = 12.4 \times 10^{-6}.$$

• **Method 2** per para.13.6.1.10.2 (2)

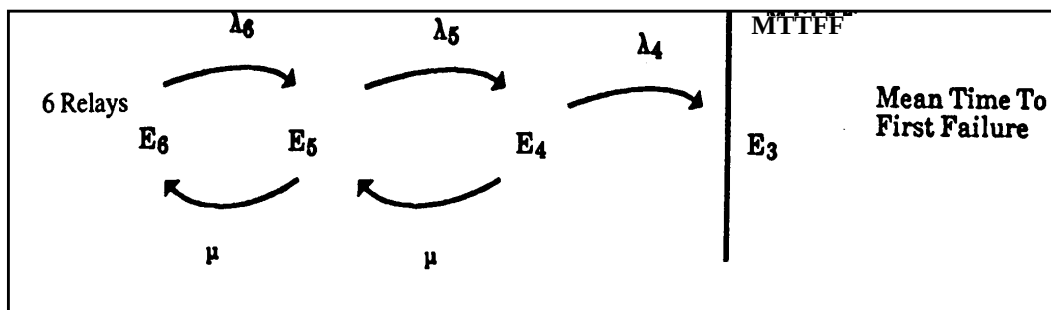


FIGURE 13.17: MTTFF TRANSITION PROBABILITIES - EXAMPLE

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Mean Time To First Failure of the Relays array; using para.13.6.1.10.2 (2)

$$MTTFF = l_{6,5} + l_{5,4} + l_{4,3}$$

$$l_{6,5} = \frac{1}{\lambda_6}$$

$$l_{5,4} = \frac{1}{\lambda_5} \left(1 + \frac{\mu}{\lambda_6} \right)$$

$$l_{4,3} = \frac{1}{\lambda_4} \left(1 + \frac{\mu}{\lambda_5} + \frac{\mu^2}{\lambda_5 \lambda_6} \right)$$

where

$$\lambda_6 = 6 \lambda$$

$$\lambda_5 = 5 \lambda$$

$$\lambda_4 = 4 \lambda$$

$$\mu = 1/40$$

$$MTTFF = 95,248 \text{ Hrs.}$$

Hence, the average failure rate is

$$\bar{\lambda}_w = 1/MTTFF = 10.5 \times 10^{-6}$$

Therefore, the average failure rate of the relays array will be between 12.4 to 10.5×10^{-6}

This can also be reduced by applying $\mu < 40$ hrs replacement time.

One relay combined failure rate

$$\lambda_{\text{total}} = \lambda_w + \lambda_c = 2.07 + 3.12 = 5.9 \times 10^{-6}$$

where λ_c (chance failure rate) = 3.12×10^{-6} from MIL-HDBK-217,

$$\lambda_w \text{ (wearout failure rate)} = 12.4 / 6 = 2.07 \times 10^{-6}$$

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 13***Example 2**

Three equal components working in parallel, with (failure rate each, and at least two must operate to complete the mission/flight.

System is inspected every $T=200$ hours.

Find mission success probability, system MTBF/Failure rate.

- a) Define the Reliability function of the system;

$$R(t) = e^{-2\lambda t} (3 - 2 e^{-\lambda t}) \quad \text{from previous sections.}$$

- b) Define the $F(t)$ c.d.f. of the system

$$F(t) = 1 - R(t),$$

- c) Define/calculate the system MTBF function with periodic inspection interval T ;

$$\theta_T = \frac{\int_0^T R(t) dt}{F(t)} \quad \text{as given above.}$$

- d) Calculate the average system failure rate

$$\bar{\lambda}_{\text{avg}}(T) = \frac{1}{\theta_T}$$

13.7 METHODS / PROCEDURES FOR RELIABILITY PREDICTIONS**13.7.1 Introduction**

Reliability prediction is the process of quantitatively assessing whether the proposed, or actual, equipment/system design will meet the specified reliability and safety requirements.

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The primary objective of reliability prediction is to provide guidance, relative to expected inherent reliability of the given design.

Basically, the purpose of reliability prediction includes feasibility evaluation, comparison of alternative configurations, identification of potential problems during design reviews, logistic support planning, and cost studies, determination data deficiencies, trade off decisions, allocation of R&M requirements, provides inputs/criteria for R&M and Safety analyses (i.e., FMECA, FTA), and also provides criteria for reliability growth and demonstration testing.

Thus, reliability prediction is a key to system development and allows reliability to become an integral part of the design process.

To be effective, the prediction technique must relate engineering variables to reliability variables.

This techniques can be roughly classified in five categories, depending on the type of data or information available for the analysis.

The categories are:

(1) Similar Equipment Techniques

The equipment under consideration is compared with similar equipments of known reliability in estimating the probable level of achievable reliability.

(2) Similar Complexity Techniques

The reliability of a new design is estimated as a function of the relative complexity of the subject item with respect to a "typical" item of similar type.

(3) Active Element Group Techniques

In the AEG method enough is known about the design so that the number and types of active elements are known or can be estimated.

(4) Parts Count Techniques

Equipment reliability is estimated as a function of the number of parts, in each of several part classes, to be included in the equipment.

(5) Stress Analysis Techniques

The equipment failure rate is determined as an additional function of all individual part failure rates, and considering part type, operational stress level, and derating characteristics of each part.

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This method relates item functional complexity and application environment to failure rates experienced in field usage.

a) **Feasibility Prediction (Type I)**

Feasibility prediction is intended for use in the conceptual phase of item development.

During this phase the level of detailed design information is generally restricted to overall aspects of the item.

Detailed configuration data generally are limited to that which may be derived from existing items having functional and operational requirements similar to those of the item being developed.

Methods **1,2,3**, describe feasibility prediction methods.

b) **Preliminary Design Prediction (Type II)**

Preliminary design prediction is intended for use in the early detailed design phase.

During this phase design configuration data are documented by engineering sketches and preliminary drawings.

The level of detailed information available may be restricted to part listings.

Stress analysis data are not generally available. Method 4 describes a preliminary design prediction method.

c) **Detailed Design Prediction (Type III)**

Detailed design prediction is intended for use in and subsequent to the detailed design phase.

This phase is characterized by drawings which identify all parts, materials, and processes needed to produce the item.

Operating stress and temperature analysis data are necessary for each part in the item.

The analysis data shall be based on design analysis and measurement techniques acceptable to the procuring activity.

Method 5 describes a detailed design prediction method.

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13.7.2 General Descriptions**13.7.2.1 Part Description**

Part and application descriptions shall be provided for any prediction based upon part failure rates.

The part identification number from the schematic diagram, the applicable specification and the specification type number shall be included.

13.7.2.2 Environmental Data

Environmental data affecting part failure rates must be defined.

These data include the specific natural and induced environments (nominal and worst case) associated with the operations, events and functions described by the logistic and operational cycles.

13.7.2.3 Environmental Categories

Environmental categories shall be defined for each service use event.

Data sources, such as MIL-HDBK-217, and NPRD which utilize environmental factors to adjust failure rates, shall apply the environmental factor which most closely matches the intended environment.

Factors utilized shall be cited and substantiated.

13.7.2.4 Part Operating Temperature

Part temperatures used for prediction purposes shall include the item internal temperature rise as determined by thermal analysis or test data.

For general guidance and detailed thermal analysis procedure, refer to MIL-HDBK-251.

13.7.2.5 Stress Analysis

Analysis shall be performed to determine the operating stresses to be experienced by each part commensurate with the prediction classification and the design detail available.

These analyses shall be based on techniques acceptable to the procuring activity.

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Failure rates shall be modified by appropriate factors to account for the effect of applied stress. Stress ratios cited in the prediction report shall be individually identified as Estimated (E), Calculated (C), or Measured (M).

13.7.2.6 Failure Distributions

The failure distribution appropriate to the specific electronic, electrical, electromechanical, mechanical, and ordnance item shall be used in computation.

In instances where the failure distribution for the item is not known, the exponential, binomial, weibull, normal, lognormal, or other failure distributions may be assumed.

The failure distributions utilized shall be cited and any assumptions substantiated in the prediction report.

13.7.2.7 Failure Rates

Failure rates for electronic, electrical, electromechanical, mechanical, and ordnance items are required for each significant event and environment defined by the service use profile.

All sources of failure data shall be approved by the procuring activity prior to use.

Basic failure rates from most data sources must be modified with appropriate factors to account for the specific item application under consideration.

Factors used shall be cited and substantiated in the prediction report.

13.7.2.8 Functional Group Failure Rates

Functional group failure rates may be derived from failure data for functionally similar groups or items.

The GIDEP Failure Rate Summaries are an available source for locating group and item failure rates.

13.7.2.9 Operating Failure Rates

Operating failure rates for electronic and electromechanical parts may be found in MIL-HDBK-217. Failure rates for other parts may be found in NPRD, the GIDEP Failure Rate Summaries, and other sources.

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13.7.2.10 Nonoperating Failure Rates

Nonoperating failure rates for parts take into consideration pertinent environmental influences or other stresses of the application.

Data sources such as RADC-TR-73-248, RADC-TR-74-269, provide non operating failure rates.

13.7.2.11 Storage Failure Rates

Storage failure rates for parts may be found in data sources such as RADC-TR-73-248, RADC-TR-74-269.

13.7.2.12 Item Reliability

Item reliability shall be computed using mathematical models and applicable failure rate data. The prediction results shall be expressed in terms consistent with the specified reliability requirements.

13.7.3 Procedure / Steps for Performing Reliability Prediction

The following basic steps apply to the prediction reliability requirements:

- Step 1** Definition of equipment
- Step 2** Definition of failure
- Step 3** Definition of operational and maintenance conditions
- Step 4** Development of reliability block diagram(s)
- Step 5** Establishment of mathematical model(s)
- Step 6** Compilation of part lists
- Step 7** "Parts count" or "Parts stress analysis" reliability prediction
- Step 8** Assignment of failure rates or reliability
- Step 9** Combination of failure rates or reliability
- Step 10** Computation of equipment reliability

The procedures for making predesign or interim reliability predictions are basically the same as for final design predictions except that the difference lies in the degree of precision (and details) with which the basic steps are implemented.

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For predictions made at any stage of development, each of the steps will be carried out to the maximum extent possible.

The system failure and operating and maintenance conditions should be defined as explicitly as possible.

Reliability block diagrams are constructed to the lowest identifiable function, and appropriate system reliability formulas are established.

Precise parts lists, of course, cannot be compiled prior to design of an equipment. It is necessary, however, to make the best possible estimate of the parts complements of the various item subdivisions, (blocks on the reliability diagram).

Stress analyses obviously cannot be made prior to design.

Therefore, for portions of the equipment that have not been designed, gross stress analyses can be accomplished.

Stress levels may be assumed and failure rate estimates can be made by applying failure rate vs. stress tradeoffs to the assumed failure rate data.

The process of combining part failure rates to obtain preliminary block failure rates or reliabilities, of adjusting block rates or probabilities, and of computing equipment reliability is the same for predesign and interim predictions as for final predictions.

13.7.3.1 Definition of Equipment

The initial step in a reliability prediction is to define the system or other item for which the prediction is being accomplished.

The task of defining the item, then, consists of explicitly describing its purpose, intended function, or mission and physical boundaries of the items which compose the item.

Particular attention must be devoted to interfaces among items so that all items will be considered in a prediction and there will be no unwanted duplication of coverage in predictions.

13.7.3.2 Definition of Failure

Equipment failure is considered as the occurrence of any condition which renders the equipment incapable of operating within its specified performance parameter limits.

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The task of defining failure consists of listing or referencing the appropriate limits.

13.7.3.3 Definition of Operational and Maintenance Conditions

Operating conditions include the equipment operational profile and the environmental conditions prevailing during the various periods of operation.

The operational profile should be defined in terms of elapsed mission times or mission phases at which the equipment is turned on and the duration of operation during each phase.

The sequence of functions necessary for success and the duty cycles of items within the equipment are also elements of the operational profile which must be defined.

During each period of operation, the pertinent environmental conditions must be established by test, reference, or assumption.

Definition of environmental conditions encompasses all the factors that might affect reliability, whether or not their effects can be quantitatively assessed.

The maintenance conditions expected to affect reliability will be established.

Pertinent items include: replacement schedules for parts with known or estimated limited lives; other preventive maintenance schedules; identification of items which may be replaced or repaired during a mission; requirements for special equipment or facilities; and so on.

Also items that include redundancy will be identified. For those redundant items that can be repaired during a mission, maintainability predictions are required.

13.7.3.4 Development of Reliability Block Diagram(s)

A reliability block diagram may be considered a logic chart which, by means of the arrangement of blocks and lines, depicts the effect of failure of equipment subdivisions on the equipment's functional capability.

Items whose failure causes equipment failure are shown in series with other items.

Items whose failure causes equipment failure only when some other item has also failed are drawn in parallel with the other items.

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One of the first tasks in constructing a block diagram is to determine the complexity of equipment items which are to be shown as separate blocks.

For a complex system it is often convenient to have several block diagrams. The first would be a simple diagram showing the first-order subdivision breakdown of the equipment.

Separate block diagrams are then constructed for each of the first-order subdivisions. This process of diagramming goes on until individual blocks represent an order complexity such that their failure rates, or reliabilities, can be readily estimated from part level data.

It is frequently not possible to convey all of the pertinent information merely by the arrangement of blocks and interconnecting lines.

Therefore, appropriate notation must be included on the diagram or in accompanying verbal descriptions.

The notation should describe types of redundancy where it is not obvious from the diagram.

Where failure of a redundant element degrades performance or places additional stresses on the items in alternate paths, it should be so noted.

Also, operating times or cycles of the individual blocks should be noted if different from equipment operating time. In addition, items that may be repaired or replaced during a mission should be identified and monitoring intervals for those items should be stated.

If equipment operation varies during a mission (or specified operating time), this variation must be considered in determining the equipment failure pattern.

For this purpose, mission time is divided into intervals, during which the equipment configuration is constant.

Separate diagrams or sets of diagrams should be developed for each interval.

It is necessary to go within each block of the system block diagram to develop a reasonable approximation of a subsystem diagram containing those units required to perform the subsystem function.

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To the extent that design information is available at the early stage of system planning, it may be desirable to go further down into the system to block diagram specific design configurations at the subsystem and lower item levels - especially if planned features of the design concept include the application of redundancy or unique devices at these lower levels.

In the development of a block diagram, items that are predominantly electronic in function are classified and symbolized as electronic units, even though mechanical elements may be involved in the performance of an output function.

Items that are predominantly mechanical or otherwise essentially nonelectronic in nature are identified accordingly.

Any redundancy contemplated in the system planning stage should be shown, as well as any planned provisions for alternate mode capability.

To the extent practicable, the block diagram should be constructed so that each item can be assumed functionally independent of its neighboring item so far as its specific transfer function is concerned.

Figure 13.18 shows the evolution of the detailed block diagram - going from the system level down to the part level - as a function of design evolution.

Level I and II diagrams shall be produced from information available in the system planning phase.

They are considered adequate for preliminary feasibility estimation and reliability allocation.

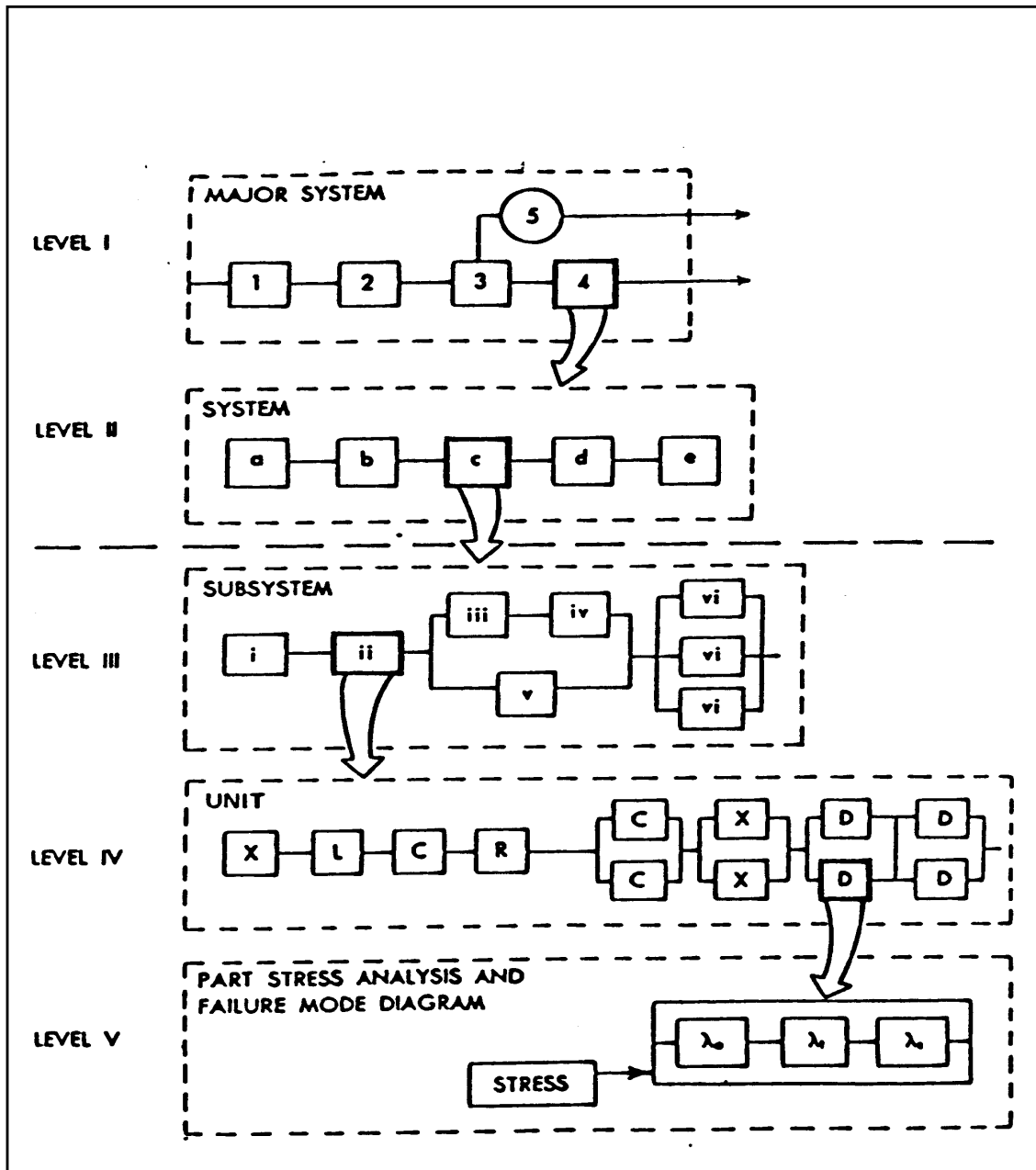
The Level III diagram is usually producible in the early design proposal stage.

The Level IV diagram is producible after a period of design formulation and review in which a definitive design has resulted.

Level V represents the failure mode diagram at the part level, where it becomes practicable to perform stress analyses and failure mode studies on individual parts within the system.

Such detailed information may be available in the early planning phase on certain critical parts known to be essential to the success of the system concept.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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BLOCK DIAGRAM**

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13.7.3.5 Establishment of Mathematical Model(s)

The mathematical model is a mathematical expression relating equipment reliability to the reliabilites of the equipment subdivisions depicted as blocks on the reliability diagram.

In the simple cases where all blocks are in a series, the reliability equation may be merely: (previous sections in this document provides details and additional guidelines)

$$R_e = R_1 \cdot R_2 \cdot \dots \cdot R_n$$

where,

R_e is equipment reliability and

$R_1, R_2, \dots, R_n$ are reliabilities of blocks 1, 2, ..., n, respectively.

Where there are no items whose failure rates change with time, no one-shot devices, etc., the equation may be even simpler, i.e.,

$$R_e(t) = e^{-\left(\sum_{i=1}^n \lambda_i t_i\right)}$$

where,

λ_i is the failure rate of the i th block

t_i is the operating time of the i th block in system operating time t .

If an equipment includes redundant items, items whose failure rates change with time, one-shot devices, provision for replacement of failed redundant elements, etc., the reliability formula will be more complex.

(previous sections in this document provides guidelines for reliability modeling and calculations)

13.7.3.6 Compilation of Parts List

For each block on the reliability block diagram, individual parts should be listed in some convenient order.

If the block contains several low order subdivisions (such as assemblies or subassemblies), parts will be listed by circuit symbol within part type within block subdivision.

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All parts within a block should be listed, with appropriate notation to identify those whose failure will not cause the block to fail.

If, for some parts, only particular failure modes will affect the block, those parts and the pertinent failure modes will also be identified.

In addition to identifying the parts within blocks, lists serve as basic worksheets for determining stresses and part failure rates, or reliability estimates.

Therefore, parts lists should include part descriptions and pertinent ratings.

They should also include space for entering operating voltages, currents, power dissipation, stress indexes, and failure rates or probabilities of survival.

An example of an appropriate parts list is shown in **Table 13.5**

TABLE 13.5: STRESS ANALYSIS RELIABILITY PREDICTION WORKSHEET

PROGRAM:				ASSY:				DATE:					
SCHEMATIC NO:				ASSY AMBIENT TEMP:									
REF DESIG	PART NUMBER /TYPE	RATED		ACTUAL					Failure rate (λ)	T _j °C	Rated Stress Parameter		
		Stress Parameter	MAX Stress	Current (mA)	Voltage (volts)	Duty Cycle (%)	Stress	Stress Ratio			MAX Stress	Stress Ratio	
CR1	JANTX1 N 5417	I _O	3A	150	-	100	150 MA	0.05	0.175	83	2.53A	0.06	Diode, PWR
		PRV	200V	-	65		65V	0.33			200V	0.33	Rect.
		I SURG	80A	18A	-		28A	0.23			80A	0.23	
CR2	932151-1	I _O	40A	1.54A	-	100	1.54A	0.04	1.169	77	40A	0.04	Diode, PWR
		PRV	175V	-	65		65V	0.37			175V	0.37	Rect.
		I SURG	300A	6A	-		6A	0.02					
											300A	0.02	
Note: AT ASSEMBLY OPERATING TEMPERATURE							Sub - Total		$\Sigma \lambda$		Failures 10 ⁶ Hours		

This worksheet has been patterned after information derived from MIL-HDBK-217, NPRD, and is used in Paragraph 13.7.3.7 also.

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(Software are available for reliability predictions; i.e Predictor)

For predesign predictions, estimate numbers of parts by type within each block.

For interim predictions, compile parts list for blocks, or subdivisions thereof, for which design information is available.

Estimate parts complements for equipment subdivisions which have not been designed as stated above for predesign predictions.

13.7.3.7 “Parts Count” or “Parts Stress Analysis” Reliability Prediction

Perform “Parts Count” analyses when applicable; during bid proposal and early design phases according to MIL-HDBK-217, NPRD and other RADC documents.

Utilize generic part types and quantities, quality levels of parts, and equipment environment which has been determined in previous steps.

For early trade studies and conceptual efforts, similar equipment of known complexity and parts content can be utilized for estimating reliability values.

Perform Parts Stress Analysis Prediction when most of the design is completed, detail parts are known, and when part stresses are available in accordance with MIL-HDBK-217, and other applicable documents.

During early design, it may be feasible to advance from the “Parts Count” technique to a “gross stress analysis” based upon rough parts count, assumed stressed levels, etc.

Part selection and control activities include the determination of actual part stress levels in the intended circuit application.

They also include failure rate calculations per MIL-HDBK-217 and employment of appropriate derating factors consistent with reliability prediction studies.

Additional improvement in part and, ultimately, equipment reliability can be realized by applying the techniques of derating, (for guidelines and details refer to Derating Analysis Procedure).

Derating can be defined as the operation of a part at less severe stresses than those for which it is rated.

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In practice, derating can be accomplished either by reducing stresses or by increasing the strength of the part.

Selecting a part of greater strength is usually the most practical approach.

Derating is effective because the failure rate of most parts tends to decrease as the applied stress levels are decreased below the rated value.

The reverse is also true; the failure rate increases when a part is subjected to higher stresses and temperature.

The failure rate model of most parts is stress and temperature-dependent.

As a general rule, the specific derating should not be conservative to the point where costs rise excessively (e.g., higher than necessary parts are selected).

Neither should the derating criteria be so loose as to render reliable part application ineffective.

Optimum derating occurs at below the point where a rapid increase in failure rate is noted for a small increase in stress.

Derating may require consideration of other constraints such as size, weight and power

13.7.3.8 Assignment of Failure Rates or Reliability

Failure rates or other appropriate measures of reliability will then be assigned to the individual parts.

For most part types the measure of reliability will be obtained from the data in MIL-HDBK-217, NPRD and other RADC, GIDEP documents.

The stress ratio determined in the preceding step, temperatures, derating, and other pertinent information are used to obtain these failure rates.

If the stress ratio or temperatures vary during a mission, a separate failure rate for each mission phase must be assigned to each affected part.

Data applicable to parts whose failure rates change with time and one-shot devices or other parts whose reliability are not time-dependent are usually expressed in the form of probabilities.

They will be recorded as such on the parts lists. If the reliabilities are time-dependent, appropriate values will be recorded for each of the time periods of interest (determined by previous steps).

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Where part failure rate or reliability are estimated by part type (as in the parts count method), the generic failure rates for the devices in the prediction must account for differences in use environment.

13.7.3.9 Combination of Failure Rates or Reliability

For blocks which contain only series parts with constant failure rates, the part failure rates will be added to obtain the block failure rate.

If a block includes series parts which do not have constant failure rates, the reliability for these parts will be substituted in the reliability mathematical model to obtain the block reliability.

If part failure rates or reliability vary during a mission, they will be appropriately combined to obtain a block reliability for each mission phase, sub phases, or other periods of interest determined in previous steps.

13.7.3.10 Computation of Equipment Reliability

Compute the equipment's reliability in the form of mean-time-between-failures or reliability for the specified time intervals.

Where all part failure rates are constant and there is no redundancy, the MTBF is the reciprocal of the sum of the block failure rates.

If the blocks of the diagram represent one-shot devices, other parts whose reliability is not time-dependent, parts whose failure rates change with time, redundant items, maintenance policies, etc., reliability is computed according to the guidelines and formulae in this document, Reliability Modeling Sections.

13.7.4 Mathematical Models for Reliability Prediction

General (all) Reliability Models for different situations and configurations are covered in the previous sections of this document.

Note 1:

For the simplest case of equipment/system consisting of N independent elements/subsystems in series, the reliability equation is

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$$R_s = \prod_{i=1}^N R_i$$

where

R_s = is the equipment/system reliability

R_i = is the reliability of each of the elements/subsystems

This equation refers simply to the probability of success; For the case where time is a factor

$$R_s(t) = \prod_{i=1}^N R_i(t)$$

where

$R_s(t)$ = is the probability that the system will not fail before time (t)

$R_i(t)$ = is the probability that the ith element of the system will not fail before time t

If we assume that each of the $R_i(t)$'s is exponentially distributed with constant failure rate, λ_i (i.e., electronic components)

$$R_s(t) = \prod_{i=1}^N e^{-\lambda_i t}$$

$$= e^{-\left(\sum_{i=1}^N \lambda_i t\right)}$$

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Also

$$\lambda_s = \sum_{i=1}^N \lambda_i$$

where

λ_s = is system failure rate

λ_i = is failure rate of each of the independent elements of the system

and; general equation of the MTBF

$$\begin{aligned} \text{MTBF} &= \int_0^{\infty} R(t) dt \quad \text{gives,} \\ &= \frac{1}{\lambda_s} = \frac{1}{\sum \lambda_i} \quad \text{as a speical case.} \end{aligned}$$

Note 2:

The use of the exponential distribution of time to failure (p.d.f.) for complex systems is usually justified because of the many forces that can act upon the system and produce failure.

For example, different deterioration mechanisms, different part hazard-rate functions, and varying environmental conditions often result in, effectively, random system failures.

Another justification for assuming the exponential distribution in long-life complex systems is the so-called “approach to a stable state,” wherein the system hazard rate is effectively constant regardless of the failure pattern of individual parts.

This state results from the mixing of part ages when failed elements in the system are replaced or repaired.

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Over a period of time, the system hazard rate oscillates, but this cyclic movement diminishes in time and approaches a stable state with a constant hazard rate.

A third justification for assuming the exponential distribution is that the exponential can be used as an approximation of some other function over a particular interval of time for which the true hazard rate is essentially constant.

Finally, the exponential distribution has been validated over the past twenty-five years on a number of electronic equipments and systems by providing results which correlate fairly closely with actual field data.

The preceding paragraphs are not intended to imply that the exponential assumption is generally valid.

Because of its mathematical simplicity and the extensive theory developed by many researchers, the exponential density plays a prominent role in reliability work.

However, if observed failure data do not support the exponential assumption or if such factors as wearout are expected to be significant, the exponential assumption can be erroneous.

In such cases, other distributions, such as the log normal, gamma and Weibull distributions are available for performing more valid predictions.

13.7.5 Reliability Predictions Techniques

13.7.5.1 Similar Equipment Method

13.7.5.1.1 Purpose

This prediction method utilizes specific experience on similar items.

The most rapid way of estimating reliability is to compare the item under consideration with a similar item whose reliability has previously been determined by some means and has undergone field evaluation.

This method has a continuing and meaningful application for items undergoing orderly evolution.

Not only is the contemplated new design similar to the old design, but small differences can be easily isolated and evaluated.

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In addition, difficulties encountered in the old design are signposts to improvements in the new design.

The similar circuit method should be considered if a similar item comparison cannot be made.

13.7.5.1.2 Procedure

- (1) Major factors for a direct comparison of similar items should include:
 - a) Item physical and performance comparison
 - b) Design similarity
 - c) Manufacturing similarity
 - d) Similarity of the service use profile (logistic, operational, and environmental)
 - e) Program and project similarity
 - f) Proof of reliability achievement

- (2) The validity of the similar item method is dependent upon the degree of equivalence between the items and not simply the generic term used to describe the items.

For example, although both are power supplies (generic type), the achieved reliability of a ten watt power supply should not normally be used as a prediction method for a proposed one kilowatt power supply as the much higher power level of the proposed power supply may result in much lower reliability achievement due to design differences and stresses.

A comparison may be made if there are scale factors to realistically relate reliability with item parameters such as power levels.

- (3) GIDEP Failure Rate Summaries are a data source for this method.

In general, these similar equipment prediction techniques involve the following steps:

- a) Defining the new equipment in terms such as general equipment type (e.g., radar), operational use (e.g., aircraft) and other known characteristics.

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- b) Identifying an existing equipment or class of equipments that most nearly compares with the new equipment.
- c) Obtaining and analyzing historical data generated during operation of the existing equipment to determine as nearly as possible the reliability of the equipment under the stated operating environment.
- d) Drawing conclusions concerning the level of reliability that will be demonstrated by the new equipment.

Such conclusions assume that similar equipment will exhibit similar reliability and that reliability achievement evolves in an orderly manner from one generation of equipments to the next.

These reliability prediction techniques permit very early estimation of the failure rate of a new equipment based on experience gained from operational equipments of similar function.

The accuracy of the estimates, however, depends on the quality of historical data and the similarity between the existing and new equipments.

Obviously, more meaningful and accurate results are achieved if a technique based on field results of similar products is used.

Also, other factors such as design practices and production techniques are more likely to be similar to those on past equipments designed and built by the same manufacturer than those of another manufacturer.

In most cases, prediction techniques such as this are used in estimating the feasibility of meeting some minimum reliability objective within the constraints of the current state-of-the-art.

13.7.5.2 Similar Complexity / Circuit Method

13.7.5.2.1 Purpose

This prediction method utilizes specific experience on similar circuits such as oscillators, discriminator amplifiers, modulators, pulse transforming networks, etc.

This method is employed either when only a circuit is being considered or the similar item method cannot be utilized.

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The most rapid way of estimating reliability is to compare the circuits of the item under consideration with similar circuits whose reliability has previously been determined by some means and has undergone field evaluation.

Individual circuit reliabilities can be combined into an item reliability prediction.

This method has a continuing and meaningful application for circuits undergoing orderly evolution.

Not only is the contemplated new design similar to the old design, but small differences can be easily isolated and evaluated.

In addition, difficulties encountered in the old design are signposts to improvements in the new design.

13.7.5.2.2 Procedure

- (1) Major factors for a direct comparison of similar circuits should include:

- a) Circuit physical and performance comparison
- b) Design similarity
- c) Manufacturing similarity
- d) Similarity of the service use profile (logistic, operational, and environmental)
- e) Program and project similarity
- f) Proof of reliability achievement

- (2) Individual circuit reliabilites can be combined into an item reliability prediction.

Circuit interconnect reliability factors should be considered when combining individual circuit reliabilites in order to determine a realistic item reliability prediction.

- (3) The validity of the similar circuit method is dependent upon the degree of equivalence between the circuits and not simply the generic term used to describe the items.

For example, although both are amplifier circuits (generic term), the

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achieved reliability of a one milliwatt amplifier circuit should not normally be used as a prediction method for a proposed ten watt amplifier circuit as the much higher power level of the proposed amplifier circuit may result in much lower reliability achievement due to design differences and stresses.

A comparison may be made if there are scale factors to realistically relate reliability with item parameters such as power levels.

- (4) Various equipment manufacturers and military agencies have preferred circuit manuals or documents with associated failure rates which may be utilized with this type prediction.

GIDEP Failure Rate Summaries may be a data source for this method.

13.7.5.3 Active Element Group Method

13.7.5.3.1 Purpose

The Active Element Group (AEG) method is termed a feasibility estimating procedure because it is useful for gross estimates of a design in the concept formulation and preliminary design stages.

Only an estimate of the number of series AEGs required to perform the design function is needed.

The AEG method relates item functional complexity (active element groups) and application environment to failure rates experienced in fleet usage.

Available data for this method is currently limited to ships and ships' missiles.

13.7.5.3.2 Documents Referenced in this Method

Naval Sea Systems Command

NAVARD OD 44622 Reliability Data Analysis and Interpretation Volume 4

13.7.5.3.3 Definitions

Active element: A part that converts or controls energy; e.g., transistor, diode, electron tube, relay, valve, motor, hydraulic pump.

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Active element group: An active element and its associated supporting (passive) parts; e.g., an amplifier circuit, a relay circuit, a pump and its plumbing and fittings.

Passive element: Any part, not itself an active element, used in conjunction with an active element to perform a desired function; e.g., capacitor, resistor, fitting.

13.7.5.3.4 Procedure

(1) General considerations

In the AEG method enough is known about the design so that the number and types of active elements are known or can be estimates.

Consideration must be given to the item reliability model in the application of AEG failure rates used to derive an item reliability prediction as AEGs may be utilized in redundant as alternate mode hardware configurations.

The AEG method is based on several generalized assumptions which can be summarized as follows:

- a) All active elements can be defined and classified as representative types, and the quantity of supporting passive elements is effectively constant for each type, regardless of the end use item.
- b) The inaccuracy inherent in assigning a single failure rate to each of the active element types is acceptable.
- c) A single failure rate can be used for each generic passive element type.
- d) The change in failure rate with environmental severity is identical for all types.

(2) Detailed Procedure

For each reliability block determine if the block's function is primarily analog, digital, or mechanical.

Once the nature of the function is determined, proceed with one of the following steps:

a) Electronic Analog Function Failure Rate Estimation

For each electronic analog reliability block, determine the number of series analog active elements necessary to perform the block's

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function.

Determine the block's failure rate from acceptable sources (i.e., MIL-HDBK-217, NPRD, RADC, GIDEP documents or existing similar data)

b) **Electronic Digital Function Failure Rate Estimation**

For each electronic digital reliability block, determine the number of series digital active elements necessary to perform the block's function.

Determine the block's failure rate from sources as above in (a), based upon the number of series equivalent digital AEGs and mission application.

c) **Mechanical Devices Function Failure Rate Estimation**

For each mechanical device reliability block, determine the number of series mechanical active elements necessary to perform the block's function.

Determine the block's failure rate from sources as in (a).

13.7.5.4 Parts Count Method

13.7.5.4.1 Purpose

The parts count method is a prediction method used in the preliminary design stage when the number of parts in each generic type class such as capacitors, resistors, etc., are reasonably fixed and the overall design complexity is not expected to change appreciably during later stages of development and production.

13.7.5.4.2 Documents Referenced in this Method

Military

MIL-HDBK-217

Other Publication

RADC-TR-73-248

Dormancy and power on-off cycling effects on electronic equipment and part reliability,

RADC-TR-74-269

Effects of dormancy on nonelectronic components and materials

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GIDEP	Government Industry Data Exchange Program, Summaries of failure rates,
NPRD	Nonelectronic Parts Reliability Data.

13.7.5.4.3 Procedure

- (1) The item failure rate can be determined directly by the summation of part failure rates if all elements of the item reliability model are in series or can be assumed in series for purposes of an approximation.

In the event the item reliability model consists of non-series elements (e.g., redundancies, alternate modes of operation), item reliability can be determined either by considering only the series elements of the model as an approximation or by summing part failure rates for the individual elements and calculating an equivalent series failure rate for the non-series elements of the model.

- (2) The information needed to support the parts count method includes:
 - a) Generic part types (including complexity for microelectronics),
 - b) part quantity,
 - c) part quality levels (when known or can be assumed), and
 - d) item environments.
- (3) The general expression for item failure rate with this method is:

$$\lambda_{\text{ITEM}} = \sum_{i=1}^{i=n} N_i (\lambda_G \pi_Q)_i$$

for a given item environment where;

λ_{ITEM} = total failure rate,

λ_{Gi} = generic failure rate for the i th generic part,

λ_{Qi} = quality factor for the i th generic part,

N_i = quantity of the i th generic part,

n = number of different generic part categories.

This equation applies to an entire item being used in one environment.

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If the item comprises several units operating in different environments (such as avionics), then the equation should be applied to the portions of the item in each environment.

These “environment-item” failure rates should be added to determine total item failure rate.

- (4) Quality factors are to be applied to each part type where quality level data exists or can be reasonably assumed.

Multi-quality levels and data exist for parts, such as microelectronics, discrete semiconductors, and for established reliability (ER) resistors and capacitors.

For other parts such as nonelectronics, $\pi_Q = 1$ providing that parts are procured in accordance with applicable parts specifications.

- (5) Failure rate data sources such as MIL-HDBK-217, NPRD, GIDEP, RADC-TR-73-248, RADC-TR-74-269 should be used with this method.

However, GIDEP should only be used if the part of interest is not included in the other stated failure rate sources.

Other failure rate data sources, including contractor in-house data, shall require procuring activity approval.

13.7.5.5 Parts Stress Analysis Method

13.7.5.5.1 Purpose

The parts stress analysis method is a prediction method used in the detailed design stage when there are few or no assumptions necessary about the parts used, their stress derating, their quality factors, their operating stresses or their environment in order to determine part failure rates.

These should be all known factors or capable of being determined based upon the state of hardware definition for which the parts stress analysis method is applicable.

Where unique parts are used, any assumptions regarding their failure rate factors should be identified and justified.

The parts stress analysis method is the most accurate method of reliability prediction prior to measurement of reliability under actual or simulated use conditions.

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13.7.5.5.2 Documents Referenced In This Method

Same as in para 13.7.5.4.2

13.7.5.5.3 Procedure

- (1) The previous method described was based upon average failure rates for each component part type. It is a well-known fact that part failure rates vary significantly with applied stresses, sometimes by several orders of magnitude.

For example, a 110-volt light bulb does not operate very long when subjected to 220 volts. It is this interaction between strength of the component and the stress level at which the component operates which determines the failure rate of a component in a given situation.

Thus, at different stress levels component parts assume different failure rates. This is the rationale for the stress analysis prediction technique.

The technique is based upon a knowledge of the stress to which the part will be subjected, e.g., temperature, humidity, vibration, etc., and the effect of those stresses on the part's failure rate.

Application of this technique is the same as was shown for the parts count technique except that each individual component's failure rate is modified to reflect the anticipated or actual stress environment to which it will be subjected.

Thus, it can be seen that the technique is more laborious and time-consuming, although it does provide the most accurate results.

It requires the use of MIL-HDBK-217, and 13.7.5.5.2 referenced documents which contains the necessary charts and tables to estimate the failure rate for each component part under the anticipated stresses.

The procedure for extracting failure rate data from MIL-HDBK-217 differs according to part class and type. In general, however, the following steps are required:

- a) A base failure rate is determined for each part. This value is established from the appropriate chart in MIL-HDBK-217 and is a function of part type, environmental temperature, and the relative level of the more significant operational stresses.

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-
- b) The value of one or more multiplicative or additive factors are determined from tables or charts in MIL-HDBK-217. These factors define the relationship between the base failure rate and the predicted failure rate for the specific application of interest.
 - c) The part failure rate is calculated using the established base failure rate and the modifying factors.
- (2) The item failure rate can be determined directly by the summation of part failure rates if all elements of the item reliability model are in series or can be assumed in series for purposes of an approximation.
- In the event the item reliability model consists of non-series elements (e.g., redundancies, alternate modes of operation), item reliability can be determined either by considering only the series elements of the model as an approximation or by summing part failure rates for the individual elements and calculating an equivalent series failure rate for the non-series elements of the model.
- (3) The information needed to support the parts stress analysis method included:
- a) Specific part types (including complexity for microelectronics),
 - b) part quantity,
 - c) part quality levels,
 - d) item environment, and
 - e) part operating stresses.
- (4) The general expression for item failure rate with this method is:

$$\lambda_{\text{ITEM}} = \sum_{i=1}^{i=n} N_i (\lambda_S \pi_Q)_i$$

for a given item environment where:

λ_{ITEM} = total failure rate

λ_{Si} = specific failure rate for the ith specific part

π_{Qi} = quality factor for the ith specific part

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N_i = quantity of i th specific part

n = number of different specific part categories

This equation applies to an entire item being used in one environment.

If the item comprises several units operating in different environments (such as avionics with units in airborne, inhabited, fighter (AIF) and uninhabited, fighter (AUF) environment), then the equation should be applied to the portions of the item in each environment.

These "environment-item" failure rates should be added to determine total item failure rate.

- (5) Quality factors are to be applied to each part type where quality level data exists or can be reasonably assumed. Multi-quality levels and data exist for parts, such as microelectronics, discrete semiconductors, and for established reliability (ER) resistors and capacitors. For other parts such as non electronics, $\pi_Q = 1$ providing that parts are procured in accordance with applicable parts specifications.
- (6) Failure rate data sources such as MIL-HDBK-217, NRPD, GIDEP, RADC-TR-73-248, RADC-TR-74-269 should be used with this method.

However, GIDEP should only be used if the part of interest is not included in the other stated failure rate sources.

Other failure rate data sources, including contractor in-house data, shall require procuring activity approval.

13.7.5.6 Modification for Nonexponential Failure Densities

Although the exponential technique indicated in the previous sections can be used in most application with little error, it must be modified; (1) if the system contains parts for which the density function of failure times cannot be approximated by an exponential over the time period of interest; or (2) if the parts which are the dominant factor in overall system unreliability do not follow an exponential density function of times to failure.

Mechanical parts such as gears, motors, and bearings usually fall in this category.

In these cases, we cannot add the failure rates of all parts because there are some parts whose failure rates vary significantly with time.

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1) The method used is to consider separately within each block diagram the portion of the block containing parts with constant failure rates, and the portion containing parts with varying failure rates.

If the former portion contains x parts, then the reliability of this portion is

$$R_1(t) = \exp \left[- \left(\sum_{i=1}^x \lambda_i \right) t \right]$$

2) The reliability of the second portion at time t is formed by using the appropriate density function for each part whose parameters have been determined through field experience or testing. If this portion contains B parts, then

$$R_2(t) = \prod_{i=1}^B R_i(t)$$

where

$$R_i(t) = \exp - \int_0^t h_i(T) dT$$

and h(t) is the time varying hazard rate of each of the B parts.

3) The reliability for the block diagram, under the assumption of independence between the two portions, is

$$R(t) = R_1(t) \cdot R_2(t)$$

By solving for various levels of t, the block and system reliability function can be plotted. Often the shape of the curve will be very similar to that for an exponential, and the system mean life can be estimated graphically by finding the time interval over which the reliability is equal to 0.37. Remember for the exponential distribution the mean life is 0.37.

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4) For example, consider the failure rates of two elements X and Y that make up a system. Let X have a constant failure rate λ of $1,000 \times 10^{-6}$ failures per hour, and Y a hazard rate $h(t)$ that varies with time and is given by $(500 \times 10^{-6} + 0.01t)$. Thus,

$$R_y(t) = \exp\left[-\int_0^t (500 \times 10^{-6} + 0.01r)dr\right]$$

The reliability of a system composed of these two independent elements would be obtained through

$$R(t) = R_X(t) \cdot R_Y(t)$$

$$= [\exp(-10^3 \times 10^{-6}t)] \left\{ \exp\left[-\int_0^t (500 \times 10^{-6} + 0.01r)dr\right] \right\}$$

$$= \exp\left[-\left(1500 \times 10^{-6}t + \frac{0.01t^2}{2}\right)\right]$$

Evaluation of the above equation for several discrete points in time permits construction of the reliability function.

5) For those systems which have a reliability curve appreciably different from the exponential, the mean life is equal to:

$$\theta_s = \int_0^{\infty} R(t) dt$$

Reliability prediction methods for those cases in which the equipment/system contains parts which are predominantly mechanical or electromechanical and for which the exponential approximation is not valid, use Normal, Weibull, Lognormal, or Extreme Value distributions of failure times.

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For those non electronic devices where the exponential approximation of failure times is valid, NPRD and RADC documents contain a listing of failure rates for various types of non electronic devices. It can be used to supplement the MIL-HDBK-217 failure rate data, which is restricted to electrical and electronic parts.

13.7.5.7 Modification to Include Nonoperating Failure Rates

The component failure rates in MIL-HDBK-217 and in the Non electronic Parts Data Book are based upon operating time. There are equipment/systems in which non operating time represents a significant portion of the useful life, e.g., fuses. For these equipment/systems the failure rate should be modified to include non operating, or dormant, failure rates. The simplest modification includes a non operating or dormant failure rate correction so that the model becomes

$$\lambda_T = \lambda_{op}d + (1-d)\lambda_{nop}$$

where

λ_T = total failure rate

λ_{op} = operating failure rate

λ_{nop} = non operating failure rate

d = ratio of operating to non operating time

As mentioned above, this modification is particularly important for these systems which spend a significant portion of their useful lives in a non operating or dormant state. (i.e. cold standby parts).

RADC-TR-80-196 Non operating failure rates for Avionics document contains data for electrical and electronic devices and avionics equipment.

Finally, the U.S. Army Command, Redstone Arsenal, AL 35809, maintains a Storage Reliability Data Bank.

This data bank consists of a computerized data base with generic part storage reliability data and storage reliability report library containing available research and test reports of non operating reliability research efforts.

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13.7.6 SMT Devices Reliability Model

13.7.6.1 Introduction

Most electronic /electrical applications today use Surface Mounted Devices (SMD) which their reliability evaluation / estimation is not well covered by MIL-HDBK-217, and it is lacking of significant field data.

This section develops reliability assessment models to be used by the vendor as a guide for electronic model reliability estimation where includes SMDs.

1) Surface mount technology (SMT) involves the placement of electronic components directly onto the surface of a printed wiring board (PWB) and soldering them into place.

The electrical contacts of the component do not penetrate plated-through holes (PTH) in the board, as do conventional through-hole leaded devices.

SMD's are specially designed to support the device mechanically, also providing the electrical interface to the substrate.

2) The benefit of SMT is its capability to reduce size and weight of electronic assemblies by increasing the interconnect density and to provide these benefits at a lower cost.

The choices and options in selecting the correct substrate, components and interconnect method are many, and not necessarily obvious.

Improper design of a SMT assembly can lead to short lived systems or field failures upsetting critical mission requirements.

This requires complete cooperation and interaction between the electrical, mechanical, components and reliability engineer (Vendor and De Havilland).

3) The larger the device, the greater the risk, and it was also confirmed that LCC's (leadless chip carrier) direct mounted to PWB's with significantly different coefficients of thermal expansion (CTE) are a reliability concern.

13.7.6.2 SMT Reliability Model

The model translates the number of cycles to failure for every component to a failure rate for surface mounted assemblies.

The models predict time-to-failure values. These time-to-failure values are transformed into failure rate values which are applicable to MIL-HDBK-217.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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1) The development of a failure rate model for solder joints on surface mount devices is approached in a new way.

The surface mount model is derived directly from the deterministic physics of the primary failure mode of the solder joint using material properties, design details, expected usage data and finite element analysis.

2) The wear out failure of the solder joint is the characteristic whereby the solder material exhibits failures due to the accumulation of stress conditions which cause physical breakdown of the solder material.

The definition of a failure is based on a solder joint fracture which will lead rapidly to an open circuit causing a loss of operating function.

3) Based on the available literature, the predominant cause of failure is thermal cycling induced stress.

This mechanism was the primary and only failure mechanism selected for inclusion in the model.

Shock and vibration was not included as the effect is extremely dependent on the application and would make the model too complex to be useful.

13.7.6.2.2 SMT Reliability Model

The basic failure rate model derived for SMT is below.

$$\lambda = \frac{(\text{Nu})^{\beta-1}}{(A \cdot B \cdot C \cdot \text{Nf})^{\beta}} \times P \times (U \times 10^6) \times \pi_Q$$

λ = is Failure Rate in failures per 10 hours

Nu = is Service Life Usage Thermal Cycles in Cycles

β = is the Distribution Parameters

A = is the Package Size Factor

B = is Standoff Height Factor

C = is Coefficient of Thermal Expansion (CTE) mismatch factor

Nf = The mean number of cycles to failure

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P = is the Number of Package Pins (i.e. = 8)

U = is Cycle Rate: Cycles / Hour overlife

π_Q = is the Quality Factor

13.7.6.2.3 Model Factors**(1) A: Package Size Factor**

Base on the physics of strain, the strain value for any package is related to the diagonal distance from the center of the package.

As the package size increases so does the strain for a given lead pitch.

The A factor shall be derived from Table 13.6 (Adjustment for package size referenced to pin count) below.

TABLE 13.6: A = PACKAGE SIZE FACTOR

Number Of Pins	Leadless	Leaded
10	x	
14	x	
16	1.00	1.00
18	0.46	0.91
20	0.43	0.82
24	0.37	0.74
28	0.33	0.65
32	0.30	0.59
44	0.23	0.46
68	0.16	0.31
84	0.13	0.26

(2) B: Standoff Height Factor

The standoff height factor, B, provides for the effects of higher standoff heights on thermal cycle life.

This effect is well established in the literature, especially for leadless devices.

The **B** values are in Table 13.7.

(this is the height of the solder joint off the PWB in inches)

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TABLE 13.7: B = HEIGHT FACTOR**Adjustment for solder Joint Height off the PWB**

Height Times 0.001 Inches	Leadless Factor	Leaded Factor
3	1.0	1.0
4	1.6	2.0
5	2.2	3.4
6	2.9	5.2
7	3.7	7.4
8	4.5	10.2
9	5.4	13.5
10	6.3	17.3

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***CHAPTER 13***(3) C: Coefficient of Thermal Expansion (CTE) Mismatch Factor**

The coefficient of thermal expansion factor, C, accounts for the effect of the difference in Coefficient of Thermal Expansion (CTE) mismatch between the part and the printed wiring board (PWR) material.

The larger the CTE difference, the lower the cycle life.

CTE Factor, C, Table 13.8.

TABLE 13.8: C = COEFFICIENT OF THERMAL EXPANSION (CTE) FACTOR

Adjustment for CTE mismatch between a device body and the PWB

PWB Material	CTE (ppm/°C)	Leadless Mismatch	C Factor Leadless	C Factor Leaded
G-10 or FR-4	16	10	1.0	1.0
Polyimide Kevlar	8	2	11.9	45.3
Expoxy CIC*	6.4	1	34.0	234.0
Expoxy Kevlar	8	2	11.9	45.3

* CIC - Copper/Invar/Copper

(4) π_Q : Quality Factor

A factor for Quality is considered necessary to account for life reduction effects due to quality of the processes used to produce the joint.

Due to lack of literature different soldering approaches such as vapor phase, Infra Red, or wave soldering could not be evaluated.

π_Q Factor Table 13.9.

TABLE 13.9: π_q = QUALITY FACTOR, PIE Q:

Mil Level	π_Q Pie Q Factor
Military	1.0
Non- Military	2.0

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(5) P: Package Pins Factor (P=8)

The SMT model derived above is based on the development of a failure rate for a single joint.

The joint used in the FEA in the end lead of the SMT package.

In a symmetrical package there are eight (8) leads which have the same stress due to symmetry.

SMT package will fail if any of the joints fail.

(6) U: Cycle Rate

$$U = Nu / t \times 10^6 \text{ per } 10^6 \text{ hours}$$

where:

U = Cycle Rate in cycles per hour

Nu = Use Cycles (No of thermal cycles over life use)

t = Use - Operating Life in hours

(7) β: Distribution Parameter

The distribution parameter, Beta (β) is a shape factor which defines the distribution of the failures about the characteristic life.

The values from literature are shown in Table 13.10.

Because the β values are greater than 1.0 and have different values for leaded and leadless devices, the value indicates that the distributions are characteristic of a wear out process and that the wear out characteristics of LCC devices are different from that of leaded devices.

(8) Nu: Service Life Usage Thermal Cycles

The model requires the definition of use cycles, equivalent use times and number of thermal cycles.

Use cycles represent the number of thermal cycles the SMT joint will experience in a service life time.

To develop this equipments life cycle and mission use profiles are necessary.

The life cycle includes all the thermal excursion events.

The mission induced thermal cycles are the predominant source of thermal cycles for the model.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***CHAPTER 13***TABLE 13.10: β = DISTRIBUTION PARAMETER**

Package Pin Count	Type LCC/Butt (I)/Gull/J	β Value
68 P	B (1)	2.2
68 P	B (1)	3.2
68 P	B (1)	4.0
2 C	L	3-6
		Mean - 3.6
		Min. - 2.2
68 P	J	4.6
68 P	J	2.58
68 P	G	3.65
68 P	J	2.62
68 P	G	4.44
68 P	J	1.15
68 P	G	4.29
68 C	J	1.7
68 C	J	2.7
N/A		1.8 - 3.0
68 P	J	6.8
68 P	G	5.5
68 P	G	3.3
44 C	G	1.4
44 C	G	3.9
44 P	G	2.5
44 P	G	5.8
P = Plastic B = Butt or I lead L = LCC J = J Lead C = Ceramic G = Gull-wing F = Flat Pack		

TABLE 13.11: β PARAMETRIC DERIVATION FOR THE MODEL

	Leaded	Leadless
Beta Range	1.15 - 6.8	2.2 - 4.0
Beta Average	3.42	3.68
Beta (Model)	1.15	2.2

The mission includes the powering of the equipment, the use of the equipment with external thermal conditions changing due to power cycling, external environmental changes, and coding provisions.

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The number of thermal cycles is the product of the number of missions times the cycles per mission.

Table 13.12 provides the default factors and their derivation basis.

TABLE 13.12: NU = SERVICE LIFE USAGE CYCLES

MIL-HDBK Environment Category (1)	Typical Delta Temperature °C (2)	Typical Life Hours (3)	Typical Cycles Cycles (4)	Typical Cycle Rate U (5)	Default Life Hours (6)	Default Cycles N _U (7)	Default Cycle Rate U (5)
G _B	45	41600	5200	0.125	45000	7500	0.17
G _F	60	20800	5200	0.25	25000	7500	0.30
G _M	80	10400	10400	1.00	12000	15000	1.25
N _S	65	43680	3640	0.08	45000	8000	0.18
N _U	80	21840	3640	0.17	25000	8000	0.32
A _{IF}	75	7200	4800	0.67	10000	10000	1.00
A _{IC}	75	9600	2400	0.25	15000	5000	0.33
A _{UF}	80	7200	9600	1.33	10000	20000	2.00
A _{UC}	80	9600	3600	0.38	15000	10000	0.67
A _{RW}	75	6000	4000	0.67	10000	8000	0.80
S _F	55	43800	27375	0.63	50000	30000	0.60
M _F	65	1	1	1	10	10	1
M _L	65	1	1	1	10	10	1
C _L	65	1	1	1	10	10	1
G_B - 8 HR/MISSION CYCLE * 5 DAYS/WEEK * 20 YRS 1 THERMAL CYCLE PER MISSION G_F - 4 HR/MISSION CYCLE * 5 DAYS/WEEK * 20 YRS 1 THERMAL CYCLE PER MISSION G_M - 2 HR/MISSION CYCLE * 5 DAYS/WEEK * 20 YRS 2 THERMAL CYCLES PER MISSION N_S - 12 HRS/DAY * 7 DAYS/WEEK * 26WKS/ YEAR * 20 YRS 1 THERMAL CYCLE PER DAY N_U - 6 HRS/DAY * 7 DAYS/WEEK * 26WKS/ YEAR * 20 YRS 1 THERMAL CYCLE PER DAY A_{IF} - 35 HRS/MO * 12 MO/YR * 20 YRS (1.5 HR MISSION) 2 THERMAL CYCLES PER MISSION A_{IC} - 40 HRS/MO * 12 MO/YR * 20 YRS (4 HR MISSION) 1 CYCLE PER MISSION A_{UF} - 35 HRS/MO * 12 MO/YR * 20 YRS 1 THERMAL CYCLE PER MISSION A_{UC} - 40 HRS/MO * 12 MO/YR * 20 YRS 1.5 THERMAL CYCLES PER MISSION A_{RW} - 25 HRS/MO * 12 MO/YR * 20 YRS 1 THERMAL CYCLE PER MISSION S_F - 5 YR MISSION, CONTINUOUS OPERATION 15 THERMAL CYCLES PER DAY M_F - 10 HR A_{UC} 2 THERMAL CYCLES PER MISSION M_L = C_L - 1 HR PER MISSION 1 THERMAL CYCLE PER MISSION A default margin was applied to account for other cycling and maintenance effects. (1) MIL-HDBK-217F proposed environment definitions (2) Derived delta temperature excursions (3) Engineering estimate based on existing typical specification values - includes all "on" time (4) Estimated from mission profile usage of various equipments typically used in the environment category. (5) $U = N_{cycles} / \text{Life Hours}$ for typical or default parameters (6) Estimate from typical life plus an estimated margin for uncertainties (7) Estimate from typical cycles plus an estimated margin for uncertainties Note: The default life and cycles provides an estimated margin to account for surge usage, wartime expanded usage and unknown contingencies. The default values margin is an estimate above the typical values. The added margin varies from environment to environment.							

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(9) **Nf: Mean Cycles To Failure**

The required parameter when using Weibull distribution is the characteristic life value N_F .

The mean life is sometimes accommodated on Weibull paper. It may be read from a percentile, as for α , (N_F) but the percentile varies according to the **value** β .

An approximate list of percentiles which may be used to evaluate the mean life is given in Table 13.13

**TABLE 13.13: MEAN LIFE PERCENTILES
FOR β PARAMETER**

β	Percentile Used to Estimate Mean Life (%)
0.5	75.0
1.0	63.2
1.5	57.5
2.0	54.5
2.5	52.5
3.0	51.0
3.44	50.0

The relationship between mean and characteristic life is defined by the mathematical relationship:

$$N_f = \{\Gamma(1 + 1/\beta)\} N_F$$

N_F = the characteristic life (α)

Γ = the gamma distribution

N_f = the mean life, cycles to failure.

This states that the mean life is related to the characteristic life by a Gamma distribution.

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Tabulated values of the Γ are available in standard mathematical tables. Table 13.14, gives the characteristic life of four types of solder joint lead attachments.

TABLE 13.14: N_F = BASELINE CHARACTERISTIC LIFE (CYCLES TO FAILURE) FOR SOLDER JOINTS

Δ Temp. °C	LCC	Gull	J Lead	S Lead
5	1.32E+10	4.03E+15	1.70E+14	3.65E+13
10	7.16E+09	1.78E+15	8.60E+13	1.95E+13
15	3.87E+09	7.82E+14	4.30E+13	1.04E+13
20	2.09E+09	3.44E+14	2.20E+13	5.59E+12
25	1.13E+09	1.52E+14	1.10E+13	2.99E+12
30	6.11E+08	6.68E+13	5.50E+12	1.60E+12
35	3.31E+08	2.94E+13	2.80E+12	8.58E+11
40	1.79E+08	1.30E+13	1.40E+12	4.59E+11
45	9.66E+07	5.71E+12	7.10E+11	2.46E+11
50	5.22E+07	2.51E+12	3.60E+11	1.32E+11
55	2.82E+07	1.11E+12	1.80E+11	7.04E+10
60	1.53E+07	4.88E+11	9.10E+10	3.77E+10
65	8.26E+06	2.15E+11	4.60E+10	2.02E+10
70	4.46E+06	9.46E+10	2.30E+10	1.08E+10
75	2.41E+06	4.17E+10	1.20E+10	5.78E+09
80	1.30E+06	1.83E+10	5.90E+09	3.09E+09
85	7.05E+05	8.08E+09	3.00E+09	1.66E+09
90	3.81E+05	3.56E+09	1.50E+09	8.86E+08
95	2.06E+05	1.57E+09	7.50E+08	4.74E+08
100	1.11E+05	6.90E+08	3.80E+08	2.54E+08
105	6.03E+04	3.04E+08	1.90E+08	1.36E+08
110	3.26E+04	1.34E+08	9.60E+08	7.28E+07
115	1.76E+04	5.90E+07	4.90E+07	3.89E+07
120	9.52E+03	2.60E+07	2.40E+07	2.08E+07
125	5.15E+03	1.14E+07	1.20E+07	1.12E+07
130	2.78E+03	5.04E+06	6.20E+06	5.97E+06
135	1.50E+03	2.22E+06	3.10E+06	3.20E+06
140	8.13E+02	9.77E+05	1.60E+06	1.71E+06
145	4.40E+02	4.30E+05	8.00E+05	9.16E+05
150	2.38E+02	1.90E+05	4.00E+05	4.90E+05

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This model must be used with an understanding of the basic limitations which include the following:

The model is derived around the wear out failure mechanism of low cycle fatigue only.

The vibration effects (high cycle fatigue) and effects of other environmental factors cannot be addressed per the existing MIL-HDBK-217 environment factor as the use environment is integral to the fatigue life cycle calculation.

The effect of power cycling of the device on cyclic life is presently assumed to be included within the temperature change factor in the base cycles to failure model.

The model does not consider corrosion, inter metallic compounds, electro-migration or leaching type failure mechanisms

Example :

TABLE 13.15: AIRBORNE UNINHABITED FIGHTER FAILURE RATE COMPUTATIONS

Calculate the failure rate for an Airborne, Uninhabited Application: The SMT package is an LCC placed on a FR-4 Printed Wiring Board . The mission thermal excursion is 60 degrees (+55 to -5°C), the thermal rise is 20 °C . The LCC standoff height from, the PWB is 3 mils. The design life is 10000 hours. The mission use causes 2 thermal cycles per use hour: Life cycles 20000 cycles The data requires use of the detailed model The Temperature delta is $60 + 20 - 3(((55-5)/2)-25) = 80$ $(T_{max} - T_{min}) - 3 ((T_{max} + T_{min})/2) - 25 = 80$							
	Delta Temp	80	80	80	80	80	80
	LCC Package Size	16	24	32	44	68	84
N _F	Characteristic Life	1.30E+06	1.30E+06	1.30E+06	1.30E+06	1.30E+06	1.30E+06
π _Q	Quality Factor	1	1	1	1	1	1
C	CTE Mismatch Factor	1	1	1	1	1	1
B	Height Factor	1	1	1	1	1	1
A	Package Size Factor	1	1	1	1	1	1
N _u	Use Cycles Over Life	20000	20000	20000	20000	20000	20000
t	Use Hours Over Life	10000	10000	10000	10000	10000	10000
U	Cycle Rate	2	2	2	2	2	2
P	Pin Life	8	8	8	8	8	8
Failure Rater Per 10 ⁴ Hours		0.0815	0.7267	1.1527	2.0681	4.5953	7.2560

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13.7.7 Software Reliability

13.7.7.1 Introduction

This section together, with other references such as EPS 1-18 De Havilland Inc. R&M specification requirements, RTCA/DO-178, DOD-STD-2167A, and RADC RL-TR-92-15 Reliability Techniques for Combined Hardware and Software, shall be used as a guide for preliminary software reliability prediction/failure rate evaluation.

Detailed S/W combined H/W reliability analysis document will be prepared later as a separate document as required which will include;

- S/W reliability allocation,
- S/W detailed reliability prediction models/methods,
- Developing S/W FMEA, and FTA.
- S/W reliability growth, testing, demonstration test procedures/models (i.e., Musa logarithmic model, Shooman model, Lloyd-Lipow model etc.)
- Validation of S/W failure rate, multivariate regression models.

13.7.7.1.1 General

Many modern/complex systems and products contains both hardware and executable software elements (i.e, Dash-8 aircraft).

Microprocessors are being embedded into all manner of devices and systems to add "intelligence".

Computers lie at the heart of real-time applications that control critical and vital functions, where system failure can have catastrophic results.

High reliability is a crucial need for our complex systems, which can inflict or prevent accidents.

As hardware becomes more and more reliable as the result of technological advances, software is assuming an increasing role in achieving system reliability requirements.

System reliability considerations have in many cases made a transition from hardware to software.

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13.7.7.1.2 Software Reliability Estimation

As we know in most reliability estimations software reliability has been assumed as perfect (i.e., $R_{s/w} = 1.0$), and only hardware reliability has been taken into account.

Methods for the prediction and measurement of H/W reliability are considerably older and more mature than those for software.

The hardware methods have become standardized and institutionalized throughout the defence and related industries through military standards and handbooks.

13.7.7.1.3 Software Failure

Software and hardware differ in several respects.

Software does not wear out; almost all hardware goes through a wear out phase.

Once a fault is removed from software it is gone forever; many hardware faults can recur. When viewed at the appropriate level of abstraction, however, H/W and S/W reliability are very similar.

Both a running program and an operating hardware item can be seen as "black boxes". Every once in a while the black box fails.

A software failure occurs when the program produces output (display, hardcopy, command, control, etc.) that deviates from what the requirements specify.

A failure can be one of conformance, in which the program does not produce the right answer, or one of performance, in which the program does not perform a required function in a timely or resource-efficient manner.

Performance failures include crashes, hangs, and software that does not meet its response or throughput time requirements.

Real-time systems need to respond to events in the outside world as those events are happening.

Software failures can be classified along several different dimensions.

One classification is by the number of discrepancies that comprise the failure.

A discrepancy is a deviation of the value of a single output variable from the required value.

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Another way failures can be classified is by the severity of their consequences: The impact of a failure could be as innocuous as a misspelling or as catastrophic as loss of life or limb.

Software reliability is one measure of software quality. "Software quality" refers to those attributes that a program is required to possess at all times.

Examples include security, robustness, maintainability, safety, availability, and portability. **Quantitatively, software reliability** is defined as the probability of failure-free operation of the software for a specified period of time, in a specified environment.

An alternative figure of merit is the **software's failure rate**, the instantaneous rate of software failures per unit time.

By "time" is meant **execution time**. The failure-inducing stress is execution time, since software that is not running cannot fail.

When combining software failure rates with one another and with hardware, the failure rate is re-expressed with respect to **system operating time**.

The **level** at which software reliability should be expressed needs to be a high one, such as Computer Software Configuration Item (CSCI), so that the interfaces between lower level items will be included.

Software failures arise from a population of software faults. **A software fault** (often called "bug") is missing, extra, or defective code that has caused or can potentially cause a failure.

Every time a fault is traversed during execution, a failure does not necessarily ensue; it depends on the machine state (values of intermediate variables).

The extent to which a source program contains faults is indicated by its **fault density**, expressed in faults per thousand lines of executable source code (KLOC).

The **fault density** does not translate directly into a **failure rate** because different parts of the program are executed with different frequencies.

Instructions inside loops will tend to be executed more often than instructions outside loops. Conditionally executed instructions tend to get executed less than unconditional ones.

How many loop iterations occur and which branches take place depend on the machine state, which in turn depends on the input state.

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The origin of **software faults** lies in human fallibility. Compounding factors are the lagging of software engineering technology behind the increasing capabilities of computers, the large number of discrete states in programs, the novelty of problems and solutions, and lack of standard off-the-shelf software “parts” and designs.

Software is very flexible because there are no physical constraints such as power, weight, quantity of parts, manufacturability, etc., so software engineers take on tasks of sometimes enormous size and complexity.

13.7.7.1.4 Software Design Approaches to Reliability

High levels of software reliability are accomplished through a triad of activities: **fault avoidance, fault elimination, and fault tolerance.**

Fault avoidance consist of applying sound software engineering practices, including standards (documentation, structured design and programming, control), quality assurance (formal reviews, audits; evaluation of personnel, methods), and verification and validation.

These methods can go a long way in keeping down the number of faults but, historically, many faults will **remain.**

Fault elimination is accomplished through testing, code reading, and walk throughs.

The only way to uncover and remove all faults in the code is through **exhaustive testing.**

Exhaustive testing of non-trivial programs is impossible from a practical point of view because the number of inputs states is astronomically large.

Formal proof of correctness, given the current state of the art, is likewise impractical for real-world software.

In a program correctness proof, the program is treated as a static mathematical object.

The correctness proof is a formal mathematical demonstration that a program is consistent with its specification. Such proofs are of great size and complexity, although mechanical verifier systems help.

A **formal specification** of the program is required, and it is impossible to demonstrate whether the specification captures the intentions of the customer.

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Even if exhaustive testing or a formal proof of correctness could be accomplished, the results of the activity are as vulnerable to human fallibility as programming is.

Fault tolerance is achieved through special programming techniques that enable the software **to detect** and **recover** from failure incidents.

Software fault tolerance is a controversial topic. The method requires “**redundant**” software elements that provide alternative means of fulfilling the same function. The different versions must be such that they will not **all fail** in response to the same circumstances.

Some have suggested that diverse software versions developed using different specifications, designs, programming teams, programming languages, etc., might fail in a statistically **independent** manner.

Empirical evidence questions that hypothesis. However, almost all software fault-tolerance experiments have reported some degree of reliability improvement.

Despite advances in software fault avoidance, elimination, and tolerance, large-scale software will have faults and it will occasionally fail.

There is a need to specify, predict, measure, allocate, model, and demonstrate software reliability.

Software reliability figures need to be meaningfully combined with hardware reliability figures to yield system reliability figures.

13.7.7.1.5 Failure Rate Model

During a hardware item's useful life (between burn-in and wearout) a constant failure rate model is generally employed.

For a program whose code is frozen, subjected to input randomly selected from a fixed operational profile, a constant failure rate model is a reasonable one.

During system test, as the code is altered as the result of fault correction activity, the failure rate will vary as a function of cumulative execution time.

The failure rate of a piece of software is a function of the **number** and **location** of faults in the code, **how fast** the program is being executed, and the **operational profile**.

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Faults cannot be directly observed, if only for the reason that any faults whose whereabouts are known would presumably have already been removed.

The way to find faults is to execute the software starting from various input states. When a failure occurs the symptoms are recorded. Fault-correction personnel analyze the symptoms and look at the code to try and locate the fault that caused the failure.

If the fault is not obvious, the personnel will try to reproduce the failure, this time running with a debugging tool or having inserted additional output statements into to program.

A **debugging tool** typically allows the user to execute the program a step at the time and lets him or her examine and deposit variable values.

Usually, the programmer finds the fault and removes it. At times the repair activity introduces new faults into the code.

13.7.7.2 Software Reliability Prediction Model

The goal is the development of a method for the prediction of **software reliability** that could be used in conjunction with MIL-HDBK-217 and other published failure rate data to obtain a **reliability prediction** for the **overall system (HW / SW)**.

Hardware reliability prediction provides a failure rate for the inherent reliability, which, in theory, is the best reliability achievable as the development and manufacturing processes are perfected.

Software does not have the same kind of inherent reliability limitation.

The reliability of software will generally **improve** over time as faults are uncovered through **testing** and are **fixed**.

There are **two conditions that limit the attainable reliability** for software:

(1) There reaches a point at which a program that has poor maintainability becomes a victim of entropy--the code has been modified so much that it has become a patchwork quilt and an attempt to fix one fault results in the introduction of at least as many new faults.

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(2) The software achieves a high level of reliability, so that the times between failures are excruciatingly long, with the result that further testing becomes impractical.

On **Reliability Growth**, the simultaneous execution of multiple identical copies of the software can be helpful in postponing that **point in time**.

When software reliability or combined hardware / software reliability is predicted, that prediction must be related to a **point in time**.

The earliest point in time for which it makes sense to predict reliability is when the system is fully integrated and is operating in an environment that emulates field use.

This point in time is the beginning of “system test” and is denoted by cumulative operating time $\tau = 0$.

The software reliability prediction (preliminary) method given in this section will forecast the reliability the software can be expected to exhibit at that point.

13.7.7.3 Summary of Prediction Technique

(For more details please refer to RADC Doc# RL-TR-92-15)

(1) With no prior information, **use**

$$\omega_1 = \frac{6 - \text{faults}}{1000 / \text{source, instructions}}$$

Predict the number of developed executable source instructions (**I_s**)

(2) Then **compute** the inherent **fault density** as

$$\omega_o = \omega_1 \times I_s$$

(3) Use 0.955 for B, or obtain it from historical data, and **obtain** the total failures as

$$v_o = \frac{\omega_o}{B}$$

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B = fault reduction factor

The fault reduction factor is the net number of faults removed per failure occurrence.

B is not generally equal to unity because of imperfect debugging.

(4) **Using** the appropriate **code expansion ratio**, from Table 13.16, **compute** the number of **object instructions I**.

From manufacturer's specifications or bench marking, **find out** the **average instruction execution rate (r)**.

Obtain the linear **execution frequency** as

$$f = r/I$$

f is the number of **program passages** there would be in unit execution time if the program's instructions were executed in linear sequence.

I is the number of **object instructions** and is obtained by multiplying the number of source instructions by a code expansion ratio.

Table 13.16, below, provides the code expansion ratios for selected programming languages.

**TABLE 13.16: PROGRAMMING LANGUAGE CODE
EXPANSION RATIOS**

Programming Language	Expansion Ratio
Assembler	1
Macro Assembler	1.5
C	2.5
COBOL	3
FORTRAN	3
JOVIAL	3
Ada	4.5

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(5) Use 4.20×10^{-7} as the value for K, or obtain K from historical information on a similar project.

Predict the initial program failure rate as:

$$\lambda_o = f \cdot K \cdot \omega_o$$

A **method** of relating **fault content** to **failure rate**, based on program structure and operational profile was developed.

In the frame work of the Basic Execution Time Model, fault content is related to failure rate through the fault exposure ratio, K.

Specifically, if there are ω_o faults in the program, then the failure rate is λ_o

(6) **The time-dependent failure rate is:**

$$\lambda(\tau) = \lambda_o \cdot \exp\left[-\frac{\lambda_o}{v_o}\tau\right]$$

where τ is **cumulative execution time** since the start of system test.

With regard to faults, the failure rate depends primarily on fault density, not on fault content.

The **initial failure rate**, λ_o , and the **inherent faults**, ω_o , are the failure rate and fault at the start of system test, but in actuality any point during system test could be arbitrarily designated the “**official start**” of system test, so the relationship holds throughout system test and during field use.

(a) As product / process metrics come in during requirements analysis, preliminary design, detailed design, and coding, and unit test, use **the regression model** to obtain a better prediction of λ_o , which is not shown in this document

(b) Once system test begins, **use actual failure data** to estimate the software reliability model parameters, with applicable models, (which is not covered in this document).

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RELIABILITY DEVELOPMENT AND GROWTH TEST PROCEDURE (RDGT)

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14 RELIABILITY DEVELOPMENT AND GROWTH TEST PROCEDURE

14.1 SCOPE

14.1.1 General

This document covers the requirements and procedures for **reliability development/growth tests**.

The **reliability development/growth test (RDGT)**, shall be planned and conducted in accordance with this document to provide engineering information on failure modes and mechanisms under natural or induced environments, to provide information needed for assessing the reliability of equipment, and to provide for reliability improvement by the iterative process of "test, analyze, and fix" (**TAAF**).

The program required by this document differs from the required Reliability Qualification/Demonstration Test in that this **RDGT** program does not have as an objective the demonstration of any specific quantitative reliability requirement (i.e., MTBF), or the acceptance of hardware, but, rather, it has an objective the **assurance** that the majority of the **reliability problems** have been solved.

Reliability improvement (growth) will result when failure modes and mechanisms are discovered and identified and their recurrence prevented through implementation of corrective action.

14.1.2 Purpose

This document provides procuring activities and development contractors the concepts, methods, guidelines, and procedures to be used in managing and conducting **reliability growth test**.

The main purpose of the test is;

To **conduct** testing that will disclose the majority of **reliability problems** early in **development phase** and will allow corrective action to preclude recurrence prior to the start of **production**.

Growth testing will emphasize performance monitoring, failure detection, failure analysis, and the incorporation and verification of design corrections to prevent recurrence of failures.

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The Reliability Growth planning curve shall be developed to provide a means of tracking reliability growth and monitoring as the test proceeds, with a view to ascertaining whether the MTBF requirement will be met.

To enhance reliability analysis, corrective action shall be undertaken for all events.

The RDGT shall be considered as an organized search and correction system, for reliability problems, that allows problems to be fixed when it is least expensive.

The growth test's **primary purpose** is to improve the design, not to evaluate the design.

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.

This procedure, when used in conjunction with knowledge of the system/subsystem and its development program, **will allow** the development of a reliability growth management plan that will aid in developing a final system/subsystem that meets its requirements and lowers the life cycle cost of the fielded system (i.e., DHC-8. series 400 aircraft).

14.1.3 Application

This document is applicable to **de Havilland Inc. procurements** for development of all systems and equipment subject to contract definition and to the development of other systems and equipment when specified in the equipment specification.

When contract definition is not involved, the application of this document shall be as specified in the Statement of Work (SOW) incorporated in the request for proposal.

14.1.4 Benefits of Reliability Growth Management

The initial **prototypes** for a complex system (i.e., DHC-8 Aircraft) with major technological advances will invariably have **significant reliability and performance deficiencies** that could not be foreseen in the **early design stage**.

The prototypes, therefore, are subjected to a development testing program to **surface problems** so that **improvements** in system design can be made.

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The ensuing system reliability and performance characteristics will **depend** on the number and effectiveness of these **fixes**.

The **ultimate goal** of the development test program is to meet the system **(DHC-8 Aircraft) reliability** and **performance** requirements.

Experience has shown that **programs** which rely simply on a **final demonstration** by itself to determine compliance with the reliability requirements **do not**, in many cases, achieve the reliability objectives with the allocated resources.

Emphasis on reliability performance prior to the final demonstration could substantially increase the chance of meeting these objectives.

This can be **accomplished** by the utilization of **reliability growth test/management**.

This involves **setting** interim reliability goals to be met during the development testing program and the necessary **allocation** and **reallocation** of resources to attain these goals.

A comprehensive approach to reliability **growth management** throughout the development program **consists of**;

- (1) planning,
- (2) evaluating,
- (3) controlling the growth process.

Reliability growth planning (prepared by the Seller/Contractor), shall **address** program schedules, amount of testing, resources available and the realism of the test program in achieving the **Buyer's requirements**.

The planning is qualified and reflected in the construction of a reliability growth program plan curve.

This curve establishes interim reliability goals throughout the program.

To achieve these goals it is important that the program manager be aware of reliability problems during the conduct of the program so that he can **affect** whatever changes are necessary, e.g., increased reliability emphasis.

It is, therefore, essential that **periodic assessments** of reliability be made during the test program (e.g., at the end of a test phase) and compared to the planned reliability growth values.

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These assessments provide visibility of achievement and **focus** on **deficiencies** in time to affect the system design.

By making appropriate decisions in regard to the timely incorporation of **effective fixes** into the system commensurate with attaining the milestones and requirements, management can control the **growth process**.

This document provides methodology and concepts to assist in reliability growth planning and a structured approach for reliability growth assessments.

The **assessment techniques** are based on demonstrated and projected values which are designed to realistically evaluate reliability in the presence of a changing configuration.

The planned growth curve and milestones are only **targets**. They do not imply that reliability will automatically grow to these values.

On the contrary, these values will be attained only with the incorporation of an adequate number of effective **design fixes** into the system.

This requires dedicated management attention to reliability growth.

The methods in this document are for the purpose of assisting in making timely and appropriate decisions to ensure sufficient support of the reliability engineering design effort throughout the development testing program.

14.1.5 Basic Reliability Activities

Reliability growth management is part of the system engineering process (MIL-STD-499).

It **does not** take the place of the other basic reliability program activities, (MIL-STD-785), such as predictions, apportionments, failure mode and effect analysis, stress analysis, and reliability demonstration tests.

Instead, reliability growth management **provides** a means of viewing all the reliability program activities in an integrated manner.

14.1.6 Reliability Growth Process

Reliability growth is the result of an **iterative design process**.

As **design matures**, it is investigated to identify actual or potential sources of failures.

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Further design effort is then spent on these problem areas.

The design effort can be applied to either product design or manufacturing process design.

The iterative process can be simply visualized as a feedback loop as in Figure 14.1.

This illustrates that there are three essential elements involved in achieving reliability growth:

- (1) Detection of failure sources,
- (2) Feedback of problems identified, and
- (3) Redesign effort based on problems identified.

Furthermore, if failure sources are detected by testing, a fourth element is necessary:

- (4) Fabrication of hardware.

Following redesign, detection of failure sources serves as:

- (5) Verification of redesign effect.

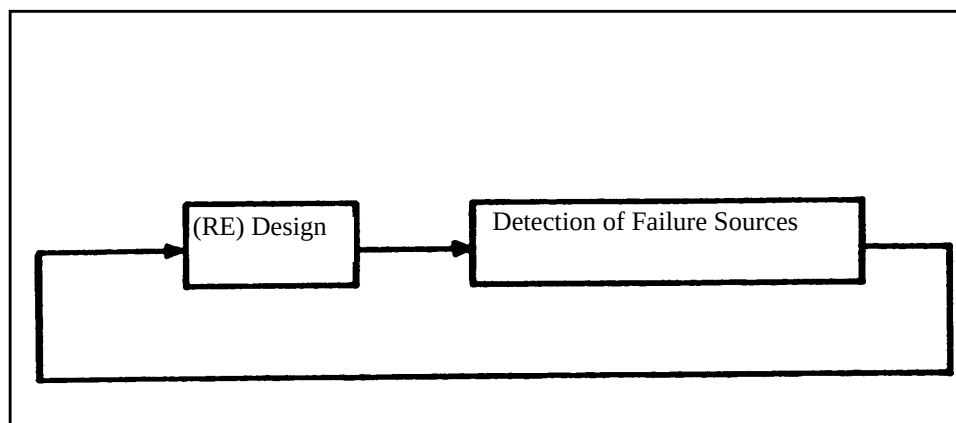


FIGURE 14.1: RELIABILITY GROWTH FEEDBACK MODEL

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14.1.7 Growth Rate

The **rate** at which reliability grows is **dependent** on how rapidly activities in this loop can be accomplished, how real the identified problems are, and how well the redesign effort solves the identified problems without introducing new problems.

Any of these activities may act as a bottle neck. The cause and degree of the bottleneck may vary from one development program to the next, and even within a single program may vary from one stage of development to the next.

14.2 APPLICABLE DOCUMENTS

14.2.1 Military Specifications

MIL-C-45662 Calibration System Requirements.

14.2.2 Military Standards

MIL-STD-280	Definitions of Item Levels
MIL-STD-721	Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety
MIL-STD-757	Reliability Evaluation from Demonstration Data
MIL-STD-781	Reliability Design Qualification and Production Acceptance Tests
MIL-STD-785	Reliability Program for Systems and Equipment
MIL-STD-810	Environmental Test Methods

14.2.3 de Havilland Inc

EPS-1-18	de Havilland Engineering Procurement Specification
DTRD-8-010	de Havilland Technical Requirement Document-General DHC-8 Series 400 Aircraft

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14.3 DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

14.3.1 Definitions

Meanings of terms not defined herein are in accordance with the definitions in MIL-STD-721, MIL-HDBK-472.

14.3.1.1 Corrective Action

A documented design, process, procedure, or materials change to correct the true cause of failure. Part replacement with a like item does not constitute appropriate corrective action.

14.3.1.2 Failure

Details involving failure criteria must be stated in the equipment specification and test procedures. For test purposes failure shall include:

- (1) The inability of an item to perform its required function within specified limits under stated conditions. Failure includes intermittent cessation of performance or lack of response to a command.
- (2) Mechanical or structural parts or components of an item broken, fractured, or damaged during environmental testing or operation within specified stress limits.

14.3.1.3 Environments

The conditions, circumstances, influences, stresses and combinations thereof, surrounding and affecting systems or equipment during storage, handling, transportation, testing, installation, and during use in standby status and mission operation.

14.3.1.4 Failure Analysis

The identification of the failure mode, the failure mechanism, and the cause (i.e., defective soldering, design weakness, contamination, assembly techniques, etc.).

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14.3.1.5 Mechanism of Failure

The original defect which initiated the failure or the physical process by which the degradation proceeded to the point of failure, identifying quality defects, internal, structural, or electrical weakness and, where applicable, the nature of externally applied stresses which led to failure.

14.3.1.6 Mode of Failure

The effect by which a failure is observed. Generally, describes the way the failure occurs and tells "how" with respect to operation.

14.3.1.7 Predicted Reliability

That reliability which is expected at some future date, postulated on analysis of the design and the failure rates.

14.3.1.8 Reliability Assessment

An estimate of the achieved reliability obtained by calculating using data gathered during tests.

14.3.1.9 Reliability Growth

The positive improvement of the reliability of equipment through the systematic and permanent removal of failure mechanisms, regardless of their sources, by taking corrective action.

14.3.1.10 Specified Mean Time Between Failures (θ_S)

The MTBF value specified in the equipment specification or contract.

14.3.1.11 Corrective Maintenance (repair)

The actions performed as a result of failure to restore an item to a specified condition.

14.3.1.12 Observed (Cumulative) Mean Time Between Failures (θ_C)

The observed MTBF is equal to the total operating time of the equipment divided by the number of relevant failures accumulated by that time (t).

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14.3.1.13 Predicted MTBF (θ_p)

Predicted MTBF is that value of MTBF determined by reliability prediction methods and is based on the equipment design and the use of environment (and shall be equal or greater than specified MTBF (θ_s) in value to ensure with probability that the equipment will be accepted during the reliability qualification test).

14.3.1.14 Test, Analyze, and Fix (TAAF)

A test procedure used during the development program to achieve reliability growth by testing the equipment under simulated use environments to induce failures due to weak design or inadequate parts.

The failures are analyzed and fixed, that is, corrective action is taken for each attributable/relevant failure to prevent recurrence.

14.3.1.15 Mission Profile

One segment of life-cycle profile, depicts the time span of the event, the expected environmental conditions, energized and non-energized periods, and so forth.

14.3.2 Acronyms and Abbreviations

AMSAA	Army Material Systems Analysis Activity
ATP	Acceptance Test Procedure
BIT	Built In Test
DHI	De Havilland Inc.
DHC	De Havilland Canada
ESS	Environmental Stress Screening
F ³	Form Fit and Function
FRACAS	Failure Reporting And Corrective Action System
FTP	Functional Test Procedure
MLS	Minimum Least Squares
MTBF	Mean Time Between Failures
RDGT	Reliability Development Growth Test

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TAAF	Test Analyze And Fix
TBD	To Be Defined
TRR	Test Readiness Review
UUT	Unit Under Test

14.4 GROUND RULES

14.4.1 Test Units

The units used for the reliability growth test shall be **preproduction** equipment.

Preproduction equipment shall be representative of production equipments to the extent possible in materials, configuration and workmanship.

Minor known anomalies are acceptable provided F^3 is not compromised. Anomalies and or concessions shall be stated to and agreed by DHI.

14.4.1.1 Test Article Construction

Test articles shall be **constructed** with fully screened parts and they shall be subjected to **environmental stress screening** as defined in ESS Procedure , **prior** to RDGT to remove defects in the test items and reduce subsequent test time

14.4.1.2 Test Timing

It is **imperative** that RDGT be conducted as soon as possible.

Delay forces corrective action into the formal configuration control cycle, which adds even greater delays for administrative processing of reliability engineering changes.

The cumulative delays may create retrofit problems later in the program and will impact the incorporation of the design corrections.

14.4.2 Test Time Accumulation

14.4.2.1 Test Length

The **test length** of individual equipments may deviate, and shall be defined in the test plan by the Seller.

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14.4.2.2 Acceptance Tests

Each equipment shall have completed **acceptance tests** prior to RDGT.

14.4.3 Malfunctions 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 to determine the cause of malfunctions and to identify possible design or part deficiencies.

14.4.4 Classification of Failures

14.4.4.1 Relevant / Non-relevant Failures

All failures occurring during reliability testing, after failure analysis, shall be classified as either relevant or non-relevant in accordance with the definitions of this document.

Based on the fault analysis, failure shall be justified as relevant or non-relevant.

14.4.4.2 Assumptions

The **RDGT model** assumes that a fix is incorporated immediately after a failure occurs (before further test time is accumulated).

14.4.4.3 Failure Selection

Only those failures occurring during the RDGT and classified relevant shall be used in computing equipment mean time between failure (MTBF) and for making reliability growth assessment.

14.4.5 Intermittent Operation

The **first occurrence** of an intermittent operation on any one item under test shall be classified as non-relevant.

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14.5 RDGT GENERAL / DETAILED REQUIREMENTS**14.5.1 Test Plan**

The contractor/seller shall prepare a Reliability Development Growth Test (RDGT) plan and obtain approval from the procuring or user activity prior to the commencement of testing.

The test plan shall reflect the requirements of the contract, equipment specification and this document.

Test planning shall consider the possibility of special tests to verify corrective action implementation and to obtain test data that reflect the effectiveness of corrective action implementation.

The **test plan** shall, as a minimum, include the following:

- (1) Test objectives and requirements including planned growth,
- (2) Test item description and number to be tested,
- (3) Test conditions, environmental, operational, and performance profiles, and the duty cycle,
- (4) Test schedules and milestones, including the test program review schedule,
- (5) Test conduct ground rules, failure criteria, interface boundaries, and "No Test" criteria,
- (6) Test facility and equipment descriptions and requirements,
- (7) Data collection and recording requirements,
- (8) Analysis requirements and methods of calculation,
- (9) Description of preventive maintenance to be accomplished during test, and
- (10) Final restoration and disposition of test items.

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14.5.1.1 Reliability Growth Models

As part of the reliability growth test planning, the contractor shall generate a reliability growth model based on previous development programs for systems/equipment of the same type as will be developed under the new procurement.

This is necessary to help determine the length of the reliability growth test period and to provide project management with a means of monitoring progress as the test proceeds.

Unless otherwise specified, the growth models of this documents shall be used.

14.5.2 Test Conditions and Stress Levels

The test levels shall describe the condition of temperature, vibration, humidity, equipment inputs (e.g., input voltage, hydraulic pressure, torque, etc.), and the cycling of these conditions to be applied to the test item(s) during the test.

The equipment inputs, the environmental conditions, and the combinations of environmental types and levels to be applied during tests and their variation as a function of test time, shall be as specified in the equipment or model specification and described in the **test plan**.

Since the **purpose** of reliability growth tests is to **induce** failures to uncover weakness in design and components, the **testing** shall be done under the conditions likely to be countered in **field use**.

Therefore, the stress types and levels shall be **selected** using the mission and environmental profiles and operational requirements as a guide.

Typical detailed requirements for specific categories of equipment are given in appendix B and E of MIL-STD-781 which cover the four types of test conditions.

The test conditions/levels shall be applied **simultaneously**, in so far as possible, and usually in a **cyclic** manner.

The specified test levels shall be tailored to the system or equipment mission and environmental profiles.

The **following conditions** are representative, but not necessarily all inclusive.

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14.5.2.1 Temperature

The temperature requirements, including temperature cycling shall be as specified in the equipment or model specification and described in the test plan.

Unless otherwise specified, a **thermal survey** shall be made in accordance with MIL-STD-781 prior to the start of the reliability development tests using the high and low storage temperatures as specified in the equipment or model specification.

14.5.2.2 Vibration

Unless otherwise specified, the test item shall be subjected to externally imposed random, pseudo-random, complex motion or acoustic vibration excitation.

The **levels**, tolerances and durations shall be as specified in the equipment specification.

The **mounting of the test** item shall be in accordance with MIL-STD -810, Method 514.

Unless otherwise specified, a **vibration survey** to determine test item resonances shall be made in accordance with the requirements of MIL-STD-810 prior to start of the reliability development tests.

14.5.2.3 Equipment Inputs

Unless otherwise specified, the inputs (voltage, hydraulic pressure, torque, etc.) to the test item shall be **varied** above and below the nominal values to the levels specified in the equipment or model specification.

Each input value (maximum, nominal, and minimum) shall be maintained for one-third of the equipment on time.

This cycling procedure is to be **repeated** continuously throughout the test as described in the approved **test plan**.

14.5.2.3.1 On-Off Cycling

For test purposes, the number of times that equipment will be turned ON for pre-operational checks or run-ups, plus the number of times turned ON and OFF from the completion of one operational mission to the completion of the next, shall be as specified in the equipment or model specification.

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Additional On-Off cycling for normal maintenance and repair shall not be included.

14.5.2.3.2 Duty Cycle

The equipment duty cycle, the time phase apportionment of modes of operation and function(s) to be performed by the test item during test, shall be as specified in the equipment or model specification.

Alternative duty cycles, when applicable, shall also be as specified.

14.5.2.4 Humidity

Humidity shall be as specified for condensation, frosting, and freezing conditions expected during service use of the equipment under test.

Humidity levels need not be controlled during the test but, at appropriate times during the test, moisture may be injected to obtain the specified condensation, frosting, or freezing conditions.

14.5.3 Test Facilities and Apparatus

Test facilities, chambers, and apparatus used in conducting the tests shall be capable of providing and maintaining the conditions specified for the applicable test levels.

The test facilities and apparatus shall be described in the test plan.

14.5.3.1 Tolerance of Test Conditions

Unless otherwise specified, tolerances of test conditions shall be as specified in MIL-STD-810.

14.5.3.2 Accuracy of Test Apparatus

The accuracy of instruments and other test equipment used to control or monitor the test parameters shall be verified periodically in accordance with the requirements of MIL-C-45662 and to the satisfaction of the procuring or user activity.

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14.5.4 Performance of Test

The electrical and mechanical performance outputs and characteristics to be monitored and measured before, during, and after the tests, including the quantitative range of acceptable performance for each parameter, shall be as defined in the equipment or model specification and described in the test plan.

Any performance outside these limits shall be recorded as a problem or failure, whether or not the equipment ceases to operate.

14.5.4.1 Pretest Performance

Unless otherwise specified, prior to conducting any test, the test item shall be tested and a record shall be made of all data to determine compliance with required performance and to provide reference levels or criteria for checking desired performance of the test item during and at the conclusion of the tests.

The pretest performance check may be made after installation of the item in the test facility if installation conditions necessitate it.

14.5.4.2 Installation of Test Item in Test Facility

Unless otherwise specified, the test item shall be installed in the test facility in the manner described in MIL-STD-810.

The equipment to be tested shall be installed in the test facility in a manner which is representative to the extent possible of the typical field installation.

Any deviation shall be advised to and agreed with Buyer.

After test item installation, the equipment and the test facility shall be operated to determine that the test set-up operates properly under the required test conditions.

14.5.4.3 Performance During Test

The performance measurements taken during the test shall be as specified in the equipment or model specification and described in the test plan.

The specified measurements taken during the test shall be compared to the pre-test data to determine whether test exposure is producing changes in performance.

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The specified performance parameters shall be monitored so as to record problems or failures at the time they occur during the duty cycle.

Periodic monitoring schemes appropriate to operational use may be used when approved by the procuring activity.

Built-in-test (BIT) included as part of the equipment design shall be used as part of the problem or failure detection method.

14.5.4.4 Post-test Performance

Unless otherwise specified, the test item shall be tested at the completion of the test, and a record shall be made of all data, and the results compared to the pretest data to determine any change in performance.

14.5.4.5 Maintenance

Maintenance during this test shall be limited to repair of failures, correction of failures, and the preventive maintenance specifically defined in the test plan.

If parts are replaced based on the preventive maintenance defined in the test plan, such replacement shall be classified as a failure and appropriate action shall be taken, but such failure shall not be counted for purposes of the reliability assessment.

Adjustments of controls which could not be accomplished readily during a mission shall be classified as a failure and appropriate action shall be taken.

Unless otherwise specified, the maintenance time for each problem, failure, or maintenance action shall be documented for inclusion in the final report.

The maintenance time shall be subdivided into the following categories as defined in MIL-HDBK-472:

- (1) Localization,
- (2) Isolation,
- (3) Disassembly,
- (4) Interchange,
- (5) Reassembly,
- (6) Alignment,

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(7) Check-out,

(8) Total.

14.5.4.6 Test Records

Test records shall be maintained continuously and as specified in the equipment or model specification and described in the test plan.

When not specified, they shall be maintained in general accord with the following:

14.5.4.6.1 Test Log and Data Record

The test log and data record shall be a complete record of required test data for each item under test and shall be maintained throughout the test.

The format shall permit ready reference of the test history of each test item.

Completed test log sheets may be duplicated but not recopied prior to submission to the procuring activity.

An entry shall be made in the test log and data record each time a test item is checked.

The date, time, time meter reading, the environmental conditions, and the exact values of any parameters measured shall be recorded.

14.5.4.6.2 Test Item Failure Record

A failure record shall be maintained for each test item. The record shall be designed to permit keeping the entire test history of each test item on a single sheet so that widely divergent differences in test behavior between test items may be easily recognized.

The test item problem and failure record shall be prepared as described in the test plan and an entry made on the occurrence of each problem or failure.

14.5.4.6.3 Failure Tag

A failure tag shall be affixed to the test item immediately upon detection of any problem or failure.

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The failure tags will provide space for the problem and failure report serial number and for other pertinent entries from the test log and test item failure record.

Failure tags shall be prepared as described in the test plan.

14.5.5 Test Items

The test items for the reliability development tests shall be defined in the Reliability Development Test Plan.

The number of items to be tested shall be as specified in the equipment specification, or in the test plan.

Test units for the RDGT shall be preproduction equipment, representation of production equipments to the extent possible in materials, configuration, and workmanship.

The Units Under Test (UUT) shall be the latest configuration and screened for parts and workmanship defects.

Each UUT shall have completed Burn-In, and Acceptance Test prior to beginning the RDGT.

Test units shall represent the current design with all engineering changes incorporated; no further engineering changes should be made unless based upon the conduct of RDGT, until its completion.

The number of items selected for test shall be based on equipment complexity, program needs, and the program schedule, and shall be specified in the contract or equipment specification, (see also Para. 14.5.6).

14.5.6 Test Length

The **total test time** (cumulative hours, cycles, etc.) for the reliability growth tests shall be as specified in the equipment specification and/or test plan.

The test shall be a **fixed length** test based on the mission profile and the life and the operational characteristics of the equipment.

Unless otherwise specified, when **two or more** test items are used, the minimum operating time for each test item shall be **not less** than one-half the average operating time for all items on test.

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The total test time devoted to reliability growth testing shall be based on the reliability growth model, the experience of the contractor, and the quantitative requirements of the equipment's reliability specification.

The test length shall be approved by the Buyer (as part of the test plan) before testing starts.

It will be the maximum time expected to achieve the growth in the current reliability necessary to reach the predicted reliability (usually in term of MTBF).

14.5.7 Test Cycle (typical)

Unless otherwise specified, the **test cycle** shown in Figure 14.2 and Figure 14.3 described below shall be used as a guide.

The particular operating and storage temperatures, vibration levels, rates and frequency of change, and equipment ON-OFF and duty cycles shall be as specified in the equipment or system specification and described in the test plan.

- (1) With test item OFF and vibration OFF, **cool** chamber to the low storage temperature and allow equipment temperature to stabilize (cold soak).
- (2) When test item temperature has stabilized at the low storage temperature, **heat** chamber to low operating temperature, **turn** test item ON and perform specified number of pre-operational checks or run-ups.
- (3) Upon completing the pre-operational checks, **heat** chamber to high operating temperature with test item ON and vibration ON and commence specified duty cycle for time specified, or if no time is specified, for two(2) hours.

Unless otherwise specified, the chamber temperature shall be cycled between the upper and lower operating temperatures of the equipment during this portion of the test cycle at the specified rate and frequency of change.

- (4) Upon completing the duty cycle period, **turn** test item and vibration OFF, **heat** chamber to the high storage temperature, and allow test item to stabilize (hot soak).

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- (5) When test item temperature has stabilized, **cool** chamber to high operating temperature, **turn** item ON and perform the specified number of pre-operational checks or run-ups.
 - (6) Upon completing specified number of preoperational checks, **cool** chamber to the low operating temperature with test item ON and vibration ON and commence specified duty cycle for the time specified, or if no time is specified, for two (2) hours.

Unless otherwise specified, the chamber temperature shall be cycled between the upper and lower operating temperatures during this portion of the test cycle at the specified rate and frequency of change.

- (7) Upon completing the duty cycle period, **turn** test item and vibration OFF and **repeat** cycle from (1) above.

14.5.8 Other Specified Tests

The data acquired during other tests described in the equipment or system specification shall be used to monitor reliability growth.

The data obtained from all testing shall be included in the planned failure reporting and corrective action system

Failure modes associated with system interfaces that are identified during testing shall be reported.

14.6 RELIABILITY GROWTH ASSESSMENT METHOD

14.6.1 Planned Growth Curves

Development of the planned growth curve shall be an application of the "lessons learned" from previous program experiences to predict the growth that can be expected in the new program.

When hard reliability data have begun to be generated (RDGT data), the results shall be compared with the predicted values given by the planned curve to determine if the reliability growth is progressing satisfactorily.

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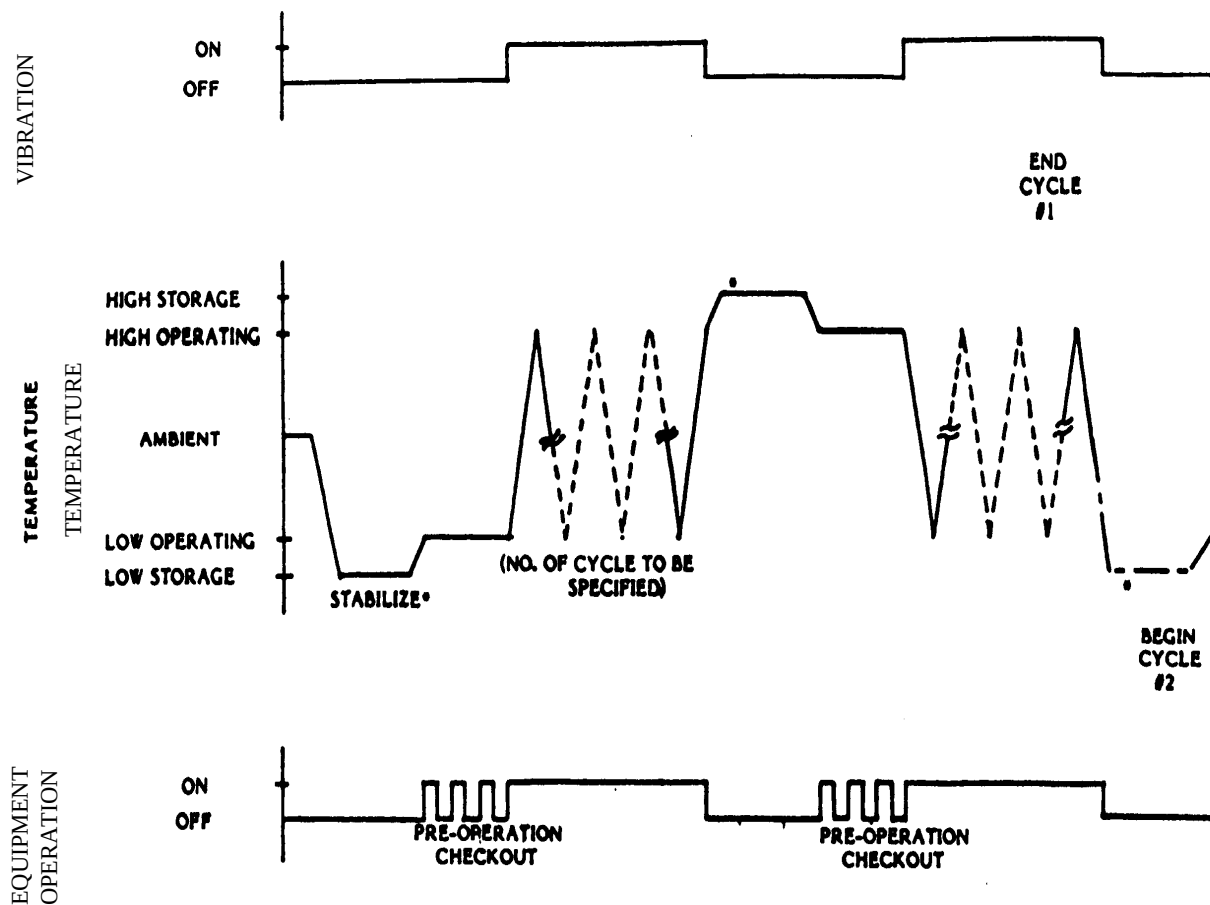
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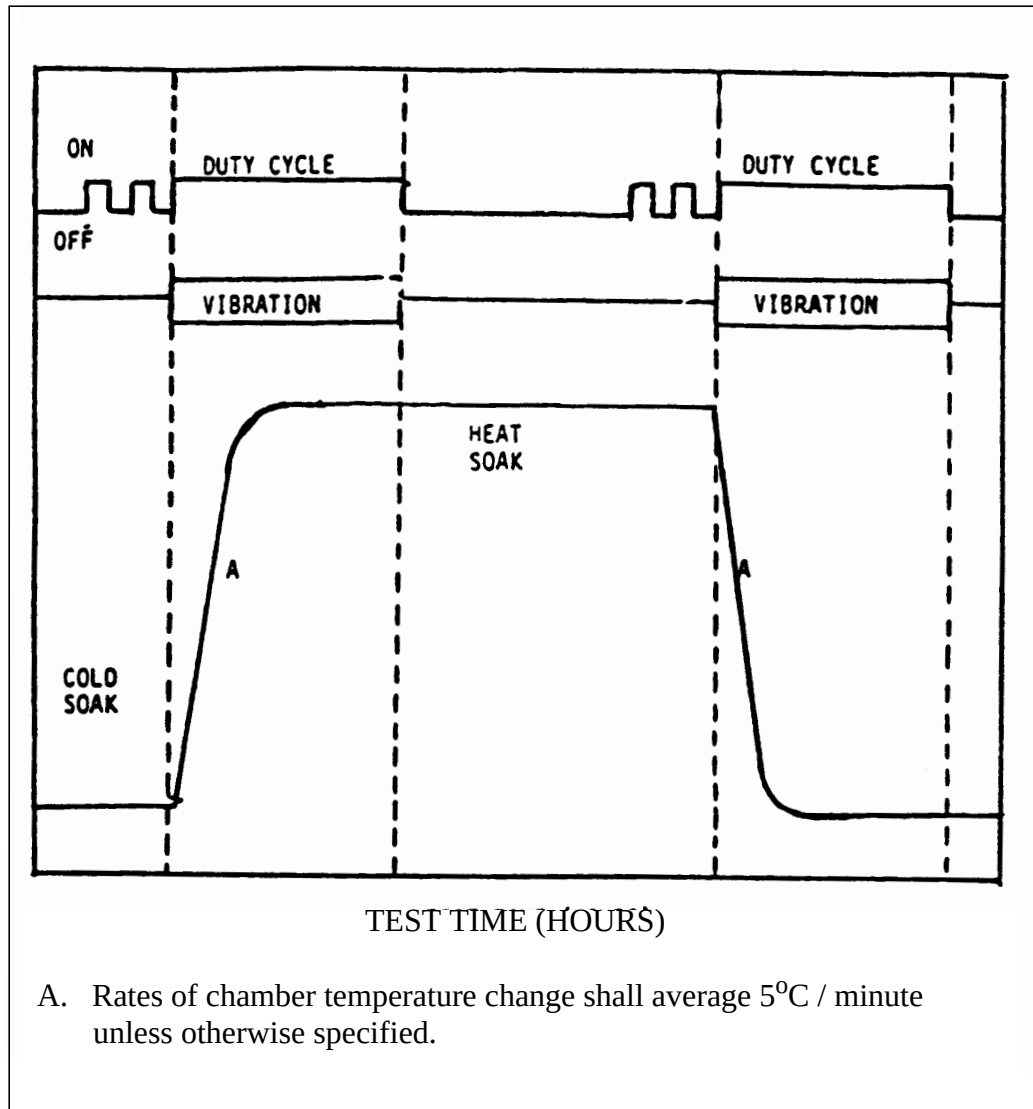
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DUTY CYCLES

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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14.6.1.1 General Development of the Planned Growth Curve

The detailed planned growth curve provides, as precisely as possible, the phase-by-phase development of reliability improvement that is expected.

Each test phase must be carefully considered to determine the type of testing that will be conducted and the impact of the fixes that can be anticipated.

The role of the idealized growth curve is to substantiate that the planned growth follows a learning curve which, based on previous experience, is reasonable and can be expected to be achieved.

The following paragraphs describe how planned growth curves may be developed for specific programs.

Every program can, however, be expected to require some modification of the suggested procedures.

14.6.1.2 General Concepts for Construction

In general, there are two basic approaches for constructing planned growth curves.

The first method is to determine the idealized growth pattern that is expected or desirable, and to use this as a guide for the detailed planned curve.

The second method is just the reverse.

In this case a proposed planned curve is first developed which satisfies the requirement and interim milestones.

The idealized curve is then constructed and evaluated to determine if this learning curve is reasonable when compared to historical experience.

If not acceptable a new detailed curve would need to be developed.

14.6.1.3 Understanding the Development Program

Development of planned growth curves requires a fairly complete understanding of the proposed development program, particularly the reliability program and all other program activities and constraints that will affect reliability.

In the case of mechanical equipment, an understanding of the hardware is useful in evaluating the delays that should be associated with design changes.

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For complex test programs a logic diagram should be used to show the relationship between those phases in which failure modes will be found and those phases which will have the resultant “fixes” in the hardware.

The expected policy for incorporating fixes must be understood.

For systems with high reliability, the expected number of failures during the test program should be determined to give an indication of the number of fixes that can be anticipated.

For initial estimating purposes this may be based on the starting MTBF.

14.6.1.4 Portraying the Program in Total Test Units

Although the planned growth curve is usually portrayed in final form as a function of calendar time for management use, the analytical development of the curve is done as a function of test units.

Test units may be hours, miles, rounds, or similar units; and in some cases, the use of multiple units (e.g., both miles and rounds) may be appropriate.

14.6.1.5 Determining the Starting Point

The initial reliability for a system under development will typically not be known at the time when the planned curve is developed.

A starting point for the planned growth curve may, however, be determined from:

- (1) using information from previous programs on similar systems,
- (2) specifying a minimum level of reliability that management requires to be demonstrated early in order to have assurance that the reliability goals will be met, and
- (3) conducting an engineering assessment of the design together with any previous test data that may exist, e.g., bench test, prototype test.

The practice of arbitrarily choosing a starting point, such as 10% of the requirement, is not recommended.

Every effort to obtain information even remotely relevant to a realistic starting point should have been exhausted before an arbitrary figure can be used.

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14.6.1.5.1 Example of Determining a Starting Point

A planned growth curve is to be developed for a system/equipment development program.

One of the first steps in this process is to determine a starting point for this curve.

To establish a starting point, the reliability growth experience of a predecessor system is analyzed.

It is found that an initial MTBF of 183 hours was demonstrated during early engineering development.

The predicted MTBF was 580 hours. So, at this point in development, the achievement was $183/580 = 0.32$ of predicted.

The system under development has about the same degree of design maturity as did its predecessor; but since the reliability program emphasis is somewhat greater, it is expected that perhaps 0.35 of the prediction, rather than 0.32 will be achieved.

With a prediction of 410 hours for the current system, $0.35(410) = 143$ would be expected as a **starting point**.

To further rationalize this estimate, some pre-development testing of the proposed system resulted in 5 failures in 493 hours.

No significant design changes were incorporated during test, so the MTBF may be estimated as $493/5 = 99$ hours.

Some design change is planned prior to engineering development testing.

It is also estimated that the design changes will be 70% effective.

The MTBF expected on entering engineering design testing is then $493/(5-(0.7)(2)) = 137$ hours.

This value gives additional support to the estimate of 143 hours.

14.6.1.6 Development of the Idealized Growth Curve

During development, management should expect that certain levels of reliability be attained at various points in the program in order to have assurance that reliability growth is progressing at a sufficient rate to meet the requirement.

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The idealized curve portrays an overall characteristic pattern which is used to determine and evaluate intermediate levels of reliability and construct the program planned growth curve.

Growth profiles on previously developed, similar type systems provide significant insight into reliability growth process and are valuable in the construction of idealized growth curves.

Reliability growth information on previous programs should be used whenever possible to develop the idealized curve directly or as input into a model for development of the idealized curve.

14.6.1.6.1 Concept

If documented reliability histories for similar type systems are not available to provide a basis for the idealized curve of the system under consideration, then a general method based on the learning curve concept is an alternative.

If the learning curve pattern for reliability growth assumes that the cumulative failure rate versus cumulative test time is linear on log-log scale, then the following method is appropriate for construction of the idealized growth curve.

This method is based on the test phase structure of a development test program for reliability growth. This approach gives a realistic method for placing the initial MTBF at the proper point in time and portrays a growth pattern which has a meaningful interpretation in terms of test phase reliability growth.

14.6.1.6.2 Summary of Method

The idealized growth curve $M(t)$ discussed in this section has the form shown in Figure 14.4 and portrays a general profile for reliability growth throughout system testing.

The idealized curve has the baseline value M_I over the initial test phase which ends at time t_1 .

The value M_I is the average MTBF over the first test phase. From time t_1 to the end of testing at time T , the idealized curve $M(t)$ increases steadily according to a learning curve pattern till it reaches the final reliability requirement M_F .

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The slope of this curve on the log-log plot in Figure 14.4 is the growth parameter α .

The parametric equation for $M(t)$ on this portion of the curve is;

$$M(t) = M_I \left(\frac{t}{t_1} \right)^\alpha (1 - \alpha)^{-1}$$

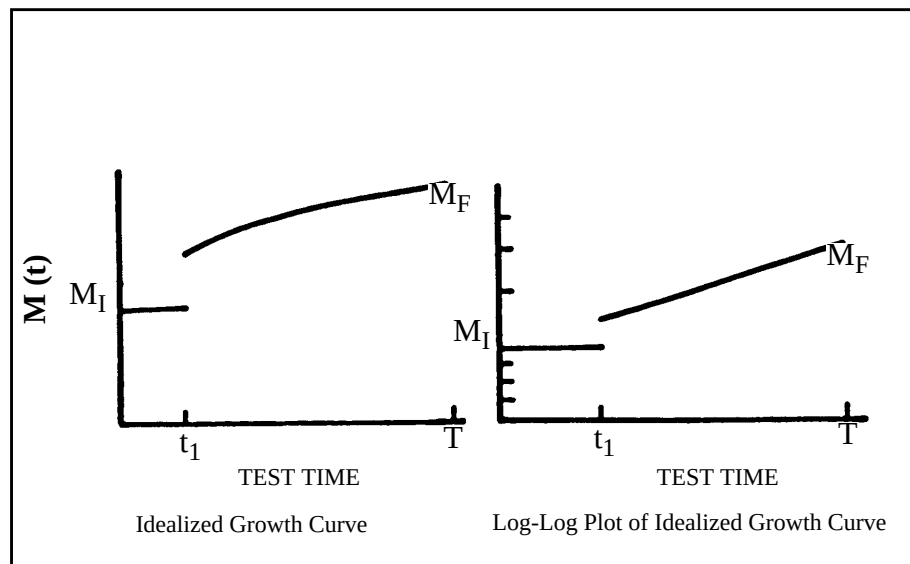


FIGURE 14.4: IDEALIZED GROWTH MODEL

14.6.1.6.3 Basis of Model

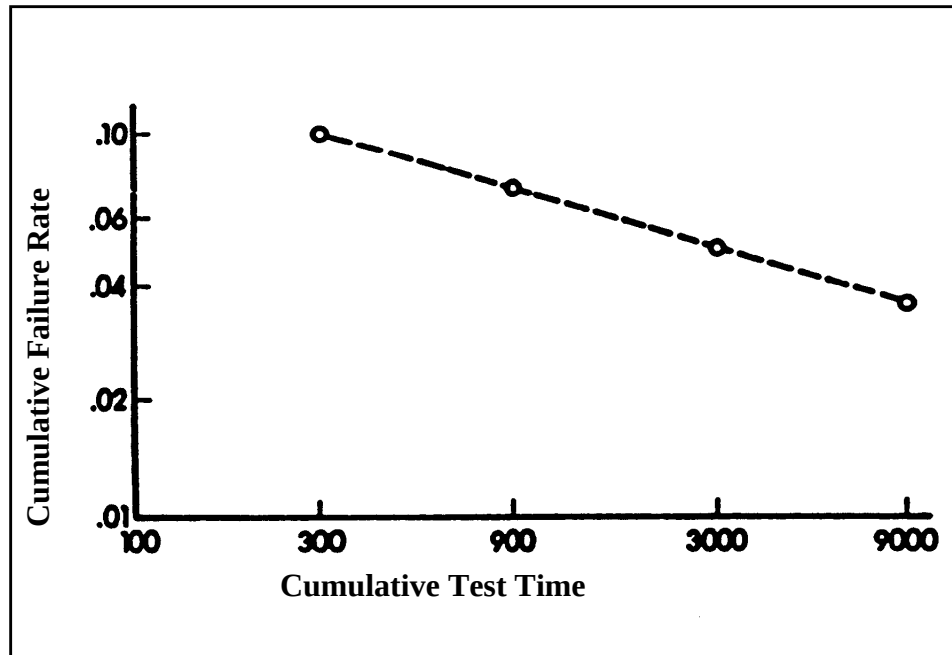
This model assumes that the cumulative failure rate versus cumulative test time is linear on log-log scale when plotted at the end of test phases or reporting periods. See Figure 14.5.

It is not assumed that the cumulative failure rates follow the same pattern within test phases.

In fact, if delayed fixes are incorporated into the system at the end of a test phase, or the reliability is held constant during a test phase, then this linear pattern within test phases would not hold.

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**FIGURE 14.5: EXAMPLE OF LOG-LOG PLOT****14.6.2 Demonstrated and Projected Reliability Values**

It is important that management have realistic demonstrated and projected reliability assessment for the system during development testing.

The demonstrated value provides a reliability estimate for the system configuration on test at the end of a phase.

This value is determined from an analysis of the actual test results. A projected reliability value estimates the system reliability expected at some future point.

A projection can account for the effect of fixes that either may have been introduced into the system very late in the test and such have not been fully reflected in the test data, or for fixes that are upcoming, such as delayed fixes between test phases.

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The demonstrated reliability value may be calculated utilizing the following techniques:

- (1) reliability growth analysis or,
- (2) engineering analysis.

When appropriate, the reliability growth analysis is the preferred method since it provides an objective mathematical assessment of the reliability of the system being tested.

The reliability growth method measures the effect that individual fixes that have been incorporated during testing have had on system reliability, and provides credit for fixes in the determined reliability value, if they have in fact proven to be effective.

It should be noted that if no fixes are incorporated during testing, then reliability growth procedures would not be necessary and the demonstrated reliability value would be determined by dividing the total test time/cycles, etc., by the number of charged failures.

In addition, if a situation arises where the reliability growth procedures cannot be applied to the test data because of data anomalies, then a method known as engineering analysis may be used for determining the demonstrated reliability.

The engineering analysis method is subjective, and will, therefore, tend to be less definitive than a data analysis based on reliability growth procedures.

The engineering analysis technique involves using engineering judgment to assess the effectiveness of fixes that have been incorporated during the test program in determining the demonstrated reliability value.

In this method, the status of charged failures will be evaluated to determine if their chargeability is changed based on the effectiveness of fixes introduced during the test program.

For the chargeability of a failure to change there must be concrete evidence based on test data that the failure rate has been reduced in the operational environment and that it does not create any new failure modes.

Useful criteria for determining if the chargeability of a failure has changed are the following:

- (1) failure analysis adequacy,
- (2) appropriateness of corrective action,

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- (3) demonstration of corrective action,
- (4) verification of effectiveness of corrective action,
- (5) verification of future implementation of corrective action

If the above has been satisfied, i.e., concrete evidence has been presented that a failure mode has been partially or completely eliminated, then the chargeable status of a failure(s) may be changed and a demonstrated value based on revised failure rates for these failure modes may be computed.

In most cases a fix will not completely remove a failure mode from the system. If the rate of occurrence of a particular mode has been reduced to a lower rate, but the mode has not been eliminated, then the failure rate estimate for the mode should be adjusted accordingly to a lower value, but not reduced to zero.

The adjustments made to the failure rates should be based on fixes that have been verified by test (component, subsystem, and/or system) as effective.

If the effectiveness of a fix cannot be verified by test, then any subjective evaluation of the impact of the fix on reliability should be reflected in a projected value but not a demonstrated value.

A projected reliability value is a particularly important consideration when the demonstrated value determined at the end of a phase is found to be below an intermediate requirement and as a result management is very much interested in determining if the final requirements will be achieved with the current test program.

In the situation where the demonstrated reliability value is meeting intermediate requirements, it still may be desired to compute a projected value to provide an indication of the system reliability at some future point in the test program.

A projected reliability value may be calculated by extrapolating a growth model or by assessing the impact of fixes (those introduced late in the test phase or those introduced after the end of the test phase).

The extrapolation of a growth model to obtain a projected value would normally be conducted if the test-fix-test level of effort in the ensuing test program is going to be about the same as in the past.

However, if a substantial amount of fixes are going to be made before the next test phase or if the test-fix-test level of effort is going to increase substantially because the demonstrated reliability estimate is considerably below current

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thresholds, then the extrapolation technique is unsuitable and an analysis of the impact of the fixes on reliability should be the method utilized.

In determining the **impact** of fixes on reliability, a number of **methods** may be implied. These include:

- (1) determine the effect that previous fixes have had on system reliability and use the fix effectiveness rate determined for assessing the impact of future fixes,
- (2) from similar systems establish the fix effectiveness rate and apply this rate to the system under test or,
- (3) assume a varying fix effectiveness rate (e.g., 25%, 50%, 75%) and determine the projected reliability estimate utilizing these rates.

It should be emphasized that not all fixes will be effective to the same degree.

Some fixes will almost entirely eliminate a failure mode (relatively rare), other fixes will reduce the rate of occurrence (but not to zero), and some fixes may introduce other new failure modes.

14.6.2.1 Data

If reliability growth is occurring, this will be reflected in the fact that the intervals between successive failure times are tending to increase as development testing continues.

Similarly, if negative growth is occurring, these intervals will be getting, on the average smaller.

For no growth the intervals can be expected to be, on the average, the same length. Therefore, to measure the growth trend, early failures as well as late failures are needed for comparison.

In general, all failure times, in their chronological order (even those with fixes incorporated into the hardware) are needed for evaluating reliability growth.

There should be no purging of the data. The estimation of the growth rate and system reliability shall involve the utilization of a reliability growth model.

Clearly, the data must be consistent with the failure definition under consideration.

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Reliability growth, of course, can be evaluated regardless of the type of failure being evaluated (e.g., flight failures, system failures, etc.).

Also major subsystems as well as the entire systems can be tracked. It is often useful to track the individual prototypes separately to determine if any significant differences in performance exist.

For example, it is not unusual for some prototypes to receive fixes well before other prototypes or for prototypes to exhibit different failure rates as a result of the test time on the prototypes (e.g., a new prototype might be exhibiting failures associated with burn-in while a prototype that has been under test for an extensive time may no longer be exhibiting burn-in failures).

In general, time to failure data are preferred over data in which the time of each failure is unknown and all that is known is the number of failures that occurred in each period of time (grouped data).

Time to failure data will obviously provide more information for estimating system reliability and growth rates.

14.6.2.2 Data Plots

A plot of the data for the test phase is an initial and basic step in reliability growth analysis.

A plot of the data will often indicate a trend, if one exists. Of interest also is whether or not any major jumps in reliability have occurred or if there is a change in the growth rate which may be caused, for example, by different test conditions, the introduction of a new system with a high initial failure rate, or the incorporation of delayed fixes.

A simple plotting method is to calculate average failure rates over the cumulative time on test T .

To construct an average failure rate plot, partition the cumulative time T into K subintervals with lengths, $T_1, T_2, \dots, T_K$.

If N_i is the number of failures in the i -th subinterval, then

$$\lambda_i = N_i / T_i$$

is an estimate of the average failure rate over this subinterval.

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If growth is occurring, then the λ_i 's should tend to decrease. If there is a major jump in the reliability due to a design change, this would be reflected in a large difference in an adjoining pair of λ_i 's, if sufficient data exists. More details are given in the sections below.

14.7 RELIABILITY DEVELOPMENT/GROWTH TEST (RDGT) ANALYSIS METHODS

1) The Duane Method

This method makes use of graphical and nonstatistical technique which provides a pictorial presentation of the changes occurring in the measured reliability parameter.

Numerical estimates of the reliability parameter also can be obtained.

2) The AMSAA Method

The AMSAA model was selected for inclusion in this document because it is an analytical model which permits confidence interval estimates to be computed from the test data for current and future values of reliability (MTBF) or failure rate (λ), (this method shall be used only when the Duane method is not applicable).

In addition, the model can be applied to either continuous (time) or discrete (cycles, rounds) reliability systems, single or multiple systems, and tests which are time or failure truncated.

14.7.1 The Duane Method

The Duane Method is a **graphical technique** which is useful in the analysis of reliability growth test data.

The technique is quick, simple, and easy to apply. The Duane plot or graph can depict facts that may be hidden by a purely statistical analysis.

For example, a goodness-of-fit test may call for rejecting the AMSAA model, but will not indicate possible reasons for the rejection.

A plot of the same data may indicate some reason for the problem. However, the reliability parameters cannot be estimated by the Duane Method as well as they can by a statistical model and of course no interval estimates can be computed.

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In addition, the Duane plot uses straight line which is fitted by eye to the data points.

The graphical and statistical methods should be viewed as complementary techniques.

This **model is based on the premise** that, if corrective actions are implemented during the course of the development test program, the reliability growth (in terms of MTBF improvement) is approximately proportional to the square root of cumulative test (operating) times.

With MTBF plotted on log-log paper, using MTBF as the ordinate and the cumulative test time as the abscissa, reliability growth approximates a **straight line**.

The **slope** of the line, m , is a measure of the **growth rate**.

A lower slope than 0.3 would indicate a relatively poor failure corrective action plan and a slope of 0.1 would represent no planned reliability growth program.

A slope of **0.6 to 0.7** represents the **maximum growth rate** to be expected when strong failure analysis and corrective action implementation activities are carried out in conjunction with the test program.

The **growth rate** that can be expected for a particular equipment depends on the complexity of the hardware, the experience of the manufacturer in developing such hardware, and the efficiency of his failure analysis and corrective action system.

The steps in developing a reliability growth test model are:

- (1) **Using** two or three cycle log-log paper, **draw** horizontal lines at the required MTBF value and at the predicted MTBF value,
- (2) **Plot** growth curve start point at 100 test hours and 10% of predicted MTBF value (for MTBFs of 200 hours or less).

If the predicted MTBF is greater than 200 hours, the growth curve should start at a test time equal to 30-50% of the MTBF.

- (3) **Draw** a line representing selected growth rate (which determines the slope of the line, m). The selected growth rate curve is considered the base line against which reliability growth can be evaluated during the reliability development test.

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- (4) The **intersection** of the selected growth rate curve and required MTBF line yields an approximation of **total test time** required.

During actual testing, cumulative values of MTBF versus cumulative test hours are plotted and compared with the selected growth rate curve.

Assessment of the reliability growth is described in Para. 14.7.1.7

14.7.1.1 Symbols

The symbols used in the equations of the Duane Method are:

$C(t)$ = expected number of failures in (t) units of development testing divided by (t),

$F(t)$ = expected number of failures in (t) units of development testing,

m = slope of the Duane plot,

λ = reciprocal of the ordinate of the Duane plot at (t) = 1

$\theta(t)$ = current MTBF,

$r(t)$ = current failure rate,

λ_i = average failure rate of grouped data in interval (I).

14.7.1.2 Construction of a Duane Plot

The Duane plot can be **constructed** as specified in **steps** (1) through (7):

- (1) The Duane model can be expressed in the form:

$$C(t) = \lambda \cdot t^{-m}$$

where:

$$C(t) = \frac{F(t)}{t}$$

Since $F(t)$ is the expected number of failure experienced by the system during (t) units of development testing, it can be estimated by $N(t)$, the observed number of failures during the testing of (t) units. Therefore,

$$N(t)/t = \lambda \cdot t^{-m}$$

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is the observed relationship. This may be expressed as a linear relationship, suitable for plotting, by taking logarithms.

$$\ln[N(t)/t] = \ln(\lambda) - m \cdot \ln(t)$$

However, since it is easier to visualize growth as an upward sloping line, a more commonly used relationship is:

$$\ln[t/N(t)] = m \ln(t) - \ln(\lambda)$$

- (2) As the testing progresses, record is kept of (t), the total units of operation accumulated among all the systems (see Table 14.1).

Thus, if three systems have been tested for 100 hours each, $t=300$.

Record also is kept of $N(t)$, the cumulative number of failure experienced during the (t) units of operation.

- (3) At selected values of (t), the quantity $t/N(t)$ is computed.
- (4) Using full log graph paper, the values of (t) and $t/N(t)$ are plotted on the abscissa and ordinate, respectively.
- (5) If the plotted points form a reasonable **straight line**, it can be concluded that the **Duane model** is a reasonable method for describing the growth pattern observed.
- (6) After fitting a straight line through these points, (λ) may be **estimated** by the reciprocal of the ordinate at $(t)=1$.

The **parameter (m)** may be estimated by the arithmetic slope of the line. Each successive point contains all the information contained in earlier points.

Therefore, the **most recent point** should be given **heaviest** weight in plotting the line.

- (7) An estimate may be made of the current values of MTBF, $\theta(t)$ and the failure rate $r(t)$ by means of the relationships;

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Any extrapolations beyond the test period are sensitive to the assumption of using the Duane model, and make the additional assumption that the program effort is to remain constant in the ensuing period.

The analysis data from several identical systems being tested simultaneously may be complicated by the fact that design modifications may not be introduced on all systems simultaneously.

This will result in a mixture of configuration ages which will make data analysis more difficult.

14.7.1.3 Problems of plotting average failure rate

One **disadvantage** of plots, such as the Duane plot which uses cumulative measures, is the fact that the most recent data tends to get buried when it is combined with all the previous data.

Plotting the average failure rate of selected intervals eliminates this problem. The lack of cumulative smoothing, however, does not make the average failure rate plot much more sensitive to sampling variation.

The average failure rate (λ_i) over any time interval is the number of failures in the interval (n) divided by the total operating time in the interval (T_i).

$$\lambda_i = \frac{n_i}{T_i}$$

The choice of intervals is arbitrary, but they should be small enough to reflect trends, yet large enough to afford some smoothing.

The **average failure rate** is plotted as a horizontal line for the appropriate interval.

If the plotted points form a reasonable straight line it can be concluded that the Duane model is a reasonable method for describing the growth pattern observed.

After fitting a straight line through test points, the parameter (m) will be determined by the arithmetic slope of the line.

Though the Duane method is a graphical and nonstatistical technique, **statistical analysis** may be applied for better evaluation as:

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- (1) Regression Analysis using MLS (Minimum Least Squares) technique for better goodness-of-fit of test data and a best fit of the linear model.
 - (2) Confidence interval estimation for the model parameters, slope and intercept, from the test data.
 - (3) Statistical Hypothesis testing for the model and for its parameters, (statistical significance of the parameters), using F-test and t-test.

14.7.1.4 Growth Rate Factors

The **slope** of the line, (m), is a measure of the **growth rate**.

Where a systematic and deliberate reliability improvement effort is being made, m is usually found to be in the range 0.3 to 0.6. The value is;

- (1) Higher for analog hardware than for digital hardware.
- (2) Higher in equipment of low maturity than in production hardware.
- (3) Higher in equipment exposed to severe test conditions than equipment (for example) undergoing bench tests (in other words; the ability to detect a problem is directly related to the ability of a particular test program to cause the failure to occur).

The **growth rate is influenced by:**

- (1) The systematic and permanent removal of failure mechanisms through taking corrective action.
- (2) The rate and efficiency in failure removal.
- (3) The statistics of the underlying distribution of failure mechanisms whose failure rates prevent the initially released system from achieving its full potential.

Removal of every systematic failure mechanism from a uniformly distributed set of sources results in a growth slope of **m=0.6**.

Removal of alternate failure mechanisms from the same source distribution causes a growth slope of **m=0.23**.

14.7.1.5 Removal of Systematic Failure Mechanisms

Available data from industry show conclusively that products initially released for manufacture exhibit a MTBF that is near 10 percent of the inherent product capability as predicted from parts performance.

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If M_p is the predicted MTBF, $M_p/10$ is the initial performance and $10 \lambda_p$ is the initial failure rate. Furthermore, regardless of the underlying failure distribution, the initial performance is evidently $M_p/10$.

This fact implies that the underlying distribution is bounded, constrained, such that the sum of the failure rates of all the systematic failure mechanisms which dilute equipment early performance and the non-pattern failures which one accepts and identifies as λ_p is $10\lambda_p$, that is:

$$\lambda_s + \lambda_p = 10\lambda_p$$

Thus, $\lambda_s = 9\lambda_p$

These systematic, or pattern, failure mechanisms have an associated failure rate λ_s that is relatively close to the equipment failure rate λ_p , which is several orders of magnitude above and, therefore, distinguishable from the failure rates of the parts themselves.

The removal of these systematic failures through an orderly and planned program of test, analyze, and fix (TAAF) is one of the **basic principles** of reliability growth management.

As the systematic failures are removed and corrected, the MTBF of the equipment will approach the predicted MTBF, or $1/\lambda_p$, based on part failure rates adjusted for actual use environments.

These real-life considerations have led to the conclusion that a practical achievable upper growth limit of **m** is 0.6, a number borne out by extensive reliability test data on a variety of electronic and electromechanical products.

14.7.1.6 Notes on Plotting

In general, only data points corresponding to the occurrence of failures should be retained on the analysis plot for the purpose of determining slope.

For presentation purposes it is desirable to update to time now and plot a point which includes all of the test time accumulated up to time now, even though the last failure occurred some time ago.

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This is a reasonable procedure for presentation but yields (theoretically) a slightly optimistic point which does not have the same information content as a failure point, and should not be included in curves used for slope determination.

When fitting a straight line to a Duane plot, the cumulative nature of the data points should be borne in mind.

The later points, having more information content, must be given more weight than earlier points, and the normal curve-fitting procedure of drawing the line through the center of gravity of all the points should not be used.

Unless the data is exceptionally noisy, the best procedure is to start the line on the last data point and seek the region of highest density of points to the left of it.

14.7.1.6.1 What to Plot

For the basic analytical curve, the ordinate is cumulative failure rate (or MTBF) and the abscissa is cumulative operating time.

The model is sensitive to the relationship among failure rate, improvement effort, and duration of effort, but does not appear to care how the duration is measured.

14.7.1.7 Reliability Growth Assessment

Reliability assessment shall be a continuing activity throughout the reliability program but during the reliability growth test period, it shall consist primarily of monitoring the reliability growth by comparing the **achieved** reliability progress with the **planned** reliability growth test model.

As long as the achieved reliability growth corresponds favorably with the planned growth, as presented in the reliability growth **test plan procedures**, satisfactory performance may be assumed.

If the growth is significantly less than planned (after enough data has been collected to establish a growth rate), a careful analysis must be made to determine the reasons for the poor performance.

Probably an increased effort will be necessary to implement a corrective action plan. This plan shall be subject to approval by the DHI.

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14.7.1.7.1 Reliability Growth Monitoring

The reliability growth shall be monitored throughout the test using a **graphic plot** of the observed MTBF expressed as a point estimate.

The **point estimate** is the cumulative MTBF and is calculated by dividing the cumulated test time by the total of the failures that have occurred up to that time.

The plot shall be made on the same graph as the reliability growth test model. This plot shall not be **adjusted** by negating past failures because of present or future design changes.

This curve shall be identified as **Cumulative MTBF**, (or **Achieved reliability**). The best fit (the method of least squares may be used) straight line through the first few (3 to 6) plotted MTBF points will establish the growth rate and can be compared directly with the planned growth line.

The **slope (m)** of the best-fit straight line drawn through the plotted points represents the **growth rate**.

14.7.1.7.2 Reliability Growth Test Conditions

The reliability growth test and its associated failure analysis and corrective action activity can be considered satisfactory if any of the conditions of a through c exist.

- (1) The plotted MTBF values remain on or above the planned growth line.
- (2) The best-fit straight line is congruent with or above the planned line.
- (3) The best fit straight line is below the planned line but its slope is such that a projection of the line crosses the horizontal required MTBF line by the time that the planned growth line reaches the same point.

If none of the above conditions exist, it can be assumed that the planned reliability growth cannot be achieved with the current level of activity.

This situation requires that a **corrective action** plan be generated and, after approval by the DHI, implemented.

Before the corrective action plan can be determined, a careful analysis of the equipment design and related failures shall be accomplished to ascertain the problem areas and possible design modifications.

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14.7.1.7.3 Adjusted Reliability

A second plot shall be made to reflect the level at which the achieved reliability would be if those failures were discounted for which acceptable corrective action has resolved a failure to the satisfaction of the DHI.

This curve shall be identified as “**Adjusted Reliability**”.

14.7.1.7.4 Moving Average

A moving average of achieved reliability is constructed by arranging the failure times (accumulated test times between failures) for the equipment on test in chronological order of occurrence.

The moving average for any specific number of failures is computed as the arithmetic mean of the failure times selected sequentially and in reverse order.

The number of failures to be used in the computation is arbitrary but is restricted to 10 or less.

An example is shown in Appendix A. This curve shall be identified as “**Moving Average**” and the number of failures used for computation shall be noted.

14.7.2 The AMSAA Method

The **AMSAA Reliability Growth Model** assumes that within a test phase failures are occurring according to a **nonhomogeneous Poisson process**.

It is further assumed that the failure rate or intensity of failures during the test phase can be represented by the **Weibull function**

$$h(t) = \lambda \cdot \beta \cdot t^{\beta-1}$$

where $\lambda > 0$, $\beta > 0$ are parameters and t is cumulative test time.

Under this model the function

$$m(t) = [\lambda \cdot \beta \cdot t^{\beta-1}]^{-1}$$

is interpreted as the **instantaneous MTBF** of the system at time t .

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When θt corresponds to the total cumulative time for the system, then $m(t)$ is the demonstrated MTBF or the MTBF of the system in its present configuration, see Figure 14.6.

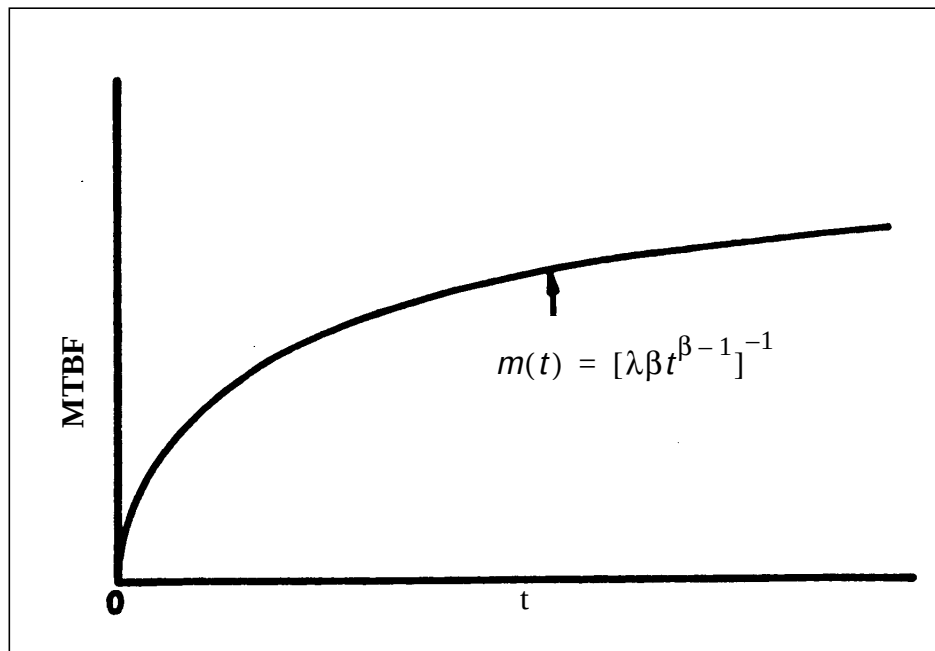


**FIGURE 14.6: TEST PHASE RELIABILITY GROWTH
BASED ON AMSAA MODEL**

14.7.2.1 Cumulative Number of Failures

The total number of failures, $N(t)$, accumulated on all test items in cumulative test time t is a random variable with the Poisson distribution.

The probability that exactly n failures occur between the initiation of testing and total test time t is;

$$P[N(t) = n] = \frac{[\theta(t)]^n e^{-\theta(t)}}{n!}$$

in which $\theta(t)$ is the mean value function; that is, the expected number of failures expressed as a function of test time.

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To describe the reliability growth process this function is of the form

$$\theta(t) = \lambda \cdot t^\beta$$

in which λ and β are positive parameters.

14.7.2.2 Number of Failures in an Interval

The number of failures occurring in the interval from test time a until test time b is a random variable having the Poisson distribution with mean

$$\theta(b) - \theta(a) = \lambda (b^\beta - a^\beta)$$

The number of failures occurring in any interval is statistically independent of the number of failures in any interval which does not overlap the first interval. Only one failure can occur at any instant according to the Weibull process model.

14.7.2.3 Intensity Function

For the reliability growth process the intensity function is;

$$h(t) = \lambda \cdot \beta \cdot t$$

The probability of the occurrence of a failure between time t and time t_i is approximately $h(t) \cdot h$ if the increment h is sufficiently small.

The intensity function is sometimes called the failure rate; however, this concept is different from that of the failure rate or hazard rate of a life distribution.

Caution should be exercised so that the two ideas are not confused.

The **parameter** λ is called a **scale parameter** because it depends upon the unit of measurement chosen for t .

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The **parameter** β is of prime importance because it characterizes the **shape** of the graph of the intensity function.

If β is equal to one, the intensity function is constant. In that case the reliability of the system is not changing since the times between successive failures are independent identically distributed random variables with an exponential distribution with mean λ^{-1} .

If β is not equal to one, the times between successive failures are not identically distributed and do not have exponential distributions.

For a development process during which the system **reliability improves**, the shape parameter β is **less than one**.

In this case the expected number of failures in an interval of fixed length decreases as its starting point increases.

In a poorly managed reliability program improper design changes can result in degradation of system reliability.

This situations characterized by values of the shape parameter β greater than one. This indicates that the number of failures expected in a fixed increment of time is increasing with time.

14.7.2.4 Mean Time Between Failures

At time t the intensity of failure is

$$h(t_0) = \lambda \cdot \beta \cdot t_0^{\beta-1}$$

In practice it is generally assumed that if no improvements are incorporated into the system after time t , then failures would continue at the constant rate with further testing.

That is, if no additional modifications are made on the system after time t , then future failures would follow an exponential distribution with mean

$$m(t_0) = [\lambda \cdot \beta \cdot t_0^{\beta-1}]^{-1}$$

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is interpreted as the **instantaneous MTBF** of the system at time t and represents the system **reliability growth** under this model.

A **summary** of the variables used in the AMSAA model is given in Table 14.2.

TABLE 14.2: SUMMARY OF VARIABLES FOR THE AMSAA MODEL

1	X	Cumulative test time to the i th failure
2	N	Total number of failures observed
3	M	$N - 1$
4	t	Total period of observation
5	μ	Statistic used to test for trend in the data. The distribution of μ is in standardized normal form.
6	$\hat{\beta}$	A growth parameter estimate used to describe the variation of the failure rate with time. If the failure rate is increasing, the parameter is greater than one. For a constant failure rate, it is equal to one. If the failure rate is decreasing (growth), then it is less than one.
7	$\bar{\beta}$	An unbiased estimate of the true value of the growth parameter
8	$\hat{\lambda}$	After the growth parameter estimate has been obtained, it is possible to estimate the scale parameter, λ by $\hat{\lambda}$
9	C_M^2	Cramer - von Mises goodness-of-fit test statistic, as calculated from the observations
10	$h(x)$	Interval estimate of the failure rate at the time of the last failure
11	$h(t)$	Interval estimate of the failure rate at a future time

14.7.2.5 Determination of Trend from Test Data

Prior to the use of the AMSAA method, any significant trend in the test results must be identified.

If the period of test **ends** with a failure, **use** the test statistic (μ) generated by equation 1 in Table 14.3.

If the failure data is **time truncated**, **use** the test statistic (μ) generated by equation 2 in Table 14.3.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***Chapter 14***TABLE 14.3: SUMMARY OF EQUATIONS, AMSAA MODEL**

1) $\mu = \frac{\left(\sum_{i=1}^M X_i \right) - \frac{1}{2} X_N}{X_N \sqrt{\frac{1}{12M}}}$	6) $C_M^2 = \frac{1}{12M} + \sum_{i=1}^M \left[\left(\frac{X_i}{X_N} \right)^{\hat{\beta}} - \frac{2i-1}{2M} \right]^2$
2) $\mu = \frac{\left(\sum_{i=1}^N X_i \right) - \frac{1}{2} t_0}{t_0 \sqrt{\frac{1}{12N}}}$	7) $\hat{\beta} = \frac{N}{N \ln(t_0) - \sum_{i=1}^N \ln(X_i)}$
3) $\hat{\beta} = \frac{N}{M \cdot \ln(X_N) - \sum_{i=1}^M \ln(X_i)}$	8) $\bar{\beta} = \frac{N-1}{N} \hat{\beta}$
4) $\bar{\beta} = \frac{N-2}{N} \hat{\beta}$	9) $\lambda = \frac{N}{t_0 \hat{\beta}}$
5) $\hat{\lambda} = \frac{N}{X_N \hat{\beta}}$	10) $C_M^2 = \frac{1}{12M} + \sum_{i=1}^M \left[\left(\frac{X_i}{t_0} \right)^{\hat{\beta}} - \frac{2i-1}{2M} \right]^2$

At the 10 percent (two-sided) **significance level**, $\mu=1.645$; therefore, if:

- (1) $\mu \leq -1.645$; significant **reliability growth** is indicated at the 10% significance level and the AMSAA model can be used for estimating parameters of interest.
- (2) $\mu \geq +1.645$; significant **reliability decay** is indicated at the 10% significance level. **Corrective action** is necessary.
- (3) $-1.645 < \mu < +1.645$; the trend is **not significant** at the 10% significance level and **additional data** should be accumulated.

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For values near -1.645 some **growth** is indicated; for values near +1.645, some **decay** is indicated; for values near zero, no trend is indicated. Additional testing should be considered in this marginal case.

Other critical values of the test statistic can be used if required, (i.e. at the 5% two sided significance level, $\mu=1.960$).

In practice, **higher** critical values will result in more test time but will yield a higher confidence of reliability growth.

14.7.2.6 Reliability Growth Analysis

If significant growth is **indicated**, **compute** the appropriate parameters using the reliability growth equations selected from Table 14.3.

Use Table 14.4 as a **guide** for equation selection. Note that for small sample sizes, the recommended estimate of (β) is the unbiased estimate, $(\bar{\beta})$, which is;

For failure-**truncated tests**, **use** equation 4,

$$\bar{\beta} = [(N-2)/N] \cdot \hat{\beta}$$

and for **time-truncated tests**, **use** equation 8,

$$\bar{\beta} = [(N-1)/N] \cdot \hat{\beta}$$

The recommended estimate of (λ) is $(\bar{\lambda})$, which is;

For **failure-truncated tests**;

$$\bar{\lambda} = N/X \bar{\beta}_N$$

and for **time-truncated tests**;

$$\bar{\lambda} = N/t_o \bar{\beta}_o$$

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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Parameter	Parameter Characteristic	Test Termination	Equation from Table 14.3			
			Large Sample $N \geq 20$	Small Sample $N > 20$	Scale Parameter	Goodness-of-fit Statistic
			$\hat{\beta}$	$\bar{\beta}$	$\hat{\lambda}$	C_M^2
MTBF, θ	Continuous	Failure terminated	3	4	5	6
MTBF, θ	Continuous	Time terminated	7	8	9	10
Probability of success	Discrete	Failure on final trial	3	4	5	6
Probability of success	Discrete	Success on final trial	7	8	9	10

The goodness-of-fit of the AMSAA model to the particular test data being generated must be tested by use of the Cramer-von Mises goodness-of-fit test, (SAS software can be used).

First, the level of significance (α) of the test must be chosen and the critical value of the test statistic (C_M^2) determined from Table 14.5.

The (C_M^2) calculated from the observations (equations 6 and 10 in Table 14.3) must then be compared to this critical value.

If the statistic is **less** than the tabulated critical value, the AMSAA model **cannot** be rejected and the **calculation procedure** in steps **(1)** through **(7)** below can be used.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 14***TABLE 14.5: CRITICAL VALUES OF C_M^2 PARAMETRIC FORM OF
THE CRAMER-VON MISES STATISTICS**

M1/	Level of Significance				
	0.20	0.15	0.10	0.05	0.01
2	0.138	0.149	0.162	0.175	0.186
3	0.121	0.135	0.154	0.184	0.231
4	0.121	0.136	0.155	0.191	0.279
5	0.121	0.137	0.160	0.199	0.295
6	0.123	0.139	0.162	0.204	0.307
7	0.124	0.140	0.165	0.208	0.316
8	0.124	0.141	0.165	0.210	0.319
9	0.125	0.142	0.167	0.212	0.323
10	0.125	0.142	0.167	0.212	0.324
15	0.126	0.144	0.169	0.215	0.327
20	0.128	0.146	0.172	0.217	0.333
30	0.128	0.146	0.172	0.218	0.333
60	0.128	0.147	0.173	0.221	0.333
100	0.129	0.147	0.173	0.221	0.336

^{1/} For M > 100, use values for M = 100

If the statistic is **greater** than the tabulated critical value, then the AMSAA model is **rejected**, follow the **procedures** given in step **8** below.

- (1) If the AMSAA model is **appropriate**, the system intensity function may be estimated as a function of time by;

$$h(t) = \lambda \cdot \beta \cdot t^{\beta-1}$$

The intensity function is equal to the derivative, at time (t), of the expected number of failures in the interval (0,t).

- (2) Then **calculate** h(t) at the end of the test (or at the point in the test at which the calculation is being made).

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- (3) From Table 14.6 for **failure-terminated** test and from Table 14.7 for **time-terminated** test, **obtain** the two-sided lower confidence bounds ($L_{N,\gamma}$) and two-sided upper confidence bounds ($U_{N,\gamma}$) for N failures and (γ) percent confidence coefficient.

- (4) **Compute** the interval estimate of MTBF from;

$$\frac{L_{N,\gamma}}{h(t)} \leq \text{MTBF} \leq \frac{U_{N,\gamma}}{h(t)}$$

- (5) If the number of failures is 20 or more, the same percentiles may be used to construct approximate confidence bounds on the future MTBF.
- (6) The MTBF is;

$$M(t) = 1 / h(t)$$

- (7) From the confidence limits on $M(t)$ previously calculated, the corresponding limits for (t) may be found from;

$$P_{ub} = 1/M_{lb}$$

$$P_{lb} = 1/M_{ub}$$

- (8) A poor fit may be caused by jumps or discontinuities in the growth pattern.

A plot of the data may suggest whether a different, continuous model should be considered; or whether program changes, which may cause breaks in the growth pattern, should be investigated.

When there are jumps or discontinuities in the growth pattern, the AMSAA model may be applied in a piece-wise fashion.

The procedures are as described above (1) through (7), except that the data prior to and following the time of discontinuity (D) is treated separately.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***Chapter 14***TABLE 14.6: CONFIDENCE INTERVALS FOR MTBF, FAILURE - TERMINATED TEST**

N \ γ	.80		.90		.95		.98	
	L	U	L	U	L	U	L	U
2	0.8065	33.76	0.5552	72.67	0.4099	151.5	0.2944	389.9
3	0.6840	8.927	.5137	14.24	0.4054	21.96	.3119	37.60
4	.6601	5.328	.5174	7.651	.4225	10.65	.3368	15.96
5	.6568	4.000	.5290	5.424	.4415	7.147	.3603	9.995
6	.6600	3.321	.5421	4.339	.4595	5.521	.3815	7.388
7	.6656	2.910	.5548	3.702	.4760	4.595	.4003	5.963
8	.6720	2.634	.5668	3.284	.4910	4.002	.4173	5.074
9	.6787	2.436	.5780	2.989	.5046	3.589	.4327	4.469
10	.6852	2.287	.5883	2.770	.5171	3.286	.4467	4.032
11	.6915	2.170	.5979	2.600	.5285	3.054	.4595	3.702
12	.6975	2.076	.6067	2.464	.5391	2.870	.4712	3.443
13	.7033	1.998	.6150	2.353	.5488	2.721	.4821	3.235
14	.7087	1.933	.6227	2.260	.5579	2.597	.4923	3.064
15	.7139	1.877	.6299	2.182	.5664	2.493	.5017	2.921
16	.7188	1.829	.6367	2.144	.5743	2.404	.5106	2.800
17	.7234	1.788	.6431	2.056	.5818	2.327	.5189	2.695
18	.7278	1.751	.6491	2.004	.5888	2.259	.5267	2.604
19	.7320	1.718	.6547	1.959	.5954	2.200	.5341	2.524
20	.7360	1.688	.6601	1.918	.6016	2.147	.5411	2.453
21	.7398	1.662	.6652	1.881	.6076	2.099	.5478	2.390
22	.7434	1.638	.6701	1.848	.6132	2.056	.5541	2.333
23	.7469	1.616	.6747	1.818	.6186	2.017	.5601	2.281
24	.7502	1.596	.6791	1.790	.6237	1.982	.5659	2.235
25	.7534	1.578	.6833	1.765	.6286	1.949	.5714	2.192
26	.7565	1.561	.6873	1.742	.6333	1.919	.5766	2.153
27	.7594	1.545	.6912	1.720	.6378	1.892	.5817	2.116
28	.7622	1.530	.6949	1.700	.6421	1.866	.5865	2.083
29	.7649	1.516	.6985	1.682	.6462	1.842	.5912	2.052
30	.7676	1.504	.7019	1.664	.6502	1.820	.5957	2.023
35	.7794	1.450	.7173	1.592	.6681	1.729	.6158	1.905
40	.7894	1.410	.7303	1.538	.6832	1.660	.6328	1.816
45	.7981	1.378	.7415	1.495	.6962	1.606	.6476	1.747
50	.8057	1.352	.7513	1.460	.7076	1.562	.6605	1.692
60	.8184	1.312	.7678	1.407	.7267	1.496	.6823	1.607
70	.8288	1.282	.7811	1.367	.7423	1.447	.7000	1.546
80	.8375	1.259	.7922	1.337	.7553	1.409	.7148	1.499
100	.8514	1.225	.8100	1.293	.7759	1.355	.7384	1.431

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 14***TABLE 14.7: CONFIDENCE INTERVALS FOR MTBF, TIME -
TERMINATED TEST**

N	γ							
	.80		.90		.95		.98	
	L	U	L	U	L	U	L	U
2	0.261	18.66	0.200	38.66	0.159	78.66	0.124	198.7
3	.333	6.326	.263	9.736	.217	14.55	.174	24.10
4	.385	4.243	.312	5.947	.262	8.093	.215	11.81
5	.426	3.386	.352	4.517	.300	5.862	.250	8.043
6	.459	2.915	.385	3.764	.331	4.738	.280	6.254
7	.487	2.616	.412	3.298	.358	4.061	.305	5.216
8	.511	2.407	.436	2.981	.382	3.609	.328	4.539
9	.531	2.254	.457	2.750	.403	3.285	.349	4.064
10	.549	2.136	.476	2.575	.421	3.042	.367	3.712
11	.565	2.041	.492	2.436	.438	2.852	.384	3.441
12	.579	1.965	.507	2.324	.453	2.699	.399	3.226
13	.592	1.901	.521	2.232	.467	2.574	.413	3.050
14	.604	1.846	.533	2.153	.480	2.469	.426	2.904
15	.614	1.800	.545	2.087	.492	2.379	.438	2.781
16	.624	1.759	.556	2.029	.503	2.302	.449	2.675
17	.633	1.723	.565	1.978	.513	2.235	.460	2.584
18	.642	1.692	.575	1.933	.523	2.176	.470	2.503
19	.650	1.663	.583	1.893	.532	2.123	.479	2.432
20	.657	1.638	.591	1.858	.540	2.076	.488	2.369
21	.664	1.615	.599	1.825	.548	2.034	.496	2.313
22	.670	1.594	.606	1.796	.556	1.996	.504	2.261
23	.676	1.574	.613	1.769	.563	1.961	.511	2.215
24	.682	1.557	.619	1.745	.570	1.929	.518	2.173
25	.687	1.540	.625	1.722	.576	1.900	.525	2.134
26	.692	1.525	.631	1.701	.582	1.873	.531	2.098
27	.697	1.511	.636	1.682	.588	1.848	.537	2.068
28	.702	1.498	.641	1.664	.594	1.825	.543	2.035
29	.706	1.486	.646	1.647	.599	1.803	.549	2.006
30	.711	1.475	.651	1.631	.604	1.783	.544	1.980
35	.729	1.427	.672	1.565	.627	1.699	.579	1.870
40	.745	1.390	.690	1.515	.646	1.635	.599	1.788
45	.758	1.361	.705	1.476	.662	1.585	.617	1.723
50	.769	1.337	.718	1.443	.676	1.544	.632	1.671
60	.787	1.300	.739	1.393	.700	1.481	.657	1.591
70	.801	1.272	.756	1.356	.718	1.435	.678	1.533
80	.813	1.251	.769	1.328	.734	1.399	.695	1.488
100	.831	1.219	.791	1.286	.758	1.347	.722	1.423

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Thus, the earlier data is treated as a time truncated test, with $T=D$ and the later data is treated separately after subtracting (D) from each observed failure time.

If a two piece AMSAA model is appropriate, the system failure rate as a function of time (t) may be estimated by;

$$h(t) = \lambda_1 \cdot \beta_1 \cdot t^{\beta_1 - 1} \quad 0 \leq t \leq D$$

$$h(t) = \lambda_2 \cdot \beta_2 \cdot (t - D)^{\beta_2 - 1} \quad t > D$$

where the parameters subscripted 1 are determined from the data prior to (D), and the parameters subscripted 2 are determined from the data after (D).

14.8 FAILURE REPORTING, ANALYSIS, CORRECTIVE ACTION SYSTEM (FRACAS)

A closed-loop failure data collection, analysis, and corrective action system is an important part of the **TAAF** concept of the reliability development/growth test.

The closed-loop **FRACAS** shall identify, report, investigate, analyze, and correct all problems or failures that occur during the reliability growth test, and prevent recurrence of all problems or failures due to design deficiencies.

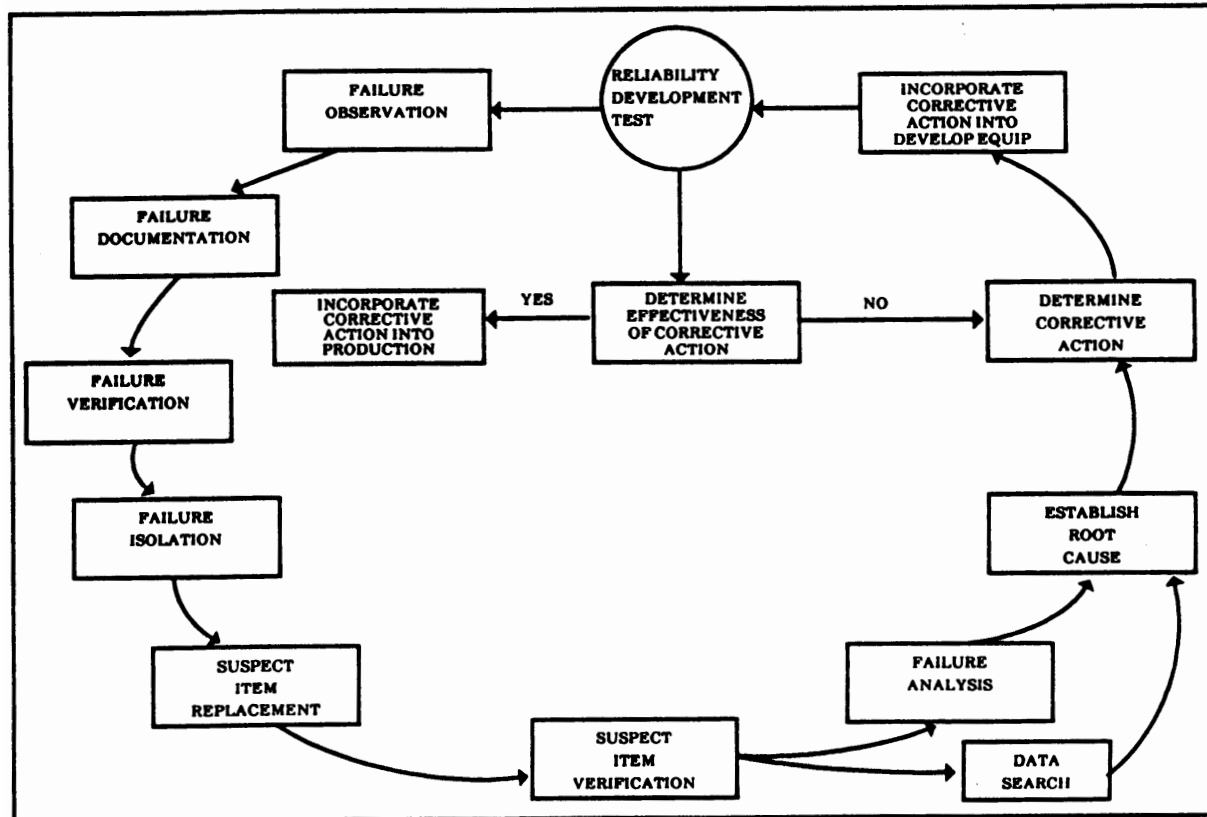
The application of FRACAS in the test is shown in Figure 14.7.

14.8.1 Failure Reporting, Analysis, and Corrective Action

The Seller/Vendor shall implement and maintain a comprehensive system for identifying, reporting, investigating, analyzing, and correcting all problems and failures which occur throughout the reliability development test program.

The contractor's existing failure reporting, analysis, and corrective action system may be utilized with minimum changes necessary to meet the requirements of this document.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***Chapter 14***FIGURE 14.7: CLOSED LOOP FAILURE REPORTING AND CORRECTIVE ACTION SYSTEM**

The system shall cover all test items and the interfaces between the test items and the test equipment, test procedures, test personnel and the handling and operating instructions.

The system shall provide for investigation and engineering analysis of each problem or failure, followed where appropriate by laboratory analysis.

14.8.2 Problem and Failure Action

At the occurrence of a problem that affects satisfactory operation of the equipment as described in the test procedure, or a failure, entries shall be made on the appropriate data logs and the equipment removed from test.

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After this equipment has been returned to specific operating condition, it may be returned to test with appropriate entries in the data logs.

Unless otherwise specified, **temporary replacement** of plug-in items is authorized to permit test continuation while troubleshooting, repair, and analysis are performed.

Individual **acceptance tests** on repaired items shall be performed prior to reinstallation in the test facility.

14.8.3 Problem and Failure Report

A problem and failure report shall be prepared at the occurrence of each problem or failure. The report shall contain the necessary information to permit determination of the origin and possible correction of failures.

The contractor's existing problem and failure report form may be used with minimum changes necessary to meet the requirements of this document.

The **information** to be recorded shall include, as a minimum, the following:

- (1) Information which will indicate symptoms of failure, test conditions, identification of failed equipment, total test time, and test item operating time at the time of failure shall be recorded at the time the problem and failure report is initiated.
- (2) Information for each independent and dependent failure and the extent of confirmation of the failure symptoms, the identification of the failures, and a description of all repair action taken shall be recorded at the time of repair.
- (3) Information which indicate the results of the investigation, the analysis of all part failures, an analysis of the equipment design, and the corrective engineering action taken shall be recorded at the completion of the failure investigation.

If no corrective engineering action is taken, then such decision must be justified.

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14.8.4 Investigation and Analysis of Problems and Failures

The cause of each problem and failure shall be determined by investigation and analysis. The investigation and analysis shall be adequate to assess causes, mechanisms, and potential effects of the problem or failure and to serve as a basis for decision on the corrective actions.

Investigation and analysis shall consist of any applicable method (such as test, application study, dissection, x-ray analysis, microscopic analysis, spectrographic analysis, etc.) which may be necessary to determine the cause of failure.

The investigations and their conclusions shall be documented and shall, as a minimum, provide the following information:

- (1) Failure date and time,
- (2) Necessary design changes have been devised and accomplished,
- (3) Necessary design changes have been verified by test,
- (4) Effectivity of corrective action has been established,
- (5) The corrective action has been made in existing identical items to which it is pertinent,
- (6) The close-out document has been signed off by the appropriate contractor technical management authority to indicate technical review and to certify completion of all close-out actions,
- (7) Procuring or user activity has concurred in all actions taken or to be taken.

14.8.5 Corrective Action

When the cause of a problem or failure has been determined, a corrective action shall be developed to reduce or prevent recurrence of the problem or failure.

The effectiveness of the corrective action shall be demonstrated by being tested under the same controlled conditions under which the original failure was observed.

Unless otherwise specified, change control procedures shall be in accordance with MIL-STD-480 change procedures for the engineering and operational testing phases of a program.

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14.8.6 Classification of Failures

For the purpose of reliability growth assessment, all failures shall be classified as specified in Appendix B.

14.9 TEST PROGRAM REVIEWS

Test program reviews shall be conducted at scheduled milestones throughout the reliability development test program and shall be identified in the approved test plan.

Attendance at these reviews will include procuring or user activity and contractor personnel and their designated representatives.

These reviews shall be documented by the contractor and submitted as an appendix to the Status Report (see Para. 14.10).

14.9.1 Test Readiness Reviews

A test readiness review shall be planned, scheduled, and conducted at least seven (7) days prior to the start of any test to assure that the test item and all supporting elements are ready to begin test.

The test readiness review shall include, to the extent applicable, the following:

- (1) Status of design and fabrication,
- (2) Results of reliability predictions,
- (3) Results of all applicable previous tests,
- (4) Summary of the open problems and failures,
- (5) Status of problem and failure closures,
- (6) Availability of test procedures approved by appropriate personnel to indicate technical review,
- (7) Status of previously assigned action items,
- (8) Assignment of action items resulting from the review,
- (9) Conclusions of review (Test start approval/disapproval).

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14.9.2 Status Reviews

Formal reviews shall be scheduled at preplanned milestones during the reliability development test program to permit the contractor and procuring or user activity to review the status of testing.

The status reviews shall be scheduled approximately monthly and shall include, to the extent applicable, the following:

- (1) Current reliability growth assessments and projections
- (2) Results of current problem and failure investigations and engineering analysis
- (3) Corrective action recommendations
- (4) Potential design problems based on the corrective action recommendations
- (5) Status of subcontractor and supplier reliability development tests
- (6) Status of previously assigned action items
- (7) Assignment of action items resulting from the review

14.9.3 Test Completion Review

A test completion review shall be scheduled at the completion of test. This review shall be conducted to evaluate the results of the testing in compliance with the requirements of the contract, equipment or model specification, and this document.

This review shall include, to the extent applicable, the following:

- (1) Current reliability growth assessments and achievements
- (2) Status of open problems and failures
- (3) Status of corrective actions
- (4) Status of previously assigned action items
- (5) Assignment of action items resulting from the review
- (6) Conclusions of the review

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14.10 REPORTS

14.10.1 Status Report

The contractor shall prepare a status report within seven days from the last date of the scheduled reporting period.

Each report shall present the test results and all pertinent data obtained during the reporting period, the total number of problems and failures for each operational mode specified in the duty cycle, plots of measured and projected reliability growth assessment data, and the estimated completion date.

The minutes of the test program reviews shall be included as an appendix to this report.

14.10.2 Failure Summary Report

The contractor shall prepare a failure summary report as of the end of each month. The summary report shall be prepared in three parts: Part I, cumulative number of failures to summary date; Part II, failures for which corrective action has not been established; Part III, cumulative listing of closed reports.

The contractor's existing failure summary may be used with minimum changes necessary to meet the requirements of this document.

14.10.3 Final Report

A final report shall be prepared and submitted by the contractor within thirty (30) days after completion of all scheduled testing.

This report shall summarize all results obtained during the reliability development test program, and shall contain copies of all test data sheets and test logs.

The report shall include, but not be limited to, a comparison of results with the reliability predictions, the conclusions drawn, a summary of problems and failures, the corrective actions taken, and an assessment of the reliability achieved.

The final report shall define the configuration of the equipment before and after incorporation of design changes resulting from the test program.

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The report shall include a tabulation of all differences between the requirements of the equipment specification and results of the test program, and provide recommendations for resolution of the noted differences.

Unless otherwise specified, the final report shall also contain maintenance times for each failure or maintenance action, subdivided into the following categories, as defined in MIL-HDBK-472.

- (1) Localization
- (2) Isolation
- (3) Disassembly
- (4) Interchange
- (5) Reassembly
- (6) Alignment
- (7) Check-out
- (8) Total

14.11 ACTION IN THE EVENT OF FAILURE

At the occurrence of a malfunction of the equipment under test, the following procedure shall be implemented;

The test will be stopped, an entry placed in the test log of the failure symptoms, test conditions at the time of failure, and elapsed time, the failure confirmed, and troubleshooting performed to identify the root cause of the malfunction and the faulty item.

Failure report will be completed.

Unit under test will be repaired by replacing the faulty component to the maximum extent possible. Temporary replacement of plug-in items is authorized but shall be kept to the minimum extent possible to permit test continuation while troubleshooting, repair, and analysis are performed.

Individual acceptance tests on repaired items shall be performed prior to reinstallation in the test facility.

There may be the extenuating case where repair is not feasible and replacement is permanent.

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Usage hours shall be notified against the equipment Master Record Index. After the repair and fix are confirmed, the test will be continued.

A log entry of the repair confirmation shall be made including the elapsed time and the coincident local time.

Project/Design Engineering activity shall analyze all part failures, analyze the equipment design, and the corrective engineering action taken.

If no corrective action engineering action is taken, then such action must be justified.

A detailed failure analysis will be performed as soon as possible to determine cause of failure and failure relevancy.

Failure analysis results will be completely documented and attached to the failure report.

Corrective action shall be developed and implemented for each failure to prevent recurrence. All test units will be upgraded to the new configuration prior to completion of RDGT.

The Buyer's (DHI) program office will be informed of the malfunction or failure and the suspected causes as soon as possible, within one DHI working day. Copies of malfunction information will be made available.

14.12 PROCURING ACTIVITY PARTICIPATION

After approval of the test plan the Buyer will be a member of the **Pretest Readiness Review Board**.

All aspects of the test must be reviewed and approved by the Buyer prior to the start of the test.

During the test, the Buyer has the option of providing test witnesses and/or participation in the test to the degree desired.

14.13 CONDITIONS PRECEDING RELIABILITY GROWTH TEST

14.13.1 Pretest Requirements

- (1) The RDGT plan shall be approved by the Buyer/DHI prior to start of test.

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- (2) The configuration of the units selected for test will be documented and be part of the Test Readiness Review (TRR).
- (3) After DHI approval of the test plan, Seller will plan and schedule a Test Readiness Review at least seven days prior to start of any test to assure that the test items and all supporting elements are ready to begin test.

The test readiness review will include, to the extent applicable, the following:

- (1) Results of reliability prediction and analysis
- (2) Status of design and fabrication
- (3) Review of RDGT installation and units to be tested
- (4) Review of Master Record Index for all units
- (5) Results of all applicable previous tests
- (6) Summary of the open problems
- (7) Summary of agreed concessions (if any)
- (8) Test plan/procedures approved by appropriate personnel, must be available prior to start of test
- (9) Conclusions of review (test start approval/disapproval)

14.13.2 Acceptance Test

Acceptance tests as per Seller's Acceptance Test Procedure (**ATP**) will provide a necessary complement to the reliability growth tests and shall be **completed** prior to the start of the reliability growth tests.

Acceptance test shall also be conducted on each equipment (UUT) using ATP every TBD test cycles and at test completion.

14.13.3 Environmental Stress Screening (ESS)

ESS shall be **conducted** on each test unit prior to Acceptance Testing as per ESS test procedure.

14.13.4 Functional Tests

The functional tests as defined in Seller's Functional Test Procedure (**FTP**) shall be used to **demonstrate** functional acceptability of each test unit.

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Functional tests shall be performed to verify the total equipment specification conformance.

These tests shall be **performed** after each valid failure repair, before commencement of RDGT, at least once a month during RDGT, and after completion of RDGT.

A record shall be made of all data to determine compliance with required performance and to provide reference levels and criteria for checking desired performance of the item during at the conclusion of the test.

14.13.5 Thermal Survey

A pre-test thermal survey shall be **performed** to verify the thermal cycle profiles. The thermal survey may be conducted concurrently with other tests.

Stabilization is defined to have occurred when the rate of change for the majority of the electronic parts in the equipment is less than 2 deg. C per hour.

Results of the thermal survey shall be made available to DHI upon request.

14.13.6 Vibration Survey

A vibration survey shall be **conducted** to verify compatibility of the ESS test holding fixture and the unit under test prior to commencing ESS.

Periodic sample re-checks shall be made to **verify** fixture vibration integrity. Results of the vibration survey shall be made available to DHI upon request.

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APPENDIX A:

MOVING AVERAGE EXAMPLE

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14.14 APPENDIX A: MOVING AVERAGE EXAMPLE

Table 14.8 is an example of the **computation** of moving average utilizing 1,2,3,...,6 failures in the computation.

The moving average is **constructed** by arranging the failure times (accumulated test time between failures) for the items on test in chronological order of occurrence.

The moving average for any given number of failure is computed as the arithmetic mean of that number of failure times selected sequentially and in reverse order.

For example, the moving average of two failures is obtained by adding the last two failure times and dividing by two; for three failures, by summing the last three failure times and dividing by three; etc.

The **number** of failures used in the computation is arbitrary but should be **restricted** to ten or less. Initially, some moving averages cannot be computed since enough failures have not occurred.

For example, the moving average utilizing the last six times between failures cannot be computed until six failures have occurred.

The failure times were selected arbitrarily for this example. The times between failures are arranged in chronological order and indexed by the cumulative failure count.

The cumulative test time is total of all time between failures up to and including the failure time indexed.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 14***TABLE 14.8: MOVING AVERAGE EXAMPLE**

Cum. Fail. Count	Cum. Test. Time	Time Between Fail.	Cum. MTBF	Moving MTBF Using Last (N) Failures (N is Table Index)					
				1	2	3	4	5	6
1	1	1	1	1	0	0	0	0	0
2	4	3	2	3	2	0	0	0	0
3	8	4	3	4	4	3	0	0	0
4	13	5	3	5	5	4	3	0	0
5	20	7	4	7	6	5	5	4	0
6	30	10	5	10	9	7	7	6	5
7	42	12	6	12	11	10	9	8	7
8	57	15	7	15	14	12	11	10	9
9	78	21	9	21	18	16	15	13	12
10	104	26	10	26	24	21	19	17	15
11	136	32	12	32	29	26	24	21	19
12	177	41	15	41	37	33	30	27	25
13	228	51	18	51	46	41	38	34	31
14	292	64	21	64	58	52	47	43	39
15	372	80	25	80	72	65	59	54	49
16	473	101	30	101	91	82	74	67	62
17	599	126	35	126	114	102	93	84	77
18	757	158	42	158	142	128	116	106	97
19	956	199	50	199	179	161	146	133	121
20	1205	249	60	249	224	202	183	167	152
21	1518	313	72	313	281	254	230	209	191
22	1879	361	85	361	337	308	281	256	234
23	2262	383	98	383	372	352	327	301	277
24	2668	406	111	406	395	383	366	342	319
25	3099	431	124	431	419	407	395	379	357

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APPENDIX B:

**FAILURE CLASSIFICATION FOR RELIABILITY
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14.15 APPENDIX B: FAILURE CLASSIFICATION FOR RELIABILITY GROWTH ASSESSMENT

14.15.1 Scope

This appendix establishes criteria for classification of failure occurring during the reliability growth tests.

The criteria included in this document shall be used to classify failures as either relevant or non-relevant for the purpose of assessing reliability growth of the equipment.

14.15.2 Definitions

14.15.2.1 Failures

In addition to the definition of failure as given in MIL-STD-721, and any definition given in the applicable reliability test specification and this standard, the following criteria for the determination of a failure shall apply:

Whenever any of the performance characteristics are outside of the requirements of the equipment specification at any specified environmental conditions, at least one failure has occurred.

14.15.2.2 Failure Classification

All failures occurring during reliability growth tests, including failures occurring during equipment burn-in under the environmental conditions specified for the reliability growth test, shall be classified and reported as either **relevant or non-relevant**.

Only those failures occurring during the reliability growth tests and **classified relevant** shall be used in computing equipment mean time between failure (MTBF) and for making reliability growth assessments.

14.15.2.3 Relevant Failures

All failures are relevant unless determined by the procuring or user activity, or an authorized representative thereof, to be caused by a condition external to the equipment under test which is not a test requirement.

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14.15.2.4 Design Failures

Failures due to design deficiencies of either the equipment or component parts shall be classified relevant.

14.15.2.5 Workmanship Failures

Failures resulting from workmanship or quality control shall be classified as relevant.

14.15.2.6 Component Part Failure

Failures due to defective component parts shall be classified as relevant failures. Each independent failure of component parts of the same type shall be considered a separate relevant failure.

14.15.2.7 Wearout Parts

Certain parts of known limited life, such as batteries, may have a life stipulated prior to the initiation of testing as approved by the procuring activity.

Failures of these parts occurring prior to the end of the stipulated period are relevant. Failures of these parts occurring after the stipulated period are non-relevant, but any dependent failures caused thereby are relevant.

14.15.2.8 Multiple Failures

In the event simultaneous part failures occur, each failed part which would independently prevent satisfactory equipment performance shall be counted as a relevant failure.

14.15.2.9 Intermittent Operation

The second and subsequent occurrences of an intermittent operation on any one item under test shall be counted as a relevant failure.

14.15.2.10 Adjustments

Each adjustment of a control which could not readily be accomplished during a mission shall be classified as a relevant failure.

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14.15.2.11 Built-in Test Failures

A failure of the built-in test (BIT) functions that degrades system performance beyond the acceptable limits shall be classified relevant. False alarms of BIT functions shall be classified as relevant failures.

14.15.2.12 Other Failures

All other failures not specifically defined as non-relevant shall be classified as relevant.

14.15.2.13 Non-relevant Failures

Although non-relevant failures are **not used** for MTBF calculations or for reliability growth assessments **all** failures, shall be recorded and investigated.

14.15.2.14 Improper Test Installation

Failures directly attributable to improper installation in the test facility shall be classified non-relevant.

14.15.2.15 Test instrumentation Failures

Failures directly attributable to a failure of the test instrumentation or monitoring equipment, except BIT, shall be classified non-relevant.

14.15.2.16 Test Operator Errors

Failures resulting from test operator error in setting up or in testing the equipment shall be classified non-relevant.

14.15.2.17 Test Procedure Errors

Failures resulting from an error in the test procedure shall be classified non-relevant.

14.15.2.18 Intermittent Operation

The **first occurrence** of an intermittent operation on any one item under test shall be classified as non-relevant.

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14.15.2.19 Repair Failures

Failures that result from trouble-shooting, repair verification or scheduled maintenance shall be classified non-relevant if the failure occurs during repair and verification as described in the test plan.

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1996-07-05

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Chapter 15

PARTS DERATING PROCEDURE

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15 PARTS DERATING PROCEDURE

15.1 INTRODUCTION

Derating for electrical, mechanical, or electromechanical parts is defined as the practice of reducing the electrical, mechanical, or environmental operating stresses below their specified or maximum levels that the part is capable of sustaining in order to **increase application reliability**.

The guidelines on **parts selection** and **parts control** assume that the parts are inherently reliable and capable of withstanding the stresses to which they will be submitted.

Additional improvement in part and, ultimately, equipment reliability can be realized by applying the techniques of derating.

- (1) Even the best parts, when operated at **maximum rated** stress levels, will have **above** average failure rates.

Therefore, if a system is **expected** to be **reliable and safe**, it will need to have a **conservative design** approach with realistic derating of parts.

Derating **increases** the margin between the operating stress level and the maximum stress level, thus **protecting** the system from unexpected design anomalies.

- (2) Derating is always a **compromise** between size, weight, cost, and reliability/safety.

Engineering judgment is necessary in choosing the most effective **level of derating**.

15.2 OBJECTIVE

Derating of parts and material shall be accomplished (by analysis and/or test) as necessary to **assure** that the required DHC-8 Aircraft **reliability and safety** is within specification, and there are **no overstressed parts** in the system design.

A **major** contributing to the success of many reliability programs has been a conservative design approach incorporating substantial **derating** of parts.

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15.3 BACKGROUND

The **parts** used in a system are the **most critical items** for achieving the required **reliability and safety**.

Previously the control of parts reliability was accomplished by use of part specifications, and testing for both the parts and the produced equipment.

Part application and **derating** was usually left to the discretion of the designer.

Reliability was usually controlled by levying specific MTBF requirements on the system.

Designers achieve this MTBF by allocating to a maximum allowable failure rate for the individual parts.

This **method** results in **two major deficiencies** in achieving the maximum cost effective **reliability and safety**.

First, testing does not duplicate all operating conditions and therefore does not disclose all possible field failure modes.

Second, since MTBF is a function of individual part failure rates, it is often possible to compute an **acceptable MTBF** even if one or more parts are operating at full **rated stress** levels or even they are **overstressed**.

A part operating at full maximum rating is **inherently** more **unreliable** and is depending upon an **unknown safety margin**, if any, built into device by the manufacturer.

Even if a failure due to **overstress** does not occur in such a part, the time induced **degradation** rate is increased.

This may account in part for the common occurrence of equipment calculated and tested to a specific MTBF which **fails** to achieve **projected reliability** in field usage.

Recognition of these factors has led to the **formalization** of **derating**, for the program by levying **derating** requirements **on all designs** within the program.

This **derating analysis** requirements are in addition to those requiring part specifications to control part quality and part receiving inspection.

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The development of stress **derating criteria** for **advanced** technology parts requires a fundamentally sound understanding of the **relationships** between the electrical, thermal, and mechanical **stresses** applied to the components and the resulting **life distributions** of the component populations.

Component reliability models are used to describe these relationships and provide insight into the functional dependence of component life distributions on the applied stresses.

The **magnitude of the stress derating** determines the amount of expected change in component life-time or shift in the life distribution of a population of components.

In general, the **more** the stress is derated, the **longer** the life of the component.

Therefore, the expected result of derating the stresses applied to a component is to **decrease** its **failure rate**.

Since most **reliability models** relate electrical, thermal and mechanical stresses to component lifetime in the form of a failure rate, it is reasonable to use the concept of failure rate as the key link between the reliability model and the **stress derating criteria**.

The minimum acceptable stress derating depends upon the **criticality** of the mission

Criticality levels referenced to mission safety and success, can be established and contrasted in terms of failure rates.

The minimum acceptable stress derating for each criticality level sets the maximum failure rate that might be experienced by the component in a mission of specified criticality.

It is reasonable to **maximize** the stress derating, when possible, to provide a greater than minimum margin of safety and success.

15.4 DEFINITIONS AND ACRONYMS

15.4.1 Definitions

The terms and definitions in this document should be interpreted according to the definitions of MIL-STD-721, except as noted.

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15.4.1.1 Derating

The use of parts (devices) in such a manner that applied stresses are less than maximum ratings.

Derating, unless otherwise specified, applies to the recommended operating or nominal condition.

15.4.1.2 Rating

Discrete parametric values; absolute maximum rating, worst case conditions, and recommended operating conditions.

In many cases, the values are the same. Rating is normally used for describing a stress parameter, such as temperature limit, power, frequency, voltage, current, etc., that increases failure rate as the stress increases.

15.4.1.3 Absolute Maximum Rating

That parameter that cannot be exceeded when used in any application; See MIL-STD-883 or MIL-S-19500 for more detail.

15.4.1.4 Worst Case Condition

The condition of highest stress on a part caused by simultaneous application of stress inducing parameters to the terminals or environment of the part, operating in its specified range. See MIL-STD-883 for more detail.

15.4.1.5 Recommended Operating Condition

Value(s) at which optimum performance and reliability of the part is obtained. In most cases, it is a value below the absolute maximum and the nominal value for most case conditions. See MIL-M-38510 or MIL-S-19500 for details.

15.4.1.6 Stress

Electrical, mechanical, or environmental forces applied to a part that affect failure rate.

15.4.1.7 Stress Ratio

Operating stress divided by the maximum rated stress.

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15.4.2 Acronyms and Symbols

AC.....	Alternative Current
APD.....	Avalanche Photo Diode
DC.....	Direct Current
DHC.....	De Havilland Canada
FET.....	Field Effect Transistor
ILD.....	Injection Laser Diode
LED.....	Light Emitting Diode
MTBF.....	Mean Time Between Failures
MOS.....	Metal Oxide Semiconductor
NR	Not Recommended
SCR.....	Silicon Controlled Rectifier
λ	Failure Rate
θ	Thermal Resistance Coefficient

15.5 REFERENCED DOCUMENTS

MIL-STD-721.....	Definitions of Terms for R&M
MIL-STD-883.....	Test Methods and Procedures for Microcircuits
MIL-HDBK-251.....	Reliability / Design Thermal Applications
MIL-HDBK-217.....	Reliability Prediction of Electronic Equipment
MIL-HDBK-5.....	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-M-38510.....	Microcircuits, General Specification for
MIL-S-19500.....	Semiconductor Devices, General Specifications for

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15.6 DERATING ANALYSIS PROCEDURE

15.6.1 General

This section and the following sections present **reliability derating analysis** guidelines, procedure for electrical, electronic, electromechanical, and mechanical parts.

These requirements are intended for use by all organizations involved in the design, use or evaluation of equipment and systems.

15.6.1.1 Necessity for Derating

It has been proven by experience and part failure rate models that **derating** (operating parts at less than their maximum ratings) is **necessary** for reliable operation.

It can be shown that there is an improvement in the predicted failure rate for a part as the operating stresses are decreased.

This failure rate reduction continues to a point where further stress reduction results in insufficient further reliability gains.

15.6.1.2 Limitation of Derating

The **derating levels** recommended in the following sections are guidelines only and should not be considered as absolute values.

Derating always represents a compromise between size, weight, cost, and failure rate.

Generally, size, weight, and cost increase with increases in derating.

Excessive derating can result in no part existing to perform the function.

Also, the excessive derating can result in unnecessary increases in parts count and consequently of the overall circuit predicted failure rate.

For most applications, the recommended guidelines will not result in significant size, weight, or cost penalties.

A careful analysis of the design to establish all the trade-offs should be performed for those cases where it may be advisable to exceed the recommended guidelines.

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Minor deviations from the guidelines usually have small effect on the predicted failure rate.

15.6.2 Equipment Derating Levels

For many part types there is a range of acceptable **derating levels** between the minimum derating point and the point of over derating.

The **optimum** derating is normally considered to occur at or below the point of stress where a rapid increase in failure rate occurs for a small increase in stress.

Three recommended **derating levels** are selected on the basis of the **criticality** of the **application**.

15.6.2.1 Derating Level I (Maximum Derating)

Equipment whose failure would substantially **jeopardize** the life of personnel, or seriously jeopardize the operational mission or for which **repairs** are unfeasible or economically **unjustified**.

Level I derating is judged to be those stress levels below which further reliability gain is negligible or where further derating will create unacceptably difficult design problems.

This is intended for the **most critical applications** where the associated design difficulty can be justified by the reliability requirement

15.6.2.2 Derating Level II

Equipment whose failure would degrade the operational mission or would result in unjustifiable repair costs.

Level II derating is considered to be still in the range where reliability gains are rapid as stress is decreased.

However, achieving designs with these reductions in allowed stress, is significantly more difficult than at Level III.

15.6.2.3 Derating Level III

Equipment of **lesser** criticality than Levels I or II. Equipment whose failure does not jeopardize the operational mission or which can be **quickly** and economically repaired.

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Level III derating is that stress level reduction which creates minor design difficulties and yet generates the largest incremental reliability gain.

The large reliability gain is realized because the effects of stress increase dramatically as the absolute maximum rating is approached.

15.6.2.4 Part Derating Level Determination

- (1) Use the definitions in Para. 15.4.1.
- (2) For better evaluation use Table 15.1, which defines the **key factors** for determining the appropriate level of derating for the given system constraints.

TABLE 15.1: 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 down-times 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, difficulty 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

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15.6.2.5 Equipment Environments

Generally, the following **criticality levels** apply, **as minimum**, for the listed operational environments:

TABLE 15.2: CRITICALITY LEVELS FOR OPERATIONAL ENVIRONMENT

ENVIRONMENT	LEVEL
Ground	III
Flight	II
Space	I
Missile Launch	I

15.6.2.6 Part Quality Level

Derating cannot be used to compensate for using parts of a lower quality than necessary to meet usage reliability requirements.

The quality level of a part has a direct effect on the predicted failure rate.

Electrical testing of all parts in a lot is not guaranteed for commercial or JAN level military parts.

For **high reliability** applications only fully tested and screened parts (including burn-in) should be used, in addition to application of the appropriate levels.

15.6.3 Derating Procedure

Derating procedures vary with different **types** of parts and their **application**.

Resistors are derated by decreasing the ratio of **operating power** to rated power, **Capacitors** are derated by maintaining the applied voltage at a lower value than the voltage for which the part is rated, **Semiconductors** are derated by keeping the **power dissipation** below the rated level.

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The **parameters to be derated**, and their values for different part types and derating levels are provided in **Appendix A**, Tables.

These tables **shall be used** for electrical, electronic and electromechanical parts.

The following steps are the steps for the Derating Procedure:

- (1) **The first step** in the procedure is to determine the **derating level** to be used, use Table 15.1 as a guide.
- (2) **The second step** is:
 - a) **knowing** the **rated** values of each part, (from part manufacturers)
 - b) **calculating** the **actual** operating values
 - c) defining the **parameters** to be derated
 - d) **using** the tables in Appendix A, **finding out** whether there are **over-stressed** parts and/or unacceptable safety margins, **using** Table 15.3 as a sample worksheet.

TABLE 15.3: DERATING ANALYSIS (SAMPLE)

(1) Part Type	(2) Derating Parameters	(3) Rated Values	(4) Actual Operating Value	(5) Stress Ratio (4:3)	(6) Allowable Stress Ratio (App.A)	(7) Results	(8) Corrective Action
1. Transistor FET	1.1 Power Dissipation	500 mW (data)	400 mW (analysis)	400/500 = 0.8	60% = 0.6 per Derating Level II	0.8 > 0.6 Part Over Stressed.	
	1.2 Breakdown Voltage						
	1.3 Maximum Junction Temperature Tj (deg. C)						

Another way is the use of specific **derating curves**, which usually relate derating levels to some critical environmental or physical factor.

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Such curves are typically included in the part specification.

A **typical** derating curve for semiconductors is shown below.

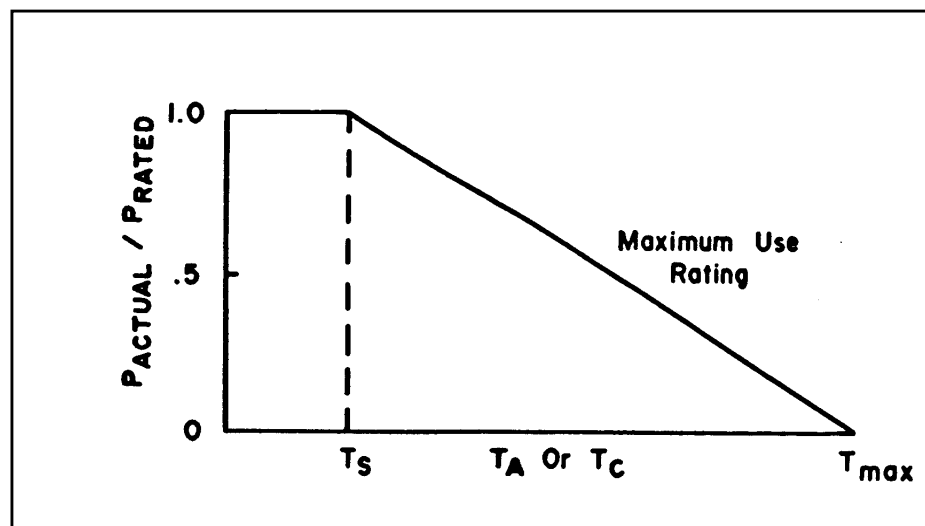


FIGURE 15.1: TYPICAL DERATING GRAPH

T_s is the temperature derating point, (usually 25 deg. C),

T_{max} is the maximum junction temperature,

T_A is the ambient temperature,

T_C is the case temperature,

P is the power dissipation (watts).

Maximum junction temperature (T_{max}) is normally 175 deg. C, for silicon and 100 deg. C, for germanium devices.

Although usually 25 deg. C, T_s can have other temperature values.

This conventional derating approach makes the approximate **assumption** that the **thermal resistance**, θ , from ambient or case to junction is a **constant**, and that the **junction temperature** is:

$$T_j = T_A + \theta_{JA} \cdot P_j$$

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or,

$$T_j = T_C + \theta_{JC} \cdot P_J$$

where,

T_j is junction temperature,

T_A is ambient temperature,

T_C is case temperature,

θ_{JA} is thermal resistance coefficient, (ambient to junction, deg.C, per watt),

θ_{JC} is thermal resistance coefficient, (case to junction, deg. C, per watt),

P_J is power (watts) dissipated at junction.

These equations indicate that operation anywhere along the derating line between T_S and T_{max} will result in a junction temperature equal to T_{max} and that the thermal resistance coefficient (θ) is constant at a value:

$$\theta = \frac{(T_{max} - T_S)}{P_{(rating)}}, \text{ deg. C, per watt.}$$

where,

$P_{(rating)}$ is power rating (watts) at temperature T .

This assumption of constant thermal resistance is **approximate**.

Example for step 2:

Consider that the transistor is used at 55 deg. C, ambient temperature rated for 500 mW at 25 deg. C, and used at two different stress levels 400 mW = 80%, and 200 mW = 40%.

Referring to Figure 15.2 and Table 15.4, below, at a stress of 80% and a temperature of 55 deg. C, the base failure rate λ_b is 0.033×10^{-6} .

It can also be seen that 80% stress or 400 mW is the maximum allowable power dissipation at 55 deg. C, for this transistor.

If, however, the transistor is stressed only 40% at 55 deg. C, the base failure rate λ_b decreases drastically to 0.010×10^{-6} .

A **considerable reliability improvement** of 3.3 to 1 has been achieved.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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(SILCON, NPN)**

T (°C)	S									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.0034	0.0041	0.0048	0.0057	0.0067	0.0079	0.0095	0.011	0.014	0.018
10	0.0038	0.0046	0.0054	0.0064	0.0075	0.0089	0.010	0.013	0.017	0.023
20	0.0043	0.0051	0.0060	0.0071	0.0084	0.010	0.012	0.015	0.020	0.029
25	0.0046	0.0054	0.0064	0.0075	0.0089	0.010	0.013	0.017	0.023	0.033
30	0.0050	0.0057	0.0067	0.0079	0.0095	0.011	0.014	0.018	0.025	
40	0.0054	0.0064	0.0075	0.0089	0.010	0.013	0.017	0.023	0.033	
50	0.0060	0.0071	0.0084	0.010	0.012	0.015	0.020	0.029		
55	0.0064	0.0075	0.0089	0.010	0.013	0.017	0.023	0.033		
60	0.0067	0.0079	0.0095	0.011	0.014	0.018	0.025			
65	0.0071	0.0084	0.010	0.012	0.015	0.020	0.029			
70	0.0075	0.0089	0.010	0.013	0.017	0.023	0.033			
75	0.0079	0.0095	0.011	0.014	0.018	0.025				
80	0.0084	0.010	0.012	0.015	0.020	0.029				
85	0.0089	0.010	0.013	0.017	0.023	0.033				
90	0.0095	0.011	0.014	0.018	0.025					
95	0.010	0.012	0.015	0.020	0.029					
100	0.010	0.013	0.017	0.023	0.033					
105	0.011	0.016	0.018	0.025						
110	0.012	0.016	0.020	0.029						
115	0.013	0.017	0.023	0.033						
120	0.014	0.018	0.025							
125	0.015	0.020	0.029							
130	0.017	0.023	0.033							
135	0.018	0.025								
140	0.020	0.029								
145	0.023	0.033								
150	0.025									
155	0.029									
160	0.033									

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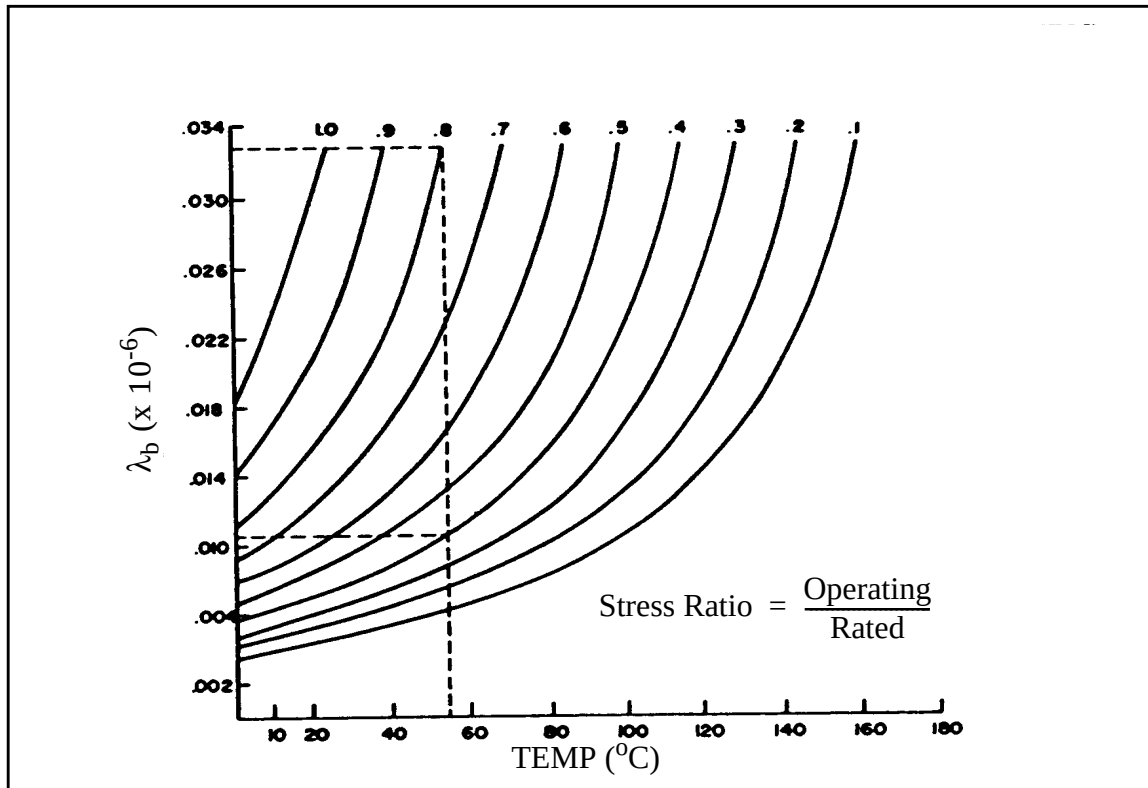


FIGURE 15.2: STRESS/TEMPERATURE PLOT FOR GROUP I TRANSISTOR (SILICON, NPN)

- (3) Third step is:
after having defined the **derating level** to be used,
- calculate** the operating values for each **parameter** to be derated, (based on operating conditions, part type, and Appendix A tables)
 - knowing the **rated values** from manufacturers parts specification, **calculate** the **stress ratio** for **each parameter** to be derated,
 - compare** these stress ratios with the Derating Tables in Appendix A,
 - define** the overstressed parts using the spreadsheet given in Table 15.3,
 - evaluate** the results,
 - recommend **corrective actions**

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In addition to the Tables in Appendix A, derating curves also may be used for part stress evaluation.

Those curves may be found in manufacturer's part data books, MIL-SPECs for parts (i.e., MIL-R-55162, MIL-R-39035 for resistors), and other referenced documents.

Example for step 3:

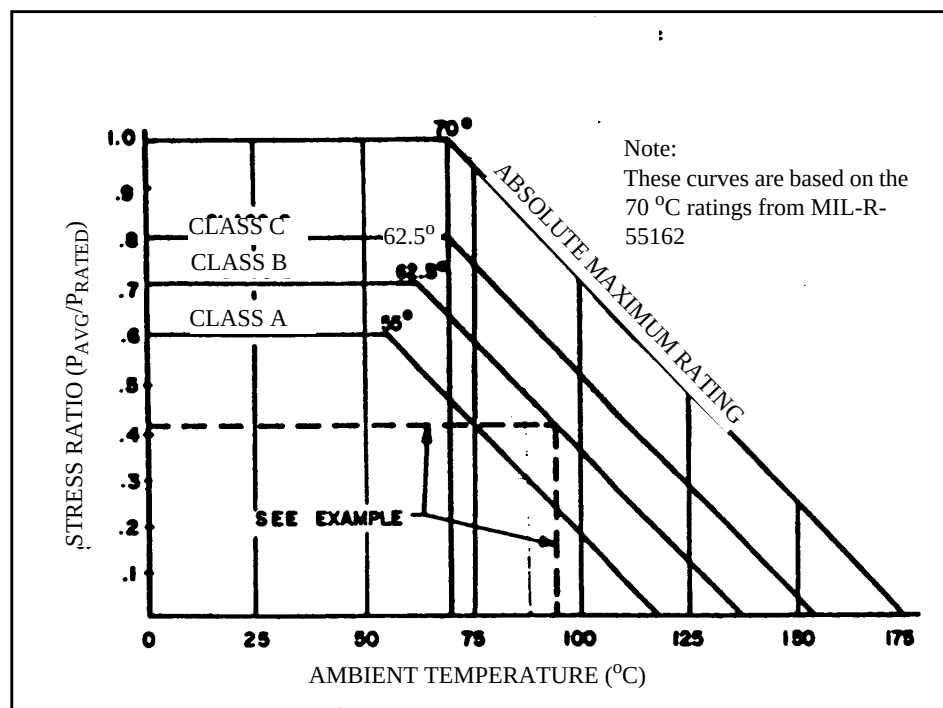


FIGURE 15.3: POWER DERATING FOR TYPE RNR RESISTORS

1. Given:

- Specified equipment high ambient operating temperature = +71°C.
- Derating for Class B (Level II) equipment has specified.
- Equipment thermal survey shows an internal heat rise of 23°C.
- Circuit requires 175 milliwatts (mw) of power dissipation.

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2. Find:

Required resistor rating for the application.

3. Solution:

- a) Part ambient operating temperature = $71^{\circ}\text{C} + 23^{\circ}\text{C} = 94^{\circ}\text{C}$
- b) **Plot** a vertical line from the 94°C point on the temperature scale to the intersection with the Class B (or Level II) derating curve.
- c) Plot a horizontal line from this point to the left hand scale.
- d) **Read** maximum allowable dissipation = 0.42 times the absolute maximum rating at 70°C .
- e) **Calculate**; $175\text{ mw} \div 0.42 = 415\text{ mw}$ rating required.
- f) **Use** RNR 65 (1/2 watt rated at 70°C).

15.6.4 Derating of Electronic Components

Derating of **electronic** parts and materials shall be accomplished as necessary to assure that the required equipment reliability is within specification.

A **common design error** is to compute worst case i.e., semiconductor junction temperatures and assume that the thermal design is adequate, if the manufacturer's maximum operating junction temperature is not exceed.

While the device may function under such conditions, its **reliability** or **life**, will generally be so low as to be **unacceptable**.

Maximum allowable semiconductor junction temperatures are meaningless unless related to required system reliability.

This normally will require considerable **derating** of the manufacturer's data.

In addition to the requirements of system reliability, maximum junction temperature **derating** is required to provide some margin of analytical error.

This **allows** for nonuniform heating without **catastrophic failure** and allows for system electrical transients.

Since most **electronic parts** are **sensitive** to temperature, the **thermal analysis** of the design should accurately provide the temperatures needed for proper application of the part.

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Of course, **lower temperatures** produce better reliability but can also produce increased penalties in terms of added loads (or constraints) on controlling the system's environment.

The **thermal analysis** should be part of the **design process** and included in tradeoff studies covering equipment performance, reliability, weight, volume, environmental control requirements, and cost.

As a **general rule**, derating should not be **conservative** to the point where costs rise excessively.

Neither should the derating criteria be so **loose** as to render reliable part application ineffective.

Optimum derating occurs at or below the point on the stress temperature curve where a rapid increase in failure rate is noted for a small increase in temperature or stress.

There is, however, a practical minimum to derating. At some minimum stress level, circuit complexity may be necessarily increased to gain performance, thus offsetting the reliability gain accomplished by derating.

15.6.5 Derating Of Mechanical And Structural Components

For mechanical and structural components, such failure rate versus stress data may be obtainable from the manufacturer or users, but time rate data may not be available.

In using a manufacturer's rating and single design stress values, the design engineer must keep in mind that they are really distributions, not single values.

Either the worst case "tolerance" for both stress and strength or a plot of the distributions must be utilized.

When there is **time dependency** for the distributions (e.g., degradation, wear out), the stress and strength distributions must be related to the cyclic or time operation in the intended environment.

The **classical approach** to mechanical and structural design is to give every part enough strength to handle the worst stress it will encounter.

Several references, such as MIL-HDBK-5 (Metallic Materials and Elements for Aerospace Vehicle Structures), are available, providing data on the strength of materials.

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Some of these provide limited data on strength degradation with time, resulting from fatigue.

Effective design procedures should provide for evaluating alternative configurations with respect to reliability.

Since failure is not always related to time, the designer needs techniques for comparing **stress vs. strength**, and determining the quantitative reliability measure of the design.

The **traditional** use of safety factors and safety margins is inadequate for providing a reliability measure of design integrity.

The **concept** of **stress strength** in design recognizes the reality that loads or stresses and strengths of particular items subjected to these stresses cannot be identified as a specific value but have ranges of values with a probability of occurrence associated with each value in the range.

The ranges of values (variables) may be described with appropriate statistical **distributions** for the item.

Stress/strength design requires knowledge of these distributions. After the strength and stress distributions are determined, a probabilistic approach can be used to calculate the **quantitative reliability** measure of the design, including confidence limits.

To illustrate the concept of stress and strength distributions related to reliable design, assume that a large number of tests of the strength of a given manufactured item have been run, with each test being run to failure.

A relationship (frequency distribution) between the number failing at any particular value of strength (or band of values) and the value can be determined.

Figure 15.4 (a) shows a generalized frequency distribution of the results. If the exact relationship were known, the probability of a randomly selected specimen failing at a particular value of stress F could be predicted.

It would be that fraction of the population, whose strength was equal to or less than a stress F .

Similarly if a large number of experiments were conducted, and the stress was recorded on each equipment, a relationship between the relative frequency of stresses and the stress can be established.

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This relationship is shown in Figure 15.4 (b). If the exact relationship were known, the probability that on any randomly selected trial the stress would exceed a strength S could be predicted.

This would be the fraction of the population (of possible trials) in which the stress exceeded the strength S .

With both of these distributions defined, unreliability is determined as the probability that the stress is greater than the strength.

Unreliability can be determined **analytically**, graphically, by numerical integration or by probabilistic techniques such as "Monte Carlo" provided the form or shape of the two probability distribution functions are known.

The curves from Figure 15.4 (a) and (b) are combined in Figure 15.4 (c) to illustrate the region of the unreliability given by the shaded area where stress exceeds strength.

Figure 15.5 illustrates normal (gaussian) stress and strength distributions, where the stress and strength variables are identified as Kips (a thousand pounds).

Looking at Figure 15.5, two things may happen with time and repeated stress. The variance of the strength distribution may change; for example the curve may extend from 13 to 23 Kips rather than the original 16 to 20 Kips.

This would result in an **increased unreliability** since the shaded area would now extend from 13 to 20 Kips.

This is shown in Figure 15.6 (a). The other factor that could change with time and stress is that the **mean** of the strength distribution might be lowered, to say 15 Kips.

This, in turn, would result in a **decreased reliability** as shown by the shaded area of Figure 15.6 (b).

The **purpose** of stress strength analysis is to **improve** the reliability of the design. That is, to find the optimum comparison of stress and strength that will have an acceptable probability of success and compete favorably with other constraints such as weight, cost, availability of material.

There are **four basic procedures** the designer may use to increase **reliability**:

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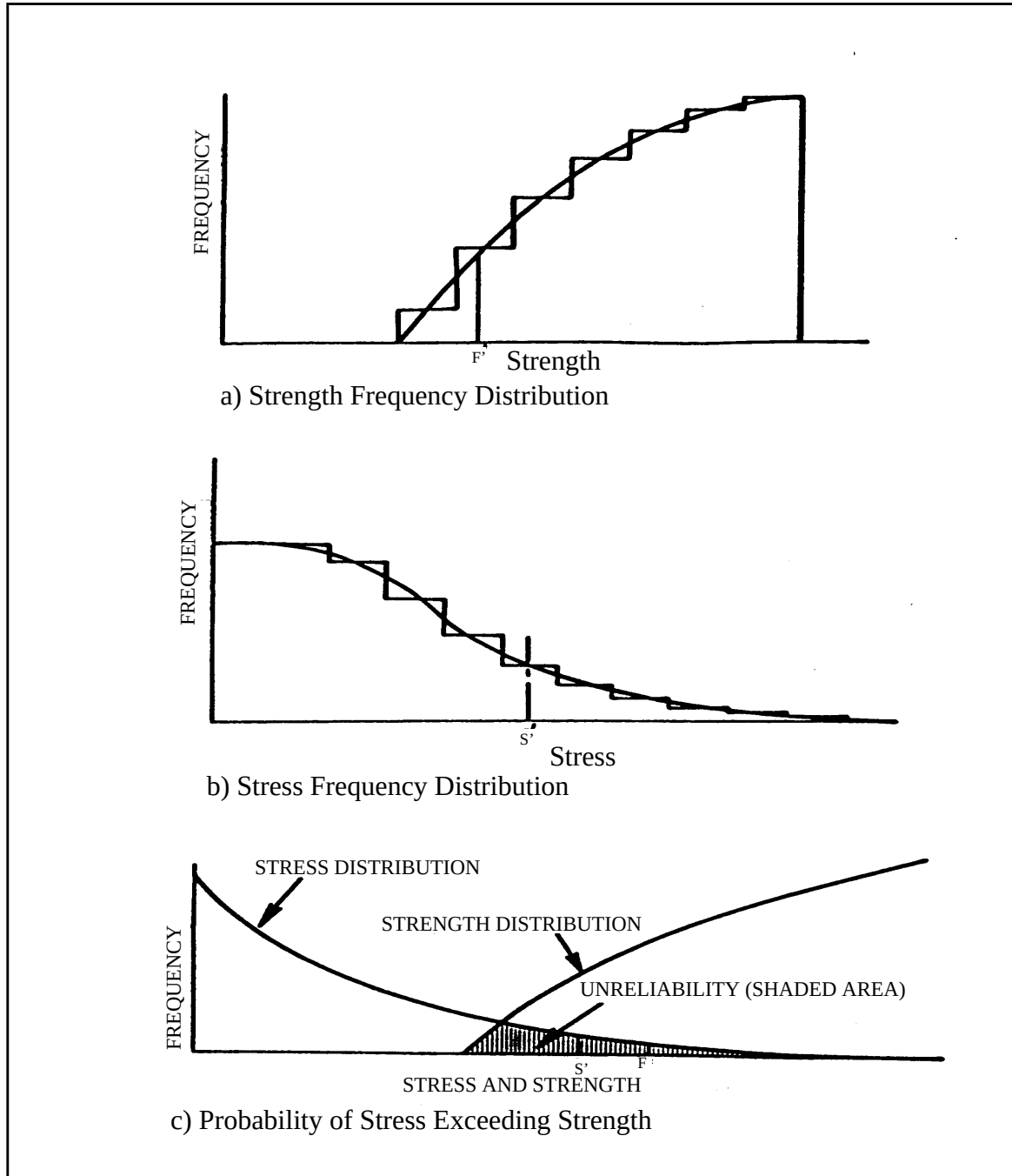
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- (1) **Increase Average Strength**
This approach is tolerable if size and weight increases can be accepted or if a stronger material is available.
- (2) **Decrease Average Stress**
Occasionally the average stress on a component can be reduced without greatly affecting its capability.
- (3) **Decrease Stress Variation**
The variation in stress is usually hard to control. However, the stress distribution can be effectively **truncated** by putting limitations on use conditions.
- (4) **Decrease Strength Variation**
The inherent part-to-part variation in strength can be reduced by improving the basic process, holding tighter control over the process, or by utilizing tests to eliminate the less desirable parts.

More details on this method are provided in Reliability Modeling And Predictions Procedure.

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**FIGURE 15.4: STRESS-STRENGTH DISTRIBUTION
AND UNRELIABILITY IN DESIGN**

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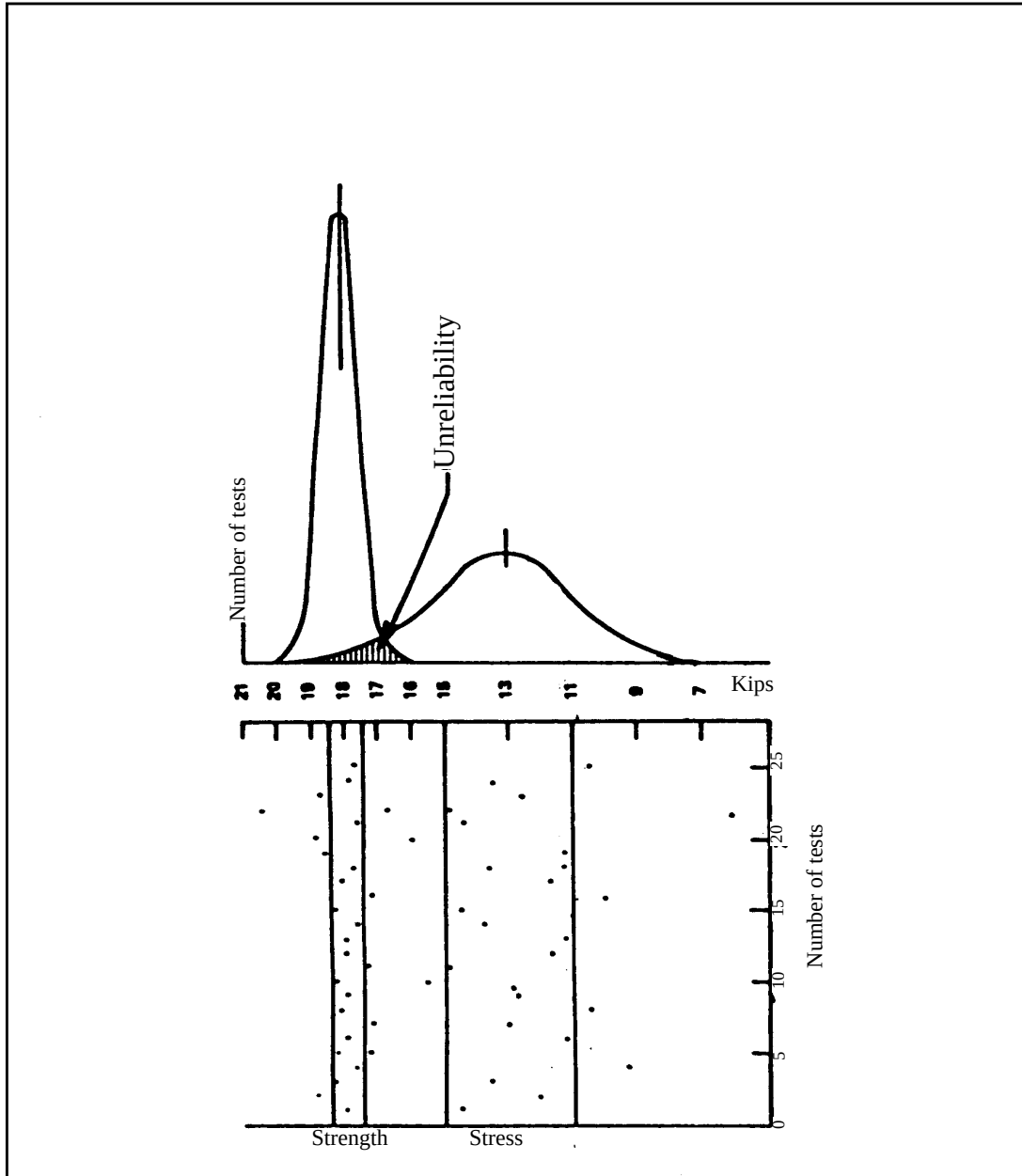


**FIGURE 15.5: NORMAL (GAUSSIAN) STRESS-STRENGTH
DISTRIBUTIONS AND UNRELIABILITY IN
DESIGN**

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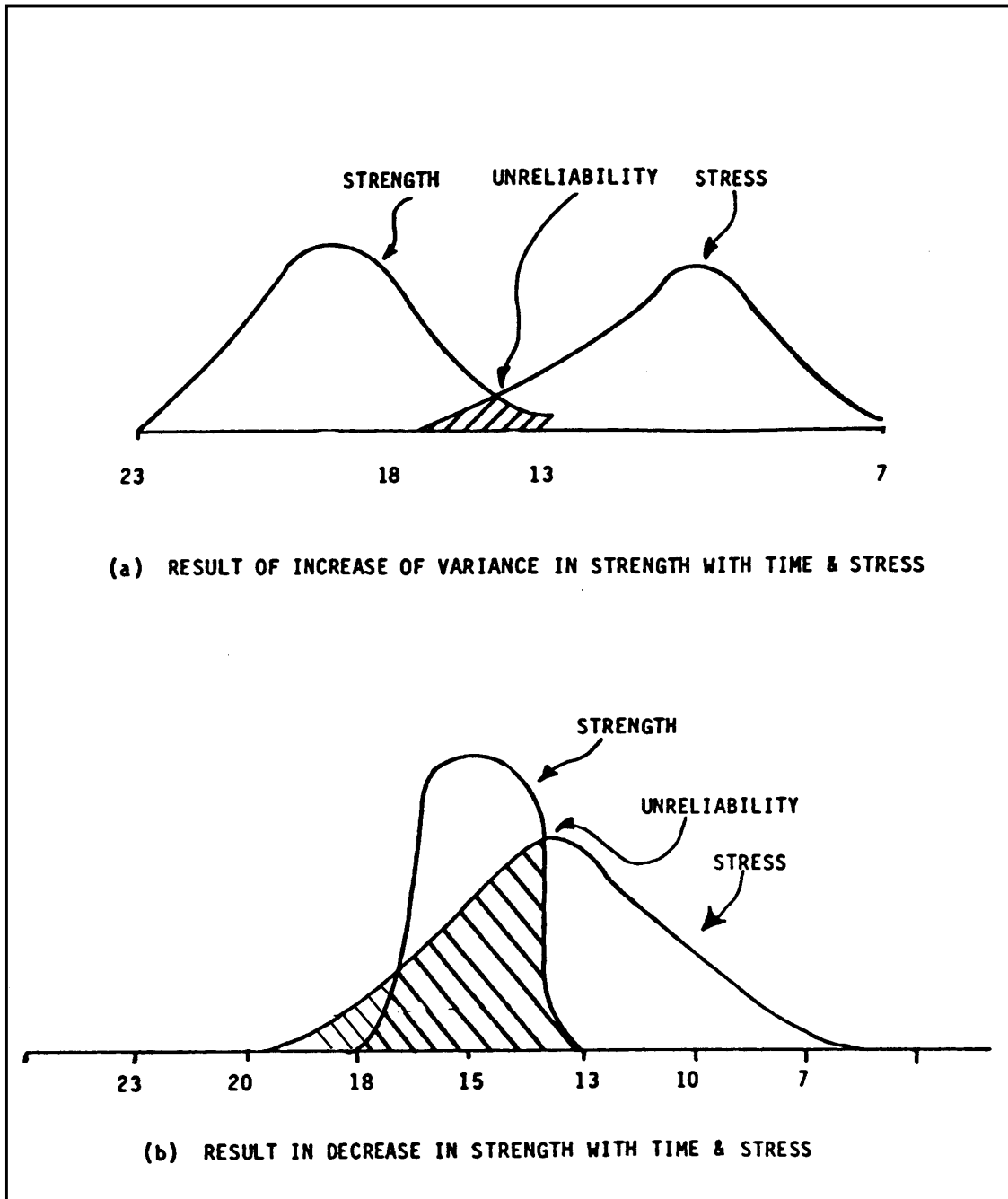
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**FIGURE 15.6: UNRELIABILITY - STRESS / STRENGTH
DISTRIBUTION**

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APPENDIX A

DERATING GUIDELINES AND CRITERIA

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 15***15.7 APPENDIX A: DERATING GUIDELINES AND CRITERIA****15.7.1 Introduction**

Derating values of electrical stress are expressed as **ratios** of applied stress to **rated** maximum stress.

The **applied** stress is taken as the maximum likely to be applied during worst case operating conditions.

Derating enhances reliability by:

- (1) **Reducing** the likelihood that marginal components will fail of the system.
- (2) **Reducing** the effects of parameter variations.
- (3) **Reducing** long-term drift in parameter values.
- (4) **Providing** allowance for uncertainty in stress calculations.
- (5) **Providing** some protection against transient stresses, such as voltage spikes.

Table 15.5 gives **basic** information for the derating of parts. **Detailed** information and tables can be found in **section** 15.7.2 of this appendix.

The specified derating ratios and applicable notes will assist the designer in obtaining reliable operation of parts.

It must be emphasized that the **designer** should evaluate **all** parts to the requirements of his applications, since he is responsible for the implementation of adequate deratings.

The recommended derating factors are based on the best information currently available.

The derating factors indicate the maximum recommended stress values and do not preclude further derating.

When derating, the **designer** must determine the difference between the part specification environmental and operating conditions and part actual environmental and operating conditions of the application, **derate**, if applicable, and then apply the recommended derating factors contained herein.

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Parts **not** appearing in these guidelines (Table 15.5 and section 15.7.2) are lacking in empirical data and failure history.

Since the operating characteristic for such parts cannot be guaranteed, it is a good **policy** to derate generously to provide an additional margin of safety.

For **new devices** it is advisable to obtain manufacturer life test data for analysis which may lead to suggested derating figures.

This is particularly true of step-stress data where distinct breakpoint may be identifiable such that reducing stress beyond breakpoint will not significantly affect device failure rate.

TABLE 15.5: DEVICE DERATING GUIDELINES (BASIC)

Part Type	Derating Parameter	Derating Level			Part Type	Derating Parameter	Derating Level		
		I	II	III			I	II	III
Capacitors					Fiber Optics				
• Film	Voltage/Temp (°C)	50% /10	60% /10	60% /10	• ILD (Injection Laser)	Power Output	50%	60%	70%
• Mica						Max Tj (°C)	95	105	110
• Glass					• APD (Avalanche Photo)	Reverse Voltage	70%	70%	70%
• Ceramic						Max Tj (°C)	95	105	125
Capacitors					Fiber Optics				
• Electrolytic Aluminum	Voltage/Temp (°C)	NR	NR	NR	• Cable	Bend Radius (% of minimum)	200%	200%	200%
• Electrolytic Tantalum	Voltage/Temp (°C)	50% /20	60% /20	60% /20		Tension Cable (% Rated Tensile)	50%	50%	50%
	(NR-Not recommended for use)					Tension Fiber (% Proof Test)	20%	20%	20%
Capacitors					Inductors				
• Variable Piston	Voltage/Temp (°C)	40% /10	50% /10	50% /10	• Pulse Transformers	Operating Current	60%	60%	60%
• Variable Ceramic	Voltage/Temp (°C)	30% /10	50% /10	50% /10		Dielectric Voltage Temp (°C) Hot Spot	50%	50%	50%
							40	25	15
Connectors					Inductors				
	Voltage	50%	70%	70%	• Coils	Operating Current	60%	60%	60%
	Current	50%	70%	70%		Dielectric Voltage Temp (°C) Hot Spot	50%	50%	50%
	Insert Temp (°C) (T from Max Limit)	50	25	25			40	25	15
Diodes					Lamps				
• Signal/Switch (Axial Lead)	Forward Current	50%	65%	75%	• Incandescent	Voltage	94%	94%	94%
	Reverse Voltage	70%	70%	70%	• Neon	Current	94%	94%	94%
	Max Tj (°C)	95	105	125					

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES****CHAPTER 15****TABLE 15.5: DEVICE DERATING GUIDELINES (BASIC) Cont'd**

Part Type	Derating Parameter	Derating Level			Part Type	Derating Parameter	Derating Level		
		I	II	III			I	II	III
Diodes • Schottky/PIN (Axial Lead)	Power Dissipation Reverse Voltage Max Tj (°C)	50% 70% 95	60% 70% 105	70% 70% 125	Microcircuits • Linear	Supply Voltage Input Voltage Output Current Max Tj (°C)	70% 60% 70% 80	80% 70% 75% 95	80% 70% 80% 105
Diodes • Power Rectifier	Forward Current Reverse Voltage Max Tj (°C)	50% 70% 95	65% 70% 105	75% 70% 125	Microcircuits • Digital	Supply Voltage Input Voltage Output Current Max Tj (°C) (F. % Absolute Max)	±3 % 80% 80% 85	±5% 90% 85% 100	±5% 95% 90% 110
Diodes • Voltage Regulator • Voltage Reference	Power Dissipation Max Tj (°C) Current Izt Max Tj (°C) (P.% Rated - Fixed Test Current, don't derate)	50% 95 95	60% 105 105	70% 125 125	Microcircuits • Hybrid	Thick Film* Thin Film* Max Tj (°C) *(Pwr Density-W/in ²)	<50 <40 85	<50 <40 100	<50 <40 110
Diodes • Suppressor Transient	Power Dissipation Average Current Max Tj (°C)	50% 50% 95	60% 65% 105	70% 75% 125	Microcircuits • Complex (LSI, VLSI, VHSIC)	Supply Voltage Frequency Output Current Fan Out Max Tj (°C) (F. % Absolute Max)	±3 % 75 70% 70% 85	±5% 80% 75% 75% 100	±5% 90% 80% 80% 125
Diodes • Microwave	Power Dissipation Reverse Voltage Max Tj (°C)	50% 70% 95	60% 70% 105	70% 70% 125	Microcircuits • Memory	Supply Voltage Output Current Max Tj (°C)	±3 % 70% 85	±5% 75% 100	±5% 80% 125
Diodes • LED	Forward Current Max Tj (°C)	50% 95	65% 105	75% 110	Transistors • Bipolar	Power Dissipation Breakdown Voltage Max Tj (°C)	50% 60% 95	60% 70% 105	70% 70% 125
Miscellaneous • Circuit Breakers • Fuses	Current Current	75% 50%	80% 50%	80% 50%	Transistors • Field Effect	Power Dissipation Breakdown Voltage Max Tj (°C)	50% 60% 95	60% 70% 105	70% 70% 125

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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Part Type	Derating Parameter	Derating Level			Part Type	Derating Parameter	Derating Level		
		I	II	III			I	II	III
Relays	Current (Res/Cap) Current (Ind) Contact Power Temp (°C) (T from Max Limit)	50% 35% 40% 20 20	75% 40% 50% 20 20	75% 40% 50% 20 20	Transistors • Field Effect	On-State Current Off-State Voltage Max Tj (°C) (It. % Rated) (VDM. % Rated)	50% 70% 95	70% 70% 105	70% 70% 125
Resistors • Composition • Film • Variable • Thermistor	Power/Temp (°C) Power/Temp (°C) Power/Temp (°C) Power/Temp (°C) (T from Max Limit)	50% /30 50%/40 30% /45 50%/20	50% /30 50%/40 50% /35 50%/20	50% /30 50%/40 50% /35 50%/20	Tubes	Power Output Power Reflected Duty Cycle	80% 50% 75%	80% 50% 75%	80% 50% 75%
Resistors • Wirewound Accurate • Wirewound Power	Power/Temp (°C) Power/Temp (°C) (T from Max Limit)	50%/10 50%/125	50%/10 50%/125	50%/10 50%/125	Saw	Input Power (dB) (Freq >500MHz) Input Power (dB) (Freq <500MHz) Temp (°C) (T.Op Max)	13 18 125	13 18 125	13 18 125
Rotating	Bearing Load Operating Temp (°C) (L. % Rated) (T from Max Limit)	75% 40	90% 25	90% 15	Switches	Current (Res/Cap) Current (Ind) Contact Power	50% 35% 40%	75% 40% 50%	75% 40% 50%

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: RADCR/RBER, Griffiss AFB NY.

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15.7.2 Device Derating Guidelines/Criteria

15.7.2.1 Microcircuit Derating Criteria

15.7.2.1.1 General Data

Microcircuits are, generally, a group of devices that includes monolithic, multichip, film, and hybrid microcircuits, microcircuit arrays; and the elements from which the circuits and arrays are formed.

The **derating levels** in this section are based on analysis of user data, stress relationships, and reliability history.

Junction, case, or other temperature parameters should be calculated using the methods in MIL-HDBK-251.

15.7.2.1.2 Microcircuit Types

For this guideline, microcircuits are **categorized** as follows:

- (1) Linear devices (bipolar and MOS)
- (2) Digital devices (bipolar and MOS)
- (3) Hybrid devices (attached element, thick film, thin film).

(1) Linear Microcircuits

a) Application

Since MOS devices are susceptible to electrostatic discharge, precautions should be taken. Design margins for linear circuits should be used, as below.

b) Derating

The principal stress parameters and levels of derating are in Table 15.6.

Note: For devices with dynamic supply voltage ranges only; all others will use manufacturer's recommended supply voltage. Derating below 80 percent of the supply voltage may operate the device below recommended operating voltages.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 15***TABLE 15.6: DERATING FOR LINEAR MICROCIRCUITS
(BIPOLAR AND MOS)**

	Level 1	Level II	Level III
Supply Voltage (Percent of Rated Value)	70	80	80
Input Voltage (Percent of Rated Value)	60	70	70
Output Current (Percent of Rated Value)	70	75	80
Maximum Junction Temperature (°C)	80	95	105

(2) Digital Microcircuits**TABLE 15.7: DERATING FOR DIGITAL MICROCIRCUITS
(BIPOLAR AND MOS)**

	Level I	Level II	Level III
Fixed Supply Voltage (Bipolar and MOS)	± 3 %	± 5 %	± 5 %
Dynamic Supply Voltage (Bipolar and MOS) Percent of Rated Value	70	85	85
Frequency (Bipolar) (Percent of Maximum Specified)	80	90	95
Frequency (MOS) (Percent of Maximum Specified)	80	80	90
Output Current (Bipolar and MOS) (Percent of Rated Value)	80	85	90
Maximum Junction Temperature (°C) (Bipolar and MOS)	85	100	110

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a) Application

For bipolar digital devices, supply voltage deviation from the specified nominal will shift internal bias points, which, coupled with thermal effects, can cause erratic performance.

Design precautions should be taken to avoid these problems.

b) Derating

The principal stress parameters and levels of derating are in Table 15.7.

(3) Hybrid Microcircuit**a) Application**

Since some hybrid circuits are susceptible to electrostatic discharge, precautions should be taken.

b) Derating

Elements attached within a hybrid must be derated, as shown in this section, for the individual devices.

For unique hybrids such as crystal oscillators or light emitting diode (LED) displays, the specific derating values for microcircuits and LEDs must be used.

In general, hybrid microcircuit derating should be done according to the levels in Table 15.8.

TABLE 15.8: DERATING FOR HYBRID MICROCIRCUITS

	Level I	Level II	Level III
Maximum Junction Temperature (°C)	85	100	110
Thick Film Power Density	< 50 watts/in ²	< 50 watts/in ²	< 50 watts/in ²
Thin Film Power Density	< 40 watts/in ²	< 40 watts/in ²	< 40 watts/in ²

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15.7.2.2 Transistor Derating Criteria

15.7.2.2.1 General Data

Transistors are generally, a group of devices that include switching, power, field-effect, microwave, and thyristors.

The basic applications are amplification and switching. The derating levels are based on analysis of user data, stress relationships, and reliability history.

Junction, case, or other temperature parameters should be calculated with the methods in MIL-HDBK-251.

15.7.2.2.2 Transistor Types

For this guideline, transistors are categorized as follows:

- (1) Bipolar Silicon Transistors (NPN OR PNP)
- (2) Unijunction Devices (not recommended for new designs)
- (3) Field-Effect Transistors (N or P channel)
- (4) Thyristors

(1) Bipolar Silicon Transistors

a) Application

For new designs, germanium and unijunction devices are not be considered.

b) Derating

High junction temperature is the most destructive stress for transistors. This parameter, along with power, voltage breakdown, and safe operating area, must be derated.

Derating levels are in Table 15.9.

(2) Field-Effect Transistors

a) Application

Perform switching or amplification.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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	Level 1	Level II	Level III
Maximum Junction Temperature (°C)	95	105	125
Power Dissipation (Percent of Rated Value)	50	60	70
Low-Power Device) Breakdown Voltage (Percent of Rated Value)	60	70	70
High-Power Device) Breakdown Voltage (Percent of Rated Value)	70V _{CE} 60I _C	70V _{CE} 60I _C	70V _{CE} 60I _C

b) Derating

Derating levels are in Table 15.10

TABLE 15.10: DERATING FOR FIELD-EFFECT TRANSISTORS

	Level I	Level II	Level III
Maximum Junction Temperature (°C)	95	105	125
Power Dissipation (Percent of Rated Value)	50	60	70
Thin Film Power Density	60	70	70

(3) Thyristors**a) Application**

Perform switching or amplification.

b) DeratingThe chief causes of failure are excessive **junction temperature** and voltage breakdown. Derating levels are in Table 15.11.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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	Level I	Level II	Level III
Maximum Junction Temperature (°C)	95	105	125
On-State Current (Percent of Rated Value)	50	70	70
Off state Voltage (Percent of Rated Value)	70	70	70

15.7.2.3 Diode Derating Criteria**15.7.2.3.1 General Data**

The categories of diodes in this section are switching, power rectifier, reference, transient suppressor, microwave, and light emitting.

The derating levels are based on analysis of user data, stress relationship and reliability history. Junction, case, or other temperature parameters should be calculated with the methods in MIL-HDBK-251.

15.7.2.3.2 Diodes Types

For this guideline, diodes are categorized as follows;

- (1) Axial lead diodes (small signal, switching): - silicon devices, schottky devices, etc.
- (2) Power rectifiers
- (3) Voltage Reference and Regulator Diodes
- (4) Transient Suppressor Diodes
- (5) Microwave Diodes
- (6) LEDs

(1) Axial Lead Diodes**a) Application**

Germanium diodes are not recommended for new designs. For reliability, metallurgically bonded and hermetically sealed diodes are preferred.

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High **junction temperature** is the most destructive stress for diodes. For silicon switching and small signal diodes, temperature, voltage, and current are the **principal** parameters.

Derating levels are in Table 15.12.

**TABLE 15.12: DERATING FOR AXIAL LEAD (SMALL SIGNAL/
SWITCHING) DIODES**

	Level I	Level II	Level III
Maximum Junction Temperature (°C) (All Diodes)	95	105	125
Reverse Voltage (Percent of Rated Value) (All Diodes)	70	70	70
Average Forward Current (Percent of Rated Value) (Silicon Diodes)	50	65	75
Power Dissipation (Percent of Rated Value) (Schottky and PIN)	50	60	70

(2) Power Rectifiers

Temperature is the principal stress parameter.

Derating levels are in Table 15.13.

TABLE 15.13: DERATING FOR POWER RECTIFIERS

	Level I	Level II	Level III
Maximum Junction Temperature (°C)	95	105	125
Reverse Voltage (Percent of Rated Value)	70	70	70
Average Forward Current (Percent of Rated Value)	50	65	75

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For voltage regulator diodes, **temperature** and **power** are the principal stress parameters.

Derating levels are in Table 15.14.

**TABLE 15.14: DERATING FOR VOLTAGE REFERENCE AND
REGULATOR DIODES**

	Level I	Level II	Level III
Maximum Junction Temperature (°C) (All Diodes)	95	105	125
Power Dissipation (Percent of Rated Value) (Regulator)	50	60	70
Current (I_{ZT}) (Reference)	Fixed Test Current	Fixed Test Current	Fixed Test Current

(4) Transient Suppressor Diodes

Temperature, current, and power are the **principal** stress parameters.

Derating levels are shown in Table 15.15.

TABLE 15.15: DERATING FOR TRANSIENT SUPPRESSOR DIODES

	Level I	Level II	Level III
Maximum Junction Temperature (°C)	95	105	125
Average Current (Percent of Rated Value)	50	65	75
Power Dissipation (Percent of Rated Value)	50	60	70

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(5) Microwave Diodes

Temperature, voltage, and power are the principal stress parameters. Derating levels are in Table 15.16.

TABLE 15.16: DERATING FOR MICROWAVE DIODES

	Level I	Level II	Level III
Maximum Junction Temperature (°C)	95	105	125
Reverse Voltage (Percent of Rated Value)	70	70	70
Power Dissipation (Percent of Rated Value)	50	60	70

(6) LEDs

Temperature and current are the principal stress parameters. Derating levels are in Table 15.17.

TABLE 15.17: DERATING FOR LEDs

	Level I	Level II	Level III
Maximum Junction Temperature (°C)	95	105	110
Average Forward Current (Percent of Rated Value)	50	65	75

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15.7.2.4 Resistor Derating Criteria

15.7.2.4.1 General Data

This section gives derating levels and application guidelines for resistors. The principal stress parameter is the hot spot temperature (the sum of the ambient temperature and the temperature due to the dissipated power).

Therefore, decreasing the ambient temperature or power dissipation will extend a resistor's expected life.

15.7.2.4.2 Resistor Types

The types of resistors in this section are defined below:

- (1) Composition, Fixed
- (2) Film, Fixed
- (3) Network, Film, Fixed
- (4) Wirewound, Fixed
- (5) Non-wirewound, Variable
- (6) Wirewound, Variable
- (7) Thermistors

(1) Fixed Composition Resistors

a) Application

When voltages are applied to carbon composition resistors, the resistance may change. Resistors below 1000 ohms are not controlled by specification, therefore, these resistors should not be used in circuits that are sensitive to this change.

b) Derating

Power and ambient temperature are the principal stress parameters. Derating levels are in Table 15.18.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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	Level I	Level II	Level III
Power (Percent of Rated Value)	50	50	50
Temperature Derating ($^{\circ}\text{C}$) (From Maximum Limit)	30	30	30

(2) Fixed Film Resistors**a) Application**

These resistors are recommended for use when very close tolerances are not required and fixed composition resistors do not have the needed accuracy or stability.

b) Derating

Power and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.19.

TABLE 15.19: DERATING FOR FIXED FILM RESISTORS

	Level I	Level II	Level III
Power (All Resistors) (Percent of Rated Value)	50	50	50
Temperature Derating ($^{\circ}\text{C}$) (From Maximum Limit)			
MIL-R-11804	75	75	75
MIL-R-22684	40	40	40
MIL-R-39017	40	40	40
MIL-R-55182	25	25	25
MIL-R-55342	25	25	25

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This resistor is stable with respect to time, temperature, and humidity. When used in high frequency circuits (200 Mhz and above), the resistance is reduced.

b) Derating

Power and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.20

TABLE 15.20: DERATING FOR FIXED NETWORK FILM RESISTOR

	Level I	Level II	Level III
Power (Percent of Rated Value)	50	50	50
Temperature (Derating (°C) (From Maximum Limit)	25	25	25

(4) Fixed Wirewound Resistors**a) Application**

These resistors are used when very **close tolerance**, long life, and a high degree of temperature stability are required.

b) Derating

Power and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.21

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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	Level I	Level II	Level III
Power (All Resistors) (Percent of Rated Value)	50	50	50
Temperature Derating (°C) (From Maximum Limit)			
MIL-R-26	160	160	160
MIL-R-18546	125	125	125
MIL-R-39005	10	10	10
MIL-R-39007	125	125	125
MIL-R-39009	125	125	125

(5) Variable Non-Wirewound Resistors**a) Application**

The conducting element determines the maximum operating temperature and power rating.

b) Derating

Power and ambient temperature are the principal stress parameters. Derating levels are shown in Table 15.22.

(6) Variable Wirewound Resistors**a) Application**

This resistor group is used as rheostats or voltage dividers.

b) Derating

Power and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.23

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 15***TABLE 15.22: DERATING FOR VARIABLE NON-WIREWOUND
RESISTORS**

	Level I	Level II	Level III
Power MIL-R-94 (Percent of Rated Value)	30	50	50
MIL-R-22097	30	50	50
MIL-R-23285	50	50	50
MIL-R-39023	NR	50	50
MIL-R-39035	30	50	50
Temperature Derating (°C) (From Maximum Limit)			
MIL-R-94	35	25	25
MIL-R-22097	45	35	35
MIL-R-23285	20	20	20
MIL-R-39023	NR	15	15
MIL-R-39035	45	35	35

(7) Thermistor**a) Application**

Operation above the maximum hot spot temperature produces permanent resistance changes. Use current limiting resistors to prevent the negative coefficient type from going into thermal runaway. Never exceed the maximum current or power ratings.

b) Derating

Power and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.24.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES****CHAPTER 15****TABLE 15.23: DERATING FOR VARIABLE WIREWOUND
RESISTORS**

	Level I	Level II	Level III
Power MIL-R-19 (Percent of Rated Value)	30	50	50
MIL-R-22	NR	NR	70
MIL-R-12934	NR	50	50
MIL-R-27208	30	50	50
MIL-R-39002	NR	50	50
MIL-R-39015	30	50	50
Temperature Derating ($^{\circ}\text{C}$) (From Maximum Limit)			
MIL-R-19	45	35	35
MIL-R-22	NR	NR	10
MIL-R-12934	NR	20	20
MIL-R-27208	45	35	35
MIL-R-39002	NR	20	20
MIL-R-39015	45	35	35

TABLE 15.24: DERATING FOR THERMISTORS

	Level I	Level II	Level III
Power (Percent of Rated Value)	50	50	50
Temperature (Derating ($^{\circ}\text{C}$) (From Maximum Limit)	20	20	20

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15.7.2.5 Capacitor Derating Criteria

15.7.2.5.1 General Data

This section gives the derating levels and application guidelines for capacitors. The principal stress parameters for capacitors are **temperature** (including the capacitor's case temperature rise from AC loading) and DC and/or AC **voltage**.

Therefore, decreasing the temperature or the voltage will extend a capacitor's expected life.

15.7.2.5.2 Capacitor Types

The types of capacitor in this section are defined below

- (1) Paper/Plastic Film
- (2) Mica
- (3) Glass
- (4) Ceramic
- (5) Electrolytic
- (6) Variable Capacitors

(1) Fixed (Paper/Plastic) Film Capacitors

a) Application

This group of capacitors has high insulation resistance, low dielectric absorption, or low loss factor over wide temperature ranges with the AC component of impressed voltage ranging from small to more than 50 percent of the DC voltage rating.

b) Derating

DC voltage, and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.25.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	50	60	60
Temperature (Derating (°C) (From Maximum Limit)	10	10	10

(2) Fixed Mica Capacitors**a) Application**

Due to the inherent characteristics of the dielectric, mica capacitors are small, have good stability and are highly reliable.

b) Derating

DC voltage and ambient temperature are the principal stress parameters. Derating levels are in Table 15.26.

TABLE 15.26: DERATING FOR FIXED MICA CAPACITORS

	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	50	60	60
Temperature (Derating (°C) (From Maximum Limit)	10	10	10

(3) Fixed Glass Capacitors**a) Application**

The fixed glass capacitor has a low dissipation factor, high insulation resistance, high temperature stability, and high frequency stability up to 500 Mhz.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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DC voltage and ambient temperature are the principal stress parameters. Derating levels are in Table 15.27.

TABLE 15.27: DERATING FOR FIXED GLASS CAPACITORS

	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	50	60	60
Temperature (Derating (°C) (From Maximum Limit)	10	10	10

(4) Fixed Ceramic Capacitors**a) Application**

Excessive heat used in soldering the leads may damage the encapsulation and weaken the electrode-to-terminal-lead contact.

b) Derating

DC voltage and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.28.

TABLE 15.28: DERATING FOR FIXED CERAMIC CAPACITORS

	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	50	60	60
Temperature (Derating (°C) (From Maximum Limit)	10	10	10

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(5) Fixed Electrolytic (Aluminum) Capacitor**a) Application**

The aluminum electrolytic capacitor provides the smallest volume, mass, and cost per microfarad except for tantalum capacitors.

This capacitor is not hermetically sealed; it is **not recommended** for airborne equipment application since it should not be subjected to low barometric pressure and low temperature at high altitudes.

b) Derating

DC voltage and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.29.

**TABLE 15.29: DERATING FOR FIXED ELECTROLYTIC
(ALUMINUM) CAPACITORS**

	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	NR	NR	80
Temperature (Derating (°C) (From Maximum Limit)	NR	NR	20

(6) Fixed Electrolytic (Solid) Tantalum Capacitors**a) Application**

A minimum circuit impedance of three ohms per applied volt should be used for improved reliability.

b) Derating

DC voltage and ambient temperature are the **principal** stress parameters. Derating levels are in Table 15.30.

(7) Fixed Electrolytic (Nonsolid) Tantalum Capacitors

DC voltage and ambient temperature are the principal stress parameters. Derating levels are in Table 15.31.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 15***TABLE 15.30: DERATING FOR FIXED ELECTROLYTIC (SOLID)
TANTALUM CAPACITORS**

	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	50	60	60
Temperature (Derating (°C) (From Maximum Limit)	20	20	20

**TABLE 15.31: DERATING FOR FIXED ELECTROLYTIC
(NONSOLID) TANTALUM CAPACITORS**

	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	50	60	60
Temperature (Derating (°C) (From Maximum Limit)	20	20	20

(8) Variable (Piston Type, Tubular, Trimmer) Capacitors**a) Application**

These capacitors are small, sealed, tubular, and trimmers designed for use when fine-tuning adjustments are periodically required.

b) Derating

DC voltage and ambient temperature are the principal stress parameters. Derating levels are in Table 15.32.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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TUBULAR, TRIMMER) CAPACITORS**

	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	40	50	50
Temperature (Derating (°C) (From Maximum Limit)	10	10	10

(9) Variable Ceramic Capacitor**a) Application**

Temperature sensitivity is nonlinear over the capacitance range; therefore, this capacitor should not be designed into circuits as a temperature compensating unit.

b) Derating

DC voltage and ambient temperature are the principal stress parameters. Derating levels are in Table 15.33.

TABLE 15.33: DERATING FOR VARIABLE CERAMIC CAPACITORS

	Level I	Level II	Level III
DC Voltage (Percent of Rated Value)	30	50	50
Temperature (Derating (°C) (From Maximum Limit)	10	10	10

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15.7.2.6 Inductive Device Derating Criteria

15.7.2.6.1 General Data

This section gives derating parameters and application guidelines for inductive devices. The reliability of inductive devices is a function of **operating hot spot temperature** as it relates to insulation capability, operating currents, in-rush transients, and dielectric stress.

The method of computing hot spot temperature is in MIL-HDBK-217.

a) Application

The winding voltage should be kept at the nominal vendor-specified value to prevent insulation breakdown, the major cause of failure for inductive devices.

Operation at lower than designed frequency range should not be allowed since overheating and core saturation may result. The devices must be designed for the proper temperature range in which they are to operate.

b) Derating

Frequency and winding voltage are not derated. The parameters to be derated are hot spot temperature, maximum current, in-rush transients, and dielectric stress. Derating levels are in Table 15.34.

TABLE 15.34: DERATING FOR INDUCTORS

	Level I	Level II	Level III
Temperature Derating (From Maximum Hot Spot)	40	25	15
Operating Current (Percent of Rated Value)	60	60	60
Transient Voltage (Percent of Rated Value)	90	90	90
Dielectric Withstanding Voltage (Percent of Rated Value)	50	50	50

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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This section gives derating parameter and application guidelines for relays.

15.7.2.7.2 Relay Types

Relays are categorized in this section as follows; electromechanical, solid state, hybrid electromechanical, and hybrid solid state.

a) Application

For **mechanical** relays, the circuits to be switched should be designed to minimize stresses on the **relay contacts**.

Nonresistive load switching requires arc suppression design techniques to protect relay contacts.

Pure solid state relays have no mechanical contacts. When using nonresistive loads, surge current can create high junction temperatures that degrade the relay or cause it to fail.

TABLE 15.35: DERATING FOR RELAYS

	Level I	Level II	Level III
Resistive Load Current (Percent of Rated Value)	50	75	75
Capacitive Load Current (Percent of Rated Value)	50	75	75
Inductive Load Current (Percent of Rated Value)	35	40	40
Motor Load Current (Percent of Rated Value)	15	20	20
Lamp (Filament) Load Current (Percent of Rated Value)	8	10	10
Contact Power (Percent of Rated Value)	40	50	50
Coil Operating Voltage (Percent of Rated Value)	90	90	90
Temperature Derating (°C) (From Maximum Limit)	20	20	20

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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Continuous contact current, coil operating voltage, and temperature are the **principal** stress parameters. Derating levels are in Table 15.35.

15.7.2.8 Switch Derating Criteria**15.7.2.8.1 General Data**

This section gives derating parameters and application guidelines for switches.

15.7.2.8.2 Switch Types

Switches are categorized in this section as follows; toggle, sensitive, rotary, and push-button.

TABLE 15.36: DERATING FOR SWITCHES

	Level I	Level II	Level III
Resistive Load Current (Percent of Rated Value)	50	75	75
Capacitive Load Current (Percent of Rated Value)	50	75	75
Inductive Load Current (Percent of Rated Value)	35	40	40
Motor Load Current (Percent of Rated Value)	15	20	20
Lamp (Filament) Load Current (Percent of Rated Value)	8	10	10
Contact Power (Percent of Rated Value)	40	50	50
Contact Voltage (Percent of Rated Value)	40	50	90

a) Application

Thermal and **altitude** variations must be considered since moisture may cause contact contamination or short circuits.

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Positive break toggle switches are preferred for high current levels. Sealed switches should be used in humid or dirty environments.

b) Derating

Contact current, power, and voltage **are** the **principal** stress parameters. Derating levels are in Table 15.36.

15.7.2.9 Connector Derating Criteria

15.7.2.9.1 General Data

The primary factors affecting the failure rate of connectors are insert material, contact current, number of active contacts, mate and unmate cycling, and the environment in which the connector is operated.

The rating of a connector is determined by the temperature of the insert material.

15.7.2.9.2 Connector Types

The three classes of connectors in this section are circular, printed wire board, and coaxial

a) Application

Scoop-proof connectors should be considered for designs susceptible to bent pin failures. When pins are connected in parallel at the connector to increase current capacity, allow for a minimum of 25 percent surplus of pins over that required to meet the 50 percent derating for each pin

b) Derating

Voltage, current, and temperature are the principal stress parameters. Derating levels are in Table 15.37.

15.7.2.10 Rotating Device Derating Criteria

15.7.2.10.1 General Data

The bearing load, winding temperature, and the ambient temperature of operation are the principal stress parameters.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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	Level I	Level II	Level III
AC, DC Voltage (Percent of Rated Value)	50	70	70
Current (Percent of Rated Value)	50	70	70
Insert Temperature Derating (°C) ² (From Maximum Limit)	50	25	25

15.7.2.11 Rotating Device Types

The rotating devices in this section are motors, synchros, resolvers, and motor-driven elapsed time meters.

a) Application

Excessive loads or low speed can create high winding temperature and excessive bearing loads. Moisture should be minimized to prevent corrosion, insulation degradation, and low resistance to electrical leakage.

b) Derating

Operating temperature and bearing load are the principal stress parameters. Derating levels are in Table 15.38.

TABLE 15.38: DERATING FOR ROTATING DEVICES

	Level I	Level II	Level III
Temperature Derating (°C) (From Maximum Limit)	40	25	15
Bearing Load (Percent of Rated Value)	75	90	90

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15.7.2.12 Lamp Derating Criteria

15.7.2.13 General Data

The derating levels in this section are based on review of historical applications and engineering judgment. Increased reliability must be balanced against the relative constraints placed on design freedom.

15.7.2.13.1 Lamp Types

Derating for incandescent and gaseous (neon-argon) lamps is as follows:

(1) Incandescent Lamp

(a) An incandescent lamp should not be exposed to extreme shock or vibration near the resonant frequency of the filament. Temperature cycling is **damaging**.

(b) The derating for all three levels is **94 percent** of the rated voltage if the lamp is operated in normal environments.

This derating will **double** the life of a lamp, with only a 16 percent drop in light output.

(2) Gaseous Lamp

(a) The starting and sustaining voltage levels are lamp characteristics and **cannot be** derated. The starting voltage level can be increased for a quicker response time, but the life expectancy will decrease.

(b) Lamp current is the **principle** stress parameter. The current derating for all three levels is 94 percent of the rated current. With that derating, the life expectancy **doubles** and the output decreases only by 16 percent.

15.7.2.14 Circuit Breaker Derating Criteria

Circuit breaker contact current is the **principal** stress parameter. The current derating for level I is 75 percent of the rated level and, for levels II and III, is 80 percent of the rated level. At these levels, the circuit can still be **protected** from a large overload.

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15.7.2.15 Fuse Derating Criteria

Current is the **principal** stress parameter for a fuse. The current derating for a fuse is 50 percent of the rated value for levels I, II, and III.

There is an additional derating of 0.5 percent/deg. C for an increase in the ambient temperature above 25°C.

Derating of the fuse voltage is 20-40 percent for fuse current ratings of 1/2 ampere or less.

15.7.2.16 Crystal Derating Criteria

The driving power for most crystal units cannot be derated since the rated frequency may not be obtainable. Consult the appropriate specifications or manufacturers' literature for possible exceptions.

The operating temperature of the crystal must be kept between the maximum and minimum limits to achieve the rated frequency.

15.7.2.17 Tube Derating Criteria

15.7.2.17.1 General Data

The derating levels in this section are based on engineering judgment, device construction, and materials.

In many cases, due to the operation of the devices, derating is inappropriate. However, when practical, the design should strive to give the maximum stress margin (below maximum rated) possible with respect to design difficulties.

15.7.2.17.2 Tube Types

Cathode ray tubes and microwave tubes covered below include traveling wave tubes, magnetrons, and klystrons.

(1) Cathode Ray Tube

The design of systems using the CRT is highly dependent on human factors such as visibility, size, color, readability, etc. Because of the specialized nature of the design field and data, setting up general application and derating guidelines is **not practical**.

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However, with vacuum tube devices, the bulb and the cathode temperatures are important for **reliability**.

Consult specifications and manufacturers' literature for the optimum conditions for minimum failure rates.

Consideration can also be given to maintaining cathode temperature, during "off" conditions, at level lower than operating temperature.

This will reduce effects of cold in-rush current and thermal cycling.

Most failures are due to either cathode failure from thermal effects or to gun assembly from mechanical stresses due to vibration or shock.

(2) Microwave Tube**a) Application**

The design use of a microwave tube is highly specialized; there is **insufficient data** to define derating guidelines for all conditions.

Use the failure rate prediction methods of MIL-HDBK-217 to optimize design and usage for the minimum failure rate.

b) Derating

The stress parameters for all levels are in Table 15.39.

TABLE 15.39: DERATING FOR MICROWAVE TUBES

	Levels I, II, and III
Temperature Derating Derating (°C) (From Maximum Limit)	20
Power Output (Percent of Rated Value)	80
Reflected Power (Percent of Rated Value)	50
Duty Cycle (Percent of Rated Value)	75

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15.7.2.18 Laser Derating Criteria

Laser system design is a specialized field in which the operating parameters of each type are unique and interdependent.

Develop designs for minimum predicted failure rate using the failure rate models of MIL-HDBK-217. Follow manufacturers' recommendations for operating parameters and conditions not defined by failure rate models.

15.7.2.19 Vibrator Derating Criteria

A vibrator is not recommended for use in electrical circuits because of limited cycling life. If an output is needed supplied by a vibrator device, a solid state device like a high-power switching transistor is recommended.

15.7.2.20 Fiber Optic Components Derating Criteria

15.7.2.20.1 General Data

The two major sources types, the LED and the injection laser diode (ILD), share most of the failure mechanisms and stress parameters.

Application of either depends on two parameters: optical power and bandwidth. ILDs are capable of coupled power to the fiber in the range of a few milliwatts and bandwidths in the low GHz region;

LEDs are generally capable of only a few hundred microwatts of coupled power and a bandwidth of a few hundred MHz.

15.7.2.20.2 Fiber Optic Component Types

The component types in this section are optical sources, optical detectors, cables, and connectors.

(1) Optical Sources (LED and ILD)

a) Application

Power supplies for ILDs must be designed to eliminate over current pulses (which cause catastrophic failure due to facet damage).

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Output power should be given a 3dB margin to account for gradual degradation. Thermal or mechanical shock causes dark line defects (crystal lattice defects) to grow and reduces output power.

Stress screening should be used to eliminate devices with dark line defects.

b) Derating

Temperature (ILD and LED), voltage, current, power dissipation (LED), and optical power dissipation (ILD) are the principal stress parameters.

Derating levels are in Table 15.40.

TABLE 15.40: DERATING FOR OPTICAL SOURCES

	Level I	Level II	Level III
Maximum Junction Temperature (°C) (For LED and ILD)	95	105	110
Average Forward Current (Percent of Rated Value) (For LED)	50	65	75
Power Output (Percent of Rated Value) (For ILD)	50	60	70

(2) Optical Detectors (PIN and Avalanche Photo Diodes)**a) Application**

Power derating is not necessary because internal dissipation is not significant. Reverse voltage cannot be derated for the APD since the voltage is used to set or adjust device gain and is typically set below the breakdown voltage.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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Temperature (PIN and APD) and reverse voltage for PIN diodes are the principal stress parameters.

Derating levels are in Table 15.41.

TABLE 15.41: DERATING FOR OPTICAL DETECTORS

	Level I	Level II	Level III
Maximum Junction Temperature (°C) (PIN and APD)	95	105	125
Reverse Voltage (Percent of Rated Value) (PIN)	70	70	70

(3) Fiber Optic Cables**a) Application**

Cable construction is the key to high reliability. The use of strength members, buffers, jackets, and moisture barriers in the development of optimum cable designs should be considered.

New products acquired under specification control for use outside known performance levels should be qualified before use.

b) Derating

Principal stress parameters should be derated as follows;

- (1) Temperature 20°C inside both upper and lower limits.
- (2) Tension fiber; 20 percent of proof test.
- (3) Tension cable; 50 percent of the rated tensile.
- (4) Bend radius; 200 percent of minimum.

(4) Fiber Optic Connectors

The primary degrading environment is temperature. See derating for conventional connectors for derating guidelines.

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15.7.3 Thermal and Stress Verification

15.7.3.1 General Data

Specifying **derating criteria** in a contract without provisions for verification may result in the standards not being incorporated into the hardware.

It is imperative that a **complete derating program** be followed including specification of derating design requirements, thermal and stress analysis, and thermal and stress testing.

Analysis includes calculating electrical and thermal stress, whereas **testing** involves actual measurements of stresses under specified conditions.

Both tasks help the Buyer verify the derating used in the proposed design.

15.7.3.2 Thermal and Stress Analysis

This analysis should be performed at the part level for each unit, during the design phase, and before hardware is made.

The emphasis shall be on optimizing reliability, not just on minimizing part function temperature.

Analysis should include detailed calculations of electrical stress, surface and junction temperature, and maximum ratings for all passive and active parts for different environments and cooling characteristics.

The overall analysis should include different types of cooling techniques, local air temperature rise, and part heat transfer to heat sinks or cooling air.

The analysis report should include results that prove that the design has achieved the derating standards, optimized the reliability, and minimized the life cycle cost of the equipment or system.

15.7.3.3 Stress Testing

Stress testing consists of using test equipment to verify that active and passive parts do not exceed specified electrical parameters and to verify derating criteria for parts are operated in the worst of the specified environments.

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15.7.3.4 Thermal Testing Using Thermocouples

This test consists of measuring case temperature of active parts, such as diodes, transistors, hybrids, and integrated circuits, using thermocouples to determine if the specified derating criteria are achieved.

At least 20 percent of the active parts and 10 percent of the passive parts should be tested.

Parts for the stress verification should be selected randomly from each circuit board or unit as applicable.

The test should be scheduled after unit performance acceptance testing is completed.

In selecting the parts to be tested, the results of the **thermal analysis** and the part **complexities** have to be considered.

Those parts that have the highest calculated temperature or are considered **critical parts** should be selected first.

The second selection process should evaluate the part complexity levels; those with the highest levels are then selected from each of the part categories.

The test will consist of placing thermocouples at the top corner of the selected parts while operating in the intended configuration at the worst environmental condition.

The measured results will be used in an off-line analysis that will determine the junction temperature of the parts.

Method(s) for calculating the junction temperature from the test measurement will be developed by the contractor and review by the procuring activity.

15.7.3.5 Thermal Testing Using Infrared Imaging

Another technique for testing thermal derating is infrared imaging measurement of the case temperature of active parts; 100 percent of the active parts can be measured with this technique.

Determination of the junction temperature still requires an off-line analysis.

This test approach is a maturing technology and should be superior to thermocouple testing.

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However, before approving this test method, the accuracy of the test equipment and the adequacy of the procedure to be used should be evaluated by the procuring activity.

15.7.3.6 Overstressed Parts

If a part does not meet the establish derating criteria, the contractor should be required to perform an in-depth analysis and recommended corrective action for the overstressed condition.

The procuring activity should review the proposed corrective action and approve or disapprove the change.

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Chapter 16

ENVIRONMENTAL STRESS SCREENING (ESS)

1996-07-05

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16 ENVIRONMENTAL STRESS SCREENING (ESS)

16.1 INTRODUCTION

The use of **environmental stress screening** (ESS) of hardware during development and production has increased significantly in the past few years, (i.e., Task 301 of MIL-STD-785).

The **basic intent** of stress screening is to detect **latent** defects, by subjecting test items to specific conditions of environmental stress, so that such defects can be **degraded** to a detectable level.

“Latent defects”, as used here, represent weaknesses in parts, workmanship, and to some extent design, which result in **much higher failure rates** than what may be indicated by **predicted inherent** failure rate values.

Equipment delivered to the field often contain latent defects traceable to the production process.

Such defects result in abnormally high failure rates and excessive repair costs in the field.

Early stress screening of modules and assemblies, during production, is a widely accepted, effective means of alleviating the problem.

16.1.1 Stress Screening Program/Plan

Stress screening **program/plan** shall be **designed** to **precipitate** and **detect latent defects** early in the production cycle when it is most cost-effective to do so.

Early stress screening can increase the likelihood of the completed equipment passing final acceptance, and reliability demonstration tests, and may eliminate or reduce the need for costly burn-in, or reliability growth programs at the **system** level.

Early life stress screening of modules and subassemblies, therefore, can offer a cost-effective means of enhancing equipment **reliability** and reducing production and field support **costs**.

16.1.2 Stress Screening Tests

Screening tests such as **temperature cycling** and **random vibration** appear to be the most effective tests.

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However, exposure levels, number of cycles, and test durations differ widely among users.

Other, perhaps less costly, tests such as sinusoidal vibration, power cycled burn-in at ambient and temperature soak are also used, but, in general, their effectiveness is believed to be less than the former tests.

Precise information of the effectiveness of the various available screening tests is not currently known.

Screening tests therefore should be selected based upon estimates of cost and test effectiveness, early development program data, and on equipment design, manufacturing, material and process variables, which at least, **narrow** consideration to the most cost effective choices.

The screening process then should be continuously monitored and test results analyzed so that changes in the process can be made, as required, to optimize the cost-effectiveness of the screening program.

16.1.3 Objective and Scope

The objective of this document is to develop quantitative and qualitative **techniques** for planing, monitoring and evaluating stress screening programs during equipment development and production.

The work effort investigated **methodologies** for test selection and control which provide assurance that reliability growth is achieved in a cost-effective manner throughout the development and production process.

The work performed was concerned **primarily** with the cost-effectiveness of stress screening at levels of assembly above the part level, i.e., assembly/module, unit/group and equipment/system.

Part level screening considerations were included in this document only to the extent that the quality grade of components used influences the initial quantity of latent defects and therefore the planning of the stress screening program.

16.1.4 Approach

The basis of stress screening is the elimination of **latent defects** at a point in the production process when it is least costly to do so.

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Figure 16.1 depicts a **typical** production process where parts and printed circuit boards (PCB) or wired chassis comprise assemblies; then manufactured assemblies, purchased assemblies and associated wiring comprise units; and finally the units, other equipment and intercabling make up the completed system.

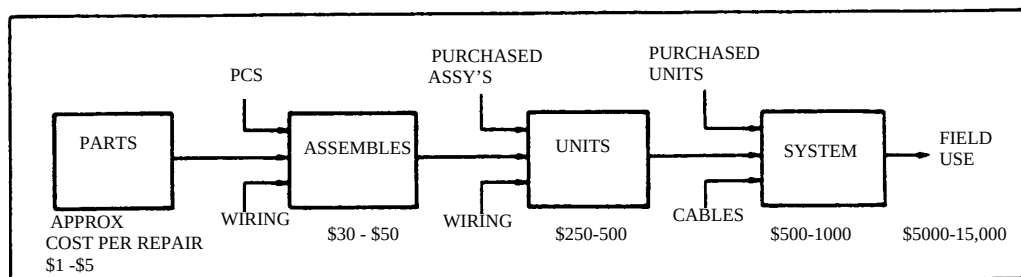


FIGURE 16.1: A TYPICAL PRODUCTION PROCESS (FINDING DEFECTS AT THE LOWEST LEVEL OF MANUFACTURE)

Latent defects are introduced at each stage in the process and, if not eliminated, propagate through to field use.

The cost of repair increases with increasing levels of assembly, being \$1 to \$5 at the part level and perhaps as high as \$1000 at the system level.

Field repair cost estimates have been quoted as high as \$15000. For economic reasons alone, it is desirable to eliminate latent defects at the lowest possible level of assembly and certainly prior to field use.

Latent defects can be transformed into **patent**, or **hard defects** through the application of environmental stresses such as elevated temperature operation, temperature cycling, or vibration.

The **probability** that a stress screen will transform a latent defect into a hard failure (given that there is a latent defect present) and that failure will be detected by the screen is called "**screening strength**".

Screening strength **varies** with the screen parameters, (e.g., the strength of a temperature cycle screen increases with increases in temperature extremes, temperature rate of change and number of cycles).

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But there is a cost associated with application of a stress screen and that cost varies with screening strength.

There are then many possible combinations of screening strengths and screening costs at each level of assembly and the objective is to find the lowest cost set of screens that produces the desired results.

16.1.5 Purpose

This document provides uniform procedures, methods, and techniques for planning, monitoring, and controlling the effectiveness of ESS program for equipment/subassembly.

16.1.6 Application

This document shall be used by procuring activities and contractors during development and production of DHC-8 Aircraft program.

It is **not** intended that the document procedures and techniques be used in a cookbook fashion.

Knowledge of the equipment and manufacturing process is essential for a properly planned and tailored ESS program.

A properly applied ESS program can significantly impact the **quality** and **reliability** of the products delivered to de Havilland Inc.

Although the Quality and Reliability disciplines are related, in practice, they are conducted as separate programs without common objectives.

This document uses the ESS program as a means for integrating Quality Control and Reliability Engineering tasks so as to assure achievement of reliability objectives during manufacture.

Supporting software is available from Rome Laboratory that fully automates the ESS program, and some manual procedures contained herein.

16.1.7 Definition of ESS

ESS is a process or **series** of processes in which **environmental stimuli**, such as rapid thermal cycling and random vibration, are applied to items in order to **precipitate** latent defects to early failure.

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An equally important and inseparable aspect of the screening process is the **testing** which is done as part of the screen, so as to detect and properly identify the defects which have been precipitated to failure.

The precipitation and testing process is basically a search for defects. Manufacturing techniques for modern electronic hardware consist of hundreds of individual operations and processes through which defects can be introduced into the product.

Many of the defects can be **detected** without the need for stress screens by use of visual inspections, functional tests and other conventional quality assurance procedures.

Such defects are termed errors and are a subset of patent defects. A small percentage of latent defects remain undetected by obvious means and, if not removed in the factory, will eventually manifest as **early life** failures during product use.

The inability to find latent defects by obvious means is a consequence of the increased complexity of modern electronic products and the processes which are used in their manufacture.

ESS is the vehicle by which latent defects are accelerated to early failure **in the factory**.

ESS can thus be viewed as an extension of the quality control inspection and testing process.

16.1.8 Organization of the Document

Section 1 (the introduction) outlines the purpose of this document and provides general introductory remarks pertaining to the quantitative approach to ESS.

Section 2 lists applicable references.

Section 3 defines terms and acronyms used. Section 4 contains general guidelines and provides the rational and background for the detailed guidelines.

Section 5 contains the detailed guidelines which are organized according to the sequence of events to be undertaken by the contractor in planning, monitoring and controlling a screening program.

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The detailed **procedures** are entitled:

- Procedure A - Optimizing Screen Selection and Placement
- Procedure B - Estimating Defect Density
- Procedure C - Estimating Screening Strength
- Procedure D - Refining Estimates of Defect Density and Screening Strength
- Procedure E - Monitoring and Controlling
- Procedure F - Product Reliability Verification Testing

Appendix A contains the mathematical relations and model descriptions used in the document. A review of Appendix A will help in gaining a quick understanding of the rationale and methodology of the document.

Appendix B provides the mathematical foundation for the Product Reliability Verification Test.

Figure 16.2 shows the sequence of application of the various tasks contained in the Document and cross-references them to the applicable procedures of the Document.

The product **development phase** is used to experiment with stress screens to refine the estimate of ESS parameters (D_{IN} , SS) and to define and plan a cost effective screening program for the production phase.

The **incoming latent defect density** is estimated (Procedure B) and screens are selectively placed at various assembly levels to develop a plan for achieving quantitative ESS goals cost-effectively (Procedure A).

The ESS plan for the development phase should be submitted as part of the Reliability Program Plan.

An ESS plan for the **production phase** is submitted based upon the experimentation and analyses of cost effectiveness.

After the screening program is implemented during production, the **fallout** from the screens are used to evaluate the screening process and to establish whether ESS program objectives are being achieved (Procedures D and E).

The details will be explained in section 4, and 5.

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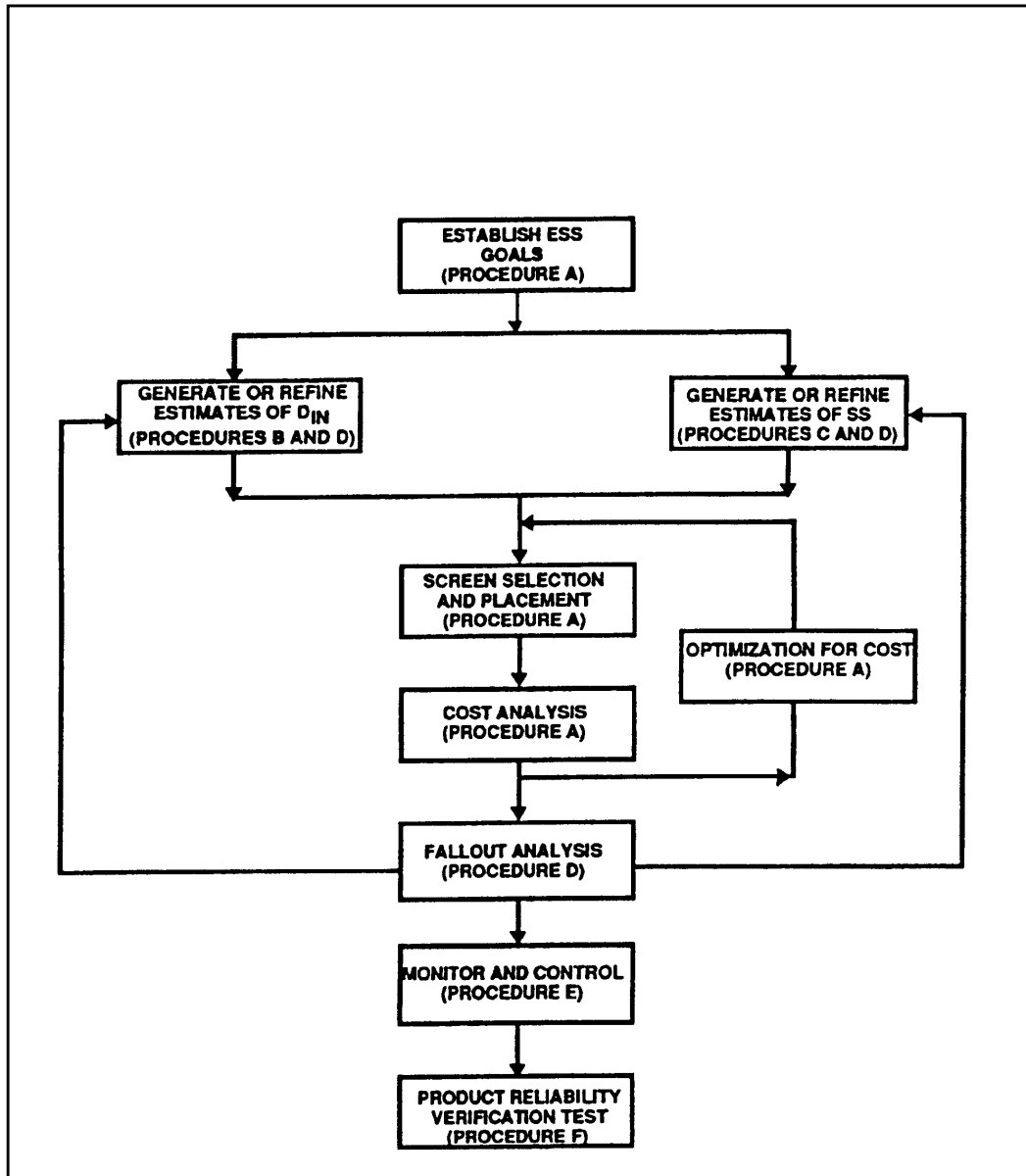


**FIGURE 16.2: CROSS REFERENCE OF ESS PROGRAM
SEQUENCE TO DOCUMENT PROCEDURES**

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16.1.9 Development and Production Phase Reliability Assurance

ESS is not a substitute for a sound reliability program conducted during the design and development phases.

The **inherent reliability** of the product is driven primarily by the **design**

However, without a viable reliability assurance program during production, the reliability which is designed into the product can be seriously **degraded**.

An equipment will eventually pass a MIL-STD-781 reliability demonstration test, either during development or on a sample basis during production.

A single equipment passing the MIL-STD-781 test does not imply that all other equipment in the production lot have the same reliability.

A relatively few **latent defects**, contained in various equipment in the lot, can significantly reduce the **field reliability**, especially for equipment with high reliability requirements.

A production reliability assurance program which complements the design/development reliability program, is therefore essential to achieve reliability objectives.

A **properly** planned, monitored and controlled stress screening program, structured as part of a production reliability assurance program, is the vehicle through which product reliability in manufacture can be maintained.

The identification and prevention of defect causes through ESS and analysis reduces defect densities for production.

This information also provides feedback to a lessons-learned data base to avoid similar deficiencies on subsequent designs or changes.

The procedures are oriented toward achieving reliability objectives through use of quantitative methods for stress screening and production reliability assurance.

16.1.10 ESS Application and the Quantitative Approach

There are several **unknowns** associated with the application of stress screens.

How **effective** are the screens?

What is considered acceptable or unacceptable **fallout** from a screen?

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How does the quantity of **defects remaining** in the equipment after delivery to the customer impact **field reliability**?

For example, if the screen fallout is “low”, it is not known whether the equipment is “good” (i.e., defect free) or whether the screen is not effective.

On the other hand, if the fallout is “high”, it is not known whether the incoming defect levels are inordinately high or whether the screen might be causing non-defectives to fail.

Screens and tests are not perfect. At each stage of manufacture where screens and tests might be applied, from device level to the final system level, **escapes** to the next assembly stage occur, and new opportunities for introducing defects are created.

The number of **latent defects** which remain in the product at delivery and their impact on **field reliability**, however, is the **primary concern**.

16.1.10.1 The Quantitative Approach

The use of a quantitative approach to stress screening **requires** that the initial part **latent defect levels**, the defect level introduced during manufacture of the product, the effectiveness of the screens, and reasonably acceptable values for the number of latent defects which remain and escape into the field be addressed.

Figure 16.3 and Figure 16.4 illustrate the quantitative aspects of stress screening.

When a quantitative approach to stress screening is used, the **key variables** of interest are the average number of **defects** per product which **enter** the screen, D_{IN} (D_{IN} comprised of latent defects, D_{LAT} , and patent defects, D_{PAT} , and incoming error density E), the **screen strength** (SS) which is the **product** of **Precipitation Efficiency** (PE) and **Detection Efficiency** (DE), and the average number of defects per product which escape the screen /test ($D_{REMAINING}$).

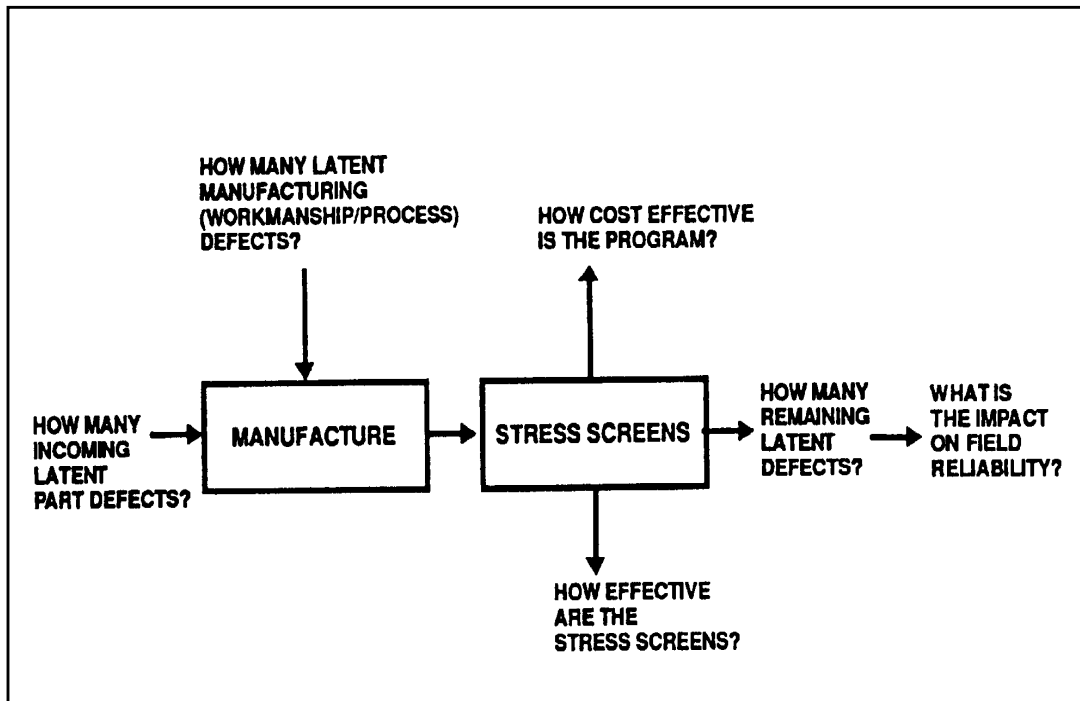
Figure 16.4 shows the relationships between these stress screening variables. The number of defects remaining in the production lot at delivery is a **function** of three factors:

a) The **quantity** of design, part and manufacturing (workmanship and process) **defects** which initially reside in the hardware prior to assembly level screening.

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**FIGURE 16.3: THE QUANTITATIVE PROBLEM**

b) The **capability** of the environmental stress to precipitate flaws in assemblies to a detectable level.

c) The **thoroughness** of the testing which is done, either during or after the screen, to assure detection of the defects precipitated to failure by the screens and the ability to fault isolate and remove the defect without introducing new flaws.

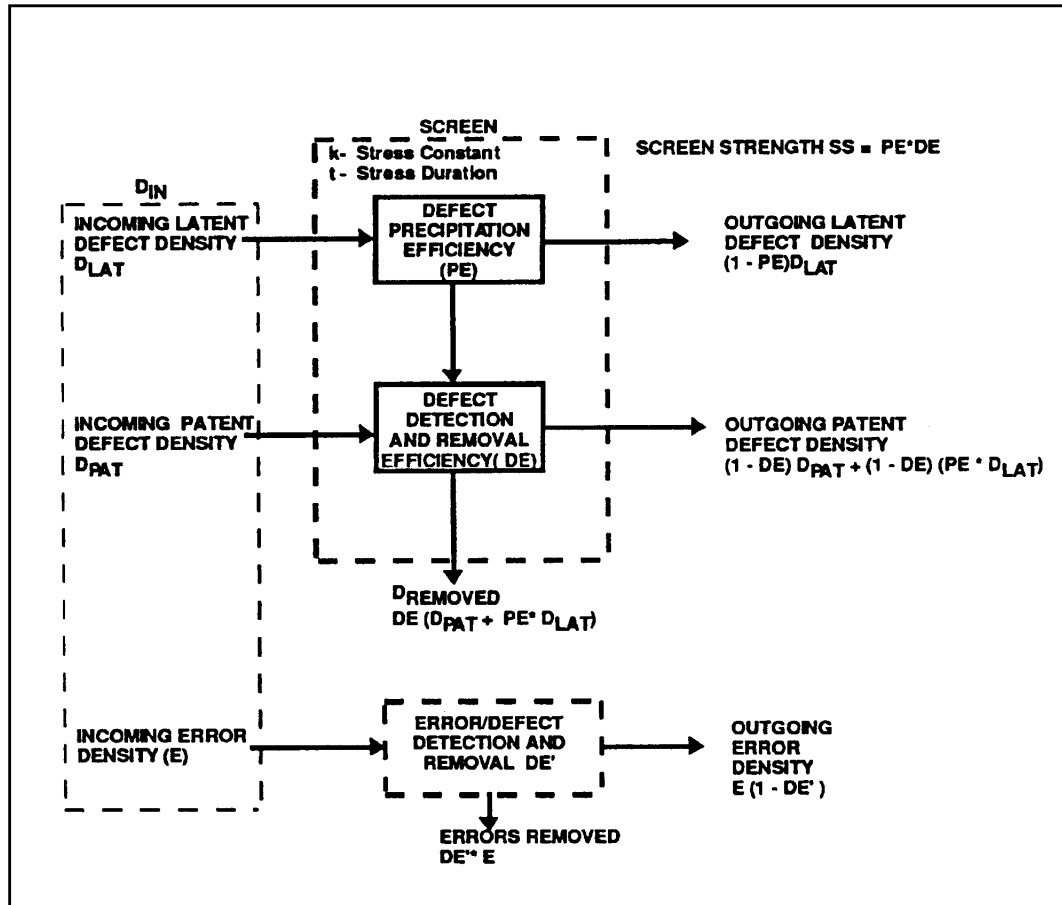
None of the three factors which impact the **reliability** of delivered products is known with certainty.

Without a basic knowledge of their quantitative value, however, **effective** screening programs cannot be properly planned and controlled

The **procedures** in the document are directed at obtaining both preliminary planning and measured estimates of the three factors in order to plan, monitor and control the screening process.

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**FIGURE 16.4: STRESS SCREENING AND VARIABLE RELATIONSHIPS**

Experience data gathered from **previous** screening programs, screening **experiments** conducted during the development phase and use of the document procedures provide the methodology and information **needed** to plan and conduct **effective** screening programs.

Once a screening program is implemented during production, the results must be **monitored** and appropriate changes made in the screening regimen **to assure** that **goals** on **remaining defects** are achieved.

The basic mechanism for assuring control is to compare the screening results with established goals so as to determine the need for corrective actions.

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For example, corrective actions might be accomplished by increasing precipitation or detection efficiencies so that more defects can be precipitated and detected, or by **reducing** incoming defect quantities through improved process controls.

Changes which reduce or eliminate screening at some levels of assembly can also be taken to reduce costs, when it is found that the screens are ineffective or unnecessary.

16.1.10.2 Benefits of a Quantitative Approach

A quantitative approach to stress screening **enables** the establishment of explicit quantitative objectives and provides a basis for planning, monitoring, and controlling the screening process to meet those objectives.

A quantitative approach also **facilitates** DHI and contractor/vendor communication on the status of the screening process and on the progress being made toward achieving DHI objectives.

Coupled with a good Failure Reporting Analysis and Corrective Action System (FRACAS), the quantitative approach also **provides** a more focused emphasis on the sources of **latent reliability** problems in the product or process as well as better control of costs

16.1.10.3 Process Capability and Defect Density

The use of a quantitative approach to stress screening requires addressing the capability of the manufacturing process to produce products which are reasonably free of defects.

Defects are introduced into a lot of manufactured products through repeated assembly, handling and testing operations.

The average number of defects per product (defect density) varies as a function of the degree of control which is exercised over the manufacturing process and the **process capability**.

The ESS program addresses the questions:

What is the process capability?

What must the process capability be in order to meet quantitative reliability objectives?

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What improvements and changes are required to achieve the reliability objectives at optimum cost?

16.2 REFERENCED DOCUMENTS

16.2.1 De Havilland Inc. Documents

EPS 1-18 R&M Specification Requirements

16.2.2 Government Documents

MIL-STD-785	Reliability Program for Systems, and Equipment Development and Production, Task 301
MIL-HDBK-217	Reliability Prediction of Electronic Equipment
MIL-STD-781	Reliability Testing for Engineering Development, Qualification, And Production
MIL-STD-2155	Failure Reporting, Analysis and Corrective Action System (FRACAS)
MIL-HDBK-781	Reliability Test Methods, Plans an Environments for Engineering Development, Qualification, and Production
MIL-STD-883	Test Methods and Procedures for Microelectronics
MIL-STD-2000	Standard Requirements for Soldered Electrical and Electronic Assemblies
MIL-HDBK-781	Reliability Test Methods, Plans, and Environments for Engineering Development, Qualification, and Production

16.2.3 Publications

RADC-TR-82-87	Stress Screening of Electronic Hardware
RADC-TR-86-138	RADC Guide to Environmental Stress Screening
RADC-TR-86-149	Environmental Stress Screening
RADC-TR-90-269	Improved Operational Readiness Through Environmental Stress Screening

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16.3 DEFINITIONS AND ACRONYMS

16.3.1 Definitions

Definitions applicable to this document are:

16.3.1.1 Assembly / Module

A number of parts joined together to perform a specific function and capable of disassembly, for example a printed circuit board. An assembly of parts designed to function in conjunction with similar or different modules when assembled into a unit, (e.g., power supply module, core memory module)

16.3.1.2 Defect Density

Average number of latent defects per item. Symbols used: D_{IN} , D_{OUT} , $D_{REMAINING}$, and D_O for incoming, outgoing, remaining and observed defect density, respectively.

16.3.1.3 Detectable Failure

A failure that can be detected with 100% detection efficiency.

16.3.1.4 Detection Efficiency

A measure of the capability of detecting a patent defect. Symbol is DE.

16.3.1.5 Error

Class of patent defect resulting from assembly and/or test correlation errors. Errors do not require environmental stress for precipitation or detection.

16.3.1.6 Escapes

The incoming defect density which is not detected by a screen and test and which is passed on to the next level.

16.3.1.7 Failure-Free Period

A contiguous period of time during which an item is to operate without the occurrence of a failure while under environmental stress.

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16.3.1.8 Failure Rate

The total number of failures within an item population, divided by the total number of life units expended by that population during a particular measurement interval under stated conditions. Symbol is λ . A reliability measure related to MTBF.

16.3.1.9 Fallout

Failures observed during, or immediately after, and attributed to stress screens. Symbol is F. Sometimes used to mean defects removed, symbol D_{REMOVED} .

16.3.1.10 Fault Coverage

In a given piece of equipment, the ratio of faults which are detectable to faults present.

16.3.1.11 Latent Defect

An inherent or induced weakness, not detectable by ordinary means, which will either be precipitated to early failure under environmental stress screening conditions or eventually fail in the intended use environment. Symbol is D_{LAT} .

16.3.1.12 Patent Defect

An inherent or induced weakness which can be detected by inspection, functional test, or other defined means. Symbol is D_{PAT} . In this procedure, D_{PAT} refers to precipitated latent defect.

16.3.1.13 Precipitation (of Defects)

The process of transforming a latent defect into a patent defect through the application of stress screens.

16.3.1.14 Precipitation Efficiency

A measure of the capability of a screen to precipitate latent defects to failure. Symbol is PE.

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16.3.1.15 Screenable Latent Defect

A latent defect which is accelerated to failure by a screen and then detected by test.

16.3.1.16 Screen Parameters

Parameters which relate to screening strength, (e.g., vibration G-levels, temperature rate of change and time duration).

16.3.1.17 Screen Regimen

A combination of stress screens applied to an equipment, identified in the order of application (i.e., assembly, unit and system screens).

16.3.1.18 Screening Strength

The probability that a specific screen will precipitate a latent defect to failure and detect it by test, given that a latent defect susceptible to the screen is present. It is the product of precipitation efficiency and detection efficiency. Symbol is SS.

16.3.1.19 Stress Adjustment Factor

The ratio of the incoming defect density at the anticipated field stress level to the incoming defect density at the base line stress level.

16.3.1.20 Stress Screening

The process of applying mechanical, electrical and/or thermal stresses to an equipment item for the purpose of precipitating latent part and workmanship defects to early failure.

16.3.1.21 Thermal Survey

The measurement of thermal response characteristics at points of interest within an equipment when temperature extremes are applied to the equipment.

16.3.1.22 Vibration Survey

The measurement of vibration response characteristics at points of interest within an equipment when vibration excitation is applied to the equipment.

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16.3.2 Acronyms and Abbreviations

ATP	Acceptance Test Procedure
BIT	Built in Test
CND	Cannot Duplicate
D	Defect Density
DE	Defect Efficiency
DHI	De Havilland Inc.
ESS	Environmental Stress Screening
FR	Failure Rate
FRACAS	Failure Reporting and Corrective Action System
GRMS	Gravitational Root Mean Square
LRU	Line Replaceable Unit
LRM	Line Replaceable Module
MLE	Maximum Likelihood Estimate
MS	Mechanical Shock
MTBF	Mean Time Between Failure
NFF	No Fault Found
PE	Precipitation Efficiency
PCB	Printed Circuit Board
PPM	Parts Per Million
PWA	Printed Wiring Assembly
R&M	Reliability and Maintainability
RMS	Root Mean Square
RTOK	Retest OK
RV	Random Vibration
SAF	Stress Adjustment Factor
SRU	Shop Replaceable Unit

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SS	Screen Strength
SPC	Statistical Process Control
TAAF	Test Analyze And Fix
TC	Temperature Cycling
TQM	Total Quality Management

16.4 GENERAL ESS GUIDELINES / METHODS

16.4.1 Contractual Aspects of ESS

ESS must remain an **adaptive process** so that the screening regimen can be changed to improve cost-effectiveness.

Contract provisions for ESS program should have flexibility to effect necessary modifications of stress screens.

During the **initial** stages of production **more severe** stress screens may be required. As the product and process mature, the screens may require adjustment such as by reducing the number of temperature cycles, the number of axes of vibration or by eliminating unnecessary screens.

In **early production**, a number of unknowns preclude adoption of optimum stress screening. Some of the more significant unknowns are:

- (1) Residual design deficiencies
- (2) Manufacturing planning errors
- (3) Worker training
- (4) New suppliers
- (5) Latent defects in new part lots
- (6) New process capability
- (7) Precipitation Efficiency
- (8) Detection Efficiency

The stress screening program, even if carefully planned, may produce unexpected results which should be addressed through modification of the screens, hardware, or processes.

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The **principle** of adaptive screening is to adjust the screens on the basis of observed screening results so that the screens are always most cost effective while meeting ESS program goals.

In long term production the quantity and distribution of latent defects change with time. Therefore contract terms should contain provisions for periodically reassessing the individual screens and the overall screening program.

16.4.2 Relation of ESS to Reliability Program Tasks

Planning an ESS program for the production phase is interrelated with many of the reliability program tasks which are required to be performed during development and production.

Every effort should be made to integrate the knowledge gained from other R&M tasks into the planning of the ESS program for production.

Proper screen selection and placement is highly dependent on the reliability and stress design characteristics of the equipment.

Information derived from reliability program tasks such as predicted and demonstrated failure rates, quality level of parts, number and type of nonstandard and MIL-parts, number and type of interconnections, design capability, field stress environments, and critical items should be used in **structuring** the ESS program for production.

16.4.3 Subcontractor and Supplier Stress Screening

Items which are furnished by subcontractors or other equipment suppliers may require stress screening.

16.4.3.1 Subcontractor Stress Screening

There are several distinct **advantages** for the subcontractors or supplier to perform the stress screening rather than the **prime contractor**.

- (1) Subcontractor/supplier concern for yield can be translated to profits which may force process improvements to minimize latent defects.
- (2) Screening at receiving inspection/test, by the prime contractor, may involve returning defective items to the subcontractor/supplier and result in shortages and schedule slippages.

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(3) Performing the additional screen can introduce latent defects due to handling, e.g., mechanical and ESD damage and electrical overstress

(4) Special stress screening facilities and test equipment do not have to be purchased, supported and operated by the prime contractor.

The **procedures** and **methodology** contained in this document can be imposed on the subcontractor/supplier.

To assure that the subcontractor/supplier is able to perform the tasks required by this document the intent must be made known prior to production.

In this manner, the subcontractor/supplier can prepare screening plan, acquire the necessary capability or arrange for an external laboratory to perform the screening.

16.4.3.2 Screening of Spares

Spares should be subjected to a screening regimen **equivalent** to that used for the production hardware.

Spares are either manufactured on the same production line or are produced separately to the same specifications as the production hardware.

The spares are most often an LRU or SRU and consequently may not receive the exposure to additional screening at higher assembly levels that non-spare items might receive.

Quantitative ESS goals for the system should be allocated down to the spare item.

The procedures of Section 5 can be used to ensure that defect density for the spares does not exceed allocated goals.

A costly and less desirable alternative would be to screen and test all spares in a mock-up configuration for the system.

As a word of caution, there are times when spare orders are placed long after the original production run has been completed.

As a consequence, the production ESS facilities may not be available. This may lead to a requirement to develop a “new” ESS process that utilizes new/existing facilities.

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Also given the potential time lag between the actual production phase and the manufacturing of the spares, processes that were in control for production may be out of control for the spares.

In such situations it is not recommended to blindly rely on the original production screening regimen.

16.4.4 Planning a Stress Screening Program

Planning a stress screening program **must** begin **early in the design phase** to ensure that the equipment can withstand the necessary ESS stress levels.

The **success** of a stress screening program is strongly dependent on knowledge of the product and the processes to be used in manufacture.

The following must be kept in mind when **planning** a stress screening program using quantitative methods:

16.4.4.1 Effectiveness of Screening

The **defects** which can potentially reside in the product and the **effectiveness** of screens in **precipitating** the defects to failure (and then **detecting** them) are not known with certainty.

By comparing planned estimates for defect fallout with actual screen fallout, the screening process can be **refined** and/or the manufacturing process improved to achieve the desired goals of a highly **reliable** product.

16.4.4.2 Experience Data

Experience data on equipment similar in composition, construction and degree of maturity, can provide very useful data for planning purposes.

Information derived from the following sources should be used in **planning** an ESS program for production:

- (1) Identification of hardware items (parts, assemblies) which have exhibited a high incidence of latent defectives on other programs
- (2) Identification of suppliers/vendors whose products have indicated high defect levels
- (3) Qualification test results
- (4) Supplier acceptance test results

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- (5) Part receiving inspection, test and screening results
- (6) Screening and test records for previous programs
- (7) Reliability growth test results
- (8) Field failure data

16.4.4.3 Dynamic Screening Program

A viable screening program must be dynamic, i.e., the screening process must be continuously monitored to ensure that it is both technically and cost effective.

Changes to the screening process should be made, as necessary, based on analysis of screening fallout data and failure analysis so that quantitative screening objectives can be achieved.

16.4.4.4 Planning A Stress Screening Program

The **basic** questions which must be addressed in planning a stress screening program are:

- (1) What are the quantitative objectives of the program?
- (2) What are the stress screens to be used and at what level of assembly should the screens be placed to achieve the desired objectives?
- (3) What are the costs associated with each of the possible alternative screening sequences and how can the screening program be made cost effective?
- (4) How will one know if the screening program is proceeding according to plan? What assurance can be provided that program objectives have been achieved?
- (5) What corrective actions must be taken to achieve desired screening program goals if the screening fallout data indicate significant departures from the planned program?

16.4.4.5 Screening Program For Production Phase

An **ESS program** for the **production phase** should include the following **major tasks**:

- (1) Preparation of ESS Plan,

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-
- (2) Establish Objectives/Goals,
 - (3) Obtain Planning Estimates of Defect Density,
 - (4) Selection and Placement of Screens to Optimize Cost.

A discussion of each of these major tasks which includes background, rationale, and general guidelines for use of the detailed procedures is contained below.

16.4.4.6 Preparation of ESS Plan

The contractor shall prepare ESS plans for both the development and production phases. The purpose of the development phase plan is to describe the proposed application of ESS during development and production and to refine the estimated values of D_{IN} and SS.

Use of the procedures contained in this document in conjunction with stress screen experimentation on pre-production prototype equipment (if cost effective) can provide invaluable data for planning.

Estimates of the type and quantity of defects likely to be present in the hardware can be evaluated against experimental data.

Screens can be designed, based upon engineering evaluation, which provide the desired stress stimulation for suspected defects in the hardware.

Test specifications can also be evaluated to ensure that possible failure modes, arising from various defect types and sources, can be detected by the tests performed either during or following the screens.

Early fallout from screens provides the maximum amount of information on likely defect sources, process capability, and design limitations.

Corrective actions taken as a result of screen experimentation during development can aid significantly in stabilizing the process for production.

The development phase and production phase ESS plans should be submitted for approval by the procuring activity (i.e. DHI) prior to production.

16.4.4.6.1 Development Phase Plan

The development phase plan should include the following:

- (1) Identification of the reliability requirements for the product and the quantitative goals for the ESS program

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- (2) Identification of the equipment to be screened and the respective production quantities
- (3) Description of the initial screens which will be applied and the screening experiments which will be conducted (if experimentation is necessary and cost effective)
- (4) Description of the data collection and analysis program which will be used. A Failure Reporting, Analysis And Corrective Action System (FRACAS) should be in place and operating
- (5) Description of subcontractor and supplier stress screening to be performed
- (6) Results of preliminary use of this document procedures
- (7) Identification of the organization elements that will be responsible for ESS planning and experimentation, and the conduct of development phase screening activity

16.4.4.6.2 Production Phase Plan

The production phase plan should include the following:

- (1) Quantitative objectives of the ESS program
- (2) Detailed breakdown to the assembly level of the equipment which will be screened
- (3) Description of the screens which will be applied, including screen parameters and exposure time. Description of the results in applying Procedures A through E of section 5 including the rationale for achieving quantitative objectives in a cost effective manner
- (4) Description of the FRACAS and the analysis procedures which will be used to evaluate and control the screening process
- (5) Identification of the organizational elements responsible for conducting and evaluating the effectiveness of the production ESS program.

16.4.4.7 Establishing Objectives / Goals

Expressed **quantitatively**, the objective of a stress screening program is to **reduce** the incoming latent defect density in a production lot of equipment to an acceptable remaining latent defect density in a cost effective manner.

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Equipment having **high reliability** requirements will have more stringent goals on remaining defect density.

Methods for determining goals on **remaining defect density** are discussed in Appendix A. The remaining latent and patent defect determine the **field reliability** according to the following expression:

$$\text{Average Failure Rate in field} = \frac{\text{Total failures in time T}}{T} = \frac{1}{\text{MTBF}}$$

$$= \text{summation of } \{(1-DE)D_{PAT} + (1-DE)D_{LAT} \cdot \text{SAF} \cdot [1 - \exp(-kt)] + \text{CFR} \cdot T\} / T$$

for all environments where:

DE = Detection Efficiency

(1-DE) D_{PAT} = Remaining patent defects

(1-DE) D_{LAT} = Remaining latent defects

SAF = Stress Adjustment Factor

k = Precipitation stress constant

Using this relationship, the required field failure rate can be used to determine the requirements for remaining defect density and consequently used to establish goals and requirements for all integration and test levels from incoming defect densities for parts through to final equipment testing.

An example relating various of $D_{REMAINING}$ to the field MTBF is shown in Table 16.1 for an assumed field precipitation rate

$$k = \frac{1}{1000\text{Hr}}$$

16.4.4.8 Obtaining Planning Estimates of Defect Density

The design of a stress screening program requires knowledge of the quantity and type of latent defects which are likely to reside in the hardware prior to assembly level screening.

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The **defect density** tables contained in Procedure B of Section 16.5 are used to obtain planning estimates of defect density.

Values in the tables are based upon studies of historical defect data from the factory and field for several part types.

Extrapolations to other part types and field environments were made based upon correlations to MIL-HDBK-217 quality level and field environment factors.

Study results and methodology are contained in RADC-TR-86-149. Procedure D provides the methodology that allows the user to refine these estimates based on experience data.

TABLE 16.1: REMAINING DEFECT DENSITY GOAL ($D_{\text{remaining}}$)

Failure Rate (Failures/Hour)	MTBF (Hours)	$D_{\text{remaining}}$ (At Field Stress)
0.009516	105	10
0.000951	1,051	1
0.000475	2,102	0.5
0.000190	5,254	0.2
0.000095	10,508	0.1
0.000047	21,017	0.05
0.000019	52,542	0.02
0.000009	105,083	0.01
0.000000	1,050,833	0.001

16.4.4.8.1 Latent vs. Patent Defects

A common understanding of the nature of the defects which the screening program should be designed to precipitate is essential for proper planning.

The **factors** which impact **incoming defect density** and the rationale for the procedures used in obtaining planning estimates of defect density should also be understood.

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For ESS purposes defects can be categorized into **two types, latent and patent**. A latent defect is characterized as an inherent or induced weakness or flaw with some residual strength that will manifest itself as a failure at some time in the future when exposed to normally encountered stress (electrical, mechanical, thermal, or chemical).

Latent defects can not be detected until precipitated as a patent defect. For simplicity, a defect with no residual strength but requiring stress concurrent with testing to be detectable can also be considered to be a latent defect until it is detected.

Some examples of **latent defects** are:

- (1) Parts
 - a) Partial damage through electrical overstress or electrostatic discharge
 - b) Partial physical damage during handling
 - c) Material or process induced hidden flaws
 - d) Damage inflicted during soldering operations (excessive heat)
- (2) Interconnections
 - a) Cold solder joint
 - b) Inadequate/excessive solder
 - c) Broken wire strands
 - d) Insulation damage
 - e) Loose screw termination
 - f) Improper crimp
 - g) Unseated connector contact
 - h) Cracked etch
 - i) Poor contact termination
 - j) Inadequate wire stress relief

A **patent defect** is a defect that is detectable in its present form and has two **subcategories**, error and precipitated latent.

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An **error** is a defect caused by workmanship or test correlation. Errors are preventable and should not occur, whereas **patent defects** due to precipitated latent defects are only preventable to the limits of the state of the art in equipment and technology.

Errors can be readily monitored using conventional SPC techniques and can be removed by simple testing or inspection without the need for ESS or environmental stress.

Errors are introduced into the product during fabrication, and assembly, and pass through various assembly stages until they are detected by a test or inspection of sufficient thoroughness and subsequently eliminated from the product.

When good quality control test and inspection procedures are applied, all but the most subtle errors should be detected and eliminated prior to shipment.

Some examples of **errors** are:

- (1) Parts
 - a) Broken or damaged in handling
 - b) Wrong part installed
 - c) Correct part installed incorrectly
 - d) Missing parts
 - e) Electrical test correlation and tolerancing
- (2) Interconnections
 - a) Incorrect wire termination
 - b) Open wire due to handling damage
 - c) Wire short to ground due to misrouting or insulation damage
 - d) Missing wire
 - e) Open etch on printed wiring board
 - f) Open plated-through hole
 - g) Shorted etch
 - h) Solder bridge
 - i) Loose wire strand

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A **precipitated latent defect** is a latent flaw that has been transformed into a patent defect by exposure to stress over time.

Since **detection efficiency** is not 100%, some precipitated latent flaws, and errors, will be escape to the field as undetected defects.

It is thus important to address the aspects of **precipitation** and **detection** separately, and also to distinguish and separately monitor errors and precipitated latent flaws.

For simplicity the document shall use the term patent defect to define a precipitated latent defect.

16.4.4.8.2 Categories of Defects

The majority of parts and connections within an electronic equipment will never fail over the product's lifetime and are thus "good".

The failures which occur during product life are traceable to design or extremely induced causes, or to latent defects which were introduced into the product during manufacture.

Such defects, if not eliminated from the product in the factory, will result in **premature** or early-life failures in the field.

Not all latent defects however, are screenable i.e., capable of being eliminated from the equipment in the factory by use of stress screens.

It is only those latent defects, whose failure threshold can be accelerated by the stresses imposed by the screens, which are screenable.

It is the screenable early life failure which the stress screening program must be designed to remove. Figure 16.5 illustrates the categories of defects and their relationship to product life failures.

The notion of **screenable latent defects** must be further examined to fully understand the rationale used for the procedures contained in this document.

The population of latent defects within newly manufactured electronic items can be viewed as a continuum which ranges from minor defects of small size to major defects of large size.

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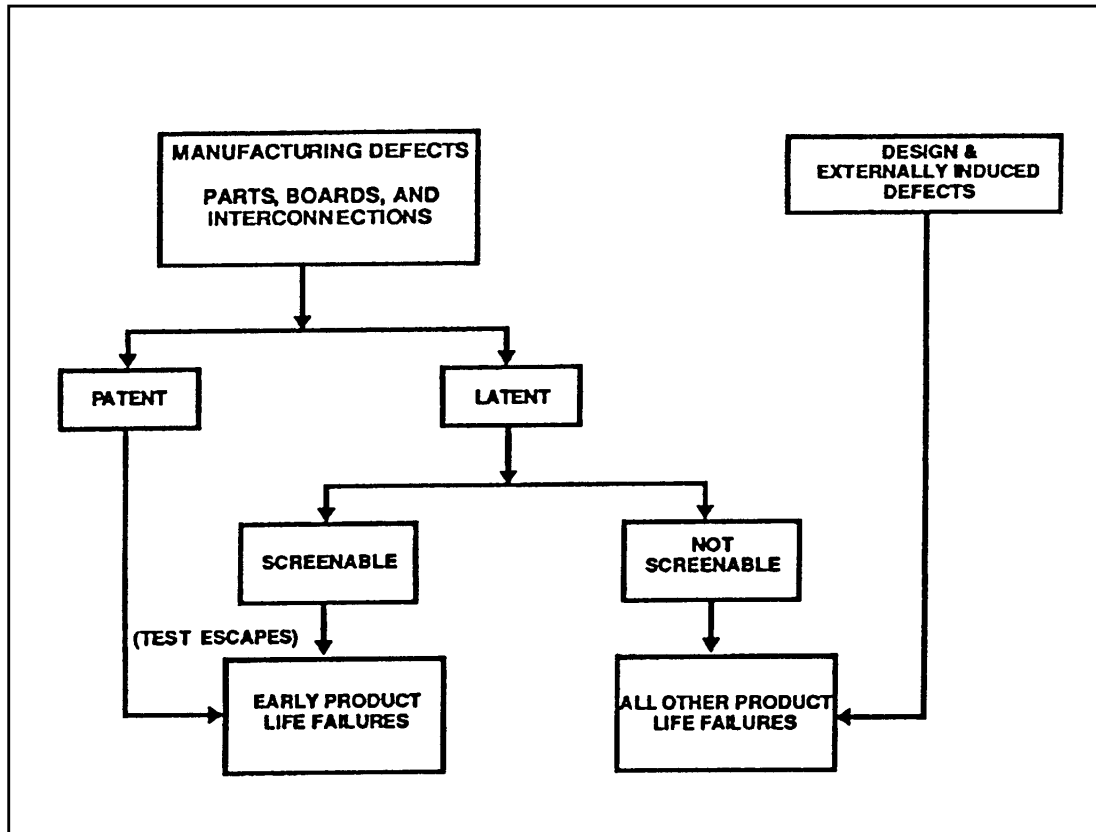
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FIGURE 16.5: DEFECT CATEGORIES AND PRODUCT LIFE FAILURES

However, it is important to note a somewhat controversial point, i.e., given the same manufacturing process, the number of latent defects which may reside in the hardware will differ, depending upon the operating environment and stress levels to which the equipment will be exposed.

The **stress/time** to which a latent defect is exposed will determine its failure threshold and time-to-failure.

The **probability** of a latent defect's failure threshold being exceeded is much higher in a harsh environment than in a more benign environment.

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Obtaining an initial estimate of defect density for an equipment must take into consideration the field operating environment to which the equipment will be exposed during product life.

Since the operating environmental stress levels are different and less than the factory ESS levels, the **field defect density** estimates is not directly applicable to the factory ESS program.

Further, the producer must design, assess, and monitor the ESS program based upon analysis of factory fallout data and causes. Some methods must thus be provided to relate defect density in the field to the factory defect density.

This is accomplished by including a **Stress Adjustment Factor (SAF)** in the model, where

$$\text{STRESS ADJUSTMENT FACTOR (SAF)} = \frac{\text{Defect Density (Field Stress)}}{\text{Defect Density (Factory Stress)}}$$

The application and measurement of the SAF is prescribed in Procedures B and E respectively of section 16.5.

16.4.4.8.3 Factors Which Impact Defect Density

The quantity and the type of defects which are introduced into a product are dependent upon **several factors**. The first six factors, listed below, are related to product or program characteristics for which manufacturing function within a company has little control.

The last two factors are related to the manufacturing process for which the manufacturing function has direct control.

- (1) Complexity - The quantity and type of parts and interconnections used in the product affects defect density. Increased complexity creates more opportunities for defects.
- (2) Part Quality Level/Grade - The quality levels of parts are established by MIL-STD part screening requirements. The number of defects which remain in a lot of screened parts is determined by the type and extent of screening and testing to which the parts are subjected under MIL-STD screening requirements.

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- (3) Stress Environment - The stress conditions to which the equipment will be exposed will affect the proportion of defects which should be screened from the product. A defect may be precipitated to early failure in a harsh field operating environment, but may survive product life in a benign field environment.
- (4) Process Maturity - New production requires time to identify and correct planning and process problems, train personnel and to establish vendor and process controls. Maturity is dependent on volume and time. Low production volume over a long period would have a low maturity rate and will thus impact defect density.
- (5) Packaging Density - Electronic assemblies with high part and wiring density are more susceptible to process, workmanship and temperature induced defects due to smaller error margins, increased rework difficulty and thermal control problems.
- (6) Concurrent Engineering - Proper design analysis and assessment and application of Concurrent Engineering principles during the design stage will tend to ensure a reliable and producible product and thus reduce the latent (and error) defect densities. Durability analyses will also ensure that the design can withstand the stresses of ESS.

The following factors are under the direct control of manufacturing function. The degree of control exercised will impact defect density.

- (1) Manufacturing Process Controls - Good process controls will tend to reduce the number of defects which are introduced into the product.
- (2) Workmanship Quality Standards - Stringent and properly enforced workmanship quality standards will enhance the reliability of the product through reduced introduction of workmanship defects into the product.

16.4.4.8.4 Part vs. Assembly Defect Density

The part defect density can have a significant impact on the assembly defect density depending upon the number of parts contained in the assembly.

The Poisson approximation is used in Figure 16.6 to illustrate the expected assembly defect density as a function of the remaining part defect density and the number of parts per assembly.

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As can be noted relatively small values of part defect density result in large values of assembly defect density depending upon the number of parts contained in the assembly.

The questions answered by the ESS methodology and procedures in this document are:

How much better must the remaining part defect density be?

What level of part defect density is needed for delivered systems?

Can such levels be achieved?

16.4.4.8.5 Part Level vs. Assembly Level Screening

Screening at the part level may be a cost effective alternative for eliminating defects prior to the parts being assembled into the production hardware.

A population of parts, even those procured to high quality levels, may appear to contain high defect density levels.

For example microelectronic devices procured to the quality requirements of MIL-STD-883 receive 100% final electrical testing by the part vendor.

Nonetheless, some manufacturers **have found** that about 1%, and as much as 4% of the parts will not pass a similar electrical test performed at the OEM (Original Equipment Manufacturer) receiving inspection.

There are several possible **reasons** for this including:

- (1) the seller's and the buyer's tests are different
- (2) the seller's testing errors
- (3) the buyer's testing errors
- (4) device damage or degradation in handling
- (5) inspection and sorting errors
- (6) latent defects

General awareness of this problem in industry has resulted in improvements in part quality and reliability.

Screening at the **assembly level** is also a means of finding and eliminating part defects from the hardware. The part fallout from early screening at the assembly level can provide much of the information needed for resolving such uncertainties and taking corrective action.

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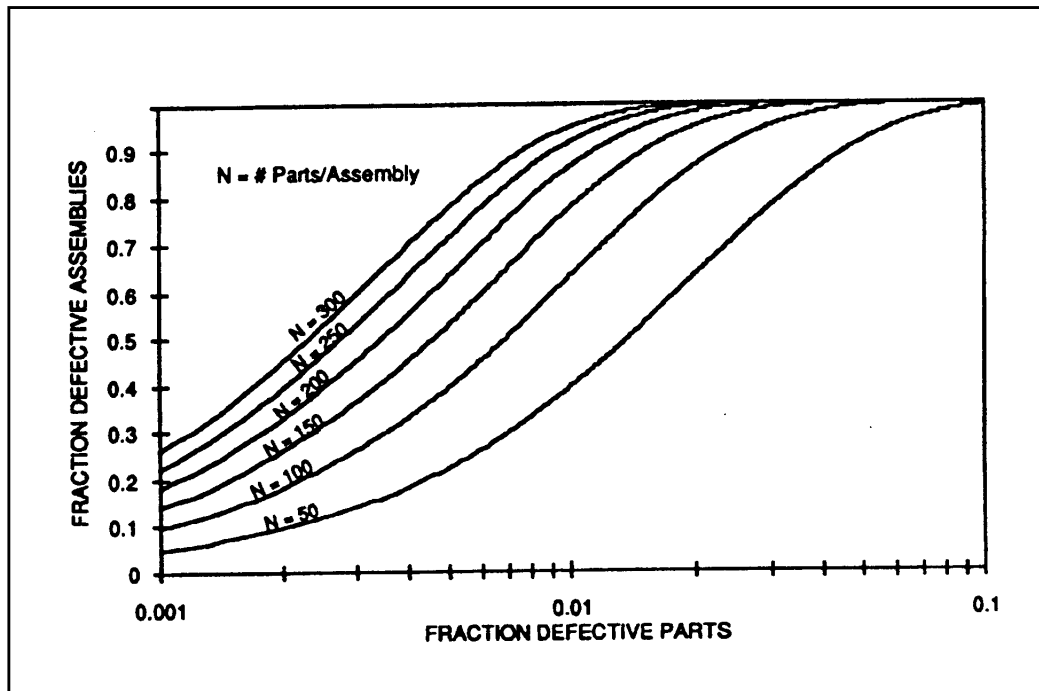


**FIGURE 16.6: FRACTION DEFECTIVE ASSEMBLIES VS.
FRACTION DEFECTIVE PARTS**

There are always **uncertainties** as to whether the part defects which are found during assembly level screening, are escapes from part level screens or whether they are newly introduced defects due to handling, test and assembly operations.

A thorough **failure analysis** of the fallout from assembly level screening can help in determining defect causes and the types of screens which should be used.

16.4.5 Screen Selection and Placement

Planning a stress **screening program** requires the selection and placement of appropriate screens at various levels of assembly so as to achieve a cost effective screening program.

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Listed below are the **factors** which affect screen selection and placement. The factors are discussed in more detail in the following paragraphs.

- (1) Precipitation efficiency - Prior knowledge of the effectiveness of the screens in precipitating defects to failure.
- (2) Screening Strength - The product of precipitation efficiency and detection efficiency, determines the capability for removing defects.
- (3) Detection efficiency - The tests which can be economically and feasibly used to detect defects which have been precipitated to failure by the screens.
- (4) Thermal and vibration response characteristics - The structural, thermal and material properties of the items to be screened and their response to applied stress.
- (5) Design limits - The environmental stress design limits of the items to be screened.
- (6) Facilities - The screening, test and instrumentation facilities available to the manufacturer to perform screening and test operations.
- (7) Costs - The costs to achieve screening program goals on remaining defect density.
- (8) Product Reliability Verification Test (PRVT) - The use of a PRVT as an integral part of an ESS program to provide confidence that field reliability will be achieved.

16.4.5.1 Precipitation Efficiency

Precipitation efficiency is defined as the **probability** that a screen will precipitate a defect to a detectable state given that a defect susceptible to the screen stress is present.

16.4.5.2 Screening Strength

Screening strength is defined as the precipitation efficiency **multiplied** by the probability that the defect will be detected and removed (i.e., the detection efficiency).

A **basic premise** of stress screening is that under specific screening stresses applied over time, the failure rates of defectives are accelerated from that which would occur under normal field operating stress conditions.

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By **subjecting** electronic items to **accelerated stresses**, i.e. rapid **temperature cycling** and **random vibration**, latent defects are thus precipitated to early failure.

More severe stresses will tend to accelerate failure mechanisms and the rate of defect failure. For example, the failure rate of a latent defect increases with more rapid rates of temperature change and larger temperature extremes.

The precipitation efficiency (and hence screening strength) of a random vibration screen increases as a function of the level and duration of the applied excitation.

Stress screens are not all equally effective in transforming latent defects into detectable failures. Table 16.2 provides a listing of latent defect types and the screens believed to be effective in precipitating them to failure.

Table 16.2 may be used as an aid in the selection of a screen type when prior knowledge on workmanship or part defects for similar assemblies is not available.

Table 16.2 indicates that vibration screens are generally **more effective** for loose contacts, debris and loose hardware while temperature cycling screens are not effective.

Thermal screens are generally more effective for part parameter drift, contamination and improper crimp or mating type defects while vibration screens are not.

For other defect classes listed in the table, both thermal and vibration screens are effective, but the relative degree of effectiveness of one screen type over the other is not precisely known.

These are some of the uncertainties which must be dealt with in planning a screening program. Historically, **on average**, 20% of the defects are found to be responsive to vibration screens and 80% to temperature cycling screens.

To improve the modeling accuracy and **to ensure** a proper balance between thermal and vibration screens, it is **recommended** that the defect population be **segregated** into Random Vibration (RV) sensitive defects and Temperature Cycle (TC) sensitive defects.

If necessary, the population responsive to either TC or RV can also be included on the model.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.2: ASSEMBLY DEFECT TYPES PRECIPITATED BY
THERMAL AND VIBRATION SCREENS**

Defect Type	Thermal Screen	Vibration Screen
Defective Part	X	X
Broken Part	X	X
Improperly Installed Part	X	X
Solder Connection	X	X
PCB Etch, Shorts and Opens	X	X
Loose Contact		X
Wire Insulation	X	
Loose Wire Termination	X	X
Improper Crimp or Mating	X	
Contamination	X	
Debris		X
Loose Hardware		X
Chafed, Pinched Wires		X
Parameter Drift	X	
Hermetic Seal Failure	X	
Adjacent Boards/Parts Shorting		X

Reference RADC-TR-82-87

16.4.5.2.1 Screen Parameters

Precipitation efficiency is a function of specific screen stresses (parameters) and the time duration of the stress application.

Equations provided in Procedure C of Section 5 provide values for precipitation efficiency as a function of relevant screening parameters.

It should be noted that these parameters pertain to the unit under test and not the chamber etc. Vibrational characteristics of the equipment (e.g., resonances, transmissibility etc.) and the various thermal conductivities and masses must be considered.

All assembled hardware consists of many paths along which a stress might be transmitted.

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The selection of screening parameters and methods of stress application must be suited to the stress transmission characteristics of the hardware design.

As a part of the screen selection and placement process, in which thermal or vibration screens are to be used, a **stress response survey** of the item to be screened should be performed.

This may require simulations and or surveys conducted on the actual or similar hardware. Care should be exercised to ensure that hardware responses are large enough to generate an effective screen while not exceeding hardware design capability.

Environmental stresses should be applied to the hardware and the response of critical hardware elements measured to determine whether maximum or minimum temperature limits are being exceeded, and whether suspected defect sites (parts, interconnections etc.) are responsive to the screen stress.

In addition, normal design provisions for isolating the hardware from stress such as the use of shock mounting, vibration isolators or cooling air should also be evaluated.

Application of environmental stress screening in such instances, should require bypassing the normal stress isolation provisions or may dictate the need for screening at lower assembly levels which do not include the stress isolation design features.

Temperature cycle, constant temperature, random and swept-sine screening parameters are defined as follows:

(1) Thermal cycle screen parameters

- a) Maximum temperature ($T_{\max}$) - The maximum temperature to which the screened item will be exposed. This should not exceed the lowest of the maximum ratings of all the parts and materials comprising the item.

Note that non-operating temperature ratings for parts are higher than operating rating.

- b) Minimum temperature ($T_{\min}$) - The minimum temperature to which the screened item will be exposed. This **should not** exceed the highest of the minimum ratings of all the parts and materials comprising the assembly.

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Note: $T_{\max}$ and $T_{\min}$ must be carefully selected either through analytical means or a thermal survey.

- c) Range (R) - The range is the difference between the maximum and minimum applied external (chamber) temperature ($T_{\max} - T_{\min}$). Temperatures are expressed in °C.

Care should be taken when $T_{\min}$ is negative not to subtract incorrectly and result in an erroneously small computed temperature range.

- d) Temperature rate of change (T_R) - This parameter is the average rate of change of the temperature of the item to be screened as it transitions between $T_{\max}$ and $T_{\min}$ and is given by:

$$T_R = \frac{\left[\left(\frac{T_{\max} - T_{\min}}{t_1} \right) + \left(\frac{T_{\max} - T_{\min}}{t_2} \right) \right]}{2}$$

Where:

t_1 is the transition time from $T_{\min}$ to $T_{\max}$ in minutes,

t_2 is the transition time from $T_{\max}$ to $T_{\min}$ in minutes.

- e) Dwell - Maintaining the hardware temperature constant, once it has reached the maximum (or minimum) temperature, is referred to as dwell. The duration of the dwell is a function of differences in the thermal mass of the items being screened.
- f) Number of cycles - The number of transitions between temperature extremes ($T_{\max}$ or $T_{\min}$) divided by two.
- (2) Constant Temperature Screen Parameters
- a) Temperature delta $\Delta(T)$ - The absolute value of the difference between the hardware temperature and 25°C.

$$\Delta T = |T - 25^\circ\text{C}|$$

Where T is the hardware temperature.

- b) Duration - The time period over which the temperature is applied to the item being screened, in hours, after the hardware has reached thermal equilibrium.

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(3) Vibration Screen Parameters

- a) Grms level for random vibration - The rms value of the applied power spectral density observed by the hardware, including resonance and transmissibility effects.
- b) Spectrum shape for random vibration - The shape taken by the range of frequencies in the frequency spectrum.
- c) G-level for swept sine vibration - The constant rms acceleration applied to the equipment being screened throughout the frequency range above 40 HZ. The g-level below 40 HZ may be less.
- d) Sweep rate for swept sine vibration - The rate at which the “forcing” frequency is varied through a range of frequencies.
- e) Duration - The time period over which the vibration excitation is applied to the item being screened, in minutes.
- f) Axes of vibration - This can be a single axis or multiple axes depending on the sensitivity of defects to particular axial inputs.

16.4.5.2.2 Design Limits

The use of screen parameters which impose stresses which exceed the design limits of the product is not recommended.

Effective screening programs can be developed without having to resort to stresses which exceed the design capability of the hardware.

Criteria for judging how much the design limits can be safely exceeded, without causing damage to the product, are non-existent or at least arbitrary.

However, to permit reasonably high ESS stress levels, it is important that the equipment be designed for ESS and thus the ESS program and required stress levels should be determined concurrently during the design stage.

Designing equipment for ESS means that the design should develop such that individual assemblies have similar response characteristics.

This should be done so that no one subassembly will be dictating the screening levels for the other subassemblies.

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Using the procedures contained in this document, the manufacturer can focus on those items in which defects are most likely to reside in the hardware and determine safe screening levels, within appropriate cost constraints, for precipitating them to failure.

The **procedures take into account** the increased defects with increased factory stress level and also require a fatigue life study to **ensure** that useful operating life has not been impacted by the amount or level of ESS.

16.4.5.2.3 Guidelines for Initial Screen Selection and Placement

The development phase ESS program is intended to expose various defect types and causes and to obtain factory data to calculate and refine the planning estimates of D and SS that were based on documents and industry data.

Additional ESS beyond that intended for production may be required to improve the estimated accuracy.

An initial screening regimen should be selected for experimental use during the development phase in conjunction with the use of the procedures.

Table 16.3 is recommended as an aid in selecting and placing screens for starting regimen.

16.4.5.2.4 R&M 2000 ESS Initial Regimen

R&M 2000 ESS studies recommend the screen types, parameters and placements outlined in Table 16.3 as an initial regimen. The screens contained in Table 16.3 have high precipitation efficiency.

After sufficient fallout has been observed, the screening regimen may be reduced. The R&M 2000 guidelines thus represent initial values for consideration during the development phase and can be reduced for production based on the planning and analysis procedures outlined in Procedures A and D, in Section 16.5

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES****CHAPTER 16****TABLE 16.3: GUIDELINES FOR INITIAL SCREEN SELECTION AND PLACEMENT**

LEVEL OF ASSEMBLY	SELECTION				PLACEMENT	
	TEMP. CYCLE	CONST. TEMP	RAND. VIB.	S.S. VIB	ADVANTAGES	DISADVANTAGES
ASSEMBLY	E ¹	M ²	M ³	N	• 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 powered screens is high.
	E - Effective M - Marginally Effective N - Not Effective Notes: 1. Particularly if power is applied and performance is monitored at temperature extremes. 2. Effective where assemblies contain complex devices (RAMS, microprocessors, hybrids, etc.) 3. Effectiveness highly dependent on assembly structure. Not effective for small, stiff PWAs.					
UNIT	E	M	E	M	• Relatively easy to power and monitor performance during screen. • Higher test detection efficiency than assembly level. • Assembly interconnections (e.g. wiring back plane) 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	E	M	E	M	• 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.

16.4.5.3 Detection Efficiency

Detection efficiency is a measure of the ability to detect and remove patent defects. Detection efficiency includes factors representing fault coverage, the requirement for concurrent stress, the test duration, and the diagnostics and rework capabilities for removing the defect.

Detection efficiency is expressed as the **ratio** of patent defects detected (and removed) by a defined test procedure to the total possible number of patent defects. While stress screens may be effective in precipitating a latent defect into a detectable failure, removal of the failed condition is dependent on the capability of the test procedures used to detect and localize the failure.

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Care should be taken **to ensure** that tests have detection efficiencies as high as is technically and economically achievable. The screens may otherwise precipitate defects to failure which may go undetected by post screen tests.

Modern electronic equipment comprised of microprocessors, large memory and LSI devices may contain defects so subtle that only the most thorough of tests can detect them.

High screening strengths at lower levels of assembly may not always be easily accomplished because of low detection efficiency. The difficulty in accurately simulating functional interfaces or the inability to establish meaningful acceptance criteria may make the development of tests with high detection efficiency at the assembly level difficult and costly.

A certain percentage of defects may **only** be detectable at the unit/system level when all or a majority of the system components are connected and operating as a system. Analysis and quantification of detection efficiencies should be an integral part of the planning for a screening program.

16.4.5.3.1 Determining Detection Efficiency

Detection efficiency is determined as the **product of factors** that represent the following considerations:

- (1) The **probability** of observing and detecting a patent defect. This includes the probability of detection and the probability of occurrence. Consideration must also be given to the extent that the tests and limits being used represent all application requirements for functional and parametric performance.

The detection of intermittent and/or situation sensitive defects may also require extended test times and may be modeled using a Poisson distribution.

- (2) The requirement for **concurrent** stress. Many of the latent flaws precipitated to failure by ESS can only be detected when stress is applied during the test.
- (3) The **probability** of isolating and then removing the defect without creating an additional defect.

On some system procurements the probability of detection is a specified parameter for built-in-test (BIT), performance monitoring (PM), and fault location (FL) capability requirements.

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When the required BIT or PM/FL capability is used to verify performance of an item being screened, the actual values of fault coverage should be used in conjunction with the factors defined above and in Procedure C. On other system procurements, requirements to perform a failure modes and effects analysis (FMEA) are specified in the contract. In such cases, the FMEA should be used to estimate the fault coverage for a given test design

16.4.5.3.2 Power-On Testing vs. Power-Off

Application of power, exercising and monitoring equipment performance continuously during the screen will greatly **enhance** detection efficiency. Subtle faults, such as contact intermittents or temperature sensitive parts, can only be detected with powered and monitored screens.

With the increased complexity of modern electronics, fault sites may be confined to smaller areas and fault symptoms may appear only during certain tests or under a special set of external conditions.

As a result, a greater incidence of “Cannot Duplicate” (CND), “No Fault Found” (NFF), and “Retest OK” (RTOK) and similar intermittent or transient phenomena can occur. **Patent defects** which have been precipitated to failure by stress screens can be **categorized** into three general types:

- (1) Type 1 - Physical defects transformed from an inherent weakness to a hard failure by the stress screen.
- (2) Type 2 - Physical defects that manifest as failures only while under thermal or mechanical stress, (e.g., intermittent caused by a cold solder joint).
- (3) Type 3 - Functional defects that manifest as performance failures or anomalies only while under thermal or mechanical stress, (e.g., timing problems).

The Type 1 defects are readily detected by post screen tests of sufficient thoroughness. Type 2 and Type 3 defects require thorough and continuously monitored tests so that they can be detected.

Type 3 defects, which include problems such as **timing**, part parameter **drift** with temperature or **tolerance build-up** can only be detected with powered and monitored tests. Type 2 and Type 3 defects can comprise 50% and as much as 80% of the latent defects present in the hardware.(Reference RADC TR-86-149).

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SCREEN TYPE PARAMETERS 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/Minute (Chamber Air Temp.)
Temperature Dwell Duration (See Note 3)	Until Stabilization	Until Stabilization
Temperature Cycles (Minimum)	25	10
Temperature On/Equipment Operating	No	(See Note 5)
Equipment Monitoring	No	(See Note 5)
Electrical Testing After Screen	Yes (At Ambient Temp)	Yes (At Ambient Temp)
QUAS-RANDOM VIBRATION (See Note 7)		
Spectral Density	(See Note 8)	6 Grms
Frequency Limits		100 - 1000 HZ
Axes Stimulated Serially or Concurrently		3
Duration of Vibration (Minimum)		10 Minutes/Axis
- Axes Stimulated Serially		10 Minutes
- Axes Stimulated Concurrently		
Power On/Equipment Operation		(See Note 5)
Equipment Monitoring		(See Note 6)
* SRU - Shop Replaceable Unit LRU - Line Replaceable Unit LRM - Line Replaceable Module Notes: 1. Temperatures beyond stated minimums are acceptable. 2. Rapid transfers of the equipment between one chamber at maximum temperature and another chamber at minimum temperature are acceptable. 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 degrees Centigrade per hour. 4. A minimum of five thermal cycles must be completed after the random vibration screen. 5. Shall occur during the low to high temperature excursion of the chamber and during vibration. If 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. A "LRU mock-up" or equivalent approach is acceptable.		

Developing tests and test strategies for use with stress screens and estimating their detection efficiency is a **vitaly important** activity in planning a stress screening program.

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The use of tests with high **detection efficiency** is of equal importance to using screens with high **precipitation efficiency** in structuring a screen program for production.

16.4.5.3.3 Pre / Post Screen Testing and Screening Strength

In order to **experimentally** determine screening strength, the following conditions are require.

- (1) The items subjected to stress screening must be **tested** thoroughly before the stress screen **to assure** that no detectable failures remain at the start of stress screening. When testing is not performed prior to stress screening, it is not known whether patent defects were present, which could have been detected without stress screening, or whether latent defects were precipitated by the stress screen.
- (2) The items subjected to stress screening must be **powered** and exercised. Performance must be continuously monitored to assure that stress-dependent defects (e.g., intermittents, temperature and timing sensitive faults) are detected.
- (3) The items subjected to screening must be tested using the **same** test(s) both before and after the stress screen to assure that the failures detected are a result of the stresses imposed.
- (4) Data must be **collected** on defect fallout after the stress screen (i.e., during subsequent stress screens, tests, or early field operation) to obtain an estimate of the number of defects which were initially present.

When such data are available and assuming perfect tests, the **screening strength** can be determined by use of the observed fallout from the screen and the **number of defects initially present** i.e.:

$$\text{Screening Strength} = \frac{\text{Fallout}}{\text{Number Of Initial Latent Defects}}$$

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However, the total number of latent defects **can not** be determined until extensive field data is available. We are thus compelled to use a modeling approach where screening strength is based upon estimates derived from a combination of the actual screening program data, experiments, and the published literature.

The precipitation efficiency models and values used in this document tables of Procedure C in Section 5, were developed using such an approach.

16.4.6 Production Phase - Monitoring, Evaluation and Control

Once a screening program is implemented during the **production phase**, the screen fallout data and the screening process must be monitored and controlled **to assure** that program objectives are achieved.

For an effective monitoring and control program, the field reliability requirements should be directly related to goals and requirements for parts, processes, and materials and assemblies for all factory integration and ESS test levels.

The **procedure** for establishing these requirements and for monitor and control are provided in Procedures A and E respectively. Use of a Failure Reporting Analysis, and Corrective Action System (FRACAS) should be an **integral** part of production phase monitoring and control tasks.

The **fallout** from the screening process provides the necessary visibility regarding the sources of defects in the product and the manufacturing process. Finding defects, determining their root causes and ensuring that the sources of the defects are eliminated from either the process or product, is the basic mechanism by which **process capability** is improved.

Analyses of screen fallout data must be performed with specific objectives in mind. Well-defined monitoring, evaluation and control task objectives will ensure that the proper data is collected, classified and correctly analyzed to meet objectives.

The **objectives** of the monitoring-evaluation and control tasks are to establish assurance that remaining defect density and reliability goals are achieved through implementing improvements in manufacturing, screening and test process capability.

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Manufacturing **process capability** is improved through taking corrective actions which reduce the number of defects that are introduced into the product. **Screening process capability** is improved by increasing both the **precipitation efficiency** of screens (by ensuring that potential sites for defects in the product are being adequately stimulated) and the **detection efficiency**.

16.4.6.1 Data Collection

The importance of timely and accurate data collection to achieving screening program objectives cannot be overemphasized. The data elements listed below should be collected during the conduct of the screening program.

Some of the data elements become available directly as observed events from the screening process. Other data elements will become available only after analysis of the failures and failure data, or after a batch of items have been exposed to screening.

- (1) Identification of the items exposed to the screen/test, e.g., description, part number, revision, and serial number
- (2) Number of like items exposed to the screen/test
- (3) Number of like items passed/failed the screen/test
- (4) Date of test
- (5) Test station or equivalent
- (6) Type and number of defects found in conjunction with the number of items exposed, passed/failed (data elements 2, 3, 4)
- (7) Description of the type of defect found (part, workmanship / process, design)
- (8) Identification of the part, interconnection site where the defect was found
- (9) Identification of the assembly level or manufacturing process operation where the defect was introduced
- (10) Screen conditions under which the defect was found (e.g., high temperature, vertical axis of vibration etc.)
- (11) Time-to-failure relative to the start of the screen
- (12) Failure analysis results which identify the **root cause** of the defect

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- (13) Corrective action taken to eliminate the cause of the defect from the product and/or process

Data elements 12 and 13 may only be available if trends, as identified by the SPC monitoring and control methodology, warrant detailed root cause analysis and corrective action.

16.4.6.2 Failure Classification

In order to establish a basis for the analysis of the screening fallout data, the failures must be properly classified. The following classification scheme is recommended.

- (1) Part defect - A failure or malfunction which is attributable to a basic weakness or flaw in a part. Subcategories may include electrical, electronic, and mechanical.
- (2) Manufacturing defect - A failure or malfunction attributable to workmanship or to the manufacturing process (cold solder joint, cracked etch, broken wire strands, etc.). Subcategories may include assembly, process, and handling.
- (3) Design failure - A failure or malfunction attributable to a design deficiency. Note that electrical or thermal overstress failures due to **inadequate derating**, are design problems. Subcategories include hardware and software.
- (4) Externally induced failures - A failure attributable to external influences such as prime power disturbances, test equipment, instrumentation malfunctions or test personnel.
- (5) Dependent failure - A failure which is caused by the failure of another associated item which failed independently.
- (6) Unknown cause failure - An independent failure which requires repair and rework but which cannot be classified into any of the above categories. An intermittent failure that recurs infrequently would be an unknown cause. Subcategories include verified and not verified.
- (7) Unable to verify (UTV), retest OK (RTOK), and NO Fault Found (NFF) classifications describe conditions where an anomaly during testing could not be reproduced.

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16.4.6.3 Preliminary Analysis of Fallout Data

A preliminary analysis of the fallout data should be performed to ensure that failure causes are properly established and to categorize the failures so that more detailed analysis related to the ESS program objectives can be performed.

- (1) All failures traceable to part, board and interconnection defects, which are precipitated and detected by a screen/test, should be considered to be latent defects provided that pre-screen testing was performed. These data should be used for monitor and control purposes.
- (2) A predominance of **design problems** which are discovered during production screening operation is a matter of **serious concern**. Every effort should be made to determine corrective actions for design problems very early in production.

It does no good to speculate that the **design problems** should have been eliminated from the hardware during the development stage. Stress screening, on a 100% basis, is an **expensive** and time consuming method for finding design problems.

If the fallout from screening indicates persistent evidence of **design problems**, methods other than 100% stress screening should be used. **Reliability growth** and Test-Analyze-And-Fix (TAAF) techniques are recommended.

- (3) **Special attention** should be given to unknown cause failures. Sufficient investigation should be made to establish that an intermittent condition does not exist. The number of failures classified as "Unknown Cause" should be kept to a minimum.

Every effort should be made to correlate the failure circumstance data with the other similar failure incidents, as well as to use failure analysis so as to establish the cause of failure. The number of "unknown cause" classification and/or "unable to verify" classification should be used in assessing the detection efficiency.

- (4) Analysis of induced failures should be performed to determine necessary corrective actions.

The detailed analyses would typically be performed if the established goals and requirements are not being achieved, either for parts, materials and processes or for assemblies at various ESS levels.

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16.4.6.4 Analysis of Screen Fallout Data

The analysis of screening fallout data is directed toward evaluating the screening process so as to achieve screening program goals on remaining defect density, $D_{\text{REMAINING}}$.

Yield goals are achieved by both improving manufacturing process capability through corrective action and by improving the screening and test process capability when it is found to be needed.

Manufacturing, screening and test process capability will determine the **remaining defect density**. The capability of these processes are measured and controlled by use of two important quantities, the **incoming defect density** (D_{IN}) and the **screening strength** (SS).

Neither one of these quantities are directly observable as a result of the screening process. The only observable statistic is the **fallout** from the screen/test, from which inferences regarding D_{IN} and SS must be drawn.

The basic approach used in Procedure D of Section 16.5, is to obtain estimates of D_{IN} and SS, using the screen fallout data and to statistically compare the observed data against the planning estimates.

Based upon the comparisons, corrective actions are determined to eliminate the source of the defect from the process and/or to change the screens so as to achieve stated objectives.

The complementary procedures are presented in Procedures D and E for performing monitoring and analyses tasks. Procedure D uses curve fitting techniques, applied to the mathematical model, to estimate D_{IN} and SS.

Procedure E uses Quality Control Charts (SPC and PARETO) for monitoring and control.

Quality control charts - The use of control charts for defect control is a standard technique (i.e., p-chart, d-chart). Control charts (SPC and PARETO) are used in Procedure E which are based upon the Poisson Probability distribution; i.e.,

$$P(x) = \frac{\exp(-D)D^x}{x!}$$

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Where D = defect density

x = number of defects in an item

$P(x)$ = probability of x defects in an item

The mean of the Poisson distribution is D and the standard deviation is $\sqrt{D}$. The primary purpose of the control chart technique is to establish baselines against which the process can be monitored and by which out-of-control conditions can be identified.

Because of varying conditions, for example improving defect density, the actual defect density, D is determined using regression analysis. This value is then used to determine the expected statistical variation due to limited sample size i.e.,

$$D \pm n \sqrt{D} / N$$

where

n is the number of standard deviations, typically 3,

and N is the sample or lot size.

Defect density is calculated, using the **fallout data**, and compared against the control chart baselines.

Part and workmanship (process) problems are rank ordered with consideration for the expected defects based on complexity, etc., and analyses are performed and corrective actions taken to eliminate the source of the defects from the product.

Procedure E of Section 5 contains the detailed methodology for implementing the control chart technique.

16.4.6.5 Mathematical Model to Evaluate Screening Results

Appendix A provides a description of the Stress Screening Mathematical Model. The factory fallout data (expressed defects per system) can be curve fitted to the expression developed therein (for D_{REMOVED}) so as to obtain **estimates** of the **model parameters**.

Parameters which can be determined using this method are D_{IN} , SS (comprising PE and DE terms), the constant failure rate (CFR), and a Stress Adjustment Factor (SAF), relating defect levels at field stress to factory stress.

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16.4.6.6 Chance Defective Exponential (CDE) Model to Evaluate Screening Results

The defect distribution for both factory and field stress environments have been empirically determined to be represented by the following expression.

$$D_{\text{REMOVED}} = DE \cdot [D_{\text{PAT}} + D_{\text{LAT}} \cdot (1 - \exp(-kt)) + \text{CFR} \cdot t]$$

where D_{PAT} represents the patent defects, D_{LAT} represents the latent defects, t the stress duration e.g., time, cycles etc., k the precipitation stress constant, CFR the constant failure rate, and DE is the detection efficiency which is 1 for the field.

The CDE model developed by Fertig and Muthy and discussed in a paper contained in the 1978 Annual R&M Symposium provides a possible explanation for this observed relationship.

Regardless of the true derivation, the empirical results have been found to be **sufficiently accurate** for the purposes of this document. Inaccuracies either in the modeling and/or the estimated parameters are initially addressed using design margins and addressed during the production phase through the use of actual factory and field data to refine the estimates.

The **observed fallout** data can be fitted to the model to obtain estimates of the model parameters. The parameters of the model provide **estimates** of the incoming defect density D , the screening strength (SS, PE, DE), the limiting failure rate of the equipment (CFR) and the stress adjustment factor (SAF).

16.5 DETAILED ESS PROCEDURES/GUIDELINES/METHODS

16.5.1 ESS Implementation Procedures

The following paragraphs outline the **procedures** required to design, implement, and monitor a factory ESS program with the objective of continuously reducing defects through preventive actions such that ESS can be reduced to a minimum.

The procedures are aimed at optimizing the combined user/producer cost of achieving a **required field reliability** under prevailing conditions.

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An **ESS program** consists of three phases - **planning, development, and production**.

The planning phase is used to:

- (1) design a cost optimized factory ESS program that achieves the required **field reliability** for an existing design and defect density
- (2) create a suite of quantitative factory requirements that are meaningfully related to the required reliability and are measurable and monitorable by the producer.

The **planning phase** uses **defect density** and **screening strength** data provided in the document and industry and user's data. Since the data are approximations, the values must be validated and refined during the development phase.

During the **development phase**, monitor and control procedures are used to quantitatively measure fallout data and thus refine the estimates for defect density and screening strength so that **appropriate modifications** can be made for production.

Similar procedures are used throughout the **production phase** to provide a quantitative assessment and feedback on whether or not **reliability** requirements are being achieved and the extent that continuous improvement is being realized.

If problems exist, the procedures assist in focusing on problem areas and/or identifying the areas requiring more in depth or root cause analysis. The methodology allows for a continual reduction in ESS/screening as defect densities are reduced through corrective action (provided customer **reliability requirements are satisfied**) and thus allows the user and producer to optimize the product cost and reliability.

The procedures also provide management with the necessary visibility and models for assessing the trade-offs between defect prevention and screening and assessing the return and effectiveness of resource allocations.

The ESS program includes a Product Reliability Verification Test (PRVT) segment that is used in conjunction with ESS data analysis to provide the necessary confidence that field reliability will be achieved. The PRVT segment is calibrated during the development phase and is a fixed segment of the system level factory ESS.

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As defects are prevented through corrective action and ESS consequently reduced, the PRVT segment becomes useful in flagging possible out of control conditions that could otherwise be missed (due to the reduced ESS).

The PRVT segment thus serves multi-purpose roles for ESS polishing, field reliability indication, and out of control identification.

There are a total of six procedures:

- (1) Procedure A entitled, “**Optimizing Screen Selection and Placement**” uses procedures B and C (which estimate defect density and screening strength respectively) to design the ESS program, and Procedure D to validate the original estimates of defect density and screening strength and refine the program.

This procedure also optimizes the cost of an ESS program.

- (2) Procedure B entitled, “**Estimating Defect Density**” is used to estimate the incoming defect density.
- (3) Procedure C entitled, “**Estimating Screening Strength**” is used to estimate the screening strength.
- (4) Procedure D entitled, “**Refining Estimates of Defect Density and Screening Strength**” is used to analyze factory fallout data to provide revised estimates of D and SS.
- (5) Procedure E entitled, “**Monitor and Control**” is used to provide a quantitative assessment of whether reliability requirements are being attained and to what extent continuous improvement is being realized.
- (6) Procedure F entitled, “**Product Reliability Verification Test (PRVT)**” is used in conjunction with Procedure E for monitor and control purposes to provide confidence that field reliability will be achieved.

16.5.1.1 Procedure A - Optimizing Screen Selection and Placement

16.5.1.1.1 Objective

To plan an ESS program such that the **required field reliability** is attained at an optimum combined user-producer cost.

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16.5.1.1.2 Methodology

The field reliability is **determined** by the latent defects remaining at the time of shipment and the existence of non-screenable defects that result in a constant failure rate. The objective of this procedure is to optimize the cost of reducing the latent defect population to an acceptable level defined as that which achieves the **required field reliability**.

In planning an ESS program the **first step** is to determine the maximum allowable remaining latent defects that allow the **required reliability** to be achieved. Having determined the maximum allowable **remaining defects**, the required factory screening strength is determined from the estimated initial defects (D_{IN} - determined in Procedure B) by solving the equation:

$$SS = \frac{D_{REMOVED}}{D_{IN}}$$

where $D_{REMOVED} = D_{IN} - D_{REMAINING}$

Knowing the required factory **screening strength**, the **next step** is to optimize the screen selection and placement based on the combined user-producer cost. This is accomplished by determining the cost of removing the required number of defects using various ESS options.

There are essentially **three stages** for applying this procedure. During the design stage initial estimates of D_{IN} and SS are derived using the mathematical modeling techniques of Appendix A and the data included in Procedures B and C augmented by any prior production history (collected and analyzed according to the techniques of Procedure D) from similar equipment.

A **design safety margin** is built in to account for accuracy limitations of the estimates. During the development and/or early production phase, additional ESS may be added to provide sufficient data to use the curve fitting technique of Procedure D to “calibrate” the factors determined in the design stage.

A **minimum** of 2 RV cycles and 10 TC cycles are recommended. During the production phase the curve fitting techniques of Procedure D are used to refine and validate the program on a continual basis.

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16.5.1.1.3 Procedure Steps

(1) Procedure A1

The objective of this procedure is to create the basic ESS model for a particular program and to **determine** the incoming defect density, allowable outgoing defect density, and factory ESS constraints.

- **Step 1**

Determine the initial defects resident in each assembly at all test and integration levels using the methods of Procedure B. **Proportion** the defects into RV and TC sensitive populations using the ratio 20% RV, 80% TC or other suitably determined ratio.

- **Step 2**

Determine the factory integration sequence and define all restrictions and requirements with respect to assembly, calibration, and acceptance testing. For example, determine exactly when in the factory integration sequence any sub-assembly calibration procedure should be performed.

Allow for final ATP and test over environment. Prepare a multi-level ESS flow diagram depicting the integration and environmental testing requirements as illustrated in Figure 16.7.

This diagram illustrates the production flow and provides the framework for ESS selection and placement.

- **Step 3**

Select and place RV and TC screens at various locations in the ESS model (flow diagram) created in step 2 above.

- **Step 4**

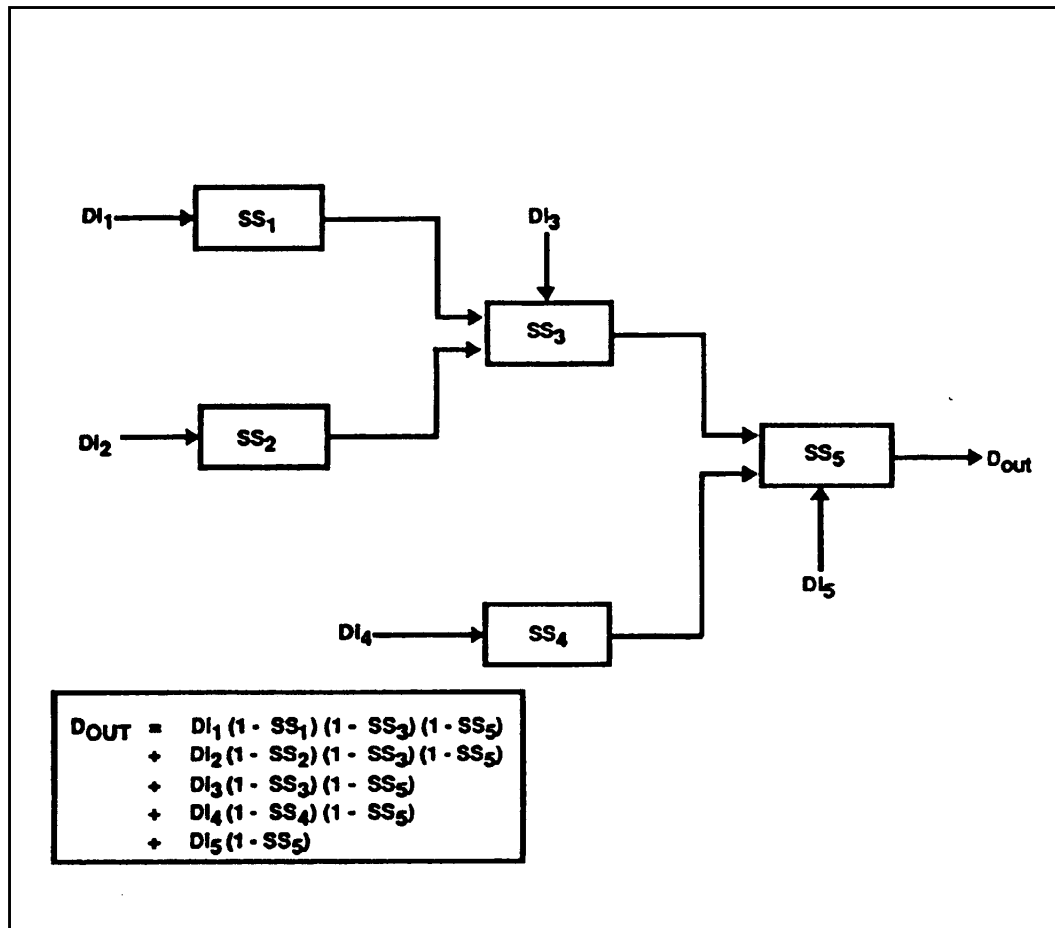
Use Procedure C to determine the screening strength for various ESS options. The model and calculations for a multilevel ESS flow are illustrated in Figure 16.7.

Note: The method of computation shown is more **accurate** for the same kind of defects, i.e., RV and TC sensitive **should not** be mixed in this type of computation.

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**FIGURE 16.7: SAMPLE MULTI LEVEL ESS FLOW DIAGRAM****• Step 5**

Given the customer's (Buyer, i.e., DHI) **reliability requirements**, **determine** the maximum number of defects permissible at the time of shipment that allow this reliability to be **achieved**. This is a three stage process as follows:

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-
- a) **Determine** whether the equipment has a limiting MTBF, i.e., the maximum inherent MTBF. The limiting inherent MTBF is the maximum that can be achieved and is limited by the state of the art in design, parts, materials, and processes and should be obtained from experience data from similar equipment.
- b) Given the customer's **required MTBF** and using a suitable **design safety margin** to allow for estimation errors (based on **derating criteria**, typically 1.5 to 2) **calculate** the permissible failure rate (FR) due to latent defects using the expression:

$$\text{FR (due to latent)} \leq \left(\frac{1}{\text{Required MTBF}} - \frac{1}{\text{Inherent MTBF}} \right) \times \frac{1}{\text{Safety Margin}}$$

- c) To **determine** the maximum number of defects permissible at the time of shipment it is necessary to determine the relationship between failure rate and remaining defects D.

The derivation of the equation to be used to determine D follows;

$$\text{FR} = \frac{D_{\text{FIELD}}(t)}{t} \quad (1)$$

where

t is the period over which MTBF is to be measured

D_{FIELD} is the number of field failures due to latent defects occurring during the interval t.

$$D_{\text{FIELD}}(t) = D_{\text{REMAINING}} \cdot SS_{\text{FIELD}}(t) \quad (2)$$

where

$SS_{\text{FIELD}}(t)$ is the equivalent screening strength of the field environment for a period t.

$$SS_{\text{FIELD}}(t) = 1 - \exp(-kt) \quad (3)$$

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where

k is the field precipitation rate

Substituting (2) and (3) into (1) gives

$$FR = D_{\text{REMAINING}}(\text{field stress}) \frac{[1 - \exp(-kt)]}{t} \quad (4)$$

Solving for $D_{\text{REMAINING}}$ yields:

$$D_{\text{REMAINING}}(\text{field stress}) = \frac{FR \cdot t}{1 - \exp(-kt)} \quad (5)$$

In this expression $D_{\text{REMAINING}}$ (the number of defects remaining after factory screening), t and k are all defined with respect to the field stress. It is thus necessary to modify this expression by the stress adjustment factor (SAF) determined in Procedure B to determine the remaining defects at factory stress.

$$D_{\text{REMAINING}} = \frac{FR \cdot t}{\text{SAF} [1 - \exp(-kt)]} \quad (6)$$

This expression is applicable to both the RV and TC sensitive defect populations. Recall from step 1 of procedure A1 to proportion the defects into appropriate RV and TC sensitive populations.

There are **two methods** for determining the value of k.

- a) If the field application environmental stresses **are known**, calculate k using the expression given in step 1 of Procedure C.
- b) If the field application stresses **are not known**, a suitable average value (based on industry or historical data) can be used. Typical values for k are 1/500 to 1/2000.

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Include the field model and parameters in the test flow diagram created in step 4 to complete the ESS model.

(2) Procedures A2 and A3

Their objective is to optimize the cost of ESS and they are not included in this version of this document.

(3) Procedure A4

After optimizing the screen selection and placement, it is necessary **to ensure** that the ESS is not too stressful and does not consume too much of the **useful (fatigue) life**.

This is **determined** by calculating the **damage index** D from the equation $D = NS^B$ where N represents the stress duration, S= stress level, and B= fatigue exponent.

The damage index should be **calculated** for both ESS and useful life. The life capabilities can be determined from design requirements, qualification test, or the anticipated end application.

For TC N = number of cycles

S = temperature range in degree Celsius

B = 2.5 (thermal fatigue exponent for solder)

For RV N = duration of vibration (hours or minutes)

B = 6.4 (vibration fatigue exponent for solder).

Example of fatigue life calculation:

a) Temperature Cycling [B = 2.5]

	Life (L)	ESS (E)
N = No. of Cycles	$N_L = 7300$	$N_E = 50$
S = Temperature Range	$S_L = 30$	$S_E = 120$
B = Thermal Fatigue Exponent	$B_L = 2.5$	$B_E = 2.5$

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	$D_L = N_L S_L^{B_L}$	$D_E = N_E S_E^{B_E}$
	$D_L = (7300)(30)^{2.5}$	$D_E = (50)(120)^{2.5}$
	$D_L = 35,985,372$	$D_E = 7,887,205$
% of useful life consumed by	$ESS = \frac{D_E}{D_L} = 21.9\%$	
b) Random Vibration [B = 6.4]		

	Life(L)	ESS (E)
N = Duration (Min.)	$N_L = 2 \times 10^6$	$N_E = 5$
S = Level (Grms)	$S_L = 1$	$S_E = 6$
B = Vibration Fatigue Exponent	$B_L = 6.4$	$B_E = 6.4$
	$D_L = N_L S_L^{B_L}$	$D_E = N_E S_E^{B_E}$
	$D_L = (2 \times 10^6)(1)^{6.4}$	$D_E = (5)(6)^{6.4}$
	$D_L = 2,000,000$	$D_E = 477,681$
% of useful life consumed by	$ESS = \frac{D_E}{D_L} = 23.8\%$	

The **allowable** percentage of useful life consumed by ESS is dependent on the particular application. The procedure described may require modifications based on individual design specifics and/or susceptibilities.

Care should be taken when using the **damage index**. The index may be misleading for short term life items.

REFERENCE: Crandall - Random Vibration, John Wiley and Sons, NY
Engelmaier - Effects of Power Cycling in LCC, Bell Laboratories, NJ.

(4) Procedure A5

Refine the program as designed using A1 through A4 by determining actual values for D_{IN} , SS, DE, PE, and SAF from factory and field data analyzed using Procedure D.

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The development of early preproduction phase should be used to verify and/or refine the original estimates. Subsequently, in **production data** should be analyzed on a regular basis to ensure the program remains optimum under changing conditions.

16.5.1.2 Procedure B - Estimating Defect Density

16.5.1.2.1 Objective

Obtain estimates of the number of defects **resident** in the system **prior** to beginning ESS.

16.5.1.2.2 Methodology

Various imperfections are introduced during the assembly and integration of the equipment due to state of the art limitations in the design, testing, and manufacturing of parts and assemblies.

The total number of imperfections is dependent upon the quantity and quality (technology, screening, reliability level, etc.) of the parts used and the assembly complexity (number of connections, processing, packaging densities, etc.).

Unless removed through **factory ESS** some fraction of these imperfections will precipitate under field stress conditions and cause equipment failure. The number of imperfections that will precipitate is dependent upon the factors mentioned above and the field stress levels.

The number of defects for either factory ESS or field must therefore be defined relative to the applicable factory and field stress levels.

To **ensure** that the ESS program has an appropriate balance of RV and TC stresses, the estimated defects must be divided in groups.

- (1) RV defects (i.e., those defects that can be precipitated by RV stress only)
- (2) TC defects (i.e., those defects that can be precipitated by TC stress only)
- (3) R-TC defects, (i.e., those defects that can be precipitated by either TC or RV stress)

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- (4) Time-Temperature-Humidity-Bias (TTHB) defects, (i.e., those defects precipitated by a combination of time, temperature, humidity, and electrical bias)
- (5) Mechanical Shock (MS) defects, (i.e., those defects precipitated by mechanical shock).

Factory ESS is effective in removing RV, MS, and TC sensitive defects with the majority of TTHB sensitive defects escaping to the field. Field defects thus comprise residual RV and TC defects approaching a constant failure rate distribution (i.e., the screening limit).

TTHB defects have a different time to failure distribution than TC or RV defects and for practical purposes are considered non-screenable and are not addressed by this document.

The procedure steps are as follows:

- (1) Estimate defects for each assembly and the total system at baseline stress and proportion the defects into RV and TC sensitive populations.
- (2) Apply stress adjustment factors to determine the defects under different factory stress levels.

The initial estimates derived using these procedures are only **approximate** and should be **refined** based on the user's actual data obtaining during the development phase or from the production of similar equipment.

Adjustment may be required on a system or individual assembly basis. The procedures for refining the original estimate are provided in Procedure D.

16.5.1.2.3 Procedure Steps

- (1) Procedure B1

Determine the number of **latent defects** resident in the equipment at the baseline stress as follows:

- **Step 1**

The equipment to be screened should be depicted in chart form down to the assembly level as illustrated in Figure 16.8 and Figure 16.9. The procedure uses a three-level equipment breakdown structure, i.e., System, Unit, and Assembly, to illustrate the methodology for planning a stress screening program.

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Other equipment breakdown structures are, of course, possible and can be adapted to the structure used herein. Figure 16.8 shows the breakdown of a system to be screened into three units.

Figure 16.9 shows the breakdown of one of the units into its constituent assemblies.

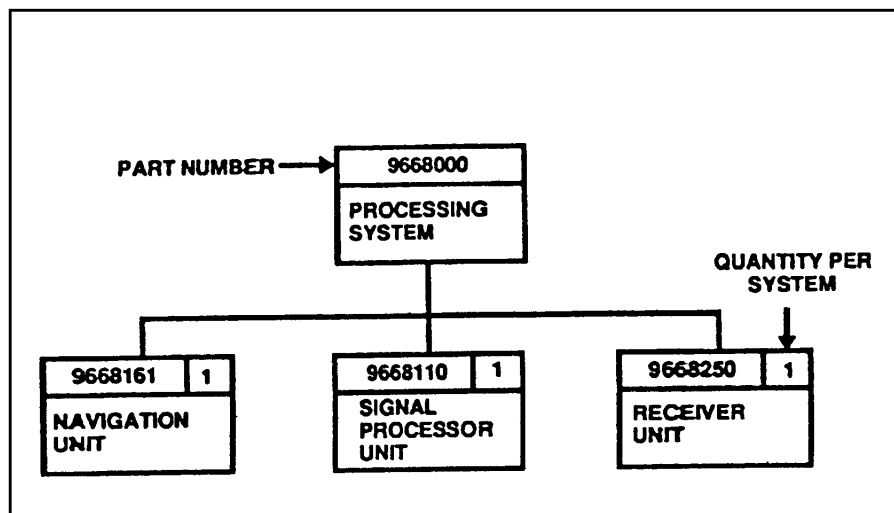
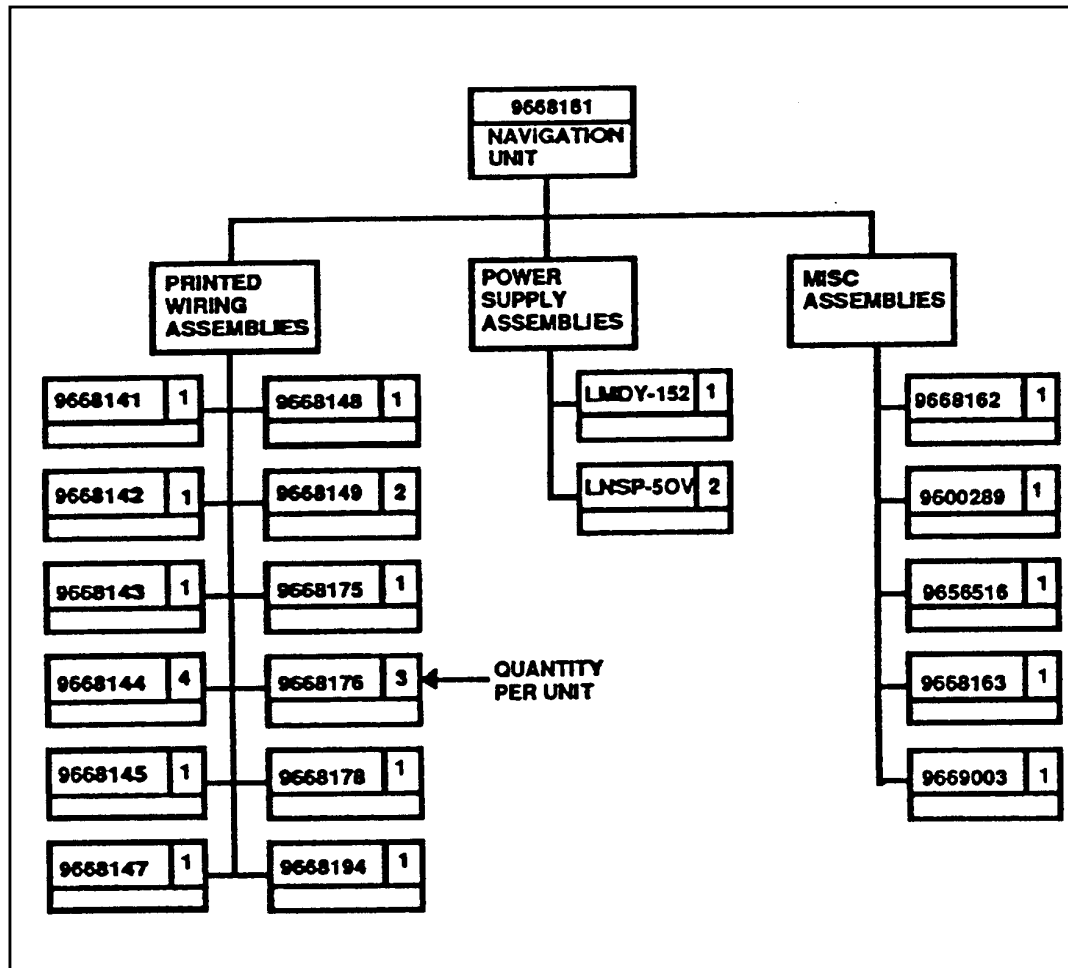


FIGURE 16.8: SYSTEM BREAKDOWN

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***CHAPTER 16***FIGURE 16.9: UNIT BREAKDOWN TO ASSEMBLY LEVEL****• Step 2**

The number of defects in a system depends on the quantity and quality of parts and workmanship characteristics. Therefore, it is necessary to **determine the system complexity** which is described by a complexity matrix.

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This matrix comprises the individual **complexity vectors** for each assembly and sub-assembly, including appropriate factors for multi-use assemblies. These complexity vectors are defined by the quantity of parts used in various part-type reliability categories and the quantity of manufacturing (assembly and soldering) characteristics present as defined in MIL-STD-2000.

A **sample** assembly **complexity vector** is shown in Table 16.5. An assembly complexity vector should be developed for each assembly depicted in the unit breakdown charts developed in step 1.

Table 16.5 and the template in Table 16.6 can aid in constructing the assembly complexity vectors. A system **complexity matrix** should then be developed by combining all assembly complexity vector values.

A sample system complexity matrix is shown in Table 16.7. The key to the figure can help to construct the system complexity matrix. Table 16.8 provides a template for the system complexity matrix.

• Step 3

Determine the initial number of defects at baseline stress by multiplying the system complexity matrix by the baseline stress defect density vector. The baseline stress defect density vector is determined from Table 16.9 or from prior industry and user data.

• Step 4

Proportion the total defects into populations that are sensitive to RV and TC. This improves the modeling accuracy and ensures a suitable balance of RV and TC is achieved.

Studies indicate that typically 20% of the total defects are sensitive to RV and 80% to TC.

Note: The population of RV and TC defects is based on the total population and not the factory fallout. Some factory fallout is affected by the relative RV and TC screening strengths.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES****CHAPTER 16****TABLE 16.5: SAMPLE, ASSEMBLY COMPLEXITY VECTOR**

ASSY # 149C3-3 (1)		QTY/NEXT ASSY.:1 (4)			SCREEN #3 (7)		
DESCRIPTION:PWR SUPPLY (2)		RV DE :0.5 (5)			TC DE:0.5 (8)		
USED ON: 456A1-1 (3)		TEST \$: \$50.00 (6)			REWORK \$: \$100.00 (9)		
(10)PART TYPE		GRADE/QUANTITY					
		S	B	B-1			
MICROCIRCUITS		0	35	61			
	JANTXV	JANTX	JAN	LOWER	PLASTIC		
TRANSISTORS	46	0	15	0	0		
DIODES	120	0	22	0	0		
	S	R	P	M	L	MIL-SPEC	LOWER
RESISTORS	0	0	277	0	0	3	0
CAPACITORS	0	0	118	0	0	14	0
	MIL-SPEC	LOWER	ROTATING DEVICES				
INDUCTORS	0	12					
RELAYS	3	0					
SWITCHES	0	0					
CONNECTORS	5	0					
PWBs	1	0					
TOTAL SOLDER CONNECTIONS: 2806 (11)			TOTAL # OF ASSEMBLIES 3742 (17)				
TOTAL # OF PARTS: 732 (12)			TOTAL # OF ASSEMBLIES = # OF PARTS + # OF LEADS + # OF TERMINALS + # OF WIRES + # OF PWBs				
TOTAL # OF LEADS: 3000 (13)							
TOTAL # OF TERMINALS: 2 (14)							
TOTAL OF WIRE CONNECTIONS: 7 (15)							
TOTAL OF PWBs: 1 (16)							

Notes:

1. Descriptive number of the assembly.
2. Description of the assembly.
3. Descriptive number of the next higher level unit that the assembly is used on.
4. The quantity of the type of assembly that is used on the next higher level unit.
5. Random Vibration Detection Efficiency as determined from Procedure C.
6. Text cost as determined from Procedure A.
7. The number assigned to the screen for this assembly.
8. Temperature Cycling Detection Efficiency as determined from Procedure C.
9. The estimated cost of rework as determined from Procedure A.
10. A listing of the quantity of all part types by quality grade.
11. DOD-STD-2000 solder normalizing number, calculated from the number of component leads + connector pins + wire connections.
12. Total number of all parts, added from block 10.
13. Total number of leads - includes all microcircuit pins and other part leads. For leadless chips use the number of solder bumps.
14. The total number of terminate.
15. The total number of wiring connections.
16. The total number of PWBs.
17. The total number of assemblies calculated as shown below block 17.

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TABLE 16.6: TEMPLATE, COMPLEXITY VECTOR

ASSAY #		QTY/NEXT ASSY.:		SCREEN #:			
DESCRIPTION:PWR SUPPLY		RV DE :		TC DE:			
USED ON:		TEST \$:		REWORK \$:			
PART TYPE		GRADE/QUANTITY					
		S	B	B-1			
MICROCIRCUITS							
	JANTXV	JANTX	JAN	LOWER	PLASTIC		
TRANSISTORS							
DIODES							
	S	R	P	M	L	MIL-SPEC	LOWER
RESISTORS							
CAPACITORS							
	MIL-SPEC	LOWER					
INDUCTORS			ALL				
RELAYS							
SWITCHES			ROTATING DEVICES				
CONNECTORS							
PWBs							
TOTAL SOLDER CONNECTIONS:			TOTAL # OF ASSEMBLIES				
TOTAL # OF PARTS:			TOTAL # OF ASSEMBLIES = # OF PARTS + # OF LEADS + # OF TERMINALS + # OF WIRES + # OF PWBs				
TOTAL # OF LEADS:							
TOTAL # OF TERMINALS:							
TOTAL OF WIRE CONNECTIONS:							
TOTAL OF PWBs:							

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES****CHAPTER 16****TABLE 16.7: SAMPLE, SYSTEM COMPLEXITY MATRIX**

EQUIPT: EXAMPLE (1)	ASSY DEF: 1.124 (2)			PART DEF: 0.806 (3)	WRK DEF: 0.318 (4)		
ENVIRON: AIF (5)	ESS \$:\$1,000 (6)			DEF REMVD: 0.00 (7)	DEF REMN: 1.1236 (8)		
(9) PART TYPE		GRADE/QUANTITY					
		S	B	B-1			
MICROCIRCUITS		0	284	261			
	JANTXV	JANTX	JAN	LOWER	PLASTIC		
TRANSISTORS	174	0	118	0	0		
DIODES	374	0	40	0	0		
	S	R	P	M	L	MIL-SPEC	LOWER
RESISTORS	0	0	1265	0	0	31	0
CAPACITORS	0	0	696	0	0	24	0
	MIL-SPEC	LOWER					
INDUCTORS	5	17					
RELAYS	12	0					
SWITCHES	0	0					
CONNECTORS	31	0					
PWBs	7	0					
TOTAL SOLDER CONNECTIONS: 2806 (10)				TOTAL # OF ASSEMBLIES 3742 (16)			
TOTAL # OF PARTS: 732 (11)							
TOTAL # OF LEADS: 3000 (12)				TOTAL # OF ASSEMBLIES = # OF PARTS +			
TOTAL # OF TERMINALS: 2 (13)				# OF LEADS + # OF TERMINALS +			
TOTAL OF WIRE CONNECTIONS: 7 (14)				# OF WIRES + # OF PWBs			
TOTAL OF PWAs: 1 (15)				TOTAL WRK: 6548 (17)			

Notes:

1. Description of the equipment.
2. Sum of the defects on each assembly referenced to the specified environment excluding the SAF. This sum does not include multiple usages of an assembly and thus is not necessarily the total defects per system.
3. The portion of ASSY defects due to parts.
4. The portion of ASSY defects due to workmanship causes.
5. The environment specified for the system in question.
6. Cost of ESS calculated as defects removed x rework cost + test cost + environmental exposure cost.
7. Total defects removed, including SAF effect and multiple usage assemblies. This is the total factory ESS fallout.
8. Remaining defects after completion of ESS relative to the specified environment excluding SAF.
9. A listing of the quantity of all part types by grade.
10. Total number of solder connections in the system.
11. Sum of the quantities of each part type.
12. Total number of leads in the system.
13. Total number of terminals in the system.
14. Total number of wire connections in the system.
15. Total number of PWAs in the system.
16. Total number of assemblies calculated as shown below block 16.
17. Total work which equals ASSY # + SOLDER #. (Block 16 + Block 10).

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TABLE 16.8: TEMPLATE, SYSTEM COMPLEXITY MATRIX

EQUIPT:	ASSY DEF:	PART DEF:	WRK DEF:				
ENVIR:	RV DE :	DEF REMVD:	DEF REMN:				
PART TYPE	GRADE/QUANTITY						
	S	B	B-1				
MICROCIRCUITS							
	JANTXV	JANTX	JAN	LOWER	PLASTIC		
TRANSISTORS							
DIODES							
	S	R	P	M	L	MIL-SPEC	LOWER
RESISTORS							
CAPACITORS							
	MIL-SPEC	LOWER					
INDUCTORS							ALL
RELAYS						ROTATING DEVICES	
SWITCHES							
CONNECTORS							
PWBs							
TOTAL SOLDER CONNECTIONS:	TOTAL # OF ASSEMBLIES:						
TOTAL # OF PARTS:							
TOTAL # OF LEADS:	TOTAL # OF ASSEMBLIES = # OF PARTS +						
TOTAL # OF TERMINALS:	# OF LEADS + # OF TERMINALS +						
TOTAL OF WIRE CONNECTIONS:	# OF WIRES + # OF PWBs						
TOTAL OF PWAs:	TOTAL WRK:						

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.9: BASELINE STRESS DEFECT DENSITY VECTORS
(PPM)**

MICROELECTRONICS DEVICES								
S			B			B-1		
104.85			209.7			419.25		

TRANSISTORS					RELAYS		SWITCHES	
JANTXV	JANTX	JAN	LOWER	PLASTIC	MIL	LOWER	MIL	LOWER
312.3	624.6	3,123.0	15,615.0	31,229.85	7,397.4	21,662.1	62.25	1,119.3

DIODES					ROTATING DEVICES		CONNECTORS	
JANTXV	JANTX	JAN	LOWER	PLASTIC	ALL		MIL	LOWER
64.2	128.55	642.75	3,213.45	6,426.9	124,561.8		2,089.65	4,139.4

RESISTORS						PWBs	
S	R	P	M	MIL	LOWER	MIL	LOWER
8.1	26.85	80.7	269.25	1,346.1	4,038.3	9,209.4	92,094.45

CAPACITORS							INDUCTORS	
S	R	P	M	L	MIL	LOWER	MIL	LOWER
12.45	41.52	124.53	415.11	1,245.36	1,245.36	4,151.25	1,693.02	5,643.45

ASSEMBLY CHARACTERISTICS					SOLDER CHARACTERISTICS			
ALL					ALL			
25					5			

Note: This table was developed for the study documented in RL-TR-91-300, Vol 1.

(2) Procedure B2

Determine the stress adjustment factor relating defects at factory (baseline stress) levels to defects at the field application stress levels as follows:

• Step 1

Use Table 16.10 through Table 16.22 to determine the defect density vector at the anticipated field stress level. These tables represent the defect density for different application environments and were derived from field data.

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For factory ESS planning purposes, these tables should be rescaled to also include the defects removed by factory screening. A factor of 1.5 is typical. **Multiply** the system complexity matrix from Procedure B1 step 2 by the field stress defect density vector to **determine** the initial number of defects at the anticipated field stress levels.

- **Step 2**

Determine the field stress adjustment factor as **the ratio** of the number of defects at the field stress level to the number of defects at the baseline stress level (from Procedure B1).

- **Step 3**

If factory stress levels do not conform to the baseline stress levels (defined as 6 Grms and 6 degrees C/min.) **apply** a suitable factory stress adjustment factor (SAF) as follows:

$$\text{For RV: } \text{SAF} = \left[\frac{\text{Actual Grams}}{6 \text{ Grms}} \right]^n \quad n \text{ is typically } 0.5 \text{ to } 1.0$$

$$\text{For TC: } \text{SAF} = \left[\frac{\text{Actual Transition Rate}}{6 \text{ Degrees C / min}} \right]^n \quad n \text{ is typically } 0 \text{ to } 0.5$$

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**TABLE 16.10: MICROELECTRONIC DEVICES DEFECT (IN PPM) FOR
VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL		
	S	B	B-1
GB	9.2	18.3	36.2
GF	19.4	38.7	77.4
GM	26.6	53.2	106.3
NS	26.6	53.1	106.3
NU	36.0	72.1	144.1
AIC	24.2	48.3	96.6
AIF	31.4	62.8	125.6
AUC	30.6	61.1	122.3
AUF	43.4	86.9	173.7
ARW	48.2	96.4	192.9
SF	11.7	23.3	46.6
MF	29.7	59.4	118.8
ML	65.1	130.2	260.3
CL	1,065.9	2,131.8	4,263.7

**TABLE 16.11: TRANSISTOR DEVICES DEFECT DENSITY (IN PPM) FOR
VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL				
	JANTXV	JANTX	JAN	LOWER	PLASTIC
GB	10.9	21.9	109.3	546.6	1,093.2
GF	34.6	69.2	346.0	1,730.2	3,460.4
GM	82.0	160.0	799.8	3,998.8	7,997.5
NS	54.3	108.7	543.3	2,716.5	5,433.1
NU	104.6	209.3	1,046.3	5,231.7	10,463.4
AIC	103.8	207.6	1,038.1	5,190.6	10,381.2
AIF	154.0	307.9	1,539.5	7,698.0	15,395.1
AUC	170.4	340.8	1,703.9	8,519.5	17,038.9
AUF	252.6	505.2	2,528.9	12,629.3	25,258.5
ARW	139.2	278.3	1,391.6	6,957.8	13,915.6
SF	8.0	15.9	79.7	398.6	797.3
MF	252.6	505.2	775.1	3,875.5	7,751.0
ML	195.9	391.8	1,958.7	9,739.5	19,587.0
CL	3,408.9	6,817.7	34,088.7	170,443.3	340,886.7

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.12: DIODE PART DEVICES DEFECT DENSITY (IN PPM) FOR
VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL				
	JANTXV	JANTX	JAN	LOWER	PLASTIC
GB	5.9	11.8	59.2	296.2	592.3
GF	8.6	17.2	86.0	430.0	860.0
GM	18.9	37.7	188.5	942.3	1,884.6
NS	9.4	18.9	94.3	471.5	943.1
NU	23.5	46.9	234.6	1,173.1	2,346.2
AIC	25.0	50.0	250.0	1,250.0	2,500.0
AIF	32.7	65.4	327.0	1,634.6	3,269.3
AUC	37.33	74.6	373.1	1,865.4	3,730.8
AUF	46.55	93.05	465.4	2,327.0	4,653.9
ARW	29.9	59.8	299.2	1,496.2	2,992.3
SF	5.9	11.8	59.2	296.2	592.3
MF	18.4	36.8	183.9	919.2	1,838.5
ML	40.5	81.1	405.4	2,026.9	4,053.9
CL	641.1	1,283.8	6,419.2	32,096.2	64,192.3

**TABLE 16.13: RESISTOR DEVICES DEFECT DENSITY (IN PPM) FOR
VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL					
	S	R	P	M	MIL-SPEC	LOWER
GB	0.4	1.2	3.7	12.3	184.2	184.2
GF	0.6	2.0	6.1	20.3	305.2	305.2
GM	1.6	5.4	16.3	54.4	815.5	815.5
NS	1.0	3.3	9.7	32.2	482.6	482.6
NU	2.7	8.9	26.7	89.1	1,337.3	1,337.3
AIC	0.9	3.0	8.9	29.6	443.6	443.6
AIF	1.5	5.0	14.9	49.8	746.3	746.3
AUC	1.8	6.1	18.4	61.3	919.0	919.0
AUF	3.3	10.8	32.2	107.4	1,611.2	1,611.2
ARW	3.5	11.6	34.8	116.1	1,740.9	1,740.9
SF	0.3	0.9	2.6	8.8	132.3	132.3
MF	2.0	6.7	20.0	66.8	1,001.5	1,001.5
ML	5.1	16.8	50.4	168.0	2,519.0	2,519.0
CL	88.4	294.7	884.1	2,947.0	44,205.0	44,205.0

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**TABLE 16.14: CAPACITOR DEFECT DENSITY (IN PPM) FOR VARIOUS
ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL						
	S	R	P	M	L	MIL-SPEC	LOWER
GB	1.2	3.8	11.5	38.4	115.3	115.3	384.4
GF	1.8	6.2	18.4	81.5	184.5	184.5	615.0
GM	10.9	36.2	108.4	361.3	1,083.9	1,083.9	3,613.1
NS	6.1	20.2	60.6	201.8	605.4	605.4	2,018.0
NU	17.8	59.5	178.4	594.5	1,783.5	1,783.5	5,945.0
AIC	4.3	14.1	42.3	140.9	422.8	422.8	1,409.4
AIF	5.2	17.3	51.9	173.0	518.9	518.9	1,729.2
AUC	9.8	32.6	98.0	326.7	980.1	980.1	3,267.2
AUF	13.3	44.2	132.6	442.1	1,326.1	1,326.1	4,420.0
ARW	27.7	92.2	276.7	922.5	2,767.5	2,767.5	9,225.0
SF	0.9	3.1	9.2	30.7	92.2	92.2	307.5
MF	15.0	50.0	149.9	499.7	1,499.1	1,499.1	4,996.9
ML	39.2	130.7	392.1	1,306.9	3,920.6	3,920.6	13,068.6
CL	703.1	2,344.7	7,034.1	23,446.9	70,340.6	70,340.6	234,468.6

**TABLE 16.15: INDUCTOR DEFECT DENSITY (IN PPM)
FOR VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL	
	MIL-SPEC	LOWER
GB	537.2	1,790.7
GF	1,222.9	4,076.4
GM	2,069.1	6,897.0
NS	1,179.2	3,930.5
NU	2,725.0	9,085.3
AIC	1,193.7	3,979.1
AIF	1,485.6	4,951.8
AUC	1,388.2	4,627.5
AUF	1,388.2	4,627.5
ARW	3,892.7	12,975.8
SF	537.2	1,790.7
MF	2,287.9	7,626.4
ML	5,351.7	17,838.9
CL	89,385.3	297,951.1

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**TABLE 16.16: ROTATING DEVICES DENSITY (IN PPM)
FOR VARIOUS ENVIRONMENTS**

ENVIRONMENT	FRACTION DEFECTIVE
GB	5,935.2
GF	11,663.1
GM	29,067.0
NS	15,628.5
NU	38,980.6
AIC	14,013.0
AIF	18,602.6
AUC	17,684.7
AUF	21,907.2
ARW	56,604.8
SF	5,935.2
MF	27,965.5
ML	78,635.2
CL	N/A

**TABLE 16.17: RELAY DEFECT DENSITY (IN PPM) FOR
VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL	
	MIL-SPEC	LOWER
GB	142.5	210.9
GF	231.4	388.8
GM	1,073.0	3,084.4
NS	621.4	1,716.0
NU	1,898.5	5,410.3
AIC	564.3	1,089.0
AIF	627.7	1,442.4
AUC	803.8	2,012.5
AUF	929.3	2,640.0
ARW	3,221.2	9,652.3
SF	142.5	210.9
MF	1,784.5	5,034.3
ML	4,623.7	13,757.3
CL	N/A	N/A

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.18: SWITCH DEFECT DENSITY (IN PPM)
FOR VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL	
	MIL-SPEC	LOWER
GB	1.4	24.4
GF	2.4	44.0
GM	10.8	194.5
NS	5.3	95.5
NU	17.2	309.7
AIC	6.7	120.7
AIF	10.8	194.6
AUC	8.4	151.6
AUF	13.7	246.1
ARW	27.1	488.4
SF	1.4	24.4
MF	15.1	271.9
ML	39.2	705.0
CL	688.3	12,388.6

**TABLE 16.19: CONNECTOR DEFECT DENSITY (IN PPM)
FOR VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL	
	MIL-SPEC	LOWER
GB	73.7	97.3
GF	83.3	248.1
GM	422.8	1,016.2
NS	248.1	476.6
NU	654.9	1,298.9
AIC	175.9	576.3
AIF	274.0	851.2
AUC	387.9	811.9
AUF	603.9	1,204.6
ARW	921.9	1,770.1
SF	73.7	97.3
MF	509.6	992.6
ML	1,298.9	2,571.2
CL	23,115.8	45,733.8

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.20: PWB DEFECT DENSITY (IN PPM) FOR
VARIOUS ENVIRONMENTS**

ENVIRONMENT	QUALITY LEVEL	
	MIL-SPEC	LOWER
GB	425.0	4,250.0
GF	690.3	6,903.2
GM	1,710.8	17,107.9
NS	1,180.2	11,801.5
NU	2,874.1	28,741.2
AIC	1,241.4	12,413.7
AIF	1,914.9	19,148.8
AUC	3,452.4	34,523.9
AUF	5,833.5	58,334.9
ARW	4,098.7	40,986.9
SF	425.0	4,250.0
MF	2,333.3	23,332.8
ML	5,833.5	58,335.0
CL	102,267.9	N/A

**TABLE 16.21: MANUFACTURING CHARACTERISTICS
(IN PPM) IN VARIOUS ENVIRONMENTS**

ENVIRONMENT	MANUFACTURING CHARACTERISTICS	
	ASSEMBLY	SOLDER
GB	0.98	1.25
GF	0.98	1.25
GM	4.90	6.27
NS	2.45	3.14
NU	7.19	9.20
AIC	2.94	3.76
AIF	3.92	5.02
AUC	3.59	4.60
AUF	5.39	6.90
ARW	10.78	13.79
SF	0.98	1.25
MF	5.88	7.53
ML	15.69	20.26
CL	274.51	351.04

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16.5.1.3 Procedure C - Estimating Screening Strength**16.5.1.3.1 Objective**

Estimate the number of flaws precipitated and detected (removed) by ESS.

16.5.1.3.2 Methodology

The **screening strength** is characterized by a precipitation term and a detection term and determines the fraction of existing flaws that are removed by ESS. The precipitation and detection terms are estimated separately and it is **their product** that determines the screening strength.

Precipitation is defined as the conversion of flaws with some residual strength (latent defect) into a flaw with no strength (patent defect); for example the propagation of a crack through a wire until it is broken.

The application of stress precipitates a certain fraction of the existing flaws. This fraction is assumed to be constant for a specified stress level and duration and the mathematics are discussed in more detail in Appendix A.

A previous ref. RADC-TR-86-149 has determined the precipitation effectiveness of various stress types and has developed mathematical expressions for each. These expressions and representative tables are provided in Table 16.22 and Table 16.23.

As in the estimation of initial defects, the original estimate based on these tables is only **approximate** and must be validated or refined based on actual user's data.

Precipitation by itself does not ensure that flaws can be detected. In many instances a concurrent stress may be required to detect and isolate the failure. For example, a broken wire may make intermittent contact at low, ambient stresses.

Also, depending upon the function affected, the defect may only cause degraded performance. Either condition could require extended testing and may require concurrent stress.

The capability of detecting a patent defect is measured by the detection efficiency. The removal of a potential defect or flaw requires the flaw to be precipitated and subsequently detected and removed.

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The **detection efficiency** is defined as the capability of detecting, isolating and removing the defect once it has precipitated. It is a measure of the extent that factory testing exercises all possible field applications and conditions and is the **product** of the following factors and considerations:

- (1) Probability of observing functional and parametric defects (i.e., probability of detection x probability of occurrence)
- (2) Necessity for concurrent stress
- (3) Probability of isolating and then removing the defect without creating additional defect(s)

Studies indicate that a large fraction of defects require **concurrent stress** to be detectable. Therefore ESS that does not employ testing during stress application is relatively ineffective. It is also the reason why **RV stress should be followed by TC**.

RV is relatively short in duration, thus the detection efficiency, which has a Poisson ($1-e^{-kt}$) distribution, may be inadequate.

16.5.1.3.3 Procedure Steps

• Step 1

Determine the precipitation efficiency. Expressed as a function of stress duration, the precipitation efficiency is given by:

$$1-\exp (-kt)$$

where

t is the stress duration in hours, cycles, etc., and

k is a stress constant determined for each type of stress according to the following formulae:

- (1) Temperature Cycling:

$$k = 0.0017 t(\Delta T + 0.6)^{0.6} [\ln(\text{RATE} + 2.718)]^3$$

where

$\Delta T = T_{\max} - T_{\min}$ in degrees C

RATE = degrees C/minute

t = # of cycles

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(2) Constant Temperature:

$$k = 0.0017 t (\Delta T + 0.6)^{0.6}$$

where

 ΔT = degrees C

t = hours

(3) Random Vibration:

$$k = 0.0046 G^{1.71}$$

(4) Swept Sine Vibration:

$$k = 0.000727 G^{0.863}$$

(5) Fixed Sine Vibration:

$$k = 0.00047 G^{0.49}$$

Note: All G values are in units of Grms, (Source of formulae: RADC-TR-86-14).

Table 16.22 and Table 16.23 provide examples of precipitation efficiency for various screening parameters. For RV screens it is necessary to include an axis sensitivity factor. RV applied in the axis perpendicular to the plane of the board will have the greatest effect.

When selecting and modeling RV stress, the precipitation efficiency is thus given by $[1 - \exp(-kt)] \times \text{AXIS SENSITIVITY FACTOR}$, where the axis sensitivity factor is the defect density component in the sensitive axis divided by the total defect density.

Transmissibility and resonance effects must be considered and the frequency spectrum may need to be suitably notched to avert overstress or wear-out effects. Similarly, thermal mass and conductivities must be considered when determining TC transition rates and required dwell times.

The stress levels for all these equations pertain to the equipment being screened and not the chambers, etc.

It should also be noted that the expressions and tables for precipitation efficiency are only **approximate** and, as in the estimation of initial defects, should be refined based upon actual users data according to the techniques of Procedure D.

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• Step 2

Determine the detection efficiency (DE). The DE term is sensitive to three factors and must be estimated accordingly. These three factors (and their respective range of values) are:

(1) Type of testing performed:	
a) Functional only	0.5 to 0.8
b) Functional and parametric	0.8 to 1.0
(2) Environmental conditions during test:	
a) Testing performed under ambient conditions only	0.2 to 0.6
b) Testing performed concurrently with stress	1.0
(3) The ability to observe and isolate the defect and the probability of successfully removing the defect without introducing another	0.8 to 1.0

The product of these factors is the **detection efficiency**.

• Step 3

Determine the screening strength as the product of the precipitation efficiency (PE) and detection efficiency (DE).

Example of ESS Calculation

For TC of 4 cycles at 5°C/minute over a 100°C range:

The precipitation efficiency (PE) = 0.6027 (from Table 16.23)

For RV of 5 minutes at 5 Grms:

The precipitation efficiency (PE) = 0.303 (from Table 16.22)

Given the following “DE” factors:

Functional and parametric test: 0.9

Test during environmental stress: 1.0

Probability of detecting, isolating and removing the defect: 0.95

The detection efficiency is (DE) = $0.9 \times 1.0 \times 0.95 = 0.855$

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES****CHAPTER 16****Stress Screening for Temperature Cycling:**

$$SS(TC) = PE \times DE = 0.6027 \times 0.855 = 0.5153$$

Stress Screening for Random Vibration:

$$SS(RV) = PE \times DE = 0.303 \times 0.855 = 0.2$$

**TABLE 16.22: PRECIPITATION EFFICIENCY FACTORS-RANDOM
VIBRATION SCREENS**

DURATION (MINUTES)	ACCELERATION (G-RMS)																			
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
5	0.007	0.023	0.045	0.072	0.104	0.140	0.178	0.218	0.260	0.303	0.348	0.389	0.431	0.473	0.514	0.563	0.591	0.827	0.661	0.683
10	0.014	0.045	0.088	0.140	0.198	0.260	0.324	0.389	0.452	0.514	0.572	0.627	0.677	0.723	0.764	0.800	0.832	0.861	0.885	0.906
15	0.021	0.067	0.129	0.202	0.282	0.363	0.444	0.522	0.595	0.861	0.720	0.772	0.816	0.854	0.885	0.911	0.931	0.948	0.961	0.971
20	0.028	0.088	0.166	0.280	0.356	0.452	0.543	0.626	0.700	0.784	0.817	0.861	0.896	0.923	0.944	0.960	0.972	0.981	0.987	0.991
25	0.035	0.109	0.206	0.314	0.424	0.529	0.825	0.708	0.778	0.835	0.880	0.915	0.941	0.959	0.973	0.982	0.989	0.993	0.996	0.997
30	0.041	0.129	0.241	0.363	0.484	0.595	0.691	0.772	0.836	0.885	0.922	0.948	0.966	0.979	0.987	0.992	0.995	0.997	0.998	0.999
35	0.048	0.149	0.275	0.409	0.538	0.851	0.746	0.822	0.878	0.920	0.949	0.968	0.981	0.989	0.994	0.996	0.998	0.999	0.999	1.000
40	0.055	0.168	0.308	0.452	0.586	0.700	0.791	0.860	0.910	0.944	0.966	0.981	0.989	0.994	0.997	0.998	0.999	1.000	1.000	1.000
45	0.061	0.187	0.339	0.492	0.629	0.742	0.829	0.891	0.933	0.961	0.978	0.988	0.994	0.997	0.998	0.999	1.000	1.000	1.000	1.000
50	0.068	0.205	0.389	0.529	0.666	0.778	0.859	0.915	0.951	0.973	0.986	0.983	0.996	0.998	0.999	1.000	1.000	1.000	1.000	1.000
55	0.074	0.224	0.397	0.563	0.702	0.809	0.884	0.933	0.984	0.981	0.991	0.996	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000
60	0.081	0.241	0.424	0.595	0.734	0.836	0.905	0.948	0.973	0.987	0.994	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
65	0.087	0.258	0.450	0.624	0.761	0.859	0.922	0.959	0.980	0.991	0.996	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
70	0.094	0.275	0.475	0.651	0.788	0.878	0.936	0.968	0.985	0.994	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
75	0.100	0.292	0.498	0.677	0.809	0.895	0.947	0.975	0.989	0.996	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
80	0.108	0.308	0.521	0.700	0.829	0.810	0.956	0.981	0.992	0.997	0.99	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
85	0.113	0.324	0.543	0.722	0.846	0.923	0.954	0.985	0.994	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
90	0.119	0.339	0.563	0.742	0.862	0.933	0.971	0.988	0.996	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
95	0.125	0.354	0.583	0.761	0.877	0.943	0.974	0.991	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
100	0.131	0.349	0.602	0.778	0.890	0.951	0.980	0.993	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
105	0.137	0.383	0.619	0.794	0.901	0.958	0.984	0.994	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
110	0.143	0.397	0.637	0.809	0.911	0.964	0.987	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
115	0.149	0.441	0.653	0.823	0.921	0.969	0.989	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.22: PRECIPITATION EFFICIENCY FACTORS-RANDOM
VIBRATION SCREENS (Cont'd)**

DURATION (MINUTES)	ACCELERATION (G-RMS)																			
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
120	0.155	0.424	0.669	0.836	0.929	0.973	0.981	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
125	0.161	0.437	0.683	0.848	0.936	0.977	0.993	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
130	0.167	0.450	0.698	0.859	0.943	0.980	0.994	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
135	0.173	0.483	0.711	0.869	0.949	0.983	0.995	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
140	0.179	0.475	0.724	0.878	0.954	0.985	0.998	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
145	0.184	0.487	0.737	0.887	0.959	0.987	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
150	0.190	0.498	0.748	0.895	0.963	0.989	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
155	0.196	0.510	0.760	0.903	0.967	0.991	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
160	0.201	0.521	0.771	0.910	0.971	0.992	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
165	0.207	0.532	0.781	0.917	0.974	0.993	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
170	0.213	0.543	0.791	0.923	0.976	0.994	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
175	0.218	0.553	0.800	0.928	0.979	0.995	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
180	0.224	0.563	0.809	0.933	0.981	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
185	0.229	0.573	0.818	0.938	0.983	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
190	0.234	0.583	0.826	0.943	0.985	0.997	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
195	0.240	0.592	0.834	0.947	0.986	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
200	0.245	0.601	0.841	0.951	0.988	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
205	0.250	0.611	0.848	0.954	0.989	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
210	0.256	0.619	0.855	0.958	0.990	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
215	0.261	0.628	0.862	0.961	0.991	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
220	0.266	0.637	0.868	0.964	0.992	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
225	0.271	0.646	0.874	0.966	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
230	0.278	0.653	0.880	0.969	0.994	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
235	0.281	0.661	0.885	0.971	0.994	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
240	0.288	0.666	0.890	0.973	0.995	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
245	0.291	0.676	0.895	0.975	0.995	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
250	0.296	0.683	0.900	0.977	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
255	0.301	0.691	0.904	0.978	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
260	0.306	0.698	0.909	0.980	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES****CHAPTER 16****TABLE 16.22: PRECIPITATION EFFICIENCY FACTORS-RANDOM
VIBRATION SCREENS (Cont'd)**

DURATION (MINUTES)	ACCELERATION (G-RMS)																			
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
265	0.311	0.704	0.913	0.981	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
270	0.316	0.711	0.917	0.983	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
275	0.321	0.718	0.920	0.984	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
280	0.325	0.724	0.924	0.985	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
285	0.330	0.730	0.927	0.988	0.993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
290	0.335	0.737	0.931	0.987	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
295	0.340	0.743	0.934	0.988	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
300	0.344	0.748	0.937	0.989	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
305	0.349	0.754	0.940	0.990	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
310	0.353	0.750	0.942	0.991	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
315	0.358	0.785	0.946	0.991	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
320	0.362	0.771	0.947	0.992	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
325	0.367	0.778	0.950	0.992	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
330	0.371	0.781	0.952	0.993	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
335	0.376	0.786	0.954	0.994	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
340	0.380	0.791	0.956	0.994	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
345	0.384	0.795	0.958	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
350	0.389	0.800	0.960	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
355	0.393	0.805	0.962	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
360	0.397	0.809	0.964	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
365	0.401	0.813	0.965	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
370	0.406	0.818	0.967	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
375	0.410	0.822	0.968	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
380	0.414	0.826	0.970	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
385	0.418	0.830	0.971	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
390	0.422	0.834	0.972	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
395	0.428	0.837	0.974	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
400	0.430	0.841	0.975	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
405	0.434	0.845	0.976	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.22: PRECIPITATION EFFICIENCY FACTORS-RANDOM
VIBRATION SCREENS (Cont'd)**

DURATION (MINUTES)	ACCELERATION (G-RMS)																			
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
410	0.438	0.848	0.977	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
415	0.442	0.852	0.978	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
420	0.446	0.855	0.979	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
425	0.450	0.858	0.980	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
430	0.454	0.862	0.981	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
435	0.458	0.865	0.982	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
440	0.461	0.868	0.983	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
445	0.465	0.871	0.983	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
450	0.469	0.874	0.984	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
455	0.473	0.877	0.985	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
460	0.476	0.879	0.985	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
465	0.480	0.882	0.986	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
470	0.484	0.885	0.987	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
475	0.487	0.888	0.987	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
480	0.491	0.890	0.988	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
485	0.494	0.893	0.988	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
490	0.498	0.894	0.989	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
495	0.501	0.897	0.989	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
500	0.505	0.900	0.990	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
505	0.508	0.902	0.990	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
510	0.512	0.904	0.991	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
515	0.516	0.906	0.991	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
520	0.519	0.909	0.992	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
525	0.522	0.911	0.992	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
530	0.525	0.913	0.992	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
535	0.529	0.915	0.993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
540	0.532	0.917	0.993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
545	0.536	0.918	0.993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
550	0.539	0.920	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.22: PRECIPITATION EFFICIENCY FACTORS-RANDOM
VIBRATION SCREENS (Cont'd)**

DURATION (MINUTES)	ACCELERATION (G-RMS)																			
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
555	0.542	0.922	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
560	0.545	0.924	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
565	0.548	0.926	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
570	0.551	0.927	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
575	0.554	0.928	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
580	0.558	0.931	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
585	0.561	0.932	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
590	0.584	0.934	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
595	0.567	0.935	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
600	0.570	0.937	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

**TABLE 16.23: PRECIPITATION EFFICIENCY FACTORS -
TEMPERATURE CYCLING SCREENS**

NUMBER OF CYCLES	TEMP. RATE OF CHANGE °C / MIN	TEMPERATURE DELTA (ΔT) - °C								
		20	40	60	80	100	120	140	160	180
2	5	.1632	.2349	.2886	.3324	.3697	.4022	.4312	.4572	.4809
2	10	.2907	.4031	.4812	.5410	.5891	.6290	.6628	.6920	.7173
2	15	.3911	.5254	.6124	.6752	.7232	.7612	.7920	.8175	.8388
2	20	.4707	.6155	.7034	.7636	.8075	.8407	.8665	.8871	.9037
2	25	.5350	.6835	.7684	.8237	.8623	.8904	.9114	.9276	.9402
2	30	.5878	.7359	.8160	.8659	.8992	.9226	.9395	.9521	.9616
4	5	.2998	.4146	.4939	.5543	.6027	.6427	.6764	.7054	.7305
4	10	.4969	.6437	.7308	.7893	.8312	.8624	.8863	.9051	.9201
4	15	.6292	.7748	.8498	.8945	.9234	.9430	.9567	.9667	.9740
4	20	.7198	.8522	.9120	.9441	.9629	.9746	.9822	.9873	.9907

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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TEMPERATURE CYCLING SCREENS (Cont'd)**

NUMBER OF CYCLES	TEMP. RATE OF CHANGE °C / MIN	TEMPERATURE DELTA (ΔT) - °C								
		20	40	60	80	100	120	140	160	180
4	25	.7837	.8998	.9464	.9689	.9810	.9880	.9922	.9948	.9964
4	30	.8301	.9302	.9662	.9820	.9898	.9940	.9963	.9977	.9985
6	5	.4141	.5521	.6399	.7024	.7496	.7864	.8160	.8401	.8601
6	10	.6431	.7873	.8603	.9033	.9306	.9489	.9617	.9708	.9774
6	15	.7742	.8931	.9418	.9657	.9788	.9864	.9910	.9939	.9958
6	20	.8517	.9432	.9739	.9868	.9929	.9960	.9976	.9986	.9991
6	25	.8994	.9683	.9876	.9945	.9974	.9987	.9993	.9996	.9998
6	30	.9299	.9816	.99387	.9976	.9990	.9995	.9998	.9999	.9999
8	5	.5098	.6574	.7439	.804	.8421	.8723	.8953	.9132	.9274
8	10	.7468	.8731	.9275	.9556	.9715	.9811	.9871	.9910	.9936
8	15	.8625	.9493	.9774	.9889	.9941	.9967	.9981	.9989	.9993
8	20	.9216	.9781	.9923	.9969	.9986	.9994	.9997	.9998	.9999
8	25	.9532	.9900	.9971	.9990	.9996	.9999	.9999	1.0000	1.0000
8	30	.9711	.9951	.9989	.9997	.9999	1.0000	1.0000	1.0000	1.0000
10	5	.5898	.7378	.8178	.8674	.9005	.9237	.9405	.9529	.9623
10	10	.8204	.9242	.9624	.9796	.9883	.9930	.9956	.9972	.9982
10	15	.9163	.9759	.9912	.9964	.9984	.9992	.9996	.9998	.9999
10	20	.9585	.9916	.9977	.9993	.9997	.9999	1.0000	1.0000	1.0000
10	25	.9783	.9968	.9993	.9998	1.0000	1.0000	1.0000	1.0000	1.0000
10	30	.9881	.9987	.9998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
12	5	.6568	.7994	.8704	.9915	.9373	.9544	.9661	.9744	.9804
12	10	.8726	.9548	.9805	.9906	.9952	.9974	.9985	.9991	.9995

DATE: 1996-07-05

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.23: PRECIPITATION EFFICIENCY FACTORS -
TEMPERATURE CYCLING SCREENS (Cont'd)**

NUMBER OF CYCLES	TEMP. RATE OF CHANGE °C / MIN	TEMPERATURE DELTA (ΔT) - °C								
		20	40	60	80	100	120	140	160	180
12	15	.9490	.9886	.9966	.9988	.9996	.9998	.9999	1.0000	1.0000
12	20	.9780	.9968	.9993	.9998	.9999	1.0000	1.0000	1.0000	1.0000
12	25	.9899	.9990	.9998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
12	30	.9951	.9997	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	5	.7128	.8465	.9078	.9409	.9605	.9727	.9807	.9861	.9898
14	10	.9096	.9730	.9899	.9957	.9980	.9990	.9995	.9997	.9999
14	15	.9690	.9946	.9987	.9996	.9999	1.0000	1.0000	1.0000	1.0000
14	20	.9884	.9988	.9998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	25	.9953	.9997	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	30	.9980	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
16	5	.7597	.8826	.9344	.9605	.9751	.9837	.9890	.9925	.9947
16	10	.9359	.9839	.9947	.9980	.9992	.9996	.9998	.9999	1.0000
16	15	.9811	.9974	.9995	.9999	1.0000	1.0000	1.0000	1.0000	1.0000
16	20	.9938	.9995	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
16	25	.9978	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
16	30	.9992	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
18	5	.7989	.9102	.9533	.9737	.9843	.9903	.9938	.9959	.9973
18	10	.9545	.9904	.9973	.9991	.9997	.9999	.9999	1.0000	1.0000
18	15	.9885	.9988	.9998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
18	20	.9967	.9998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
18	25	.9990	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
18	30	.9997	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.23: PRECIPITATION EFFICIENCY FACTORS -
TEMPERATURE CYCLING SCREENS (Cont'd)**

NUMBER OF CYCLES	TEMP. RATE OF CHANGE °C / MIN	TEMPERATURE DELTA (ΔT) - °C								
		20	40	60	80	100	120	140	160	180
20	5	.8317	.9313	.9668	.9824	.9901	.9942	.9965	.9978	.9986
20	10	.9678	.9943	.9986	.9996	.9999	1.0000	1.0000	1.0000	1.0000
20	15	.9930	.9994	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	20	.9983	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	25	.9995	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	30	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
22	5	.8592	.9474	.9764	.9883	.9938	.9965	.9980	.9988	.9993
22	10	.9771	.9966	.9993	.9998	.9999	1.0000	1.0000	1.0000	1.0000
22	15	.9957	.9997	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
22	20	.9991	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
22	25	.9998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
22	30	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	5	.8822	.9598	.9832	.9922	.9961	.9979	.9989	.9993	.9996
24	10	.9838	.9980	.9996	.9999	1.0000	1.0000	1.0000	1.0000	1.0000
24	15	.9974	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	20	.9995	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	25	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
26	5	.9014	.9692	.9880	.9948	.9975	.9988	.9993	.9996	.9998
26	10	.9885	.9988	.9998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
26	15	.9984	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
26	20	.9997	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
26	25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***TABLE 16.23: PRECIPITATION EFFICIENCY FACTORS -
TEMPERATURE CYCLING SCREENS (Cont'd)**

NUMBER OF CYCLES	TEMP. RATE OF CHANGE °C / MIN	TEMPERATURE DELTA (ΔT) - °C								
		20	40	60	80	100	120	140	160	180
26	30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
28	5	.9175	.9765	.9915	.9965	.9954	.9993	.9996	.9998	.9999
28	10	.9918	.9993	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
28	15	.9990	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
28	20	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
28	25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
28	30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	5	.9310	.9820	.9939	.9977	.9990	.9996	.9998	.9999	.9999
30	10	.9942	.9996	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	15	.9994	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	20	.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

**16.5.1.4 Procedure D - Refining Estimates of Defect Density and
Screening Strength****16.5.1.4.1 Objective**

To refine the estimates of ESS modeling parameters (D_{IN} , SS, $D_{REMAINING}$, etc.) using actual factory and field data.

16.5.1.4.2 Methodology

The most important parameter for ESS is the **defects remaining** at the time of shipment since this determines the **field reliability**. Other significant parameters are the initial defect density, and the screening strength of various screens.

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The difficulty, however, is that none of these parameters are directly observable by the producer. Only the defects removed through factory ESS can be measured.

This procedure provides the means for determining these other critical parameters from the factory data.

16.5.1.4.3 Procedure Steps

• Step 1

Collect the necessary factory (test and failure) data from a FRACAS system. When assembling this data it is imperative to distinguish between errors and defects. Errors are preventable and usually detectable without environment stress.

The primary concern of this procedure is the elimination of latent defects.

The minimum data requirements for the **FRACAS** system are:

- (1) ESS Test Equipment
- (2) Stress Duration - times at start of test, completion of test, and time of failure
- (3) Test Type
- (4) Number of units tested - number that pass/fail
- (5) Assembly-Sub Assembly-part failed
- (6) Failure Cause
- (7) Details of the ESS process
- (8) History of environment leading to failure

Collect the **fallout data** for each type of environment (i.e., temperature cycling, random vibration etc.) separately and **prepare graphs** with the cumulative defects, normalized as defects per system as the **ordinate**, and the stress duration as the **abscissa**.

• Step 2 Determination Of D_{IN} , PE, SS, and $D_{REMAINING}$

The method of determining D_{IN} , PE, SS, and $D_{REMAINING}$ is either through use of a computerized or hand curve fitting technique depending on available resources. Step 2a describes the computerized approach and step 2b the hand approach.

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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This method is preferred as it will yield more accurate results. An automated least squares error multiple regression, maximum likelihood or other estimation tool is required. Several **computerized methods** and **software tools** are available (i.e., SAS).

Curve fit the factory fallout data (determined in step1) and field data to the following expression:

$$D_{\text{REMOVED}} = DE \{D_{\text{PAT}} + D_{\text{LAT}} [1 - \exp(-kt)] + \text{CFR} \times t\}$$

Set up the curve fitting technique to extract values of D_{PAT} , D_{LAT} , k , and CFR . Figure 16.10 illustrates a sample curve fitting analysis. The derivation of the expression for D is discussed in Appendix A and Rome Laboratory technical report RL-TR-91-300 and has been found to be adequately representative of the real world.

Proceed to Step 3 to determine values of D_{IN} , PE , SS , and $D_{\text{REMAINING}}$.

• Step 2b Hand Curve Fitting Approach

In general, the user will see an exponentially distributed plot similar to that shown in Figure 16.11.

From the plot, the user can derive rough approximations of D_{PAT} , D_{LAT} , k , and CFR as follows. It is first necessary to divide the curve into two areas as illustrated in Figure 16.12.

Estimation of D_{PAT}

D_{PAT} is estimated from the “y” intercept extrapolated from the plot.

Estimation of CFR

CFR is approximately equal to the slope of the straight line region of the plot.

Estimation of D_{LAT} and k

Background: The curved region of the plot can be represented as:

$$D_{\text{REMOVED}} = D_{\text{LAT}} [1 - \exp(-kt)]$$

The first derivative of this expression yields $kD_{\text{LAT}} e^{-kt}$. To estimate D_{LAT} and k it is necessary to plot values of the slope between points on the original plot (that plotted in step 1 above).

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The values are to be plotted on **semilog paper**. Taking the natural log of the above expression yields $\ln(kD_{LAT}) - kt$. This can be approximated as a straight line on semilog paper,

where

k is approximately equal to the negative value of the slope

kD_{LAT} is approximately equal to the “y” intercept

The **following steps** walk through the method to estimate D_{LAT} :

- (1) On semilog paper **plot** values of the slope of each line formed by consecutive points of the original plot as the ordinate and time as the abscissa. See Figure 16.8.
- (2) **Determine** the “**best fit**” **straight line** through the plotted points.
- (3) From this line **calculate** the slope. The estimated stress constant k is equal to the value of (-slope).
- (4) The “y” intercept is equal to kD_{LAT} . Determine D_{LAT} as $D_{LAT} = y / k$

• Step 3 Determination of D_{IN} , PE, SS, and $D_{REMAINING}$.

Determination of D_{IN} :

D_{IN} is simply calculated as:

$$D_{IN} = D_{LAT} + D_{LAT}$$

where

D_{PAT} and D_{LAT} are those values found in Step 2a or 2b as appropriate.

Determination of PE and SS:

Recalling Procedure C, screening strength is the product of precipitation efficiency (PE) and detection efficiency (DE). Curve fitting the factory fallout data yields the “k” value (stress constant). PE is calculated as

$$PE = 1 - e^{-kt}$$

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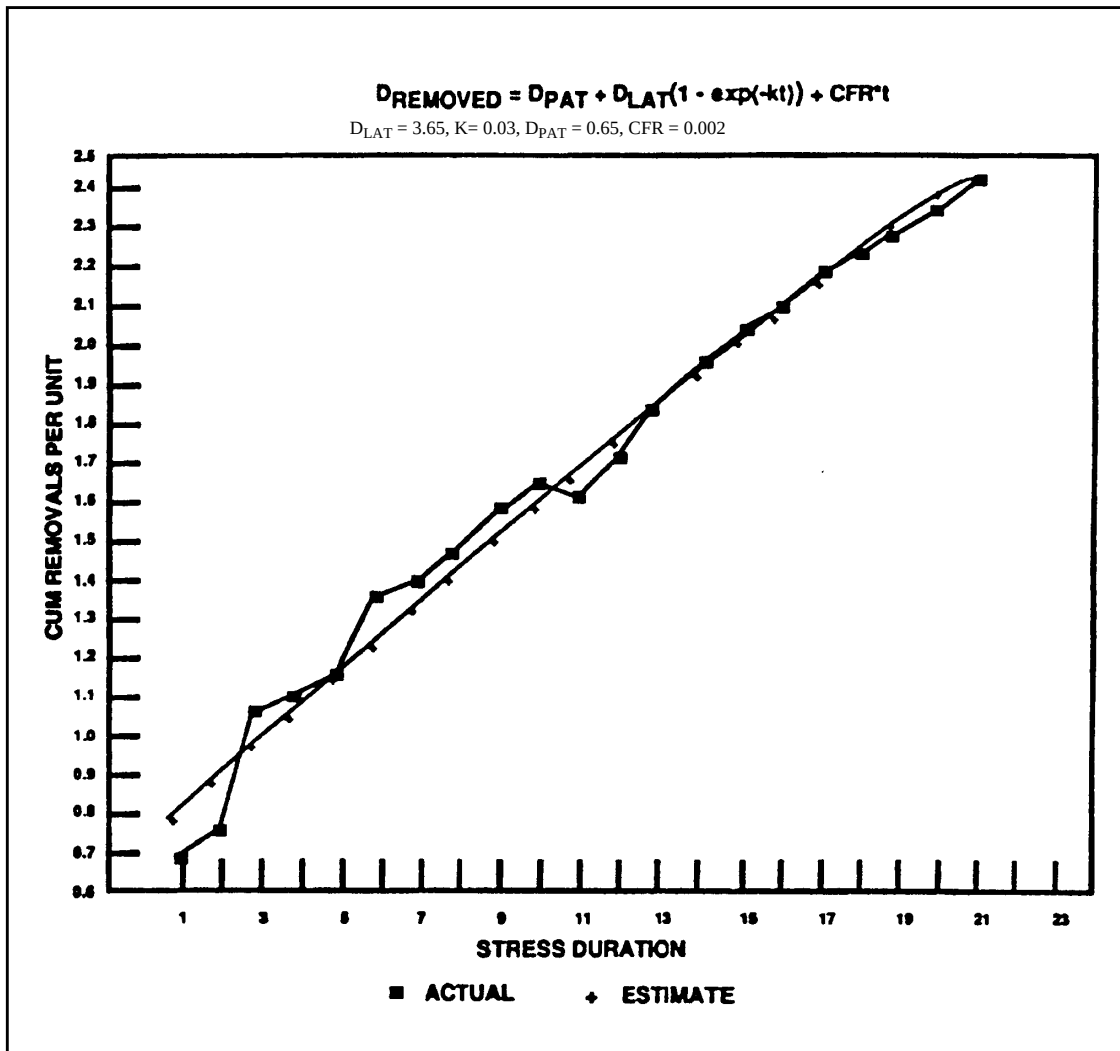


FIGURE 16.10: SAMPLE CURVE FITTING ANALYSIS

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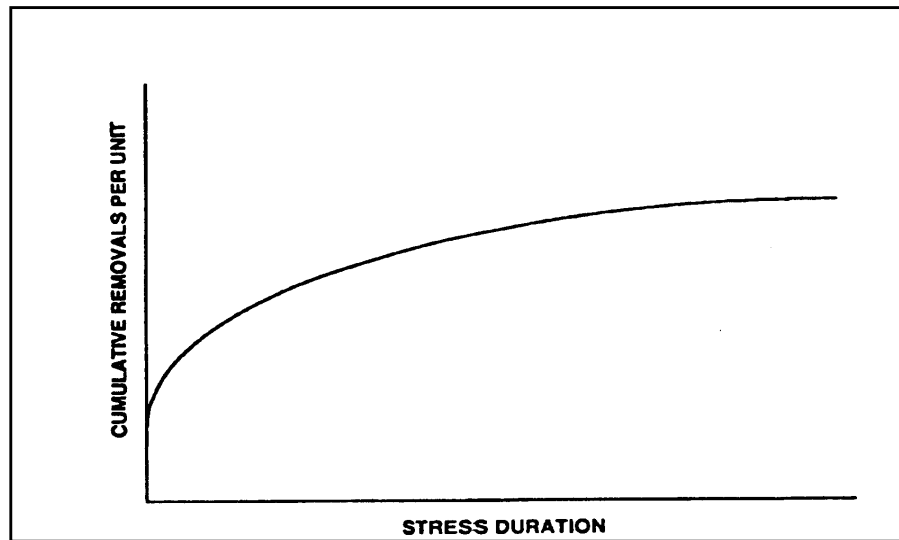


**FIGURE 16.11: EXPECTED FORM OF HAND
PLOTTED DEFECT DISTRIBUTION**

If field data is available, the detection efficiency of factory ESS can be determined as follows:

$$DE \text{ (factory)} = \frac{D_{PAT}(\text{field})}{\text{Factory Fallout}}$$

where

D_{PAT} is determined in Step 2a or 2b above.

SS is then calculated as:

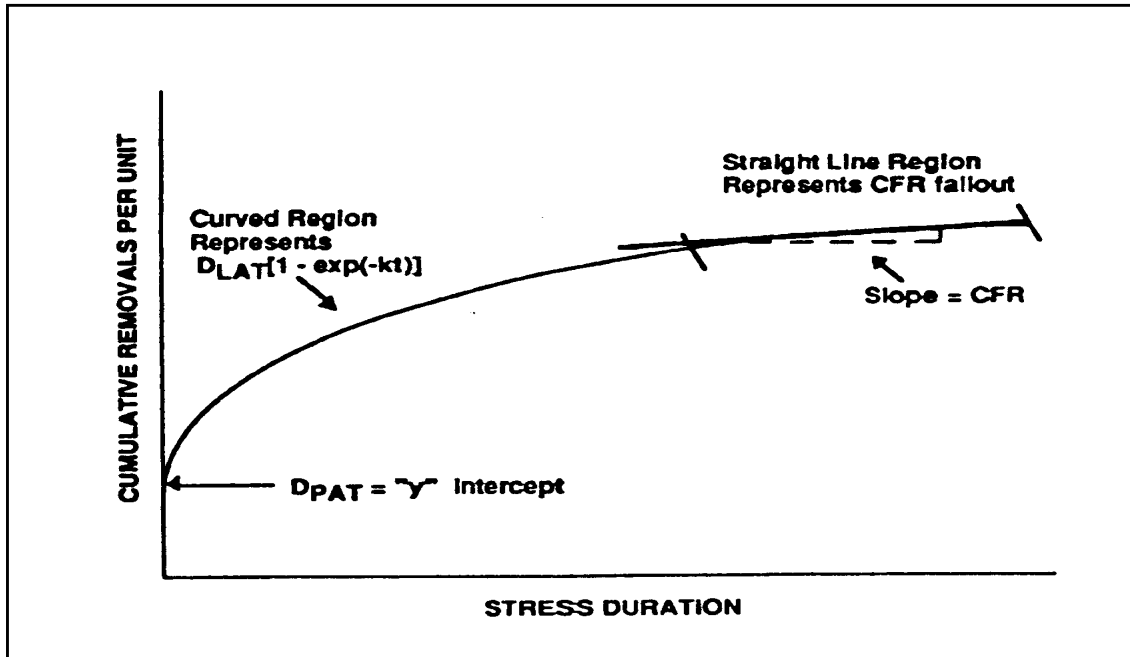
$$SS = PE \times DE$$

Note: If field data isn't available assume $DE = 1$.

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**FIGURE 16.12: BREAKDOWN OF DEFECT DISTRIBUTION CURVE****Determination of $D_{\text{REMAINING}}$:**

$D_{\text{REMAINING}}$ is simply calculated as:

$$D_{\text{REMAINING}} = D_{\text{IN}} - D_{\text{REMAINING}}$$

where

D_{IN} is found in the first part of Step 3

$D_{\text{REMAINING}}$ is determined through fallout observation

Determination of Stress Adjustment Factor (SAF):

If field data is available the SAF can be determined as:

$$\text{SAF} = \frac{D_{\text{LAT}}(\text{field})}{[D_{\text{LAT}}(\text{factory}) \cdot (1 - \text{SS}(\text{factory}))]}$$

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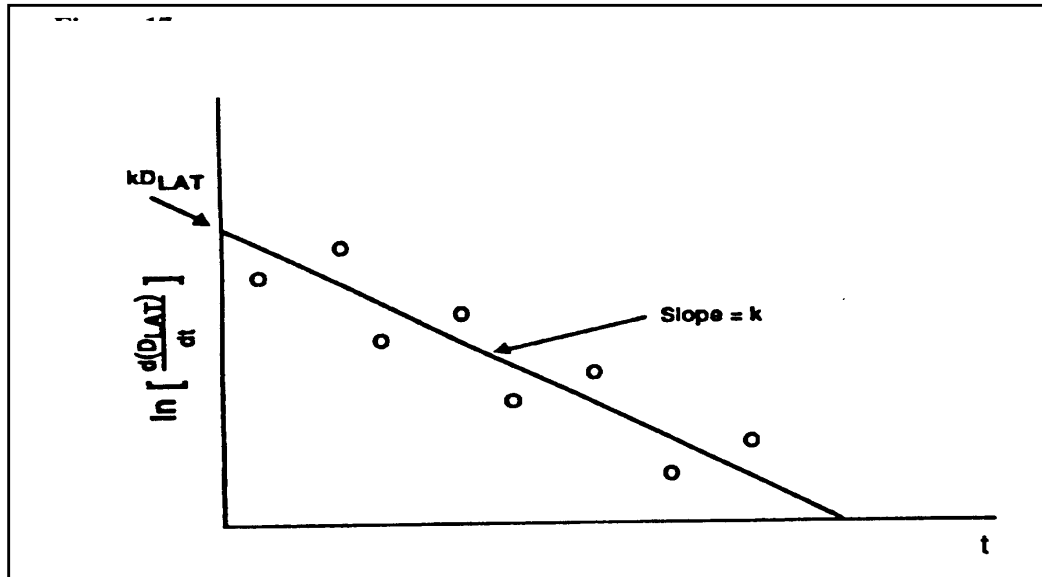


**FIGURE 16.13: GRAPH FOR ESTIMATING LATENT DEFECTS
(DLAT)**

16.5.1.5 Procedure E - Monitor and Control**16.5.1.5.1 Objective**

To implement a program to monitor and control the ESS program (consistent with TQM philosophy) thereby ensuring that the program remains cost effective under the evolving conditions.

16.5.1.5.2 Methodology

The parameters of interest for monitor and control (D_{IN} , SS , $D_{REMAINING}$, etc.) are determined in Procedure D.

Modified SPC and PARETO charts are prepared to monitor these parameters against the requirements established in Procedure A.

Details of SPC methods are not covered in this document. See a sample SPC chart in Figure 16.14.

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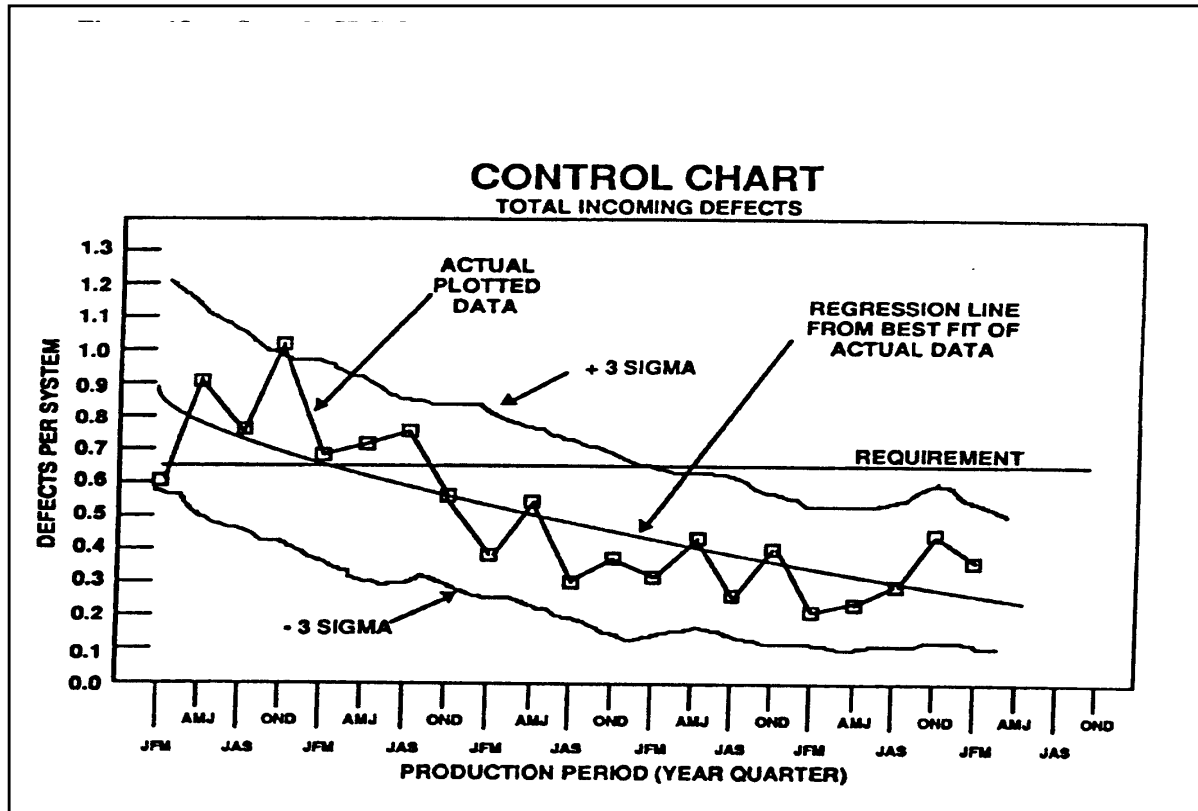


FIGURE 16.14: SAMPLE SPC CHART (FOR DEFECTS)

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APPENDIX A

STRESS SCREENING MATHEMATICAL MODEL

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 16***16.6 APPENDIX A: STRESS SCREENING MATHEMATICAL MODEL****16.6.1 General**

The fundamental **objective** of a stress screening program is to reduce the **number of latent defects** in a production lot of equipment to an acceptable level by use of cost effective screening regimens.

As **basic principles**, one would like to be able to use strong screens and efficient tests, within prescribed cost constraints, which have a high probability of precipitating and detecting defects and thus achieving reliability objectives.

To transform these principles into quantitative procedures, it is necessary to define various measures and their relationships to the screening process.

This appendix defines a mathematical model that predicts/establishes relationships between quantities such as defect density, precipitation efficiency, detection efficiency, screening strength, and yield.

16.6.2 General Mathematical Models / Relations

Not included in this document; available upon request.

1996-07-05

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Chapter 17

WORST CASE ANALYSIS

1996-07-05

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17 WORST CASE ANALYSIS

17.1 INTRODUCTION

The **purpose** of this task is to examine the effects of parts/circuits electrical tolerances and parasitic parameters over the range of specified operating requirements.

17.1.1 Scope

Normal scope of Worst Circuit Case Analysis (WCCA) is;

(1) Primary Considerations

Analysis of electronic circuits for performance margin using extreme values of parameter variation.

Analysis of parts for proper application and worst case stresses vs. derating requirements.

(2) Secondary Considerations

Testability; Test tolerances and BIT requirements.

Mechanical assembly and packaging; Shielding, noise, EMI. Ground loops. Temperature control.

Worst Case Analysis (WCA) assures early development of parts parameter data base as a program oriented task.

WCA should be an **integral** part of the **design process**, including the test program to verify worst case performance, and circuit simulations.

WCCA should be performed in conjunction with, and in support of, the;

- (1) Part selection process
- (2) Thermal analysis
- (3) Failure Mode and Effects Analysis (FMEA)

A formal WCCA plan shall be developed, which documents environments, interfaces, mission profile, critical attributes, analysis approach, etc.

Plan shall be **approved** by seller management and/or buyer (DHI).

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17.2 APPLICABLE DOCUMENTS

17.2.1 de Havilland Inc. Documents

EPS 1-18 R&M Specification Requirements

17.2.2 Government Documents

MIL-STD-785 B Task 20
Reliability Program for Systems, and Equipment
Development and Production

17.3 ACRONYMS AND ABBREVIATIONS

ABM	Advanced Bill of Materials
CAE	Computer Aided Engineering
DTRD	De Havilland Technical Requirements Document
ECN	Engineering Change Notice
EVA	Extreme Value Analysis
M.C.	Monte Carlo
MIN	Minimum
MAX	Maximum
NOM	Nominal
PDR	Preliminary Design Review
P.D.F.	Probability Density Function
RSS	Root Sum Square
SOW	Statement Of Work
U/L	Upper Limit
W.C.	Worst Case
W.C.A	Worst Case Analysis
W.C.C.A	Worst Case Circuit Analysis

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17.4 WCCA APPROACH

17.4.1 General Approach

The **general** approach to WCCA:

- (1) **Breakdown** total circuit into simple functional blocks
- (2) The **WCCA** will then be **performed** on each critical block.

17.4.2 Detailed Approach

- (1) **Document** detailed description of each block under analysis and usage of each part within:
- (2) **Establish** worst case minimum and maximum (extreme values) for each part
- (3) **Establish** performance requirements and attributes for each block and show how all blocks play together to meet the overall unit requirements in the worst case
- (4) **Perform** critical application review and worst case stress analysis for each part
- (5) **Develop** circuit models and equations for each block

17.5 INFORMATION NEEDED FOR WCCA

- (1) Performance specification
- (2) Schematics and block diagrams
- (3) Interconnection lists and wiring diagrams
- (4) Parts list
- (5) Theory of operation
- (6) Mission profile-life, environments, modes
- (7) Part parameter data base
- (8) Part specification and application notes
- (9) Program part derating requirements

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17.6 APPLICATION

17.6.1 Definition

- (1) Worst Case Circuit Analysis is the **evaluation** of circuits for tolerance to "Drift".

A rigorous evaluation of a circuit's performance attributes against performance tolerance limits, with all the most unfavorable conditions being at realizable limits simultaneously:

- a) Part parameter variations
- b) Environmental Extremes (temperature, etc.)
- c) Input power
- d) Input stimuli
- e) Load variations
- f) Interface (I/F) interference

- (2) Worst Case Circuit Analysis is also the **evaluation** of parts for:

- a) Improper applications
- b) Over stresses in worst case conditions

17.6.2 Critical Circuitry

Parts / circuits worst case analysis (WCA) shall be conducted on **critical circuitry** as defined in the contractor preliminary analysis results.

17.6.3 Critical Factors

These analyses **shall verify** that, given reasonable combinations of within specification characteristics and parts tolerance build-up, the circuitry being analyzed will perform within specification performance.

In making these analyses the contractor shall examine the effect of component parasitic parameters, input signal and power tolerances, and impedance tolerances on electrical parameters, both at circuit nodes (component interconnections) and at input and output points.

Since all of the stated factors may not be significant to all circuits, only the **critical factors** for that circuit shall be considered.

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17.6.4 Circuit Node Parameters

Maximum variations in input signal or power supply voltage, frequency, bandwidth, impedance, phase etc., shall be used in the analyses.

Circuit node parameters (including voltage, current, phase, and waveform), circuit elements rise time, timing of sequential events, circuit power dissipation, and circuit load impedance matching under worst case conditions shall also be considered.

These parameters shall be analyzed for their effect on the performance of circuit components.

17.6.5 Critical Functions / Circuits

A list of those **critical functions/circuits** to be analyzed shall be presented at PDR. The most unfavorable combination of realizable conditions to be considered in the parts/circuits worst case analysis shall be defined for approval by the procuring activity (i.e., DHI).

17.6.6 Performance / Reliability

Because of within specification **part tolerance build-up**, an output from a circuit, subassembly, or equipment may be outside spec values and therefore unacceptable. In such cases, **fault isolation** will not identify any part as failed or input as unacceptable.

To preclude the existence of these conditions, a part/circuits WCA is conducted. This analysis has proven cost effective in identifying equipment **performance/reliability** problem areas so that they can be corrected prior to production.

17.6.7 Component Value Variations

The **analysis considers** expected component value variations due to manufacturing variances (purchased tolerances), drift with time (life-drift), and temperature. Some of the characteristics examined are relay opening and closing times, transistor gain, resistance, inductance, capacitance, and component parasitic parameters.

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Maximum within spec input signal or power voltage, phase, frequency, and bandwidth, impedance of both signal and load should also be considered. Circuit mode parameters, such as voltage, current, phase, and waveform, can be analyzed for their effect on circuit component performance.

Finally, under worst case conditions, the timing of sequential events, circuit load impedance, power dissipation and element rise time shall be considered.

17.6.8 Other Design Analyses

The **worst case analysis is performed** in conjunction with other design analyses including:

- (1) Part selection to satisfy program requirements
- (2) Thermal analysis
- (3) Part stress derating to satisfy program requirements.

17.6.9 Analysis Procedure

The **analysis procedure**, in brief, requires a preliminary design using the components selected from the preferred / approved Parts List, circuit design simulation schematics, computer analysis, comparison with the statistical or absolute worst case performance, and stress budget, breadboard test and verification of the simulation model, system integration, and documentation of the results and the WCA.

17.7 GENERAL GUIDELINES

The **guidelines** contained in this document are primarily oriented towards how to accomplish the worst case analysis with the understanding that the results interact with the other design analyses.

The total **circuit** shall be **broken down** into functional blocks and analyzed by blocks.

This allows the analysis to assume a more manageable size for both analysis and review.

The **initial step** is the derivation of **performance requirements** for each block to develop an appropriate criterion for the subsequent analysis. The defining document must be referred to or included in the worst case analysis report.

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If any design changes should occur after the WCA has been completed, it is necessary to update the analysis to include the effects of the design modification. Please see **Appendix B** for WCA Guidelines Review **Check List**.

17.7.1 Parameters

Parameters to be considered in the performance analysis of a given circuit include the **variability** of the **part parameters** as well as the variability in the circuit inputs, loads, and supply voltages.

17.7.1.1 Part Parameters

The part parameter variability can be divided into 4 categories;

17.7.1.1.1 Initial Tolerances

A five percent resistor, for example, must be considered as being either a plus or a minus five percent value for worst case purposes. See Figure 17.1.

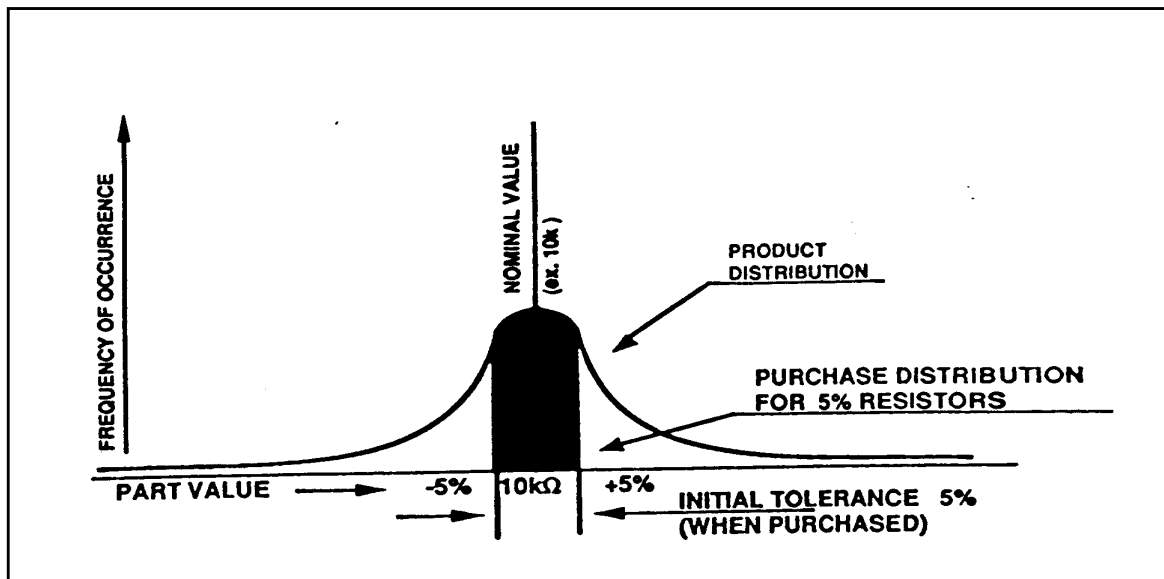


FIGURE 17.1: INITIAL TOLERANCE OF PARTS (SAMPLE)

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17.7.1.1.2 Environmental Factors

In general this is accounted for by temperature change and radiation absorption. The range of the actual environments for the specific unit should be used. If the qualification test requirements are -20°C to +60°C the temperature extremes for parts within the unit should include the effects of localized heating and where necessary take into account the junction temperatures.

Although radiation is technically an environmental factor it is convenient to consider its effect as a separate item.

17.7.1.1.3 Time or End of Life Factors

The aging effects on part parameters due to extended mission requirements.

17.7.1.1.4 Radiation Factors

The total radiation dose at the part level is specified, i.e., as 1×10^5 RADS. The degradation to part performance parameters arising from exposure to this dosage is specified in the Programs Parts List. If this degradation is unacceptable in the circuit, additional shielding must be considered either in the unit enclosure or at the part level.

17.8 WCA DOCUMENTATION GENERAL REQUIREMENTS

17.8.1 Format

The **analysis** shall follow a uniform format, which is outlined below; This is to facilitate Buyer (i.e., DHI) review and understanding of the formal deliverable item for WCA.

- (1) Assembly functional **description**
- (2) **Partitioning** of assembly into functional modules
- (3) Module and functional specifications, **performance characteristics**
- (4) **Summary** of results (tables, comparison analysis versus specifications)
- (5) **Definition** of configuration to be analyzed (circuit schematic, ECN status, revision letter)

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-
- (6) **Parameters** to be analyzed and method of analysis for each functional block (closed loop, gain, response, timing, sensitivity)
Numerical approach to WCA (i.e., Extreme Value Analysis - (EVA), Root-Sum-Squared Analysis - (RSS), Monte Carlo Analysis)
 - (7) Details of analysis and results, supporting mathematics/computer analysis
 - (8) Non-compliances
 - (9) Supporting standards and specifications
 - (10) Piece part data base

17.8.2 Formal Document

The **final** WCA report shall be "The document" which substantiates the baseline design. For an acceptable sample format for the report see Table 17.1.

17.8.2.1 Guidelines For Generating The Final Report

- (1) A good **summary** up-front is important:
 - a) It allows management to see the "Bottom Line" immediately
 - b) Should be clear and concise
 - c) Highlight all problem areas
 - d) Show requirements versus results
 - e) State necessity for change (i.e., mandatory, desirable)
 - f) State recommendations for fixes
 - g) Refer to section/page in analysis for details
 - h) If problems are numerous, use a matrix format
- (2) **Develop** a consistent format for the "Detailed Analysis" section:
 - a) **Redraw** circuit, isolated from system
 - b) **Describe** circuit function and usage of each part
 - c) Show circuit interface parameters
 - d) Show circuit parts list and worst case system values

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- e) Define **critical** attributes of circuit
- f) Perform part application critique and worst case stress
- g) Perform circuit analysis for each critical attribute

See a sample WCA preparation worksheet, Table 17.2.

TABLE 17.1: A SAMPLE FORMAT FOR THE FINAL REPORT

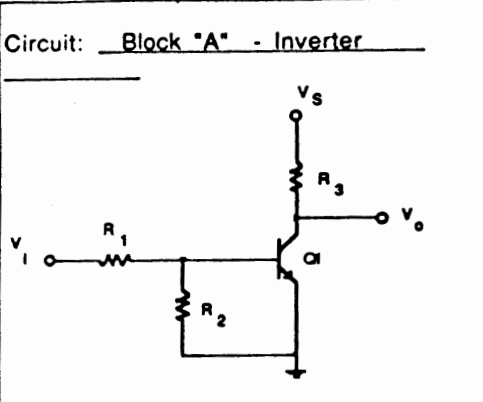
SECTION	TABLE OF CONTENTS	PAGE
1.0	INTRODUCTION	
2.0	APPLICABLE DOCUMENTS	
3.0	SUMMA	
4.0	GROUND RULES & ASSUMPTIONS	
	- MISSION	
	- ENVIRONMENTS	
5.0	SYSTEM DESCRIPTION	
6.0	DETAILED ANALYSIS	
	6.1. BLOCK "A"	
	6.1. BLOCK "B"	
	6.1. BLOCK "A"	
7.0	CONCLUSIONS/RECOMMENDATIONS /RESOLUTION OF PROBLEMS	
	APPENDICES	
A	- PARTS DATA BASE SHEETS	
B	- COMPUTER PROGRAMS	
TABLE NO.	LIST OF TABLES	
1		
2		
FIGURE NO.	LIST OF ILLUSTRATIONS	
1		
2		

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TABLE 17.2: SAMPLE WCA PREPARATION WORKSHEET

DIAGRAM	SUBSYSTEM NETWORK	REV	DATE																																						
Circuit: <u>Block "A" - Inverter</u> 		<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th rowspan="2">CIRCUIT</th> <th rowspan="2">PART DESCRIPTION & VALUE</th> <th colspan="2">EXT. VALUE</th> </tr> <tr> <th>MIN</th> <th>MAX</th> </tr> </thead> <tbody> <tr> <td>R1</td> <td>RESISTOR, RC05, 5.1KΩ</td> <td>4.18k</td> <td>5.79k</td> </tr> <tr><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td></tr> </tbody> </table>		CIRCUIT	PART DESCRIPTION & VALUE	EXT. VALUE		MIN	MAX	R1	RESISTOR, RC05, 5.1KΩ	4.18k	5.79k																												
CIRCUIT	PART DESCRIPTION & VALUE	EXT. VALUE																																							
		MIN	MAX																																						
R1	RESISTOR, RC05, 5.1KΩ	4.18k	5.79k																																						
SCHEMATIC		PARTS LIST																																							
CIRCUIT DESCRIPTION: _____																																									

INTERFACE AND ENVIRONMENTAL PARAMETERS																																									
	MIN	MAX	INPUT	OUTPUT	INPUT	OUTPUT																																			
POWER SUPPLY VOLTAGE			SIGNAL VOLTAGE		FREQUENCY																																				
POWER SUPPLY CURRENT			SIGNAL CURRENT		PULSE DURATION																																				
TEMPERATURE RANGE			RESISTANCE		RISE TIME																																				
PROPAGATION TIME			CAPACITANCE		FALL TIME																																				
RADIATION			INDUCTANCE																																						
REQUIRED ATTRIBUTES:																																									
1. _____																																									

2. _____																																									

3. _____																																									

4. _____																																									

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- (3) Analysis must be verifiable and justifiable:
 - a) **List** all applicable documents used to aid the analysis, dates and revision numbers:
 - Part parameter data base
 - Thermal analysis reports
 - All applicable specifications
 - Program Worst Case derating requirements
 - Test reports
 - Memos, etc.
 - b) **Justify and describe** all software and computer programs used and associated semiconductor models; use appendices for including this material
 - c) **Show** details of equations; use footnotes when using equations from textbooks
 - d) State and justify all assumptions
- (4) Analysis must be readable and understandable from a reviewer's viewpoint:
 - a) **Report** should include schematics, functional block diagrams, general theory of operation and descriptive write-ups of detailed operation for all levels (i.e., box, blocks, circuits).
 - b) **Generate** sufficient narrative material throughout the analysis section describing what it is to be proved.
 - c) **Explain** equations and models as appropriate to permit the reviewer to follow and understand the analysis.
 - d) **Plan and outline** each analysis; all work being generated should be filling in a section of the report.
 - e) **Resolve** "Fails to meet" items as they are encountered so that the final report reflects a design which meets all of its requirements under worst case conditions.

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The design will usually undergo some changes while the WCA in progress. Try to plan accordingly. Check part reference designators (circuit symbols, R1, Q4, etc.) in final report. Final report should have the latest of everything (schematics, etc.).

17.9 GENERAL WCA REQUIREMENTS

17.9.1 Definition

Analysis of circuit performance under the worst predictable combination of component parameter tolerances at the worst predictable temperatures, considering long-term parameters such as drift, stability of settings on potentiometers, etc.

17.9.2 Minimum Requirements

WCA as a minimum shall include

(1) **An introduction** containing:

- a) **A listing** of worst case **combinations** of temperatures, applied voltages (power and signal per applicable engineering specification), and loads
- b) **A listing** of ground rules for End-of-life parameter degradation factors for determination of component parameter tolerance standard deviations, and parameter changes versus voltage, temperature, and time
- c) **A brief description** of the **method** used to combine parameter deviations and worst case temperatures/voltages
- d) **A listing** of the functional parameters which will be analyzed
- e) An Advanced Bill of Materials (**ABM**)
- f) A complete **schematic** of the exact configuration analyzed

(2) **A functional analysis** section in which:

- a) Functions shall be individually listed and shall be graphically represented, to include the components involved. Full or partial copies of the schematics are acceptable.

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- b) A **worst case analysis** using either absolute parameter limits or local statistical parameter combinations to arrive at the 3 sigma limits for functional performance. Justification must be given for parameter combinations that are not readily obvious.
 - c) For functional analysis, simultaneous worst case temperatures and applied voltage shall be assumed.
 - d) **Worst case variations** for all function outputs and transfer functions shall be summarized or listed or otherwise high lighted, and compared to the limits specified in the assembly specification.
- (3) A detailed individual component worst case section in which:

Note: this section may be combined with the functional analysis section.

- a) All components for which no specific worst case analysis is performed, because they are not critical, shall be listed. During the course of the analysis, unless the reasons are obvious, the analysis shall provide a rational for not analyzing these components.
- b) All components included in the worst case analysis shall be highlighted.
- c) Components in circuit worst case analysis shall be grouped or indexed in a logical manner to facilitate retrieval of information.
- d) **Absolute worst case** for all applicable parameters shall be used to determine if a component rating is exceeded.

17.9.3 Computer Aided Worst Case Analysis

Computer Aided Engineering (CAE) analysis may be performed on a variety of work-stations, using a number of software packages.

17.9.3.1 Digital Analysis

- (1) **DAISY:** Simulation, Timing verification.

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- (2) **VAX:** Some vendor supplied software is used on VAX or other host to perform simulation and/or worst case timing verification.
 - (3) **PC:** Timing calculations using Spreadsheets such as Lotus 1-2-3 or Excel simply implement the manual calculations of time delays (series worst case). Such calculations are acceptable, providing that the cell content and algorithm is disclosed.

17.9.3.2 Analog Analysis

- (1) **ADT:** Those stations implement Spice and are acceptable, provided the component models used are validated.
- (2) **VAX:** Use of the current versions of Spice is acceptable, provided the component models used are validated.
- (3) **PC:** Same comments as above.

17.10 NUMERICAL METHODS / APPROACHES

17.10.1 Methods

Two methods are usually used:

- (1) **Deterministic Method:** Extreme Value Analysis (EVA)
- (2) **Probabilistic Methods:**
 - a) Root-Sum-Square (RSS)
 - b) Monte Carlo

17.10.1.1 Extreme Value Analysis (EVA)

This is absolute worst case analysis, deterministic method, and it is the primary approach/method for WCA.

- (1) Worst case limits used for piece parts (maximum or minimum, depending on directional sensitivity)
- (2) Results are worst case limits for circuit parameter under analysis (pass/fail)
- (3) Results are very conservative highly unlikely that all parts will be at worst case limits simultaneously
- (4) Easiest method to apply

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17.10.1.2 Root-Sum-Square (RSS) Analysis

- (1) Random and bias portions of piece part tolerances are treated separately
- (2) Results are bias and standard deviation of circuit parameter under analysis
- (3) **Allows probability** of meeting requirement to be estimated (manufacturing yield)
- (4) Assumes variables are normally distributed (Gaussian)
- (5) Results are more optimistic than EVA approach

17.10.1.3 Monte Carlo (MC) Analysis

- (1) Uses **actual** part tolerance distributions, if known
- (2) Result is histogram of probable values for circuit parameter under analysis
- (3) Allows probability of meeting requirement to be estimated (manufacturing yield)
- (4) Requires knowledge of piece part tolerance distributions
- (5) Most accurate if distributions are known
- (6) Requires use of computer

17.10.2 Recommended Approach / Method

17.10.2.1 Perform Extreme Value Analysis (EVA)

- (1) If requirements are met:
 - a) **High confidence** that design has margin against drift
 - b) **The analysis is finished.** As circuit passes the Worst Case Analysis, EVA method, it will never fail as long as the input parameters are maintained within the tolerance limits established by the analysis.
- (2) If requirements are **not met, examine:**
 - a) Magnitude of margin

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- b) Status of hardware (fielded system?)
 - c) Probability that requirements will not be met, (apply RSS or Monte Carlo if necessary)

17.10.2.2 Make Management Decision (Buyer and Seller)

When the design/circuit under WCA fails to meet requirements, the available options are:

(1) Small Negative Margin

Normally solvable via analyst, design engineer, and parts engineer, with minor changes.

- a) Part type, part value, or part rating changes
- b) Screen parts to tighter tolerances
- c) Minor impact circuit redesign
- d) Use select-at-test parts or trim circuit

(2) Moderate Negative Margin

Normally solvable at next immediate level of management, with penalty of more time and money spent.

- a) If analysis performed via EVA, try RSS or Monte Carlo
- b) Re-evaluate problem items versus extremes of worst case scenario. Application may be less severe, data base may be too pessimistic

(3) Large Negative Margin

Normally requires management decisions and/or customer negotiations.

- a) **Major redesign.** Evaluate cost and schedule impact
- b) **Fly with present design.** Establish what is an acceptable risk
- c) 100% screening of production units to "beginning of life" (BOL) limits for "box" performance attributes
- d) Relax "box" performance specification. Negotiate with customers/buyers, requirements may be unattainable

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- e) Forcing functions for decisions:
 - i) **Criticality to mission:**
 - Catastrophic
 - Major
 - Minor
 - Negligible
 - ii) **Criticality to program:**
 - Effectiveness of corrective action
 - Timeliness of corrective action
 - Cost of corrective action
 - iii) **Probability of occurrence:**
 - Very high
 - Moderate
 - Negligible

17.10.3 General Worst Case Circuit Analysis Methodology

Basic methodology flow of WCA is the same for each approach. The details of execution differ in how we handle the numerics of variables and the form of the part parameter data, see the chart in Table 17.2.

17.10.4 Worst Case Analysis (WCA) Methods

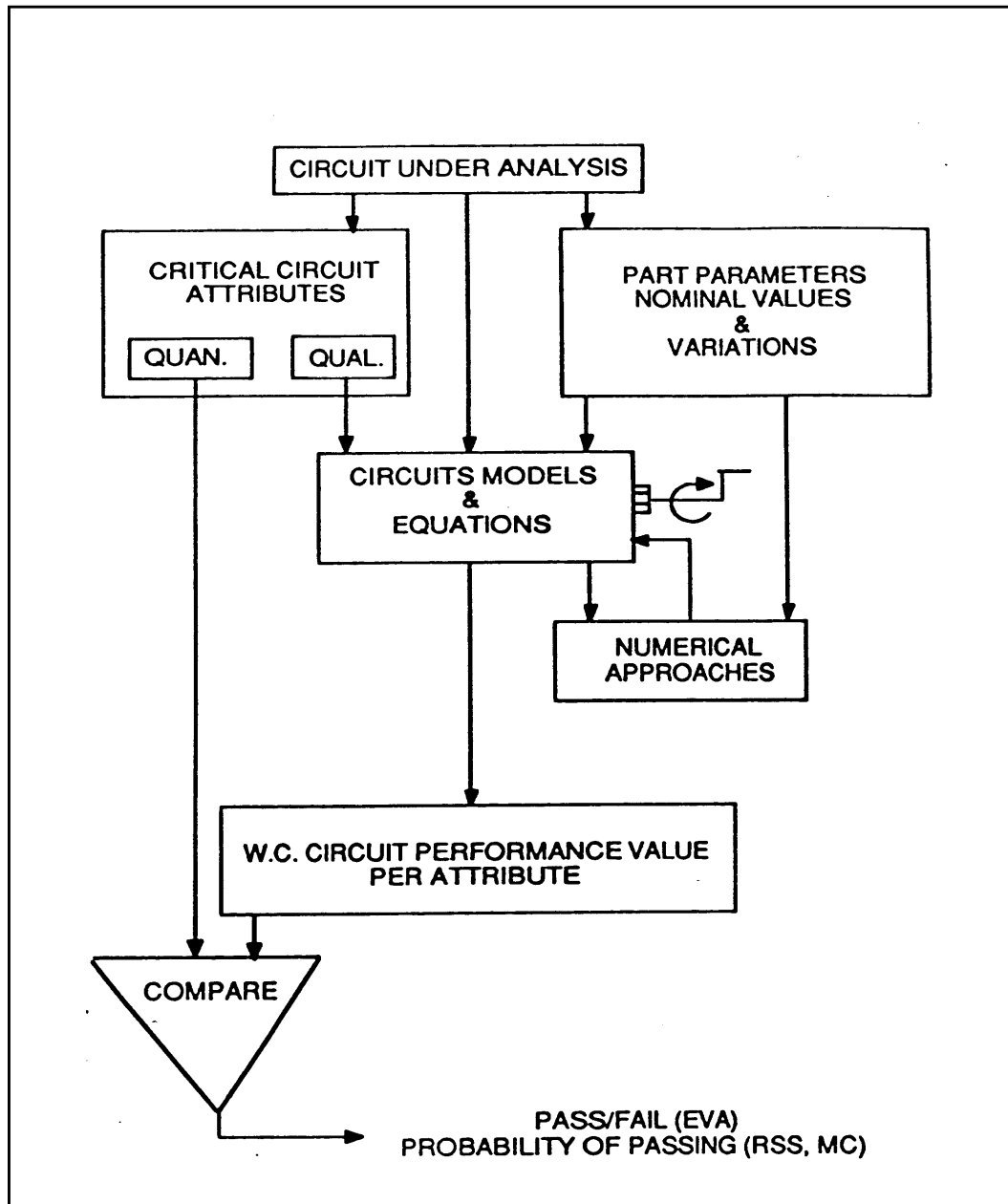
Use EVA as the basic approach to WCA. If the design fails to meet the requirement, fix it by applying Para. 17.10.2.2.

17.10.4.1 Comments on the three methods

- (1) **Extreme Value Analysis:** is the easiest, deterministic but most pessimistic method.
- (2) **Root-Sum-Square:** the results are probabilistic and errors are inherent due to assumptions of linearity of sensitivity, and normal distributions.

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**FIGURE 17.2: GENERAL WORST CASE CIRCUIT ANALYSIS
METHODOLOGY**

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- (3) **Monte Carlo:** typically yields most accurate results, given a knowledge of the “parts” distributions in lieu of the development of a parts data base. Monte Carlo requires use of a computer.

17.10.4.2 Comparison of Methods

17.10.4.2.1 Inputs

- (1) **Extreme Value Analysis:** defined by the limits of the variability and the circuit directional sensitivities to part variations.
- (2) **Root-Sum-Square:** defined by the Biases and standard deviations of the parts variability and circuit sensitivities (Magnitude and direction).
- (3) **Monte Carlo:** defined by the probability distribution of the variability.

17.10.4.2.2 Outputs

- (1) **Extreme Value Analysis:** results in two discrete numbers: WC Max & WC Min. Yields Pass/Fail results only (nonstatistical, deterministic).
- (2) **Root-Sum-Square:** result is a mean and standard deviation of the circuit attribute probability distribution. Predicts probability of circuit attribute falling within specified limits.
- (3) **Monte Carlo:** result is a histogram of the circuit attributes probability distribution. Predicts probability of circuit attribute falling within specified limits.

Note: For Sensitivity Analysis details for the above methods see Appendix A.

17.10.5 Extreme Value Analysis (EVA)

17.10.5.1 Goal

The determination of worst case values (Min&Max) of a circuit attribute by substituting the extreme values of all parts into the circuit equations, in a direction (i.e., part min. or max.) which causes the circuit attribute to go towards its extreme value.

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17.10.5.2 Approach

Most circuit functions vary in a monotonic fashion over the range of WC part variations.

17.10.5.3 Effect of Parameter Variability on a Circuit Performance Characteristic

17.10.5.3.1 Single Parameter

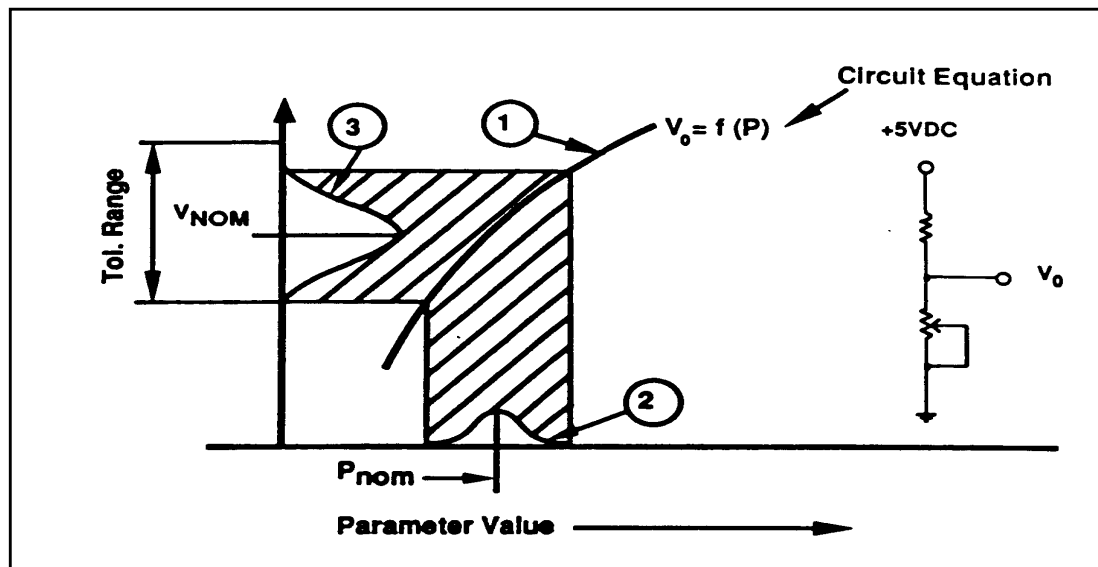


FIGURE 17.3: EFFECT OF PARAMETER VARIABILITY ON A CIRCUIT PERFORMANCE CHARACTERISTIC (SINGLE PARAMETER)

- (1) **Curve 1:** A circuit performance characteristic (e.g., a node voltage) plotted as a function of a circuit piece part (e.g., a resistor connected to that node). All remaining part parameters remain constant.
- (2) **Curve 2:** Range and frequency distribution of the part's (resistor's) value about its nominal value.
- (3) **Curve 3:** Range and frequency distribution of the performance characteristic (node voltage) about its nominal value (V_{NOM}) as a result of the resistor's variability. The curve lies within the specified tolerance limits.

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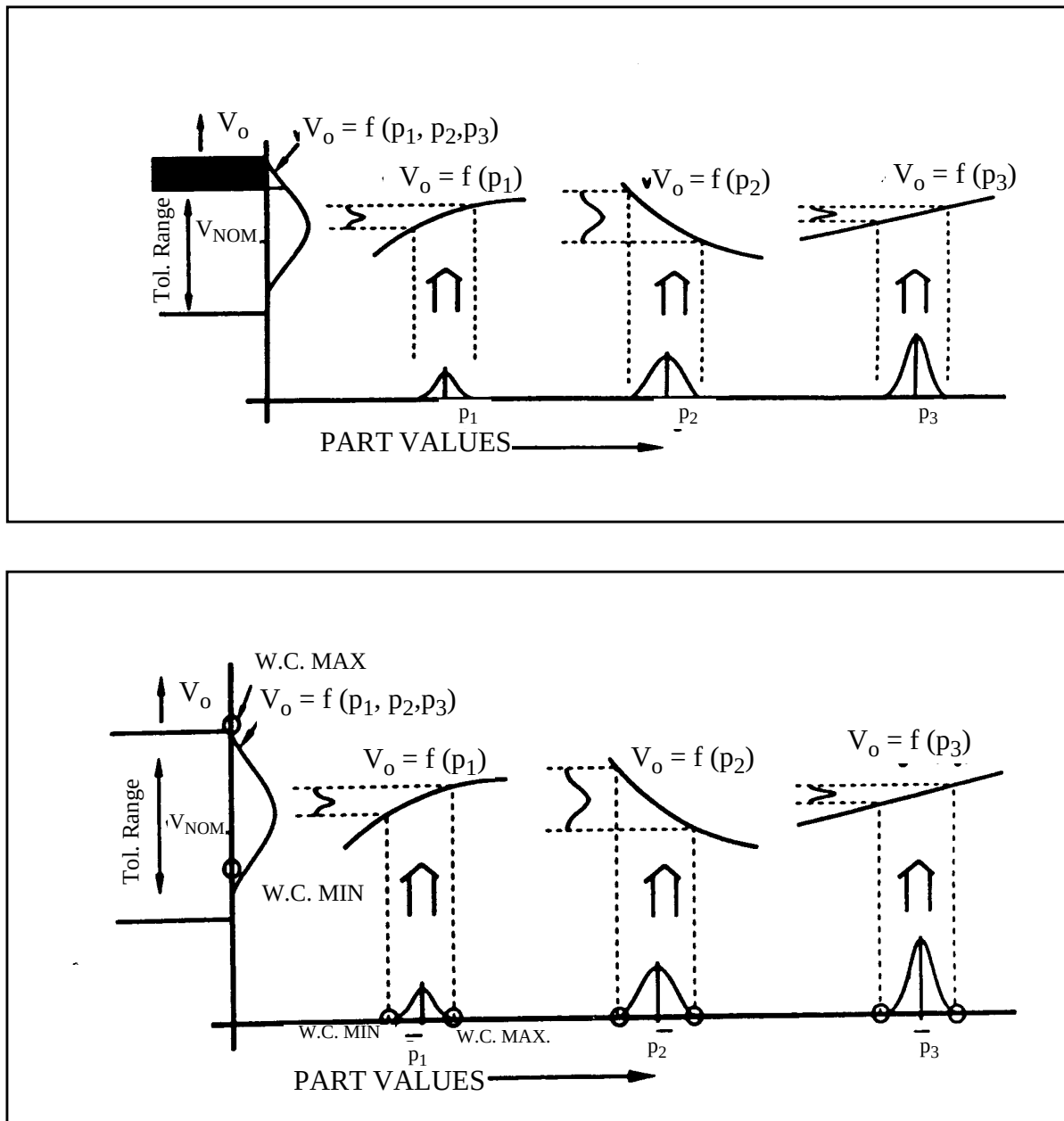
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FIGURE 17.4: EFFECT OF PARAMETER VARIABILITY ON A CIRCUIT PERFORMANCE CHARACTERISTIC (MULTIPLE PARAMETERS)

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17.10.5.3.2 Multiple Parameters

- (1) Performance variability shown influenced by several parameters simultaneously.
- (2) Parameters P_1 , P_2 appear to have a strong but opposite effect on V_O .
- (3) Parameter P_3 has only a weak influence on V_O .
- (4) The portion of the net frequency distribution curve beyond the specification tolerance limit represents drift failure (shaded region).

17.10.5.4 EVA Method

With this **WCA technique** we shall try to define the variations of the output while all parameters of the circuit at acceptable tolerance limits.

For this purpose **we shall use**:

- (1) The development of “**Taylor Series**”, for (n) variables, and partial derivatives
- (2) **Directional Sensitivity** (see Appendix A for more details)

Taylor Series Development:

For (n) variables

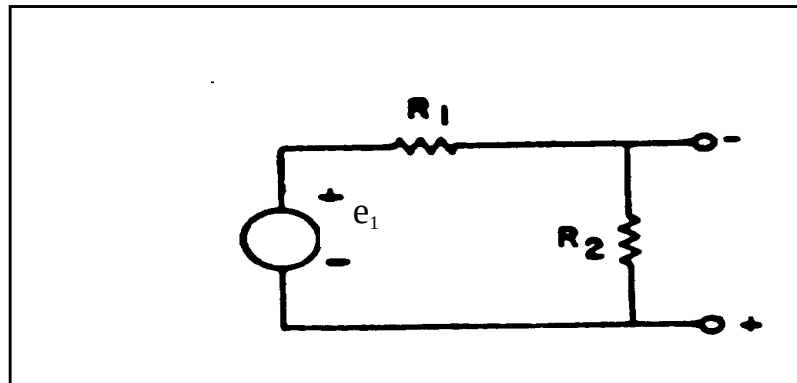
$$\begin{aligned}
 & f(X_1 + \Delta X_1, X_2 + \Delta X_2, X_3 + \dots X_n + \Delta X_n) \\
 &= \sum_{k=0}^{\infty} \frac{1}{k!} \left[\left(\Delta X_1 \frac{\partial}{\partial X_1} + \Delta X_2 \frac{\partial}{\partial X_2} + \dots + \Delta X_n \frac{\partial}{\partial X_n} \right)^k \cdot f \right] \\
 &= f(X_1, X_2, \dots, X_n) + \Delta X_1 \frac{\partial f}{\partial X_1} + \Delta X_2 \frac{\partial f}{\partial X_2} + \dots + \Delta X_n \frac{\partial f}{\partial X_n}
 \end{aligned}$$

17.10.5.5 EVA Method Examples

Example 1

To illustrate the **Worst Case EVA** method (using Taylor Series Development), let us consider a simple voltage divider.

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$$e_1 = 100 \text{ V} \pm 5 \text{ V} \dots\dots\dots 5\%$$

$$R_1 = 300 \, \Omega \pm 30 \, \Omega \dots\dots\dots 10\%$$

$$R_2 = 100 \, \Omega \pm 5 \, \Omega \dots\dots\dots 5\%,$$

The output voltage, e_2 , required is about $25 \text{ V} \pm 10\%$.

Step 1

The output voltage equation is:

$$e_2 = e_1 \frac{R_2}{R_1 + R_2} = 25 \text{ V}$$

which is perfectly acceptable.

Step 2

The **tolerance** on resistors indicates the range of values they may have when purchased, with some statistical probability that we will hit the exact value in very few cases.

Apply the WCA method.

We wish to know the **total range of output voltage** if in fact get extreme values of the input voltage and resistors, the minimum and maximum worst case value of the output voltage should be obtained.

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Applying Taylor Series:

$$e_1 + \frac{\partial e_2}{\partial e_1} \cdot \Delta e_1 + \frac{\partial e_2}{\partial R_1} \cdot \Delta R_1 + \frac{\partial e_2}{\partial R_2} \cdot \Delta R_2$$

The **partial derivatives** from the output equation are:

$$\frac{\partial e_2}{\partial e_1} = \frac{R_2}{R_1 + R_2} = 0.25$$

$$\frac{\partial e_2}{\partial R_1} = \frac{-e_1}{R_2 \left(1 + \frac{R_1}{R_2}\right)^2} = -\frac{1}{16}$$

$$\frac{\partial e_2}{\partial R_2} = \frac{-e_1 R_1}{R_2^2 \left(1 + \frac{R_1}{R_2}\right)^2} = \frac{3}{16}$$

Step 3

Calculate e_2 (max), and e_2 (min) values:

Values for e_2 (max) are: $\Delta e_1 = +5 \text{ V}$

$\Delta R_1 = -30 \Omega$

$\Delta R_2 = +5 \Omega$

Values for e_2 (min) are: $\Delta e_1 = -5 \text{ V}$

$\Delta R_1 = +30 \Omega$

$\Delta R_2 = -5 \Omega$

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Note that the **selection** of these values are based on **sensitivity analysis** (details can be found in Appendix A) which makes the equation max or min.

$$e_2(\text{max}) = 25 + 0.25 \cdot 5 + (-1/16) \cdot (-30) + 3/16 \cdot 5 = 29.06 \text{ V}$$

$$e_2(\text{min}) = 25 - 0.25 \cdot 5 - 30 \cdot 1/16 - 5 \cdot 3/16 = 20.94 \text{ V}$$

Step 4

Results: The output, e_2 **variation** based on EVA is approximately $25 \pm 16\% \text{ V}$

Step 5

Conclusion: As the required tolerance on the output voltage is to be within (10%, than something must be done, because there is a probability that randomly selected values of available 5 and 10 percent tolerance parts/resistors will not do the job.

An obvious **corrective action** is the possibility of one or the other;

- a) Both resistors having a **tighter tolerance**, such as 1%,
- b) Possibly the **use of** an electronic voltage regulator (which will increase the failure rate of the circuit due to added complexity), or
- c) **More control** on the input voltage may be required.

Note that for this special simple case we could solve it in a simple way (using directional sensitivity as in example 2), but for more complicated cases we shall use Taylor Series development method.

Example 2: Two Stage Amplifier

- a) **Critical Attribute** Gain (A)

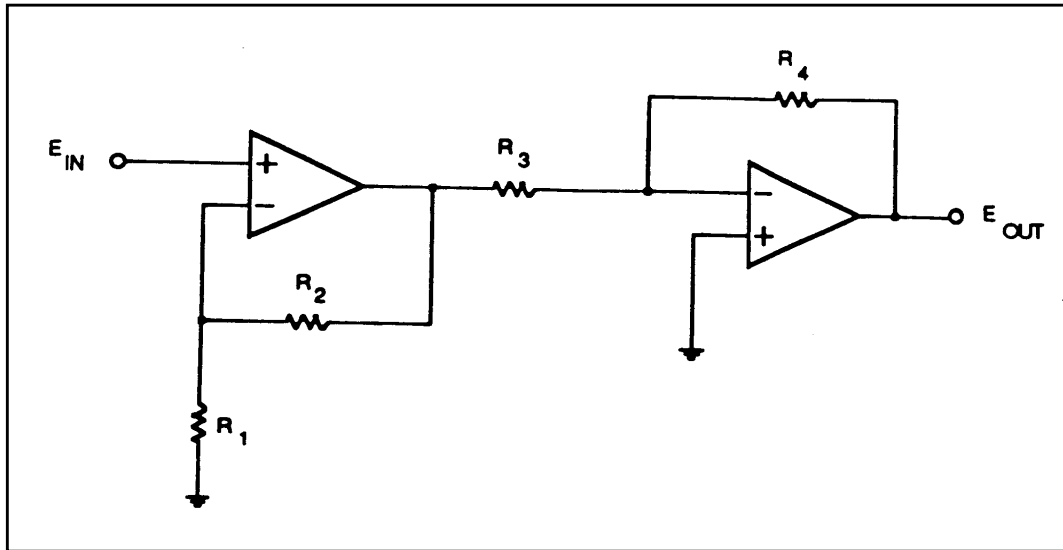
Requirement: $A = 100 \pm 3\%$

Part Values:

- $R_1 = 1\text{K} \pm 1\%$
- $R_2 = 10\text{K} \pm 1\%$
- $R_3 = 1\text{K} \pm 1\%$
- $R_4 = 9.09\text{K} \pm 1\%$

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**FIGURE 17.6: TWO STAGE AMPLIFIER CIRCUIT DIAGRAM****b) Gain Equations**

Assume ideal Op Amp

$$A_{\text{OPEN-LOOP}} = \infty$$

$$Z_{\text{IN}} = \infty$$

$$Z_{\text{OUT}} = 0$$

First stage: $A_1 = 1 + \frac{R_2}{R_1}$

Second stage: $A_2 = -\frac{R_4}{R_3}$

Overall Gain: $A = A_1 \cdot A_2 = -\frac{R_4}{R_3} \left[1 + \frac{R_2}{R_1} \right]$

$$|A| = \frac{R_4}{R_3} \left[1 + \frac{R_2}{R_1} \right]$$

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES****CHAPTER 17****c) Perform Extreme Value Analysis (EVA)****Step 1****First** find extreme values for each part parameter.

For two-stage amplifier:

TABLE 17.3: WCA PART PARAMETER VALUES, WC DRIFT = $\pm 1\%$

Parameter	Nominal	Maximum	Minimum
R1	1K	1.01K	0.99K
R2	10K	10.1K	9.9K
R3	1K	1.01K	0.99K
R4	9.09K	9.181K	8.999K

$$A = \frac{R_4}{R_3} \left[1 + \frac{R_2}{R_1} \right] \quad (7)$$

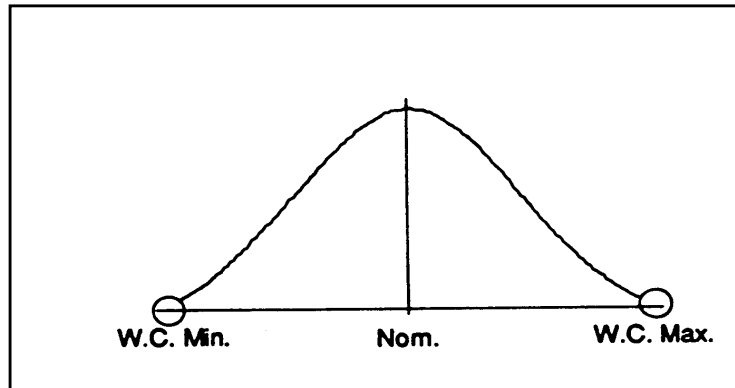
Step 2**Find “A” max and “A” min**, by substituting WC Min and Max part values into above equation.

The problem is how do we substitute worst case Min and Max part values into equation #(1) to drive “A” to its absolute worst case max and min performance values.

Step 3**Determine a Directional Sensitivity** (see Appendix A for details), to each parts directional drift, i.e.,As each part WC Max, $A = \uparrow$ or $\downarrow$?As each part WC Min, $A = \uparrow$ or $\downarrow$?**The sensitivity of “A”** to each term in equation (1) can be found by substituting of part Min and Max values individually into equation (1), **holding** all other terms at nominal values, or by inspection

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**FIGURE 17.7: WORST CASE DISTRIBUTION****Answers By Inspection (if not complicated)****TABLE 17.4: SENSITIVITY OF GAIN “A” BY INSPECTION**

R_1	“A”	Varies Inversely	↓ (-)
R_2	“A”	Varies Directly	↑ (+)
R_3	“A”	Varies Inversely	↓ (-)
R_4	“A”	Varies Directly	↑ (+)

(1) Solve for “A” Max**TABLE 17.5: SOLUTION FOR MAXIMUM GAIN “A”**

$R_1 \Rightarrow R_1 \text{ Min}$	0.99 K
$R_2 \Rightarrow R_2 \text{ Max}$	10.1 K
$R_3 \Rightarrow R_3 \text{ Min}$	0.99 K
$R_4 \Rightarrow R_4 \text{ Max}$	9.181 K

$$A_{\text{MAX}} = 103.9$$

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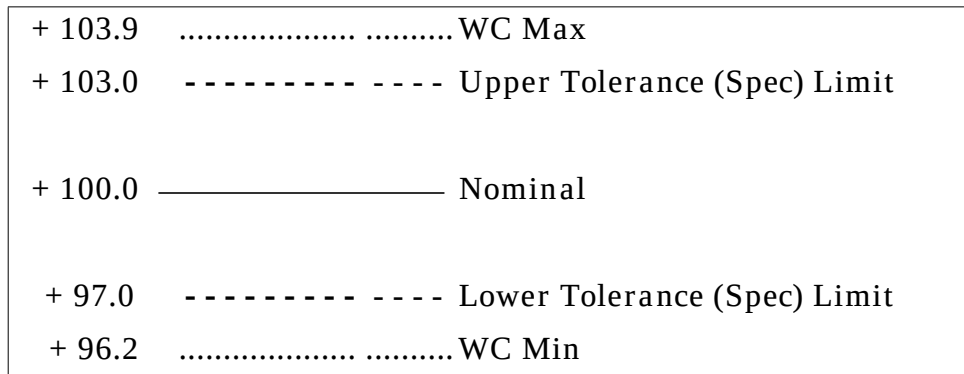
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(2) **Solve for “A” Min:****TABLE 17.6: SOLUTION FOR MINIMUM GAIN “A”**

$R_1 \Rightarrow R_1 \text{ Max}$	1.01
$R_2 \Rightarrow R_2 \text{ Min}$	9.9
$R_3 \Rightarrow R_3 \text{ Max}$	1.01
$R_4 \Rightarrow R_4 \text{ Min}$	8.999

$$A_{\text{MIN}} = 96.2$$

Step 4**Compare “A” WC Min and Max values to its Tolerance Limits.****FIGURE 17.8: CONTROL CHART FOR GAIN “A”****Step 5**Results: We have **Negative Margin**.

“A” Max, “A” Min fall outside specification (tolerance) limits using extreme value analysis,

“A” fails EVA.

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17.10.6 Root-Sum-Square (RSS) Method

17.10.6.1 Goal and Approach

This is a **probabilistic**, difficult method, and not always is possible to solve the probability function.

17.10.6.2 RSS Method

- (1) Randomness of parameter values is depicted by an appropriate statistical model, probability density function (pdf).
- (2) **RSS** method is a **statistical** technique for combining standard deviations. The RSS approach is based on the “**Law of Large Numbers**”, (**Central Limit Theorem**), which states that if a large number of independent variables are statistically combined, the resulting distribution is a **normal distribution** independent of the form of the distributions of the individual variables which are combined.
- (3) **The circuit shall be designed** so that the distribution of the tolerance shall have standard deviation equal to RSS standard deviation of the circuit parts.
- (4) **The expected mean value** of the required parameter (i.e., e_2 or A as in our examples) is:

$$E(X) = f(X_1, X_2, \dots, X_n) + \frac{1}{2} \sum_{i=1}^n \frac{\partial^2 f}{\partial X_i^2} \sigma_i^2 \quad (8)$$

- (5) **The variance** of the required parameter is:

$$\text{Var}(X) = \sum_{i=1}^n \left(\frac{\partial f}{\partial X_i} \right)^2 \cdot \sigma_i^2 \quad (9)$$

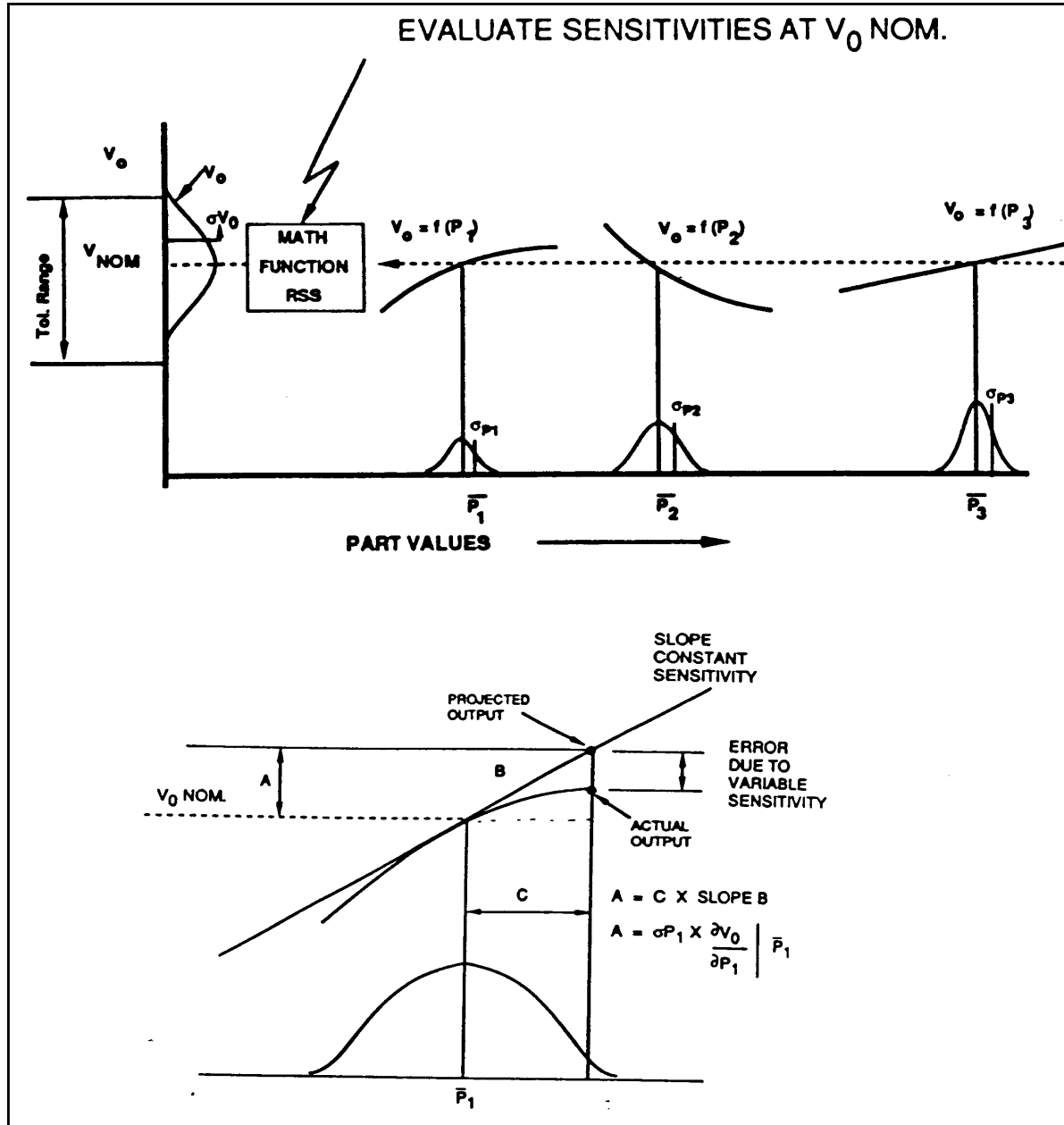
This equation **determines** the standard deviation of a normal distribution of any circuit attribute by mathematically combining of the standard deviations of each piece part, based on the **sensitivity** of the circuit attribute to the value of the piece-part. See Figure 17.9

Note: the Taylor series partial derivatives solve the **sensitivity** problem.

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**FIGURE 17.9: OUTPUT STANDARD DEVIATION AND CONSTANT SLOPE ASSUMPTION**

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PROCEDURES***CHAPTER 17***17.10.6.3 RSS Method Examples****Example 1****Step 1**

Assume that the tolerance is at 2σ (specified tolerances, upper and lower limits) then:

$$\sigma(e_1) = 2.5 \text{ V}$$

$$\sigma(R_1) = 15 \Omega$$

$$\sigma(R_2) = 2.5 \Omega$$

Step 2

The **second order derivations** of the output are:

$$\frac{\partial^2 e_2}{\partial e_1^2} = 0$$

$$\frac{\partial^2 e_2}{\partial R_2^2} = \frac{2e_1 R_1}{R_2^3 \left(1 + \frac{R_1}{R_2}\right)^3} = -\frac{3}{3200}$$

$$\frac{\partial^2 e_2}{\partial R_1^2} = \frac{2e_1}{R_1 R_2 \left(1 + \frac{R_1}{R_2}\right)^3} = \frac{1}{9600}$$

Step 3

Find the **expected value** and the **variance** of the required output (e_2):

$$E(X=e_2) = 25 + \frac{1}{2} \left(15^2 \cdot \frac{1}{9600} - 2.5^2 \cdot \frac{3}{3200} \right)$$

$$E(X=e_2) \approx 25 \text{ V}$$

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$$\text{Var}(X = e_2) = (0.25)^2 \cdot 2.5^2 + \left(-\frac{1}{16}\right)^2 \cdot 15^2 + \left(\frac{3}{16}\right)^2 \cdot 2.5^2$$

$$\text{Var}(X = e_2) = 1.473 \text{ V}$$

Hence, **standard deviation** is:

$$\sigma(e_2) = 1.21 \text{ V}$$

and the **Tolerance** of the output is:

$$T(e_2) = 2 \cdot \sigma \cdot 100/25$$

$$T(e_2) = \pm 9.7\% \text{ V}$$

Step 4

Compare the WC limits (e_2 max and min values) to its specification required tolerance limits.

As the results shows that we have **negative margin** ($9.7\% > 5\%$), e_2 circuit output **fails worst case analysis (WCA), RSS Method**.

Example 2

Having determined the standard deviation (σ) for the circuit attribute, the statistical worst case condition is then found based on examination of the resulting population, assuming a normal distribution.

We can state the results also as:

Given a specified tolerance range for the output f /or V_0 (U/L limits), we can state what percent of population of circuits will fall within these limits.

For the **two stage Amplifier** the **circuit output equation** is:

$$A = \frac{R_4}{R_3} \left[1 + \frac{R_2}{R_1} \right]$$

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$$A = A_{\text{NOM}} \pm \Delta A$$

where

ΔA = Deviation from nominal, which is generally taken to be the 2σ or 3σ limit

In this sample we shall take 3σ ,

$$\Delta A_{\text{LIMITS}} = \pm 3\sigma_A$$

where

from general equation (3) in sample 1, the Standard Deviation is:

$$\sigma_A = \sqrt{\left[\frac{\partial A}{\partial R_1} \sigma_{R_1}\right]^2 + \left[\frac{\partial A}{\partial R_2} \sigma_{R_2}\right]^2 + \left[\frac{\partial A}{\partial R_3} \sigma_{R_3}\right]^2 + \left[\frac{\partial A}{\partial R_4} \sigma_{R_4}\right]^2}$$

Therefore, to **determine the 3σ limits** we need to calculate the **circuit sensitivities** and also to determine the standard deviations of each part (σ_{Ri}).

Step 1

Calculate **sensitivities** from the output equation:

$$\frac{\partial A}{\partial R_1} = \frac{-R_2 R_4}{R_3 R_1^2} = \frac{(-10K)(9.09K)}{(1K)(1K)^2} = -0.0909/\Omega$$

$$\frac{\partial A}{\partial R_2} = \frac{R_4}{R_3 R_1} = \frac{(9.09K)}{(1K)(1K)} = 0.00909/\Omega$$

$$A = \frac{R_4}{R_3} \left[1 + \frac{R_2}{R_1} \right]$$

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$$\frac{\partial A}{\partial R_3} = \left[1 + \frac{R_2}{R_1} \right] \cdot \left[\frac{-R_4}{R_3^2} \right] = - \left[1 + \frac{10 \text{ K}}{1 \text{ K}} \right] \cdot \left[\frac{9.09 \text{ K}}{1 \text{ K}^2} \right] = -0.1/\Omega$$

$$\frac{\partial A}{\partial R_4} = \left[1 + \frac{R_2}{R_1} \right] \cdot \left[\frac{1}{R_3} \right] = - \left[1 + \frac{10 \text{ K}}{1 \text{ K}} \right] \cdot \left[\frac{1}{1 \text{ K}} \right] = -0.011/\Omega$$

Step 2

Calculate the **Standard Deviation** of the parts.

- a) If **type** of distribution (pdf) is **known**, then standard deviation can be calculated as:

$$\sigma^2 = \int_{-\infty}^{\infty} x^2 \cdot f(x) dx$$

- b) If distribution is **not known**, then assume **normal distribution** or **uniform distribution**.

Assume also that random variation (tolerance) listed on parts data sheets represents 2σ or 3σ limits.

For the **Two-Stage Amplifier** example:

Assume that the resistor tolerances are known to be **uniformly distributed**. Maximum values (Tolerances) = $\pm 1\%$.

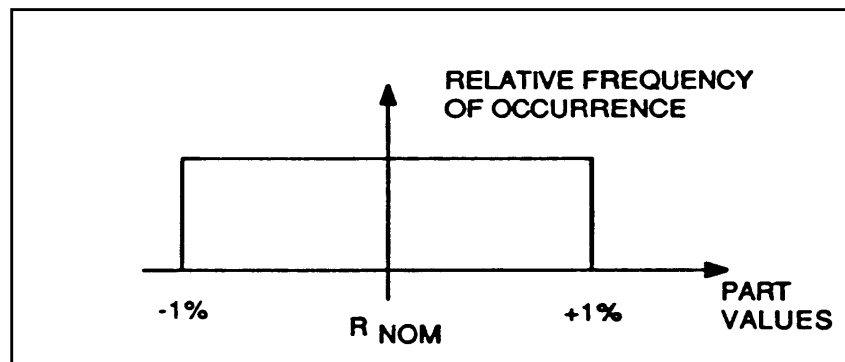


FIGURE 17.10: UNIFORM DISTRIBUTION

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For a **uniform distribution**, the standard deviation is equal to the maximum limit divided by $\sqrt{3}$.

Hence,

$$\sigma_R = \frac{1\%}{\sqrt{3}} = 0.577\%$$

Step 3

Solution:

TABLE 17.7: SENSITIVITY AND STANDARD DEVIATION OF GAIN “A”

Resistor	Sensitivity	Standard Deviation (0.577%)
R ₁	- 0.0909/Ω	5.77 Ω
R ₂	0.00909/Ω	57.7 Ω
R ₃	- 0.1/Ω	5.77 Ω
R ₄	0.011/Ω	52.45 Ω

Hence

$$\sigma_A = \sqrt{\sum_{i=1}^4 \left[\frac{\partial A}{\partial R_i} \sigma_i \right]^2}$$

$$\sigma_A = 1.103$$

Step 4

RSS Results

As we found the output “A” standard deviation, $\sigma_A = 1.103$

If we use the 3σ limits (for 99.73% confidence level), as the **worst case criteria**:

$$A_{MAX} = 100 + 3 \cdot (1.103) = 103.3$$

$$A_{MIN} = 100 - 3 \cdot (1.103) = 96.7$$

Comparing the spec. limits

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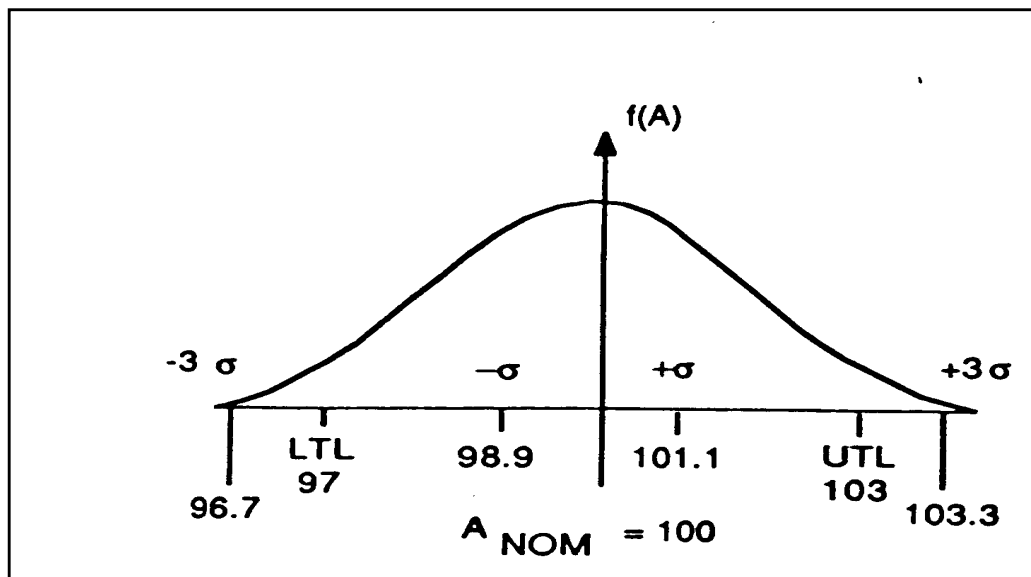
Upper Tolerance Limit = 103

Lower Tolerance Limit = 97

Hence, we have **Negative Safety Margins**, output "A" fails **Worst Case Analysis, Root-Sum-Squared method**.

However, RSS provides additional useful information.

See Figure 17.11 **pdf of output A**.

**FIGURE 17.11: P.D.F. OF OUT PUT A**

The spread of the upper and lower tolerance limits (which is $2.72\sigma < \pm 3\sigma$ spread) is approximately equal to 99.3% of the population of the "A" pdf.

Hence, **we can state** that approximately 99.3% of all amplifiers circuits manufactured will fall within specified tolerance limits. But, based on this WCA results, some circuits will fail to meet the required performance limits.

This may or may not be acceptable to DHI, and needs evaluation and approval by DHI R&M Engineers.

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17.10.6.4 RSS Conclusions

- (1) The **root-sum-squared approach** yields a more realistic value (from statistical standpoint) for worst case conditions, than an extreme value analysis, (deterministic).
- (2) The **RSS approach** yields results which are always within the bounds established by valid extreme value analysis.
- (3) The **RSS approach** can be applied no matter what probability distribution represents the circuit piece-parts.
- (4) The **RSS approach** can lead to **small error** if the circuit **sensitivities** are not constant throughout the range of variations.
- (5) The **RSS approach** assumes that the circuit parameter of interest varies as a normal distribution.
- (6) **Comments on the “Constant Slope” Assumption:**
 - a) Error (not significant in most cases) arises because slope is calculated at nominal point and assumed to be constant over range of standard deviation.
 - b) Error can be eliminated by using circuit equation to map piece-part standard deviation to output, rather than using slope at nominal point to project output, (needs a computer program, i.e., turbo basic program).

17.10.7 Monte Carlo (MC) Analysis

It is the empirical determination of the statistical distribution of any circuit parameter by the repeated evaluation of that parameter under various circuit conditions in which the values of each piece-part are randomly selected. See Figure 17.12.

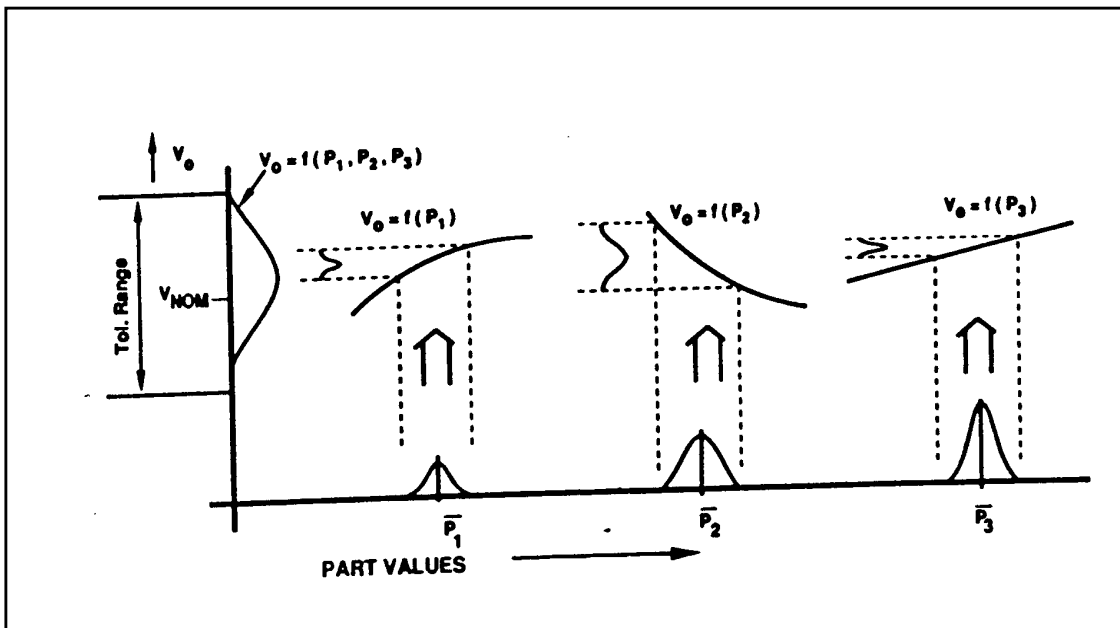
17.10.7.1 Monte Carlo Analysis Process

- (1) **Repeatedly** select random sets of values.
This produces a randomly chosen replica of the circuit functional performance distribution. See Figure 17.13.
- (2) **Calculate** the output “**A**” for each set via the circuit equation.

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$$A = \frac{R_4}{R_3} \left[1 + \frac{R_2}{R_1} \right]$$

**FIGURE 17.12: CIRCUIT PARAMETER STATISTICAL DISTRIBUTION**

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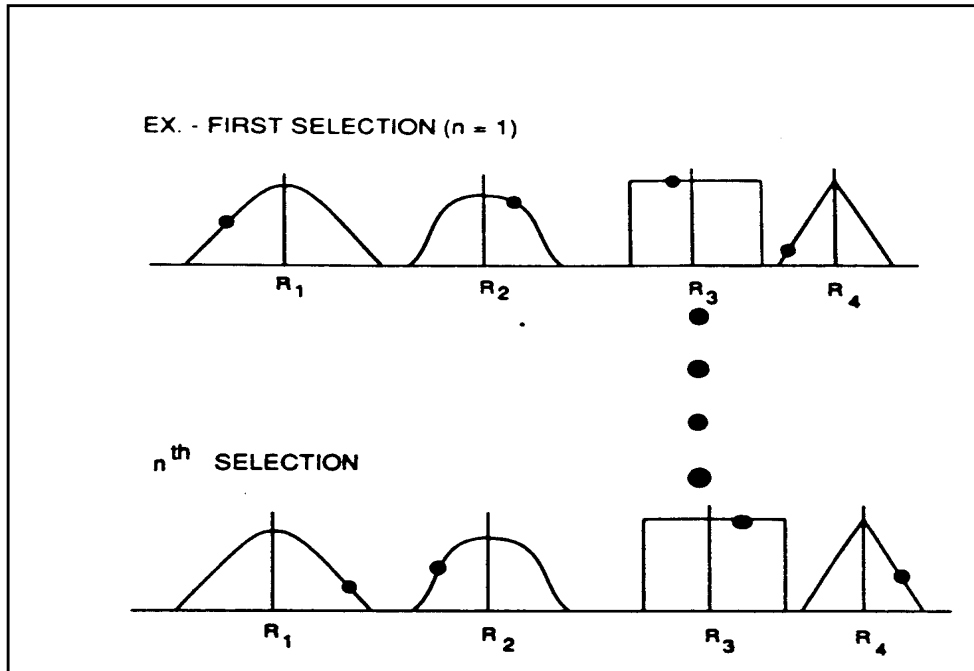
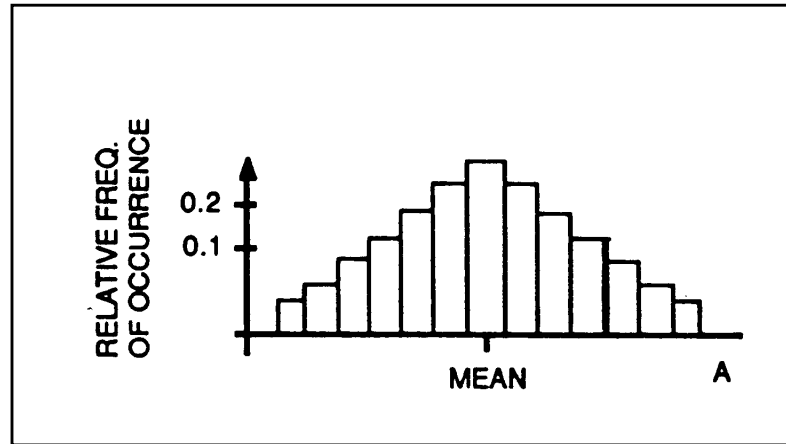


FIGURE 17.13: CIRCUIT FUNCTIONAL PERFORMANCE DISTRIBUTION

- (3) **Repeat** “n” times, ($n \gg \#$ parameters)
- (4) **Sort** and **Group** the results
- (5) **Generate** histogram of frequency distribution. See Figure 17.14

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**FIGURE 17.14: FREQUENCY DISTRIBUTION
HISTOGRAM**

- (6) **Determine** % of units that meet specification limits
- (7) **Calculate** mean value and standard deviation from data

$$\bar{A} = \frac{A_1 + A_2 + \dots + A_n}{n}$$

$$\sigma_A = \sqrt{\sum_{i=1}^n \frac{(A_i - \bar{A})^2}{n}}$$

Where

A_i represents gain of i_{th} iteration

Note: **Generate** random numbers in range of 0 to 1 by a computer.

Amplifier circuit parts have tolerance range of $RNOM = \pm 1\%$. See Figure 17.15.

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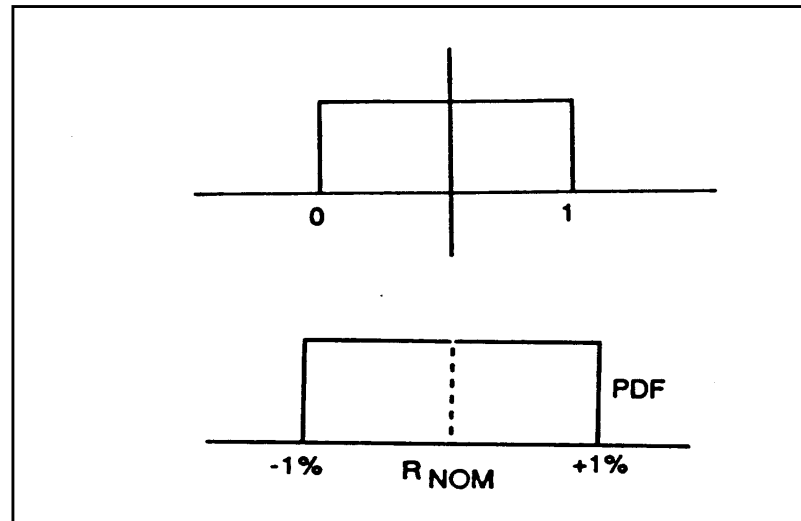


FIGURE 17.15: TOLERANCE RANGE

Therefore, piece-part samples can be obtained by scaling and offsetting the random numbers:

$$R_{\text{sample}} = R_{\text{nom}} (0.99 + 0.02 x)$$

where

x is the random generated by the computer.

17.10.7.2 Procedure

- (1) **Independently** (computer generated random numbers) select a sample value for each resistor.
- (2) **Using** these values, **calculate** the corresponding gain value.
- (3) **Repeat** steps 1 and 2, a large number of times.
- (4) **Calculate** the mean and standard deviation of the gain results.
- (5) **Calculate** gain limits that correspond to 99.73%, (3σ), probability of success.

Note: If resultant distribution is not Normal, then 99.73% limits will not necessarily be equal to 3σ limits. Computer generated MC analysis results are not shown in this document.

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17.10.7.3 Monte Carlo Summary

- (1) **The Monte Carlo approach** yields a more realistic value (from a statistical standpoint) for worst case conditions, than an extreme value analysis.
- (2) The Monte Carlo approach **yields** results which are always within the bounds established by valid extreme value analysis.
- (3) The Monte Carlo approach **can be applied** no matter what probability distribution represents the circuit piece-part parameters.
- (4) The Monte Carlo approach **can easily be extended** to include any correlation which might exist between the circuit parameters.
- (5) The Monte Carlo approach **can be applied** to any circuit topology without error, while the Extreme Value and RSS approaches can lead to small error if the circuit sensitivities are not constant (sign and magnitude).

17.10.7.4 Monte Carlo Software

- (1) There are numerous analysis software packages available which offer Monte Carlo Analysis options (e.g., P-Spice, Analog workbench, etc.).
- (2) Most (if not all) PC versions assume uniform tolerance distribution.

17.11 APPLICATION OF THE VARIOUS METHODS

- (1) **Use EVA** as the **basic approach** during the design and development phase.
- (2) **If the design fails** to meet its requirement via an EVA, fix the design.
- (3) However, there are occasions when this is not appropriate:
 - a) When the design is in production or in the field.
Note: Use RSS or Monte Carlo, which are statistically correct but less conservative than EVA analysis, to evaluate magnitude of problem.
 - b) When the design topology is such that an EVA analysis is too conservative.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***CHAPTER 17***17.12 COMPARISON OF ADVANTAGES / DISADVANTAGES OF THE
WCA METHODS****TABLE 17.8: ADVANTAGES / DISADVANTAGES OF WCA METHODS**

METHODS	ADVANTAGES	DISADVANTAGES
EVA	Permits most readily obtainable estimate of circuit Worst Case performance. Does not require statistical input for circuit parameters.	Results in pessimistic estimate of circuit Worst Case performance.
RSS	Result in more realistic estimate of Worst Case performance than EVA. Knowledge of parameter pdf not required.	Standard deviation of part parameter's probability distribution is needed. Uses approximation; circuit performance variability is normally distributed. Assumes circuit sensitivities remain constant over range of parameter variation.
MC	Most realistic estimate of the true Worst Case.	Requires use of computer. Knowledge of parameter pdf is required.

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17.13 WCA GUIDELINES FOR CIRCUIT PARTITIONING & BLOCK DIAGRAMS

- (1) **Partitioning** is to establish the fine dividing lines or boundaries between circuits.
- (2) Block diagrams are pictorial relationship in block form of lower level assemblies of a system.

The **goal** is to breakdown the complex circuit for visibility and focus, i.e., reduce to simple analyzable circuits to limit the number of attributes, and to limit the number of simultaneous equations.

17.13.1 Guidelines

See Figure 17.16.

17.13.1.1 Limit complexity of blocks

- (1) **Manual Analysis** - Limit number of active elements to 3, (one is best).
- (2) **Computer Analysis** - Number of nodes must be kept within limits of program capabilities.

17.13.1.2 Select a Logical and Convenient Breakpoint

- (1) **Functionally** inseparable parts
- (2) Point of steep impedance gradient:
 - a) Op Amp outputs
 - b) Transistor collectors (common emitter configuration)
- (3) **Minimum** active device count domains:
 - a) One transistor or darlington with passive parts
 - b) One Op Amp with passive parts
- (4) Points of minimum or homogeneous lines
 - a) Single digital outputs
 - b) Digital buses

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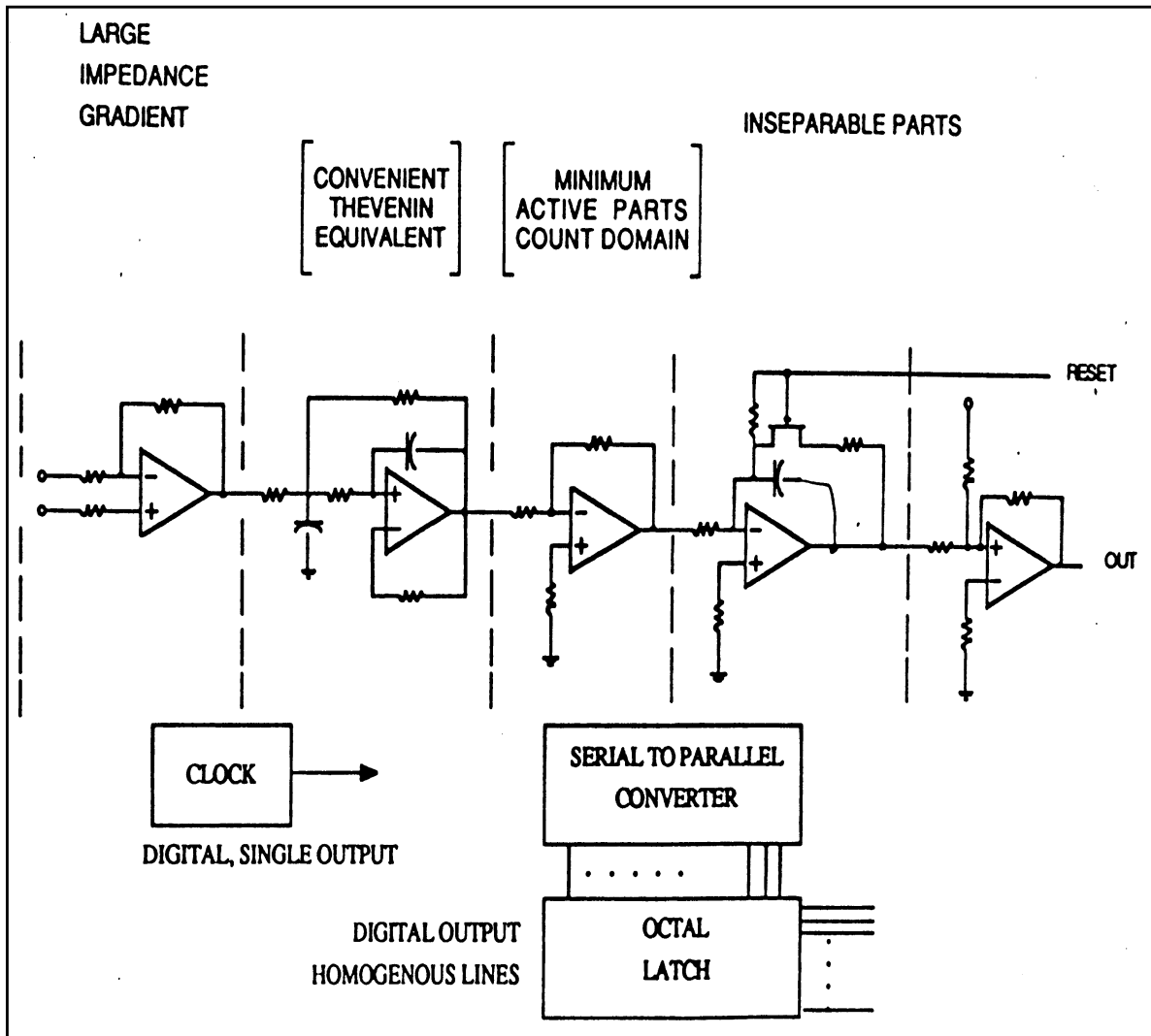


FIGURE 17.16: SAMPLE APPLICATION OF PARTITIONING GUIDELINES

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17.14 GUIDELINES FOR ATTRIBUTES & PLANNING THE WCA

- (1) **Study** the circuit of each block for familiarity and the determination of each block
- (2) **Get** a “first impression of what you have to work with and how the design engineer approached the meeting of requirements and plan a method of **WC proof** for each critical attribute
- (3) **Size up** difficulty of analysis to be done
- (4) **Look** for areas troublesome to analyze:
 - a) non-linearities
 - b) multiple feedback loops
 - c) heavy in magnetics
 - d) too many approximations required?
- (5) The formal documentation of an appropriate set of program specific guidelines should be an effort at the “department” level and prepared **early in the program** for use by both design engineers and WCCA analysts.
- (6) **Detailed guidelines** should be developed for all the various classes of circuits anticipated for use on the particular program, such as
 - a) Digital Circuits
 - b) General Analog Circuits, Amplifier, Oscillators, etc.
 - c) Power Conditioning Circuits
 - d) R.F Circuits, etc.
- (7) As an example, **guidelines** for the class of digital circuits are **covered shortly** in this section.

The detailed specific guidelines **developed** by the vendor should specify:

- a) What to analyze:
 - Specified circuit attributes
 - Non-specified but critical conditions e.g., races, hazards, transient overstress, single event upset.

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- b) Worst Case quantitative level:
 - e.g., worst case minimum time for memory retention during power transients or radiation pulses.
 - Worst case minimum safety factors for relay coil energizing periods should be $n \times$ maximum pull-in time.
 - c) Worst case conditions for specified circuit features:
 - e.g., Worst case condition for power supply start-up is cold temperature and max. d.c. loads and capacitance.
 - Worst case conditions for inductor suppression are maximum voltage and duty cycle.

17.14.1 Digital Circuits Worst Case General Guidelines

- (1) Function Verification
- (2) Timing Analysis
- (3) Fanout and circuit loading
- (4) Logic compatibility
- (5) Power budgets

17.14.1.1 Function Verification

- (1) **Verify** the logic of each functional block using:
 - a) Truth Tables
 - b) State Tables
 - c) Karnaugh Maps
 - d) Timing Diagrams
- (2) **Assure** that ambiguous logic output states are prevented; Unwanted state lockup is prevented.
Power-up and down states are OK.
- (3) **Decoupling**
Specify the worst case minimum number of capacitors required to suppress self-induced switching.

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17.14.1.2 Timing Analysis

Produce a timing diagram with worst case times (including) effects of load capacitance, power supply variation, etc.). This timing diagram should be analyzed to determine the effects of uncertainties in switching times.

The analysis should verify:

- (1) The critical functions of all circuits operate under worst case minimum and maximum propagation delay times
- (2) Absence of race conditions which could cause an erroneous output (or an undetermined output) to propagate through the system
- (3) Worst case set-up and hold times with respect to clock edges for flip flops and data input lines
- (4) Minimum pulse width requirements
- (5) Memory circuit timing
 - a) Read cycle time
 - b) Write cycle time
 - c) Access time
- (6) Recovery from single event upsets (traps)
 - a) Power transients
 - b) Radiation transients

Use component specifications as a baseline for worst case minimum and maximum propagation delays, hold times, etc.

17.14.1.3 Fanout and Circuit Loading

The worst case analysis should insure that the maximum fanout is not exceeded for any output. The state, high or low, with the lowest fanout capability should be used as the limit for fanout.

Wired-or connections impose additional loads on an output and should be added to the loading analysis.

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17.14.1.4 Power Consumption

The worst case analysis should insure that the specified margin exists between the worst case power requirements and the capacity of the power supplies. A conservative margin above maximum power requirements is advised (10% is recommended).

17.14.1.5 Logic Compatibility

Analyze interfaces between different integrated circuit families or between integrated and discrete logic elements to insure that logic levels are compatible and that proper operation is demonstrated under worst case conditions.

- (1) Timing compatibility
- (2) Signal level compatibility
- (3) Noise margin at IC/Discrete I/F's

A typical interface requirement would require noise margins of 10% of VCC or 0.5V.

Consult application notes in part vendor catalogs.

17.14.2 WCCA Guidelines For Other Classes

As previously mentioned the same type of guidelines as just discussed for digital circuits, should be developed and tailored to program requirements for all applicable circuit families; e.g.

- (1) Power conditioning
- (2) R.F. circuits
- (3) General analog circuits, (Amplifiers, Oscillators, etc.)

A general Worst Case Analysis Guideline Review Checklist is included in Appendix B.

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APPENDIX A

SENSITIVITY ANALYSIS

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17.15 APPENDIX A - SENSITIVITY ANALYSIS

17.15.1 Definition

17.15.1.1 Sensitivity Analysis

The incremental change in a circuit performance attribute (i.e., gain, frequency response) resulting from an incremental change in one of the circuit part parameter values, with all other circuit parameters held constant.

Sensitivity can be reduced to a quantitative term comprised of an absolute magnitude and polarity or direction of change, +/-.

17.15.1.2 Directional Sensitivity

- (1) Circuit attribute varies directly with the part parameter value = **Positive Directionality**.
- (2) Circuit attribute varies **inversely** with the part parameter value = **Negative Directionality**.

17.15.2 Purpose and use of Sensitivity

17.15.2.1 Sensitivity Quantity

- (1) The sensitivity quantity is **used to** determine the worst case minimum and maximum values for a particular circuit attribute.
- (2) **It provides** a means of expressing the variation of any circuit attribute in terms of the predicted or calculated variation of all of its piece part values.

17.15.2.2 Attributes

(1) Directionality

Determine directional (+/-) change of circuit attribute under examination with respect to each part variation, including variation in external stimuli.

(2) WC Maximum Value

Set all component parameters with (+) directionality to their maximum values and those with (-) directionality to their minimum values.

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Substitute these values into the circuit equation and solve for the desired attribute. The resulting value is a worst case maximum.

(3) WC Minimum Value

Set all component parameters with (+) directionality to their minimum values and those with (-) directionality to their maximum values.

Substitute these values into the circuit equation and solve for the desired attribute. The resulting value is a worst case minimum.

17.15.3 Sensitivity Analysis Methods

- (1) **Inspection of circuit equation-** Only useful if the piece part parameters occur in isolated terms of the circuit equation.
- (2) **Testing of circuit equation via substitution of part values-** Tedious for complex equations, results can be misleading.
- (3) **Use of partial derivations** - May not be suitable for complex equations, prone to error if done by hand.

Method “1” is normally used in manual analysis.

Methods “2” and “3” are normally performed in computer-aided analysis (i.e. MathCad, Spread Sheets, etc).

17.15.4 Mathematical Representation of Sensitivity

17.15.4.1 Derivation of Sensitivity

Partial derivatives are used to find the variation in a function with respect to a single variable. In this discussion, the function is any network transfer function and the variables are the piece part parameter values. The derivation of sensitivity is as follows:

Let $F(S, X_i)$ be a network function, where S is the usual complex frequency operator and X_i is one of a set of real physical parameters of the network (i.e., piece part values and external stimuli).

17.15.4.2 Tolerance

The tolerance or sensitivity problem is associated with determining the perturbed network function $F(S, X_i + \delta X_i)$. That result from a finite perturbation of a particular X_i by the incremental quantity δX_i .

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The difference between the network function evaluated at X_i and δX_i can be expressed by the **Taylor Series**:

$$F(S, X_i + \delta X_i) - F(S, X_i) = \sum_{n=1}^{\infty} \frac{d^n \cdot F(S, X_i) \cdot (\delta X_i)^n}{n! \cdot dX_i^n}$$

Note: Derivative terms are actually partial derivatives.

17.15.4.3 Formula Derivation

In performing the sensitivity analysis, we are only interested in the “change” in the network function, $\delta F(S, X_i + \delta X_i)$ which can be written as:

$$\delta F = \left[\frac{dF}{dX_i} \cdot \delta X_i \right] + \frac{d^2 \cdot F[\delta X_i]^2}{dX_i^2 \cdot 2!} + \frac{d^3 \cdot F[\delta X_i]^3}{dX_i^3 \cdot 3!} + \dots$$

The expression on the right side of the “=” sign would be **repeated** for each variable δX_i in the network equation. The resulting equation can be simplified by eliminating the higher order terms and only using the first order terms.

The first term is considered to be the first order sensitivity. The equation to be used is repeated below.

$$\delta F = \sum_i \left[\frac{dF}{dX_i} \cdot \delta X_i \right]$$

Where

δF is the change in F resulting from a small change in X $\delta(X_i)$. “ X ” represents a piece part parameter.

This result can be used to determine the Worst Case minimum and maximum values of the function under investigation. These values can be expressed as:

$$Y_{WC} = Y_n + \sum_i \left[\frac{dY}{dX_i} \right] \cdot [X_i - X_{in}]$$

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Where

- Y_n = The nominal value of the transfer function
 Y_{WC} = The Worst Case value of the transfer function
 dY/dX_i = Function sensitivity to ith part change
 $(X_i - X_{in})$ = Worst Case change of ith part

17.15.4.4 Limitations of the Derivation

- (1) **The sign** of the sensitivity must be constant over the interval (X_i , X_{in}); That is, the sensitivity is assumed to be **monotonic** and linear for all values of the piece part parameter between its minimum and maximum value.

This constraint is a result of ignoring the higher order sensitivity terms.

- (2) The change in any piece part value is small relative to its nominal value; This results from using “deltas” instead of true differentials. This condition implies that the function delta must be obtained by integration if the piece part parameter deltas are substantial relative to their nominal values.

Note: Even simple resistive circuits can fail to meet the requirements stated above. A simple technique to check that the conditions are met is presented later in this section.

The following brief examples illustrate the points made in the previous sections (Examples 1 and 2).

17.15.5 Determining Directional Sensitivity**17.15.5.1 Simple Equations**

For simple equations, Directional Sensitivity can be arrived at by inspection.

$$f_o = \frac{1}{2\pi} \cdot \sqrt{\frac{R_1 + R_3}{R_1 \cdot R_2 \cdot R_3 \cdot C_1 \cdot C_2}}$$

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R_1 and R_3 appear in both the numerator expression and the denominator. The effect of a change in either value is not obvious from the equation.

A more **rigorous technique** must be used- or, can the equation be manipulated to remove the numerator terms?

In this case, the equation can be **simplified**:

$$f_o = \frac{1}{2\pi} \cdot \sqrt{\frac{1}{R_2 \cdot R_3 \cdot C_1 \cdot C_2} + \frac{1}{R_1 \cdot R_2 \cdot C_1 \cdot C_2}}$$

Now all the piece part parameters are in the denominator expressions. It is obvious that f_o varies **inversely** with each part.

The conclusions is that all piece parts in this equation exhibit **negative (-) directionality**.

The following equation is the dc gain of an Op Amp configured as a simple inverter. The open loop gain is "A" and the feedback resistor is " R_2 ".

$$G = \frac{-A \cdot R_2}{(A + 1) \cdot R_1 + R_2}$$

This is another example of an equation which can be easily **simplified**.

Divide the numerator and denominator by R_2 :

$$G = \frac{-A}{(A + 1) \cdot \frac{R_1}{R_2} + 1}$$

The **Directional Sensitivity** can now be determined by inspection. Increasing R_1 will increase the denominator thereby resulting in a decreasing in "G". The opposite is true for R_2 . **The conclusion then is:**

R1 Directional Sensitivity: - (Negative)

R2 Directional Sensitivity: + (Positive)

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Two methods will now be used to determine Directionality of the Sensitivity in **complex equations**.

17.15.5.2.1 Computer Program

The first method relies on a simple **computer program** which can be implemented in the programming language of your choice.

The Op Amp **gain equation** used previously is repeated here. The open loop gain "A" is replaced by a single pole model; with the pole location determined by R_3 , C.

$$G(S) = \frac{-\left[\frac{A \cdot R_2}{R_3 \cdot (R_1 + R_2) \cdot C} \right]}{S + \frac{(A+1) \cdot R_1 + R_2}{R_3 \cdot (R_1 + R_2) \cdot C}}$$

(1) Directionality of Sensitivity

It will be assumed that we are interested in the change of gain resulting from a variation in the piece part parameters. At this point we are concerned only with **directionality**.

The directionality of sensitivity is not obvious in this equation. Furthermore, the equation **does not** lend itself to **simplification**.

There are several means by which the desired information can be obtained. In this case, a **simple computer program** can be used to determine the directionality, (alternative methods such as spreadsheets, programmable calculators, etc.also can be used). See Table TABLE 17.9: for the results.

The first entry in the 'Results' table is the value of G(S) with **nominal part values**. This is used as a reference for comparison to the other table entries.

The other entries were obtained by varying each component, individually.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***Chapter 17***TABLE 17.9: COMPUTER RESULTS FOR DIRECTIONALITY OF SENSITIVITY IN COMPLEX EQUATIONS**

R1	R2	R3	C	A	[G(S)]
1000.00	10000.00	1000.00	1.60e-05	1.00e+05	-9.9989060
1500.00	10000.00	1000.00	1.60e-05	1.00e+05	-6.6661580
1000.00	10500.00	1000.00	1.60e-05	1.00e+05	-10.498800
1000.00	10000.00	1500.00	1.60e-05	1.00e+05	-9.9989140
1000.00	10000.00	1000.00	1.75e-05	1.00e+05	-9.9989070
1000.00	10000.00	1000.00	1.60e-05	1.00e+06	-9.9989900

The conclusions from this test are:

Directional Sensitivity to R_1 is: - (NEG)

Directional Sensitivity to R_2 is: + (POS)

Directional Sensitivity to R_3 is: + (POS)

Directional Sensitivity to C is: + (POS)

Directional Sensitivity to A is: + (POS).

This method can be applied to very **complex equations**. The complexity of the computer program required does not increase proportionally with equation complexity.

Another advantage to this method is that the same computer program can be used to calculate the Worst Case minimum and maximum values of the equation of interest.

(2) Magnitude of Sensitivity

The previous examples have dealt with the **Directionality** of the Sensitivity quantity. The **Magnitude** of the Sensitivity is dealt with next.

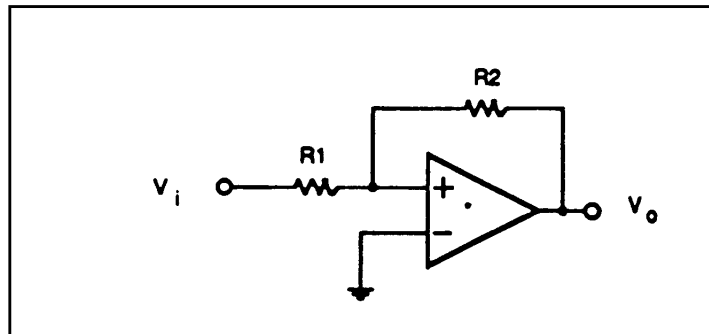
Example 1

Circuit: Inverting Amplifier

(Ideal Op Amp except for finite open loop gain).

The gain equation (V/V) for dc (freq=0) is provided below;

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND PROCEDURES***Chapter 17***FIGURE 17.17: INVERTING AMPLIFIER CIRCUIT**

$$A_v = \frac{-A \cdot R_2}{(A + 1) \cdot R_1 + R_2}$$

where “A” is the open loop gain.

Performance attribute under examination, is A,

Circuit parameters are; R_1 , R_2 , and A.

Now to **calculate the Sensitivity**:

a) Sensitivity of A_v to R_2

$$A_v = \frac{-A}{(A + 1) \cdot \frac{R_1}{R_2} + 1}$$

This equation was obtained by dividing numerator and denominator by R_2

It is obvious that R_2 has (+) **Directionality**. Now **calculate the Magnitude** via **differentiation**.

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$$\frac{dA_v}{dR_2} = \frac{A \cdot (A + 1) \cdot R_1}{[(A+1) \cdot R_1 + R_2]^2}$$

holding “A” and “R₁” constant;

Substitute nominal values used previously:

$$A = 10^5 \quad R_1 = 1000 \quad R_2 = 10000;$$

$$\frac{dA_v}{dR_2} = 0.00099979$$

This is the **Magnitude of the Sensitivity** of A_v to R₂.

It is obvious from the form of this equation that it is always greater than zero, which is in agreement with the Directionality determined previously.

b) Sensitivity of A_v to R₁

It is obvious that the **Directional Sensitivity** of A_v to R₁ is (-). Now calculate the Magnitude.

$$\frac{dA_v}{dR_1} = \frac{-A \cdot (A + 1) \cdot R_2}{[(A+1) \cdot R_1 + R_2]^2}$$

holding “A” and “R₂” constant.

Substituting nominal values for the piece parts;

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$$\frac{dA_v}{dR_1} = -0.009998$$

This is the **Magnitude of the Sensitivity** of A_v to R_1 .

The negative result confirms that the **Directionality** is negative. So far, A_v is most sensitive to changes in R_1 .

c) Sensitivity of A_v to “A” (Open loop gain)

$$\frac{dA_v}{dA} = \frac{R_2 \cdot (R_1 + R_2)}{[(A+1) \cdot R_1 + R_2]^2}$$

The form of the equation verifies that the **Directional Sensitivity** of A_v to “A” is positive.

Substituting nominal values for the piece parts;

$$\frac{dA_v}{dA} = 1.1 \times 10^{-8}$$

This is the **Magnitude of the Sensitivity** of A_v to “A”.

The sensitivity of A_v to “A” is very small as is expected for an Operational Amplifier.

Using the Directionality results, we can now calculate the **Minimum** and **Maximum Worst Case values for A_v** .

Assume the following piece part data:

$$R_1(\text{nom}) = 1000 \quad \delta R_1 = \pm 50 \quad R_2(\text{nom}) = 10000 \quad \delta R_2 = \pm 500$$

Given the **part values** and calculated **Directionality** we can now calculate the Worst Case values of gain, A_v .

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$$A_v(\text{MAX}) = \frac{A \cdot [R_{2 \text{ NOM}} + \delta R_2]}{(A+1) \cdot [R_{1 \text{ NOM}} - \delta R_1] + R_{2 \text{ NOM}} + \delta R_2}$$

$$A_v(\text{MAX}) = 11.0513 \dots \dots \dots \text{Worst Case Maximum}$$

$$A_v(\text{NOM}) = \frac{A \cdot R_{2 \text{ NOM}}}{(A+1) \cdot R_{1 \text{ NOM}} + R_{2 \text{ NOM}}}$$

$$A_v(\text{NOM}) = +9.9989 \dots \dots \dots \text{Nominal Gain,}$$

NOTE: Notice the small error due to finite open loop gain.

$$A_v(\text{MIN}) = \frac{A \cdot [R_{2 \text{ NOM}} - \delta R_2]}{(A+1) \cdot [R_{1 \text{ NOM}} + \delta R_1] + R_{2 \text{ NOM}} - \delta R_2}$$

$$A_v(\text{MIN}) = 9.04671 \dots \dots \dots \text{Worst Case Minimum}$$

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Tabular Method can also be used to facilitate calculation of Directionality.

The following Table 17.10: provides an example worksheet,(i.e., Excel or Lotus spreadsheet).

The number of calculations required can be determined from the following equation:

$$\# \text{ CALCS} = 2 * \# \text{ COMPS} + 1$$

Where;

CALCS is the number of calculations

COMPS is the number of piece parts.

EXAMPLE 2

A more complex problem; Figure 17.18, which is an ideal Op Amp.

Attribute under examination is A_{fo} center frequency voltage gain. The relevant circuit equation and is provided below:

Find: Worst Case Minimum and Maximum values of A_{fo}

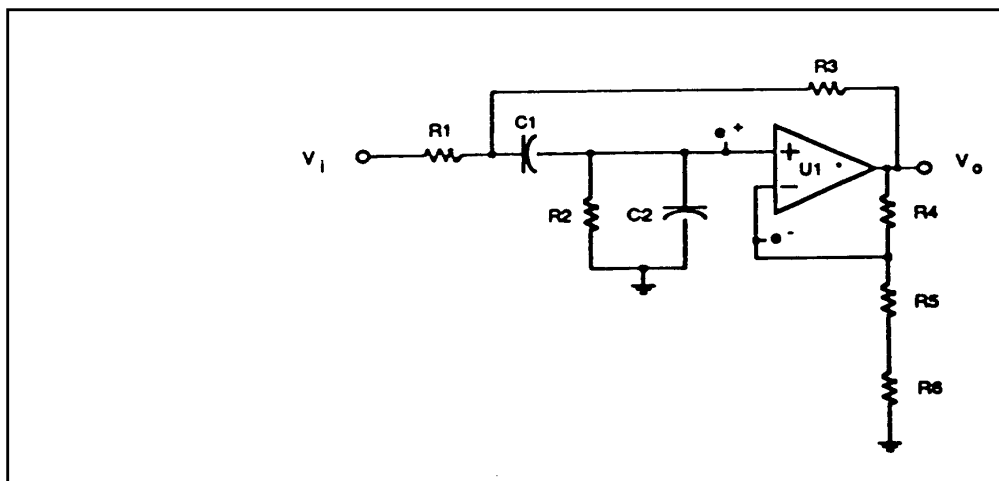


FIGURE 17.18: IDEAL OP AMP CIRCUIT

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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Design	P1 C1	P2 C2	P3 R1	P4 R2	P5 R3	P6 R4	P7 R5	P8 R6	P9	Result	DiR. of R for
Nom Value	1E-9	1E-9	22.1K	22.1K	22. 1 K	40.2 K	10K	1.21K		R _{nom}	Max P
Max. Value	1022	1022	22365.2	22365.2	22365.2	40682	10120	1224.52		11.0797	Min
Min. Value	977	977	21834.8	21834.8	21834.8	39717.6	9880	1195.48			P
Run #1	1022	1000	22100	22100	22100	40200	10000	2100		R1 12.3659	↑/
#2	977									R2 9.9935	↓
#3	1000	1022								R3 10.01512	↑/
#4		977								R4 12.3976	↑
#5		1000	22365.2							R5 11.61378	↑/
#6			21834.8							R6 10.31552	↓
#7			22100	22365.2						R7 11.4065	↑/
#8				21834.8						R8 10.7639	↓
#9				22100	22365.2					R9 10.59620	↑/
#10					21834.8					R10 11.96957	↑
#11					22100	40682				R11 12.48134	↑/
#12						39717.6				R12 9.94215	↑
#13						40200	10120			R13 10.06446	↑/
#14							9880			R14 12.32934	↑
#15							10000	1224.52		R15 10.94587	↑/
#16								1195.48		R16 11.21703	↑
#17								1210		R17 11.07974	ok/
#18										R18	
#19										R19	/
#20										R20	
#21										R21	/
#22										R22	
#23										R23	/
#24										R24	
R Max:	1022	977	22365.2	22365.2	21834.8	40682	9880	1195.48		26.74708	
R Min:	977	1022	21834.8	21834.8	22365.2	39717.6	10120	1224.52		6.95477	

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Circuit 10 KHz BP Filter

Working equation: $R = f(Po-n)$

$$A_{fo} = \frac{\frac{1}{R_1 \cdot C_2}}{\frac{R_5 + R_6}{R_4 + R_5 + R_6} \left[\frac{R_1 + R_3}{R_1 \cdot R_3} \left[\frac{1}{C_1} + \frac{1}{C_2} \right] + \frac{1}{R_2 \cdot C_2} \right] - \frac{1}{R_2 \cdot C_2}}$$

This requires **Directionality** information:The **Directional Sensitivity** is not obvious from inspection of the A_{fo} equation,We could use the **Partial Differentiation Technique**, but without computer aid this takes a long time to get the desired results.**Suggested Method:**

- (1) **Test A_{fo} equation Directional Sensitivity.** Let each component assume a maximum value, **one at a time**, while remaining components are set to their nominal values.
- (2) **Compute A_{fo} and compare** to the nominal value of A_{fo}
- (3) **Repeat** the procedure using the minimum component values

Important Results:

- (1) Directionality of A_{fo} with respect to each component.
Use Directionality results plus component extreme values to compute A_{fo} (Min), and A_{fo} (Max)
- (2) **Use** a computer program (i.e., Excel spread sheet) to exercise the A_{fo} equation for each component, then use same program to calculate A_{fo} (Max,Min).

The **tolerances** used for this example are:Resistors = $\pm 1.2\%$ Capacitors = $\pm 2.2\%$

Data Points (piece part values) used in the computer program are provided in Table TABLE 17.11:.

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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PROGRAM**

R1	R2	R3	R4	R5	R6	C1	C2	Afo	DS
22100.00	22100.00	22100.00	40200.00	10000.00	1210.00	1e-9	1e-9	11.07975	REF
22365.20	22100.00	22100.00	40200.00	10000.00	1210.00	1e-9	1e-9	11.61378	+
22100.00	22365.20	22100.00	40200.00	10000.00	1210.00	1e-9	1e-9	11.40651	+
22100.00	22100.00	22365.20	40200.00	10000.00	1210.00	1e-9	1e-9	10.31552	-
22100.00	22100.00	22100.00	40682.40	10000.00	1210.00	1e-9	1e-9	12.48134	+
22100.00	22100.00	22100.00	40200.00	10120.00	1210.00	1e-9	1e-9	10.06446	-
22100.00	22100.00	22100.00	40200.00	10000.00	1224.52	1e-9	1e-9	10.94587	-
22100.00	22100.00	22100.00	40200.00	10000.00	1210.00	1.022e-9	1e-9	12.36598	+
22100.00	22100.00	22100.00	40200.00	10000.00	1210.00	1e-9	1.022e-9	10.01512	-
21834.80	22100.00	22100.00	40200.00	10000.00	1210.00	1e-9	1e-9	10.59267	-
22100.00	21834.80	22100.00	40200.00	10000.00	1210.00	1e-9	1e-9	10.76389	-
22100.00	22100.00	21834.80	40200.00	10000.00	1210.00	1e-9	1e-9	11.98957	+
22100.00	22100.00	22100.00	39717.60	10000.00	1210.00	1e-9	1e-9	9.94215	-
22100.00	22100.00	22100.00	40200.00	9880.00	1210.00	1e-9	1e-9	12.32934	+
22100.00	22100.00	22100.00	40200.00	10000.00	1195.48	1e-9	1e-9	11.21703	+
22100.00	22100.00	22100.00	40200.00	10000.00	1210.00	0.978e-9	1e-9	9.99353	-
22100.00	22100.00	22100.00	40200.00	10000.00	1210.00	1e-9	0.978e-9	12.39763	+

The results of the program provide the required Directional Sensitivity data from which the minimum and maximum values of A_{fo} can be determined.

The minimum and maximum values of A_{fo} , and the corresponding piece part values, are in Table 17.11.

**TABLE 17.12: MINIMUM AND MAXIMUM VALUES OF A_{fo} , AND THE
CORRESPONDING PIECE PARTS**

R1	R2	R3	R4	R5	R6	C1	C2	Afo
22365.20	22365.20	21834.80	40682.40	9880.00	1195.48	102e-9	9.78e-10	26.74708
21834.80	21834.80	22365.20	39717.60	10120.00	1224.52	9.78e-10	1.02e-9	6.95477

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17.15.6 Important Points In Sensitivity Analysis

17.15.6.1 Monotonic Variation

Most circuit attributes exhibit a **Monotonic Variation** with respect to any of the circuit parameters over typical limits of the piece part parameter variability.

Result: Sensitivity does not ordinarily undergo a change in sign as parameter values move from nominal to their extreme tolerance value.

Suggestion: In order to be safe, **verify** that the monotonic/linear assumption is valid for the equation under investigation, see Figure 17.19.

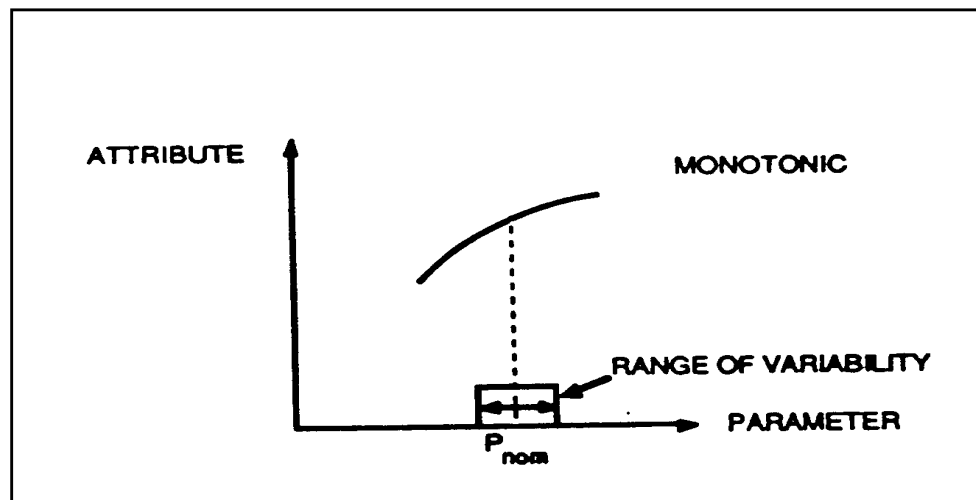


FIGURE 17.19: MONOTONICITY

17.15.6.2 Non-Monotonic Variation

An attribute exhibiting a **non-monotonic** function could result in a sensitivity sign change over the range of the parameter variation.

In the situation indicated above, **iterative testing** of **Directional Sensitivity** is recommended. A graphical example of a Non-Monotonic function is provided in Figure 17.20.

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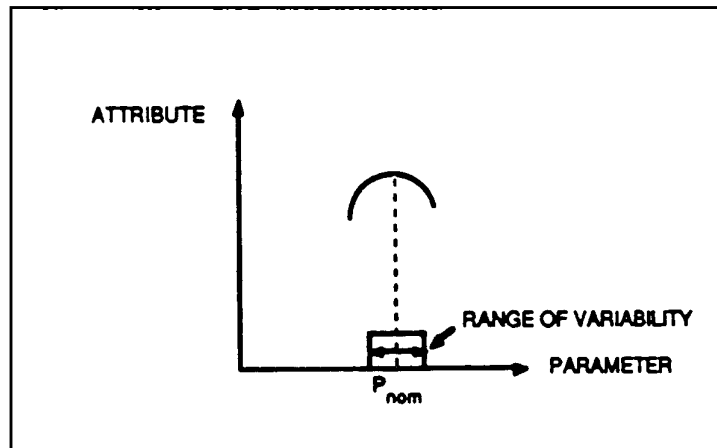


FIGURE 17.20: NON-MONOTONICITY

17.15.6.3 Sensitivity, Non-Monotonic

An **Iterative** procedure for determining Directional Sensitivity:

- (1) **Initially determine** Directional Sensitivity of the attribute to each parameter around its nominal value.
- (2) To **Re-Examine** the Directional Sensitivity of the attribute to a particular parameter at the Worst-Case performance limits (Max or Min): With all remaining parameters at their appropriate extreme value (from results of previous example) vary the particular parameter to its extreme value in a direction opposite that dictated by the results of previous example.

The resulting Sensitivity should have the same algebraic sign as that in previous example.

- (3) If a sign change has occurred now, the W.C. performance occurs with the parameter at either the opposite to that initially determined in previous example or at intermediate level. Repeat this procedure in small incremental steps.

17.15.6.4 Sensitivity, Magnitude

The use of Sensitivity Magnitude:

- (1) **In Redesign-** Circuit parameters which result in a **high product** of

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$$\frac{\partial f}{\partial x}(x - x_n)$$

have the greatest impact on the circuit attribute.

Focus on these if some redesign is necessary to reduce attribute variability (e.g., tighten purchase tolerance on high sensitivity components), see Figure 17.21.

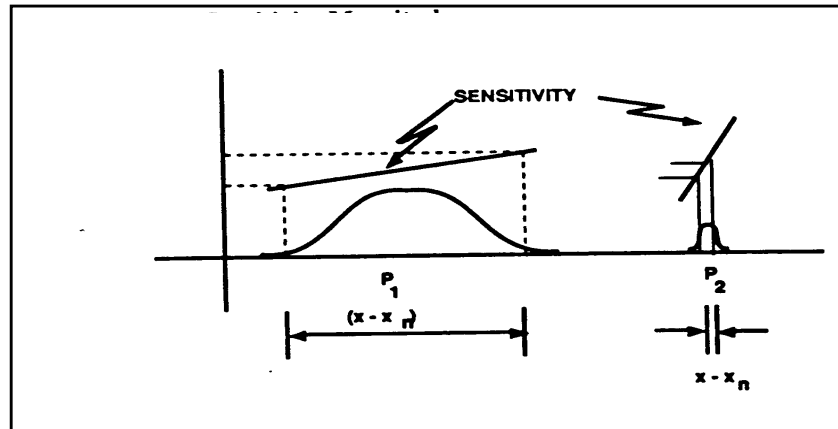


FIGURE 17.21: SENSITIVITY MAGNITUDE

- (2) **RSS ANALYSIS** - This is an alternate WCA Methodology which requires the **magnitude of the sensitivity** of each circuit parameter as an input to the analysis.

17.15.7 Sensitivity Summary

What can the **Magnitude** and **Direction of Sensitivity** be used for?

- (1) They are required when using the “**RSS**” analysis technique.
- (2) In the case of a **marginal attribute** (i.e., one that does not meet spec tolerance) **sensitivity** magnitude information indicates which part is most appropriate to change.
- (3) The **variation** in an attribute resulting from a variation in a piece part parameter can be calculated.
- (4) The Worst Case Maximum and Worst Case Minimum values of an equation, representing a circuit attribute, can be calculated.

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APPENDIX B

**WORST CASE ANALYSIS GUIDELINES
REVIEW CHECKLIST**

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 17***17.16 APPENDIX B - WORST CASE ANALYSIS GUIDELINES
REVIEW CHECKLIST**

The following checklist is provided for use in the review of a Worst Case Analysis. This checklist is provided as a guide, not as a requirement.

17.16.1 General**TABLE 17.13: GENERAL CHECKLIST**

CHECKLIST ITEMS		YES	NO
(1)	Part Derating Factors/Criteria		
(2)	Schematic Diagrams		
(3)	Functional Description		
(4)	Worst Case Analysis of Subassembly/ Components (critical ones)		
(5)	Computer Models (ADT/Daisy/Spice)		
(6)	Magnetic Designs		
(7)	Experimental Data		
(8)	Deviations		
(9)	Layout Designs		
(10)	Controlling Documents		
(11)	Requirements defined		
(12)	Parts properly selected		
(13)	Critical Parts determined and justified		
(14)	Critical Layout Items defined		
(15)	Reliability Requirements satisfied		

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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CHECKLIST ITEMS	YES	NO
(16) Worst Case Analysis done completely and accurately (using EVA, RSS or Monte Carlo Methods)		
(17) Design to Cost Requirements Satisfied		

Note: Every **non-compliant** item shall be explained.

Have each of the above items been used or reviewed in the preparation of this Worst Case Analysis?

17.16.2 Analog Circuits Checklist**TABLE 17.14: ANALOG CIRCUITS CHECKLIST**

CHECKLIST ITEMS	YES	NO	N/A
(1) Proper Decoupling provided between Signal and Power			
(2) Gain Loops verified to be stable			
(3) Adequate Amplifier Bandwidth is available			
(4) Amplifier Output Power is adequate			
(5) The Effects of Input and Output Impedance, Gain, and Phase Shift Offset Drift Noise etc. have been shown to be acceptable			
(6) Oscillator Circuits have been shown to be stable within limits of Amplitude and Frequency			
(7) Harmonic Contents and Waveforms of Oscillator Outputs are acceptable			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
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CHECKLIST ITEMS	YES	NO	N/A
(8) Oscillators are Self-Starting			
(9) Comparators are set at a proper threshold within a suitable degree of precision			
(10) Comparator Speed is adequate			
(11) Wide to eliminate Noise Problems and does not adversely affect Circuit Performance			

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PROCEDURES***Chapter 17***17.16.3 Digital Circuits Checklist****TABLE 17.15: DIGITAL CIRCUITS CHECKLIST**

CHECKLIST ITEMS	YES	NO	N/A
(1) Logic Circuits are functionally verified			
(2) Fanout does not exceed derated limits or Output Current limits are not exceeded			
(3) Unused Inputs are properly terminated			
(4) Clock and Data Inputs are properly synchronized			
(5) Setup and Release Times are adequate for Flip-Flops and Latches			
(6) Race Conditions are all eliminated			
(7) Ambiguous and unwanted Output States are prevented			
(8) A minimum number of Logic Elements are used			
(9) Unwanted States are minimized			
(10) Clock Signals are protected against negative overshoot			
(11) Minimum enable time is used			
(12) Switching Transients are prevented during Enable Clock			
(13) Oscillators are gate buffered before use as a clock			
(14) Logic Interfaces are compatible among different Logic Families and between Logic and Discrete Circuitry			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 17***TABLE 17.15: DIGITAL CIRCUITS CHECKLIST (Cont'd.)**

CHECKLIST ITEMS	YES	NO	N/A
(15) Bypass Capacitors are capable of suppressing all self-induced switching transients			
(16) Logic Power is regulated to within required limits			
(17) Additional Capacitors are placed near driving and receiving devices to suppress line induced transients			

17.16.4 Power Circuits Checklist

If not applicable to this analysis review, do not perform this section.

TABLE 17.16: POWER CIRCUITS CHECKLIST

CHECKLIST ITEMS	YES	NO	N/A
(1) Analysis of Control Loop performed to demonstrate stability with adequate Phase and Gain margins			
(2) Dynamic Range meets requirements			
(3) Regulation Ripple and Noise are within required limits			
(4) The effects of Reactive Loads on Stability Dynamic Range Regulation etc. have been determined to be within acceptable limits			
(5) Operating Frequency is chosen at the optimum value			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 17***TABLE 17.16: POWER CIRCUITS CHECKLIST (Cont'd.)**

CHECKLIST ITEMS		YES	NO	N/A
(6)	Transient response characteristic are known and are shown to meet requirements			
(7)	Input Filter is adequate to meet Conducted Emissions requirements			
(8)	Input Filter Power Stage etc. are adequate to meet Conducted Emission Susceptibility requirements			
(9)	Inrush Current is determined and shown not to exceed required maximum profile			
(10)	Output Filter is adequate to meet Output Ripple requirements			
(11)	Output Filter and Output Load are characterized for their effects on Stability Dynamic Range Regulation etc.			
(12)	Inductors are all properly suppressed			
(13)	Dry Choke possibilities are investigated and eliminated if required			
(14)	Transformer DC Imbalance is investigated and minimized if required			
(15)	Inductor Saturation from dc currents AC Voltages and Surges is addressed			
(16)	Ratio of Bop to Bmax is determined in all Magnetics			
(17)	Transformer Saturation from DC Currents AC Voltages and Surge is addressed			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 17***TABLE 17.16: POWER CIRCUITS CHECKLIST (Cont'd.)**

CHECKLIST ITEMS	YES	NO	N/A
(18) Analysis of base Drive Circuitry is provided showing adequate Turn-on Sustaining Turn-off and Hold-off capabilities			
(19) Effects of Storage time Modulation are examined in Regenerative and Proportional Base drives and shown to produce no Instabilities			
(20) Power Transistor Crossover is eliminated or its effects controlled and understood			
(21) Possibility of Mode-Shifts is integrated and shown to produce no circuit failures			
(22) Overvoltage Circuitry is provided when required			
(23) Undervoltage circuitry is provided when required			
(24) Overload Protection Circuitry is provided			
(25) Overvoltage Undervoltage and Overload Circuitry are designed to a suitable Trip-point within an adequate degree of precision.			
(26) Overvoltage Undervoltage and Overload circuitry are prevented from latching up at turn-on and are not susceptible to spurious noises.			
(27) Supply is protected against unwanted Transients at the source.			
(28) Supply meets all EMI requirements			

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*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 17***TABLE 17.16: POWER CIRCUITS CHECKLIST (Cont'd.)**

CHECKLIST ITEMS	YES	NO	N/A
(29) Components and Wiring are laid out in a manner consistent with good design practices			
(30) Snubbers are used where practical to reduce Emissions and improve Reliability			
(31) Interface Impedance are all defined			
(32) Power-up and Power-down sequences are understood and all unwanted events are prevented during these periods			
(33) A sufficient number of Test Points are provided			
(34) Test Points are adequately protected against ground and power faults			
(35) All interface Pins and Wire Routings are separated by category as required			
(36) Proper shielding and isolation are provided as appropriate			
(37) Proper ground isolation is provided as required			
(38) Proper wire sizes are chosen			
(39) All component stresses are determined and are within Derated limits			
(40) Voltage Stresses DC and AC are determined for all components			
(41) Current Stresses DC and AC are determined for all components			

*Engineering Standard Practice***RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES***Chapter 17***TABLE 17.16: POWER CIRCUITS CHECKLIST (Cont'd.)**

CHECKLIST ITEMS	YES	NO	N/A
(42) Power dissipation is determined for all components dissipating appreciable power			
(43) Self-heating effects are determined and controlled for all components dissipating appreciable power			
(44) The effects of the native environment are considered in determining component tolerances gain reliability etc.			
(45) The effects of aging are considered in determining component tolerances gain reliability etc.			
(46) Power switch circuitry grounds and signal grounds are properly isolated			
(47) Relay Coils are properly suppressed			
(48) Rise and fall times of relay circuit and the duration of contact bounce down are acceptable			
(49) Secondary breakdown in solid-state Switches is suitably avoided			
(50) Switch circuitry is properly decoupled			
(51) Contact ratings or current and voltage ratings are not exceeded			
(52) Sufficient drive capabilities are provided			
(53) Power FET dV/dT and dI/dT are less than 50% of rating			

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Engineering Standard Practice

**RELIABILITY AND MAINTAINABILITY POLICIES AND
PROCEDURES**

Chapter 17

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