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**EFFECTS OF DORMANCY ON NONELECTRONIC
COMPONENTS AND MATERIALS**

D. F. Cottrell, et al

Martin Marietta Aerospace

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Rome Air Development Center

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et al**

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FOREWORD

This final report was prepared by the Orlando Division of Martin Marietta Aerospace, Orlando, Florida, under Contract No. F30602-73-C-0185 and Job Order No. 55190267. This report is submitted as the technical report input for CDRL Sequence No. A003. It covers the period from May 1973 to June 1974. This report was prepared under the direction of Mr. T. R. Gagnier. Major technical contributors to the report were J. A. Bauer, L. G. Buchy, D. F. Cottrell, T. R. Gagnier, N. Johnson, Jr., E. W. Kimball, T. E. Kirejczyk, N. Moya, E. Sonnenshine, W. Verreen, and E. L. Weaver. The RADC Project Engineer was Mr. Donald W. Fulton (RBRS).

This report has been reviewed by the Office of Information, RADC, and approved for release to the National Technical Information Service (NTIS).

This report has been reviewed and is approved.

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ABSTRACT

Martin Marietta conducted a 12-month program to collect and analyze reliability data on nonelectronic components and materials in the dormant mode. Approximately 170 billion part-hours of dormant data were collected on approximately 90 different component/part types. This report contains a complete listing by component/part type of the data collected and the resulting dormant failure rates.

CONTENTS

1.0	INTRODUCTION	1
2.0	SUMMARY	3
3.0	DATA ANALYSIS	5
3.1	Statistical Methods, Assumptions, and Ground Rules	5
3.1.1	Assumption of Exponential Distribution	5
3.1.2	Calculation of Confidence Limits	5
3.1.3	Statistical Test for the Equality of Two Life Distributions	6
3.2	Part Classes and Failure Rates	9
4.0	RELIABILITY MODELS	19
4.1	Service Life Model	19
4.2	Dormancy Models	21
4.2.1	No Test Concept	25
4.2.2	Periodic Test Concept	25
5.0	CONCLUSIONS AND RECOMMENDATIONS	31
5.1	Conclusions	31
5.2	Recommendations	31
6.0	REFERENCES	33
7.0	BIBLIOGRAPHY	35
	APPENDIX A DATA COLLECTION	39

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ILLUSTRATIONS

4.1-1	Service Life Model for Dormant Missile with Constant Monitor	20
4.2.1-1	Reliability Degradation with No Test Deployment Concept . .	26
4.2.2-1	Missile Reliability after 5 Years of Dormant Deployment Under "Wooden Round" and Periodic Test Concept	29

TABLES

2.0-I	Summary of Dormancy Data Collected	3
3.2-I	Summary of Dormancy Data Collected by Part Type and Environment	10
4.2-I	Electronic Parts List and Failure Rates for a Hypothetical Tactical Missile	22
4.2-II	Nonelectronic Parts List and Failure Rates for Hypothetical Tactical Missile	23
4.2-III	Electronic and Nonelectronic Failure Rates for Hypothetical Missile	24

1.0 INTRODUCTION

In the past, the complex electronics portion of a system contributed the major part of the total system failure rate. More recently, as the reliability of electronic parts has increased because of the continuing development in solid state technology and increased emphasis on screening tests, nonelectronic component reliability has become a primary factor in system survivability. This is especially true for systems designed for long term dormant installation. Therefore, a pressing need developed for dormant failure rates for nonelectronic components.

This need prompted Rome Air Development Center (RADC) to award a contract to Martin Marietta in May 1973:

"Effects of Dormancy on Nonelectronic Components and Materials,"
Contract F30602-73-C-0185

The objective of this contract, as the title implies, was to determine the effects of dormancy on the reliability of nonelectronic components and materials. This report details the result of that contractual effort. The effort included an extensive data collection and analysis program followed by the compilation of dormant failure rates for nonelectronic components. A discussion of the statistical methods and ground rules used in analyzing the data is also provided.

In this study the term "nonelectronic" refers to mechanical, electromechanical, optical, and rotating components/parts. Dormancy is the state wherein a device, a component, or a part is connected to a system in the normal operational configuration and experiences below normal or periodic structural, mechanical, electrical, or environmental stresses for prolonged periods up to five years or more before being used in a mission.

2.0 SUMMARY

This report comprises the results of a 12-month program conducted by Martin Marietta Aerospace. The purpose of the program was to collect and analyze reliability data on nonelectronic components and materials in the dormant mode.

The data were obtained as a result of an extensive data collection program which extended to private contractors, government facilities, research institutions, and educational institutions throughout the country. The collected data were grouped, analyzed, and statistically tested. This report contains a complete listing by component/part type of the data collected.

Approximately 170 billion part-hours of dormant data have been collected covering 90 major part classes and subclasses. Table 2.0-I summarizes the quantity of part-hours collected for both the submarine and ground environments.

TABLE 2.0-I

Summary of Dormancy Data Collected

Environment	Part-Hours (Millions)
Ground	167,455.012
Submarine	<u>193.078</u>
Total	167,648.090

Only dormancy data for the ground and submarine environments were available from the more than 400 data sources contacted during this program. As a direct result, data on other environments such as spaceflight, airborne, shipboard, helicopter, or missile launch, could not be obtained and included even though they were requested and sought. The reason for the scarcity of dormancy data in these other environments becomes apparent upon examination. This scarcity can be directly attributed to the fact that, under normal mission requirements encountered in other than ground stationary or submarine environments, nonelectronic parts, components, or devices are primarily operating rather than dormant. Only in the cases where redundant or standby systems are employed could some part or components have been considered dormant. Again such data were not available.

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3.0 DATA ANALYSIS

3.1 Statistical Methods, Assumptions, and Ground Rules

Failure data on nonelectronic components in a dormant environment have been collected, analyzed, and summarized in the form of failure rates for individual component types. The following sections describe the basic ground rules and assumptions used in this analysis, and also describe the statistical tests utilized. The methods used in calculating failure rates and associated confidence limits are also included. Examples are given for the statistical tests and for the calculation of confidence limits.

3.1.1 Assumption of Exponential Distribution

It is generally accepted that failure times for most electronic parts are exponentially distributed. Although this acceptance does not extend to the majority of nonelectronic components, the assumption of the exponential failure distribution ordinarily is used, nevertheless, in performing reliability calculations for these components. There are two primary factors involved in the widespread use of this assumption:

1. There is a pronounced lack of time-to-failure data on most nonelectronic components with which to determine a more descriptive failure distribution.
2. It would take a combination of both large sample sizes and long periods of time in a dormant environment to observe enough failures to statistically determine a more descriptive dormant life cycle failure distribution with any degree of precision and confidence.

Both factors were evident during the data collection phase of this study program. Most sources could provide only the total quantity of part-hours and failures rather than time-to-failure data. Therefore, it was necessary to assume the exponential distribution during the calculation of failure rates for this program.

3.1.2 Calculation of Confidence Limits

Two-sided limits of a 90% confidence interval have been derived for the failure rates in this report with one general exception:

When the part type under evaluation had zero failures, the failure rate point estimate was calculated as a function of total part hours and the Chi-Square (χ^2) value obtained from the upper single-sided 60% confidence level at $2r+2$ degrees of freedom. Therefore, no confidence limits are given for failure rates calculated in this manner.

Assuming the data are time truncated, the upper confidence limit can be obtained using the component part-hours and the upper 95% Chi-Square value at $2r+2$ degrees of freedom, where r is the number of observed failures. The lower limit value is obtained using the component part-hours and the lower 5% Chi-Square value at $2r$ degrees of freedom.

The general equations used for obtaining the upper and lower confidence limits on the component failure rates in this report are as follows:

$$\frac{\chi^2(\alpha/2, 2r)}{2T} = \text{Lower Confidence Limit}$$

$$\frac{\chi^2(1-\alpha/2, 2r+2)}{2T} = \text{Upper Confidence Limit}$$

where:

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

$\alpha/2$ = the 5% percentile coordinate used to determine the χ^2 value at the lower confidence limit

$1-\alpha/2$ = the 95% percentile coordinate used to determine the χ^2 value at the upper confidence limit

T = the total number of component part-hours.

For example, 5 failures have been observed during 2.002×10^6 part-hours in a dormant submarine environment on hydraulic servo valves. The failure rate and associated 90% two-sided confidence limits, based on a table of χ^2 values from Reference 1, are as follows:

$$\text{Failure rate} = \frac{\text{failures}}{\text{part-hours}} = \frac{5}{2.002 \times 10^6} = 2.498 \frac{\text{failures}}{10^6 \text{ part-hours}}$$

$$\begin{aligned} \text{Lower 90\% Confidence Limit} &= \frac{\chi^2(.05, 10)}{2T} = \frac{3.94}{4.004 \times 10^6} \\ &= 0.984 \text{ failures}/10^6 \text{ part-hours} \end{aligned}$$

$$\begin{aligned} \text{Upper 90\% Confidence Limit} &= \frac{\chi^2(.95, 12)}{2T} = \frac{21.0}{4.004 \times 10^6} \\ &= 5.245 \text{ failures}/10^6 \text{ part-hours} \end{aligned}$$

3.1.3 Statistical Test for the Equality of Two Life Distributions

It is generally accepted that environments such as airborne, helicopter, and ground have significantly different effects on the components operating within them. Hence, the failure rate of an item can be

seen to vary depending upon the environment in which it is being applied. However, situations exist which are not as obvious and hence, as easily answered. For instance, are there significant differences between the submarine dormant and ground dormant environments? Are there significant differences in a component failure rate between storage and dormancy? The literal differences between dormancy and storage are defined as follows:

Dormancy is the state wherein a component or equipment is connected to a system in the normal operational configuration and experiences below normal and/or periodic operational stresses and environmental stresses. The system may be in a dormant state for prolonged periods (up to five years or more) before being used in a mission.

Storage is defined as the state wherein a device is not connected to a system, but is packaged for preservation and experiences somewhat benign environments.

To answer the question of dormancy versus storage, a statistical test for the equality of two life distributions was performed on data at the component level. In the majority of tests, the failure rates for these two modes proved not to be significantly different. Therefore, the storage and dormant part type data were combined and identified as being dormant. Brownlee's test, the statistical test used in making the above determination, was obtained from Reference 2 and is described with an example in the following paragraphs.

Let f_1 and t_1 be from population 1 and f_2 and t_2 from population 2 where f_i is the number of failures observed in t_i part hours from the i^{th} population. The failure rate of the i^{th} population can then be estimated as $\lambda_i = f_i/t_i$. A test of the null hypothesis, $H_0: \lambda_1 = \lambda_2$ versus the alternative hypothesis, $H_a: \lambda_1 > \lambda_2$ with significance level α is desired. The procedure for the test is as follows:

- A. Choose notation such that $\frac{f_1}{t_1} > \frac{f_2}{t_2}$
- B. Calculate the statistic $\hat{F} = \left[\frac{f_1}{f_2 + 1} \right] \left[\frac{t_2}{t_1} \right]$
- C. Determine the rejection value $F_r = F_\alpha (\gamma_1, \gamma_2)$ from a table of the "F distribution" for $\gamma_1 = 2(f_2 + 1)$ degrees of freedom and $\gamma_2 = 2f_1$ degrees of freedom.
- D. If $\hat{F} \geq F_r$, reject H_0 and accept H_a declaring that populations 1 and 2 have different failure rates. If $\hat{F} < F_r$, additional consideration is necessary before accepting H_0 and stating that populations 1 and 2 are identical. If the differences between λ_1 and λ_2 is small, a large quantity of data will be

needed for it to be detected. If the experimenter deems that sufficient data are present to detect any important difference in the two populations, then $F < F_r$ does imply that H_0 should be accepted and the two populations can be declared identical.

Brownlee's test requires that an estimate of the failure rate exists for both of the populations being compared. Thus, if no failures have been observed in either population, then Brownlee's test cannot be applied.

An example of this test is demonstrated by data on relays:

Nonoperating Condition	Failure Rate $\lambda_1 \times 10^{-6}$	Failures f_1	Part-hours t_1
Storage	0.034	18	523.000×10^6
Dormant	0.016	1	64.413×10^6

Since the ratio, f_1/t_1 , is greatest for the storage condition, it will be deemed population 1, thereby making the dormant condition population 2. Then,

$$F = \left[\frac{f_1}{f_2 + 1} \right] \left[\frac{t_2}{t_1} \right]$$

$$F = \left[\frac{18}{2} \right] \left[\frac{64.413}{523.000} \right]$$

$$F = 1.108$$

By looking in the tables of the F statistic in Reference 4 for the value of F at the 10% level of significance with 38 and 2 degrees of freedom, the value is:

$$F_r = F_{0.90(38,2)} \approx 9.47$$

Since $F < F_r$, the null hypothesis, $H_0: \lambda_1 = \lambda_2$, is accepted. This indicates that there is no significant difference between the failure rates and that the storage and dormant environments can be combined for this particular part type.

In analyzing submarine dormant and ground dormant failure data, statistical determination of differences between the two modes was obviated by lack of sufficient amounts of data to deem any results significant at a high degree of confidence. Since statistically significant differences were found between both environments in the operating mode, the decision was reached to list the dormant ground and dormant submarine environments separately.

3.2 Part Classes and Failure Rates

The primary tasks involved in this program have been the collection, study, and analysis of reliability data on nonelectronic components and materials in the dormant mode. These data, so collected, studied, and analyzed, have been categorized by specific component type and environmental application. The results are presented in Table 3.2-I. No aging tests of components have been done to obtain data, but rather an extensive data survey and collection effort was undertaken to locate and obtain necessary data. Appendix A lists the sources from which the data were collected.

The equipment studied were typical of those used in performing non-electronic or electromechanical functions in normal military applications.

Component failure is defined as the inability of the component to properly perform its intended function, resulting in its being repaired or replaced. Whenever detailed failure information were available, all secondary failures, premature removals, procedural, and personnel errors were censored.

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

For most nonelectronic components, quality grades are not well defined. This is quite the opposite of electronic parts which have military standards and specifications delineating specific quality grades. Information concerning component quality was rarely available from the contributors since it would have required additional time and manpower to search through component specifications and drawings. Data source contributors are generally reluctant to incur large expenditures to further refine the free data and information that they provide. They are also hesitant to allow visitors unrestricted access to their detailed records. Quality levels could not be synthesized and are not indicated in Table 3.2-I. The basic assumption made in constructing Table 3.2-I is that this table contains average failure rates for parts over the quality grade spectrum specified for and used in most military equipment. For components which the user knows to be either well above or below the average quality grade, a failure rate may be chosen between the upper and lower confidence limits given for many of the failure rate entries in Table 3.2-I. Each value shown in this table for the various failure rate entries is in failures per million part-hours (failures/10⁶) of field experience.

TABLE 3.2-1

Summary of Dormancy Data Collected by Part Type and Environment

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
ACCELEROMETERS						
Linear	Ground	0	0.456	2.009	-----	-----
Angular	Ground	0	0.252	3.664	-----	-----
Pendulum	Ground	6	3.119	1.924	0.836	3.799
ACCUMULATORS						
Hydraulic	Ground	0	3.051	0.3000	-----	-----
ACTUATORS						
Linear, Hydraulic	Ground	0	31.000	0.030	-----	-----
	Submarine	5	6.012	0.832	0.328	1.747
Linear, Pneumatic	Ground	0	0.628	1.459	-----	-----
Explosive	Ground	13	207.100	0.063	0.037	0.100
BATTERIES						
Rechargeable	Ground	2	313.175	0.006	0.001	0.020
BEARINGS						
Ball	Ground	4	351.520	0.011	0.004	0.026
	Submarine	3	1.002	2.994	0.818	7.735
BELLOWS						
General	Ground	0	13.520	0.068	-----	-----
Explosive	Ground	0	65.600	0.013	-----	-----
BLOWERS AND FANS						
General	Ground	0	2.210	0.414	-----	-----

TABLE 3.2-I (Cont'd)

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
BLOWERS AND FANS (cont.)						
Axial	Ground	0	7.260	0.125	-----	-----
Centrifugal	Ground	0	0.410	2.234	-----	-----
BOARDS						
Printed Circuit	Ground	1	1210.000	0.00083	0.00004	0.00392
CAPACITORS, VARIABLE						
Air	Ground	1	40.630	0.025	0.001	0.117
Glass	Ground	0	8.840	0.104	-----	-----
CIRCUIT PROTECTION DEVICES						
Fuse	Ground	0	2.079	0.441	-----	-----
Electrical Surge Arrester, Spark Discharge	Ground	1	84.790	0.012	0.0006	0.056
COMPUTER PERIPHERAL DEVICES						
Magnetic Cores	Ground	0	35799.142	0.000025	-----	-----
Memory Disc	Ground	1	6.760	0.148	0.008	0.702

TABLE 3.2-I (Cont'd)

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
CONNECTIONS						
Solder	Ground	0	34900.000	0.000026	-----	-----
CONNECTORS						
General	Ground	17	11603.406	0.0015	0.0009	0.0022
	Submarine	0	6.288	0.146	-----	-----
CONNECTOR PINS	Ground	0	79861.280	0.0000115	-----	-----
DIAPHRAGM, BURST	Ground	0	0.662	1.384	-----	-----
ENGINES, DIESEL	Ground	7	7.792	0.898	0.422	1.688
FILTERS, NONELECTRIC						
Liquid	Ground	0	26.562	0.035	-----	-----
FITTINGS						
Quick Disconnect, Liquid	Ground	0	0.662	1.384	-----	-----
	Submarine	4	8.012	0.499	0.170	1.142
Hydraulic	Ground	0	0.330	2.776	-----	-----
GASKETS & SEALS						
Gasket	Ground	0	81.120	0.011	-----	-----
Seal	Ground	0	40.560	0.023	-----	-----
O-Ring	Ground	0	11.699	0.078	-----	-----
Packing	Ground	0	581.360	0.0015	-----	-----

TABLE 3.2-I (Cont'd)

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
GYROS						
Rate	Ground	18	34.367	0.524	0.339	0.777
HEATERS, ELECTRICAL	Ground	0	2.578	0.355	-----	-----
HOSES						
Flexible Metal	Submarine	7	4.009	1.746	0.819	3.280
IGNITION PARTS & EXPLOSIVES						
Igniter, Solid Propellant	Ground	0	1.714	0.534	-----	-----
Igniter, Electric	Ground	10	516.500	0.019	0.011	0.033
Explosive Squib	Ground	0	1.719	0.533	-----	-----
Explosive Bolt	Ground	0	16.300	0.056	-----	-----
Explosive Motor	Ground	0	23.900	0.038	-----	-----
Explosive Switch	Ground	2	415.000	0.0048	0.0009	0.015
Explosive Timer	Ground	0	28.200	0.032	-----	-----
Squib Switch	Ground	0	2.610	0.326	-----	-----
MANIFOLDS	Ground	0	0.495	1.851	-----	-----
	Submarine	2	2.002	0.999	0.178	3.147

TABLE 3.2-1 (Cont'd)

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
MECHANISMS, POWER TRANSMITTAL						
Gearbox	Ground	1	6.850	0.146	0.008	0.693
Coupling	Ground	0	2.079	0.441	-----	-----
MOTORS, ELECTRICAL						
Instrumentation	Ground	0	0.160	5.725	-----	-----
Torque, DC	Ground	0	4.158	0.220	-----	-----
3 H.P., AC	Submarine	1	2.004	0.499	0.026	2.368
GENERATORS, AC	Ground	11	13.827	0.796	0.445	1.316
PUMPS						
Fuel	Ground	0	8.070	0.114	-----	-----
Hydraulic	Ground	0	21.375	0.043	-----	-----
	Submarine	3	2.004	1.497	0.409	3.867
REGULATORS						
Temperature	Ground	0	5.024	0.182	-----	-----
RELAYS						
General	Ground	19	587.413	0.032	0.028	0.057
	Submarine	0	144.169	0.006	-----	-----
Crystal Can, Latching	Ground	0	43.469	0.021	-----	-----
Latching, General	Ground	1	12.333	0.081	0.004	0.385

TABLE 3.2-1 (Cont'd)

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
MECHANISMS, POWER TRANSMITTAL						
Gearbox	Ground	1	6.850	0.146	0.008	0.693
Coupling	Ground	0	2.079	0.441	-----	-----
MOTORS, ELECTRICAL						
Instrumentation	Ground	0	0.160	5.725	-----	-----
Torque, DC	Ground	0	4.158	0.220	-----	-----
3 H.P., AC	Submarine	1	2.004	0.499	0.026	2.368
GENERATORS, AC						
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TABLE 3.2-1 (Cont'd)

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
RELAYS (cont.)						
Thermal	Ground	0	0.458	2.000	-----	-----
Non-Latching, General	Ground	0	9.363	0.098	-----	-----
RESISTORS, VARIABLE						
General	Ground	0	46.127	0.020	-----	-----
	Submarine	1	10.566	0.095	0.005	0.449
Plastic	Ground	0	0.756	1.212	-----	-----
Wirewound	Ground	4	24.604	0.163	0.055	0.372
RESOLVERS	Ground	2	14.196	0.141	0.025	0.14
SLIP RING ASSEMBLIES	Ground	0	8.316	0.110	-----	-----
SOLENOIDS	Ground	0	3.056	0.300	-----	-----
SWITCHES						
General	Ground	0	43.378	0.021	-----	-----
Inertial	Ground	9	137.100	0.066	0.034	0.115
Pressure	Ground	4	48.300	0.083	0.028	0.189
Pushbutton	Ground	0	0.603	1.519	-----	-----
Sensitive	Ground	0	1.644	0.557	-----	-----
Stepping	Ground	2	5.000	0.400	0.071	1.260
Toggle	Ground	0	1.010	0.907	-----	-----

TABLE 3.2-1 (Cont'd)

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
TANKS						
Compressed Gas	Ground	1	4.211	0.237	0.012	1.127
TRANSDUCERS						
Pressure	Submarine	4	2.002	1.998	0.682	4.570
TRANSFORMERS, VARIABLE						
	Ground	0	0.662	1.384	-----	-----
TURBINES						
Rocket Engine	Ground	0	3.680	0.249	-----	-----
VALVES						
General	Ground	0	54.210	0.017	-----	-----
Sequence	Ground	1	5.150	0.194	0.010	0.921
Solenoid	Ground	0	0.550	1.665	-----	-----
Valve, Freon	Ground	0	0.662	1.384	-----	-----
Valve, Fuel						
General	Ground	0	7.220	0.127	-----	-----
Fuel Check	Ground	1	4.250	0.235	0.012	1.116
Fuel Pressure Regulator	Ground	0	0.383	2.392	-----	-----

TABLE 2.2-1 (Cont'd)

PART TYPE	ENVIRONMENT	FAILURES (F)	PART HOURS (x10 ⁶)	FAILURE RATES (F/million part hours)		
				Best Estimate	90% CONFIDENCE	
					LOWER	UPPER
VALVES (cont.)						
Valve, Hydraulic						
General	Submarine	1	1.002	0.998	0.051	4.736
Hydraulic Ball	Ground	0	2.447	0.374	-----	-----
Hydraulic Relief	Ground	0	0.727	1.260	-----	-----
	Submarine	1	2.004	0.499	0.026	2.368
Hydraulic Restrictor	Ground	0	0.165	5.552	-----	-----
Hydraulic Servo	Ground	1	2.080	0.481	0.025	2.281
	Submarine	5	2.002	2.498	0.984	5.245
Valve, Pneumatic						
General	Ground	1	4.670	0.214	0.011	1.016
Pneumatic Check	Ground	0	4.140	0.221	-----	-----
Pneumatic Pressure Regulator	Ground	0	0.628	1.459	-----	-----

4.0 RELIABILITY MODELS

In recent years, an increasing number of electronic systems have been developed which are likely to be in a nonoperating or dormant mode for long periods, varying from a year to 5 or 10 years, before being used in their intended missions or replaced. In many instances, after having first been in a dormant environment for extended periods of time, these systems must be capable of operating successfully when called upon either without warning, or with very short notice. In order to predict the system probability for successfully completing a mission at any point in time under conditions as described above, mathematical or service life models which accurately portray the life cycle of a system must be developed.

4.1 Service Life Model

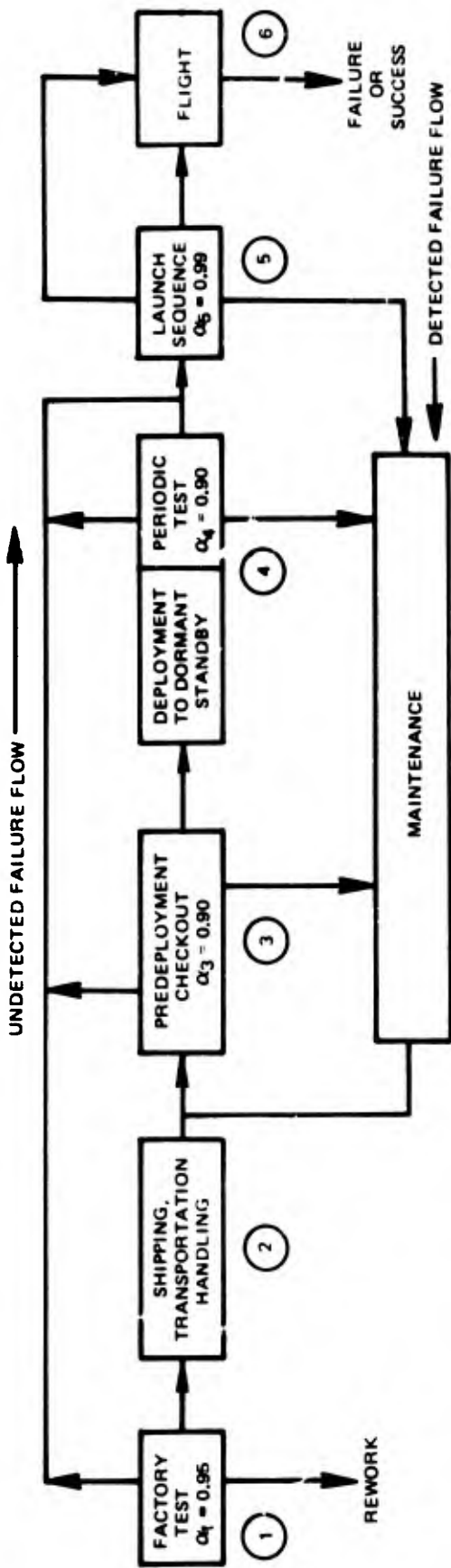
The basic modeling techniques required for the prediction of system reliability in the dormant mode were established and validated in 1967 in Reference 3 and updated in 1973 in Reference 4. These basic techniques were primarily for electronic systems or the electronic portion of a system with a heterogeneous part mixture. This was due to a general lack of well documented dormant failure rate data on nonelectronic components. With the addition of the nonelectronic dormant failure rates generated during this study, service life models can be applied to entire systems with much more accuracy.

The service life model evaluates system reliability in terms of system design characteristics and useful deployment schemes, which include the effects of:

- 1 Service life environmental (deployment) modes
- 2 Expected time in each mode
- 3 Failure detection capability of the system
- 4 Accumulation of failures from the operating and dormant environments
- 5 Frequency of periodic test and checkout.

A simplified service life model is shown in Figure 4.1-1 for a theoretical missile system which is periodically monitored for failures after deployment. From the figure, note that the predicted reliability of the missile, after being in a dormant environment, is a function of:

- 1 The undetected failures accumulated from prior modes
- 2 The dormancy failure rate and time in dormancy



1 UNDETECTED FAILURES THROUGH MODE 4: $F_4 = 0.05 \lambda_1 t_{D_1} + 0.10 (\lambda_2 t_{D_2} + \lambda_3 t_{D_3}) + 0.90 \lambda_4 t_{D_4}$

SYSTEM RELIABILITY THROUGH MODE 4: $R_4 = e^{-F_4}$

2 FAILURES DETECTED DURING MODE 5: $F_5 = 0.99 [F_4 + \lambda_5 t_{D_5}]$

PROBABILITY OF PASSING MODE 5: $R_5 = e^{-F_5}$

3 UNDETECTED FAILURES PASSED TO MODE 6: $F_6 = 0.01 [F_4 + \lambda_5 t_{D_5}]$

FLIGHT RELIABILITY: $R_6 = e^{-F_6}$

Figure 4.1-1 Service Life Model For Dormant Missile with Periodic Test

3 The effectiveness or testability factor, α_1 , of the system.

An example relating to this model will be given in the following sections.

4.2 Dormancy Models

As evidenced by Figure 4.1-1, the service life of a system encompasses several phases such as factory test, deployment, and final end use. Therefore, within the overall service life model, individual submodels can be developed to depict the system reliability during these different phases. For many military systems the deployment mode initiates a long period of dormancy before the system is used in its intended mission. Two basic types of deployment techniques exist for dormant systems, the "no test" concept and the "periodic test" concept. Dormancy models have been developed for each of these deployment techniques to provide accurate estimates of system reliability at any time during the dormant period.

The "no test" model, used in conjunction with the most basic deployment survival technique, predicts the reliability of systems designed to the "wooden round" concept. Under this concept, the system deployed may be in a storage or dormant state for as long as 10 years; yet, it is never tested or is tested just before being used in its intended mission. For some of the less complex systems, the utility, applicability, and simplicity of this technique provides a most effective deployment concept. However, as system complexity increases, other means must be found to assure that an acceptable level of reliability is maintained throughout deployment.

The second deployment survival technique is used for higher complexity systems which can experience considerable degradation over long periods of dormancy. In this technique, which is the periodic test concept, the deployed system is tested at periodic intervals, such as every 6 months, and any necessary repairs are made after each test.

A third deployment technique, the constant monitor concept, has been used occasionally but will not be considered in this analysis. With this technique the system is constantly operating at very low level power such that failures are detected immediately.

To visualize the differences between the two basic deployment survival techniques, examples are provided which compare the effects and results of each method through respective service life mathematical models. A hypothetical tactical missile will be evaluated during its deployment period. The missile is constructed of high reliability electronic components and standard grade nonelectronic items. Also, the missile is to be contained in a controlled dormant environment during deployment. Parts lists for the primary electronic and nonelectronic components are given in Table 4.2-I and Table 4.2-II respectively. These tables also provide the operating and dormant failure rates for the individual parts/components. Table 4.2-III contains the combined electronic and nonelectronic component failure rates in the ground operating and dormant configurations.

TABLE 4.2-1
Electronic Parts List and Failure Rates for a Hypothetical Tactical Missile

Part Type	Quantity Used (P)	Dormancy Failure Rates* failures/10 ⁶ part-hours A _D	P _T	Operating Failure Rate* failures/10 ⁶ part-hours λ _T	P _E
Capacitor, Ceramic	662	0.0007	0.46340	0.0080	5.2960
Glass	34	0.0001	0.00340	0.0026	0.0884
Plastic	11	0.0015	0.01650	0.0044	0.0494
Solid Tantalum	368	0.0005	0.18400	0.0014	0.5152
Variable Glass	5	0.0050	0.02500	0.0150	0.0750
Resistor, Carbon Composition	5	0.00007	0.00035	0.0050	0.0250
Metal Film	1,841	0.0001	0.18410	0.0002	0.0002
Power Wirewound	837	0.0005	0.41850	0.0750	0.3685
Precision Wirewound	427	0.0010	0.42700	0.0680	0.2736
Transistor, Low Power NPN	706	0.0010	0.70600	0.1040	0.73420
High Power NPN	112	0.0070	0.78400	0.4320	48.3840
Low Power PNP	127	0.0015	0.19050	0.1240	15.7480
High Power PNP	82	0.0100	0.82000	0.7660	62.8120
Diode, Low Power	1,462	0.0003	0.43860	0.0226	33.0410
Medium Power	259	0.0010	0.25900	0.0630	16.3170
High Power	5	0.003	0.01500	0.0940	0.4700
Low Power Zener	161	0.0007	0.11270	0.1180	18.9980
Integrated Circuit, Digital	1,926	0.0020	3.85200	0.1600	308.1600
Integrated Circuit, Linear	468	0.0070	3.27600	0.4800	224.6400
Hybrid, Thin Film	81	0.0200	1.62000	3.0000	243.0000
Filter	18	0.0044	0.07920	0.1085	1.9530
Coil	57	0.0030	0.17100	0.0925	5.2725
Connector	415	0.0020	0.83000	0.0880	36.5200
TOTALS	10,069		14.87625		1,186.9667

*Failure rates are for a high reliability class of parts (ER, TX, or MIL-STD-883 Class B)

TABLE 4.2-II

Nonelectronic Parts List and Failure Rates for Hypothetical Tactical Missile

	Quantity (P)	Dormant Failure Rate (failures/10 ⁶ pt-hrs) (λ_{DN})	$P(\lambda_{DN})$	Operating Failure Rate (failures/10 ⁶ pt-hrs) (λ_{EN})	$P(\lambda_{EN})$
Accelerometer	2	2.009	4.018	52.523	105.046
Accumulator, Hydraulic	2	0.300	0.600	7.351	14.702
Actuator, Linear	4	0.030	0.120	15.228	60.912
Connector, General	209	0.0015	0.314	0.515	107.635
Filter, Liquid	6	0.035	0.210	2.987	17.922
Fitting, Quick Disconnect	4	* 0.374	1.496	** 7.800	31.200
Gyro, Rate	3	0.524	1.572	137.950	413.850
Pump, Hydraulic	1	0.043	0.043	1.675	1.675
Resolver	1	0.141	0.141	18.443	18.443
Switch, Pressure	4	0.083	0.332	2.095	8.380
Valve, Hydraulic Servo	8	0.481	3.848	** 12.298	98.384
Valve, Solenoid	<u>1</u>	1.665	<u>1.665</u>	2.404	<u>2.404</u>
Totals	245		14.359		880.553

*Synthesized failure rate given in Reference 4.

**Estimated

TABLE 4.2-III

Electronic and Nonelectronic Failure Rates
For Hypothetical Missile

Part Category	Dormant Failure Rate (failures/10 ⁶ part-hours)	Operating Failure Rate (failures/10 ⁶ part-hours)
Electronic	14.876	1186.967
Nonelectronic	14.359	880.553
Totals	29.235	2067.520

In referring to Figure 4.1-1, mode 4 of the service life model (deployment) is the only variation to be considered in the following examples. Therefore, the undetected failures through mode 3 can be calculated to determine the missile reliability, R_3 , at the end of mode 3 or at the beginning of deployment:

$$F_3 = (1 - \alpha_1) \lambda_E t_{E_1} + (1 - \alpha_3) (\lambda_D t_{D_3} + \lambda_E t_{E_3})$$

where:

F_3 = Expected failures through Mode 3

α_1 = 0.95 = Test efficiency of factory test

λ_{E_1} = 2067.520 $\frac{\text{failures}}{10^6 \text{ part-hours}}$ = System operating failure rate

t_{E_1} = 340 hours = Total operating time prior to shipment

α_3 = 0.90 = Test efficiency of predeployment checkout test

λ_D = 29.235 $\frac{\text{failures}}{10^6 \text{ part-hours}}$ = System dormancy failure rate

t_{D_3} = 720 hours = Total dormant time through Mode 2

t_{E_3} = 5 hours = Total operating time during predeployment checkout

The expected failures prior to deployment can now be estimated:

$$F_3 = \left[0.05 \right] \left[\frac{(2067.520)340}{10^6} \right] + \left[\frac{(29.235)(720) + (2067.520)(5)}{10^6} \right] \left[0.10 \right]$$

$$F_3 \equiv 0.0383$$

System reliability just prior to deployment can now be calculated and is:

$$e^{-F_3} = 0.962$$

4.2.1 No Test Concept

If the "no test" concept is chosen for the missile, then the system will remain in a dormant, unenergized state throughout the deployment phase of its service life.

No system failures will be detected during this period and the total undetected failures which occur during Mode 4 (deployment) of the system service life are found as follows:

$$F_{N_4} = \lambda_D t_{D_4}$$

where:

F_{N_4} = Expected failures during Mode 4 under "no test" concept.

λ_D = 29.235 failures/ 10^6 part-hours = Dormant failure rate.

t_{D_4} = 1 to 5 years = Expected deployment time.

The model may be solved for the total expected failures for various durations; and, by utilizing the exponential equation, system reliability can be calculated.

Figure 4.2.1-1 shows the system reliability degradation during the deployment mode under the "no test" concept. Note that the initial reliability is not 1.0, but 0.962, as calculated in the previous section, which is a result of the undetected failures through Mode 3. Therefore, at the end of five years the system reliability would be approximately 0.26 which is not acceptable for most tactical missiles.

4.2.2 Periodic Test Concept

In order to maintain a higher reliability throughout deployment, a periodic test strategy may be chosen. Usually, trade studies are involved in selecting the optimum checkout interval. However, it shall be assumed that the trade studies have already been performed, and a periodic test interval of one year selected.

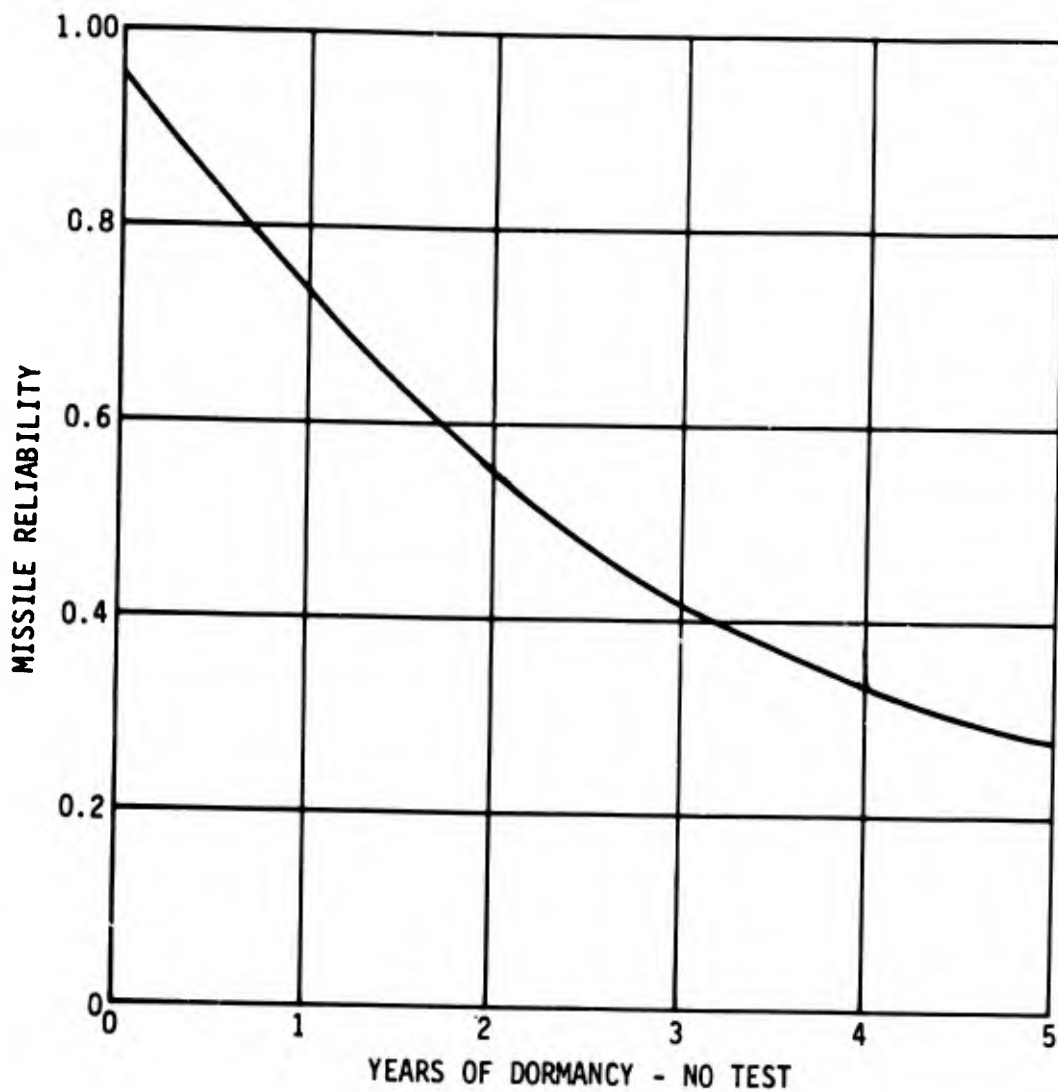


Figure 4.2.1-1. Reliability Degradation with No Test Deployment Concept

An important consideration with the periodic test concept is the effects of power on-off cycling on the system reliability. If the system does not have adequate transient suppression circuitry, the power cycling may have a disastrous effect upon system reliability and availability. It shall be assumed that the system under consideration does have protection against transients. However, the power cycling will still cause some degradation to the system. This degradation will be assumed to occur only on the electronic portion of the system. Data from Reference 5 will be used to quantify the effects of on-off cycling on the system reliability.

For calculating the estimated number of failures that occur between periodic tests, certain values relating to the test must be established. The interval between periodic tests will be one year. The total operating time during periodic test is assumed to be three hours, which also is sufficient time for the internal temperature rise to stabilize at the maximum operating value. The model for calculating the estimated failures is as follows:

$$F_p = \left[(N_C K_{C/D}) \lambda_{DE} + r_D \lambda_D + r_E \lambda_E \right] t_{D_4}$$

where:

F_p = Expected failures during one periodic test interval

N_C = 0.00023 = Ratio of total power cycles to total periodic test interval time (cycles per hour)

$K_{C/D}$ = 270 = Ratio of cyclic failure rate to dormancy failure rate (estimated for an average mix of high reliability parts)

λ_{DE} = 14.876 failures/ 10^6 part-hours = Dormant failure rate of electronic parts

r_D = 0.99966 = Ratio of total dormant time to total periodic test interval time

λ_D = 29.235 failures/ 10^6 part-hours = System dormant failure rate

λ_E = 2067.520 failures/ 10^6 part-hours = System energized failure rate

r_E = 0.00034 = Ratio of total operating time to total periodic test interval time

t_{D_4} = 8760 hours = Total periodic test interval time

The failure rate values are taken from Table 4.1-III. The ratios, r_D and r_E , are based upon the assumption of a one year periodic test interval (8760 hours) with a three hour operating time during test. A total of two power on-off cycles are assumed per test interval, from which N_C is obtained. The value of $K_{C/D}$ is assumed to have been for this system based upon such factors as high reliability parts, part mix, cyclic rate and duration,

transient suppression capabilities, and energy level attained during cycling. Substituting these values into the model:

$$F_p = [(0.00023)(270)(14.876 \times 10^{-6}) + (0.99966)(29.235 \times 10^{-6}) + (0.00034)(2067.520 \times 10^{-6})] 8760$$

$$F_p = 0.2703 \text{ failures}$$

By combining the value calculated for F_p with that previously obtained for F_3 and applying the sum to the exponential equation, the system reliability just prior to the first periodic test is obtained:

$$R = e^{-(F_p + F_3)} = e^{-(0.3086)} = 0.734$$

Thus, by using the exponential equation, system reliability can be calculated at the time of test. Immediately after the periodic test, the reliability will be higher since detected failures will have been repaired. However, the reliability will not regain its former level at the previous periodic test because there are undetected failures remaining in the system.

For comparative purposes it shall be assumed that the value of α_4 , the efficiency of the test in detecting failures, is 90 percent. The system reliability following first periodic test can be calculated in the following manner:

$$R = e^{-[(1 - \alpha_4)(F_p) + F_3]}$$

$$R = e^{-[.10(0.2703) + 0.0383]}$$

$$R = e^{-0.0653} = 0.937$$

Figure 4.2.2-1 shows the resulting reliability degradation over a five year deployment period; the "no test" degradation for the same period of time is also designated by the dashed lines. Other than the dormant failure rate, the most significant contributors to achieving long term dormancy system reliability are the test efficiency and the frequency of periodic test.

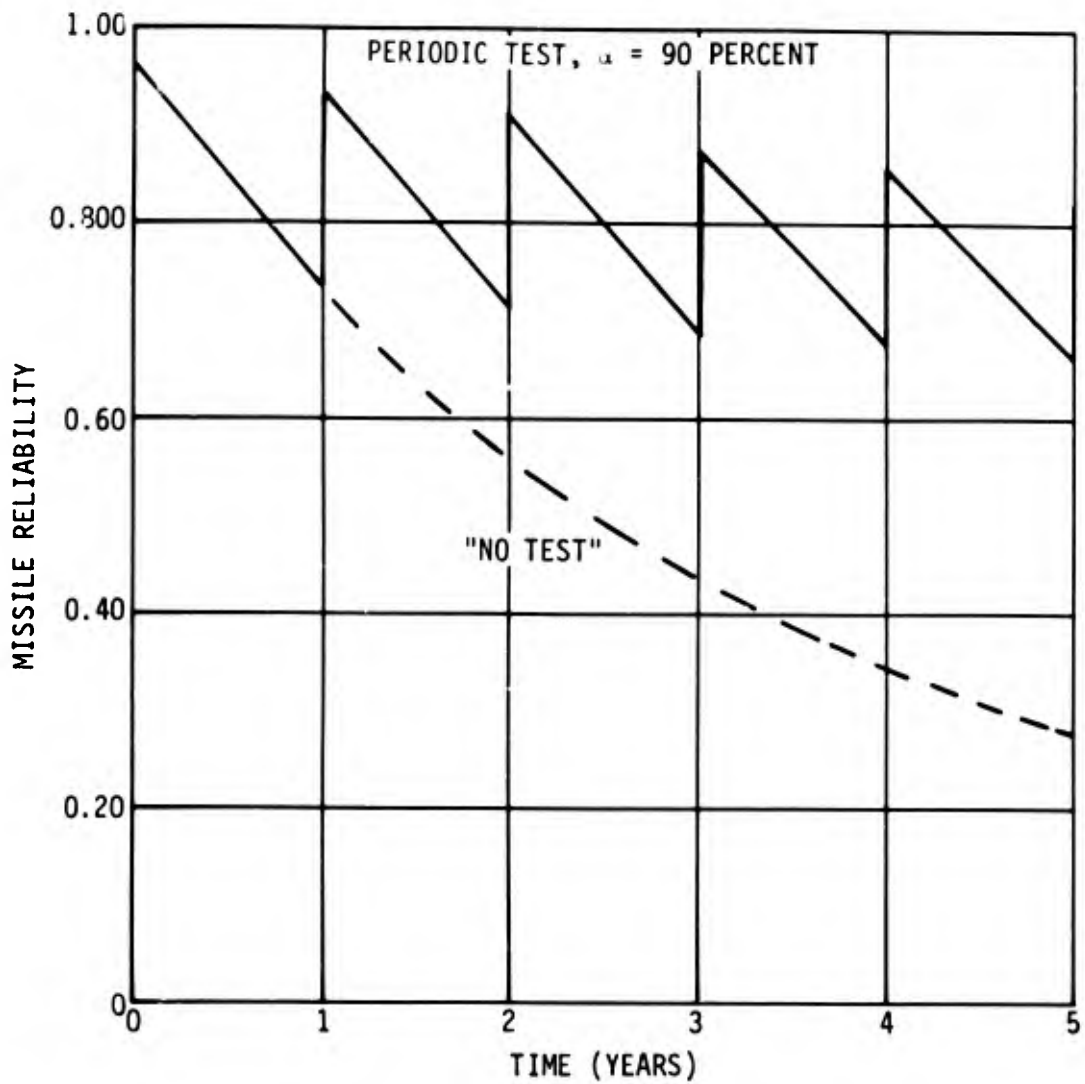


Figure 4.2.2-1. Missile Reliability after 5 Years of Dormant Deployment Under "Wooden Round" and Periodic Test Concept

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Martin Marietta has thoroughly conducted and successfully concluded the RADC sponsored program, "Effects of Dormancy on Nonelectronic Components and Materials," Contract F30602-73-C-0185.

Approximately 170 billion part-hours of dormant data have been collected covering 90 major part classes and subclasses. Dormant failure rates are now available for the first time for many nonelectronic parts. This greatly increases the scope and enhances the precision by which reliability predictions can be performed for a system during its service life cycle.

In previous studies concerning the effects of dormancy on electronic equipment (References 3 and 5), a service life model was developed and refined which reflects the entire life cycle of an electronic system from factory to replacement or use in its mission. As a result of this dormancy study on nonelectronic parts, the model can now be used in conjunction with complete systems consisting of nonelectronic as well as electronic parts. Many of our strategic missile systems, both in the field today and under development, have a planned life cycle of approximately 10 years and must be capable of successful operation at any instant during this period. Thus, the importance of having a reliability mathematical model which accurately portrays the system reliability prior to and during deployment becomes paramount. Since many of these systems are dormant during the deployment period, the addition of the dormant failure rates on nonelectronic components/parts developed under this contract increases the accuracy even more.

A statistical analysis of the dormant and storage data collected during this study program indicates that there is no significant difference between failure rates for equivalent part types in the storage and dormant modes. As a result of this finding, the dormant and storage data have been combined for all analyses.

Quality grades are not well defined for most nonelectronic components. Therefore, to categorize these components to some quality grading scale would require extensive searching through component specifications and drawings. Data contributors are generally reluctant to incur large expenditures to further refine the data and information that they provide free of charge. They are also hesitant to allow visitors unrestricted access to their detailed records. Therefore, quality levels for nonelectronic components are not included in this study. The basic assumption made is that the combined data reflects average failure rates for parts over the quality grade spectrum specified for and used in most military equipment.

5.2 Recommendations

The following recommendations are submitted for consideration and possible implementation:

1 Consideration should be given to the feasibility of incorporating the means by which large quantities of dormant data on nonelectronic components can be collected through existing data collection systems. No such provisions exist; nor are complete dormancy data on any current major military systems available from a single source.

2 Investigation and study should be made into the effects of power on-off cycling on electromechanical components such as motors, generators, relays, switches, gyros, etc. A limited quantity of data on these components was reported in RADC-TR-73-248. However, that study emphasized electronic parts.

3 In order to provide the huge quantities of dormancy data necessary, consideration should be given to selecting a future major military system for special data collection provisions on dormancy. These special provisions must include the detailed and documented failure analysis provisions down to the component/part level to ascertain and validate the state in which failure occurred.

4 Military standards and/or specifications should be written to standardize quality grades of major nonelectronic components. This would not only aid in the collection and classification of field performance data, but would also enhance reliability prediction techniques for non-electronic components.

5 Government documents establishing and defining overall reliability program requirements should be updated and upgraded to include management and/or technical provisions that stipulate and implement reliability requirements in terms of operational service life, rather than just the energized (operating) state.

6 Government technical manuals, handbooks, and guidelines should be issued or revised to include the methods, data, and references on how to cohesively conduct and to systematically perform quantitative reliability analyses for the total service life of military equipment. Such analyses must be based on required operational capabilities over the anticipated service life. Degradation effects on both electronic and nonelectronic equipment in various activation states, such as shelf-life, transportation, handling, testing, dormancy, and power on-off cycling must be considered in addition to only those of the normally energized (active) state.

7 Detailed Government procurement documents, specifications, and contracts should also be revised and written to include reliability requirements and studies based upon total service life considerations. The reliability studies, including mathematical models, trade-offs, parametric analyses, allocations, or predictions, should be directed with the intent to promote attainment of optimum system reliability consonant with minimum cost and time impacts. These studies are applicable to all phases of the Government procurement cycle; i.e., Concept Formulation, Advanced Development, Research and Development, Production, Deployment, and Operational.

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APPENDIX A

DATA COLLECTION

Data have been collected by Martin Marietta from thirteen contractors and government agencies, and as a result of a comprehensive literature review.

I. Literature Review

More than 600 documents have been reviewed for information or data pertinent to the effect of dormancy on nonelectronic components. These documents were obtained from DDC, RADC, FARADA, other government data sources and agencies, private contractors and vendors, research institutions and educational institutions.

II. Data Source Contacts

Data sources were initially contacted by letter questionnaires in which personnel were requested to respond upon life test and field data that had been accumulated in the past five years.

The responses were reviewed for those sources which appeared to have pertinent data. These sources were then contacted by telephone or personal visits to obtain data pertinent to the program.

A summary of those sources contributing to this study program is shown in Table A-I.

TABLE A-I

List of Dormancy Data Sources

Aerojet ElectroSystems
Azusa, CA.

Ogden Air Materiel Area (OOAMA)
Hill Air Force Base, UT.

Aerojet Solid Propulsion Co.
Sacramento, CA.

Planning Research Corp.
Los Angeles, CA.

AVCO
Systems Division
Wilmington, MASS.

Rockwell International
Autonetics Division
Anaheim, CA.

Chandler Evans, Inc.
West Hartford, CN.

Rome Air Development Center
Griffiss Air Force Base, NY

Martin Marietta Corp.
Denver, CO.

Sandia Corporation
Albuquerque, NM.

Martin Marietta Corp.
Orlando, FL.

U. S. Army
Corps of Engineers
Huntsville, AL.

Massachusetts Institute of Technology
Charles Stark Draper Laboratory
Cambridge, MA.



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