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Reliability Program Environmental Testing and Sample Size Guide

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Prepared for COMMANDER SPACE SYSTEMS DIVISION

UNITED STATES AIR FORCE

Inglewood, California



ENGINEERING DIVISION • AEROSPACE CORPORATION
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TESTING AND SAMPLE SIZE GUIDE**

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ABSTRACT

Environmental testing is a critical function in the evaluation and improvement of reliability of missile and space vehicles. When equipment and/or a subsystem operate successfully in the laboratory or factory, but fail to function satisfactorily in flight or in the field, the cause can often be attributed to incomplete or incorrect environmental test or simulation during the test program.

This report considers environmental testing required for equipment and/or subsystems based on a balance of factors determining the high- or low-risk nature of a specific mission. It also considers determination of sample size requirements as an extension of over-all environmental testing.

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I. INTRODUCTION

The operational environment for missiles and space vehicles is radically different from that of other types of airborne equipment. The difference is a combination of the increased severity inherent in the new operational environments and the increased performance required of the equipment, even when operating in a familiar environment. In the development of experimental equipment or vehicles for programs having a limited number of launches, the reliability of each unit is of critical importance. Environmental conditions must be thoroughly evaluated to verify design concepts, identify modes of failure, provide safety factors to assure reliability, and prove the acceptability of the workmanship involved in the production processes.

Environmental testing is a critical function in evaluating and improving the reliability of missiles and space vehicles. When an equipment and/or subsystem operates successfully in the laboratory or at the factory, but fails to function satisfactorily in flight or in the field, the cause often can be attributed to incomplete or incorrect environmental testing or simulation. This report considers:

A. The definition of environmental testing required for individual equipments and/or subsystems, based on an optimum balance of those factors which determine the high or low risk nature of a specific mission. Environmental testing of lesser units (e.g., parts, components, subassemblies) is not discussed.

B. Determination of sample size guide requirements which are a logical and proportionate extension of the over-all environmental testing effort.

The environmental testing of equipments and/or subsystems is considered to be of primary concern for the following reasons:

1. Generally, it is the highest level of in-plant or factory test activity.
2. It involves a maximum of functional and environmental interactions for development study and evaluation.

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3. It is the test phase most likely to interfere with the design and production of hardware requirements and therefore requires the maximum of advance planning.
 4. It applies test conditions to equipment which are subsequently related most readily and meaningfully to flight test and/or in-service measurements of performance in the operational environment.

Because of these considerations, the environmental testing program exerts a critical influence on the design and engineering phases, and on the requirements and objectives of the field and flight test programs. The environmental laboratory, in fact, becomes an extension of the developmental laboratory. Neither the designer nor the engineer has completed his task until each equipment and/or subsystem has demonstrated a capability to operate satisfactorily under realistic environmental conditions. Environmental testing is a tool which permits designs to be checked under controlled conditions, and deficiencies which result from unknown or anticipated factors to be identified and corrected during the early design stages. The results of environmental testing also are complementary to and serve as a data backup for, field and flight testing later in the program. Their complementary function is indicated by the fact that:

1. Environmental testing is conducted under controlled conditions that are realistic only to some limited degree;
2. Flight test conditions are uncontrolled but are completely realistic;
3. Captive or sled test conditions are partially controlled and partially realistic, but are incomplete.

Flight tests demonstrate missile performance under actual operational and environmental conditions but information on sources of trouble or causes of failure may not be obtained because of limitations in telemetry or telemetry facilities, and because hardware usually cannot be retrieved for examination. The greatest possibility for identifying the cause of performance deficiencies or

flight test failures is achieved by correlating missile performance during flight with problem source possibilities indicated during environmental testing. On the other hand, captive and sled test programs, in which the hardware may be retrieved for examination, may serve to reduce the need for environmental testing in some areas.

The definition and extent of the over-all environmental testing effort are governed by the high-risk or low-risk nature of each program. Reliability requirements, considering these factors, will dictate the bases for environmental testing specifications. For purposes of this report only, a high-risk program is defined as one which has a limited number of units (e.g., vehicles), an accelerated time schedule, a limited budget, a critical objective, or a high degree of sophistication or complexity in relation to known technology; or some combination of these factors. A high-risk program requires a carefully designed environmental test program that will produce an optimal reduction in risk from an effort which is severely limited by other program considerations (funds, time, number of units, etc.).

Conversely, a low-risk program includes a larger number of units, a more normal schedule and funding level and is generally within existing technological tradeoff capabilities. The environmental testing effort, therefore, can be extended throughout a series of field or flight tests, permitting reliability to be developed and demonstrated on a basis of continuing growth rather than as an a priori fact to a single or limited number of flights. Also, in a low-risk program, the peripheral details of environmental testing problems can be given more serious consideration because more time, money, and equipment are available. These considerations, plus an accumulation of experience and knowledge obtained from previous studies or programs using the same environment and identical or similar equipment, result in an improvement of the risk position.

Based on the high- or low-risk nature of the program, the kind of environmental testing requirements is established in accordance with such factors as reliability level desired, scope of the program, and time (schedules)

and funds available. Desired reliability level considerations include the mission requirements, present knowledge and experience in hardware items, the operational environment, and over-all state-of-the-art of environmental testing. Program scope considerations include the number of end items committed to flight and the over-all sophistication, complexity, and production availability of the equipment, the weapon system, and the supporting elements. Finally, as with all efforts, the environmental testing requirements must be compatible with the approved time schedules for all other phases of the program, with the operational date for the total program, and with the funding levels established.

II. ENVIRONMENTAL TESTING PHASES

The following paragraphs outline the basic philosophy of the five major types of environmental testing and indicate basic requirements and inter-relationships for the progressive accomplishment of desired reliability objectives. Figure 1 shows these interrelationships in graphic form, relating program milestones with time. Table 1 shows the type of equipment used in various types of environmental testing.

A. Developmental and Evaluation Testing

This test phase is performed continuously during the development of equipment, primarily to determine the validity of new designs, previously unused combinations of existing designs or components, and new methods of fabrication. The equipment tested is non-operational and is expended during the test effort. Following the initial development phase, the testing usually progresses through two subsequent phases:

Phase A - Identifies major modes of performance degradation and/or failure and corrects design as required.

Phase B - Determines remaining modes of degradation and/or failure; investigates wear effects; extrapolates results to obtain an estimate of service conditions; makes further corrections to design as necessary; establishes preventative maintenance measures; obtains logistics and training program information for planning purposes on new equipments; and correlates accomplishments with control acceptance tests.

Phase A testing should be started as early in the program as possible and should result in an early and rapid improvement in design accomplishment and reliability expectations. These tests must be completed prior to the start of flight testing. Formal evidence that Phase A objectives were accomplished successfully is provided by the Flight Proofing (Type) Tests.

Phase B is a continuation of the Phase A effort and should indicate the remaining modes of failure and provide some level of confidence through

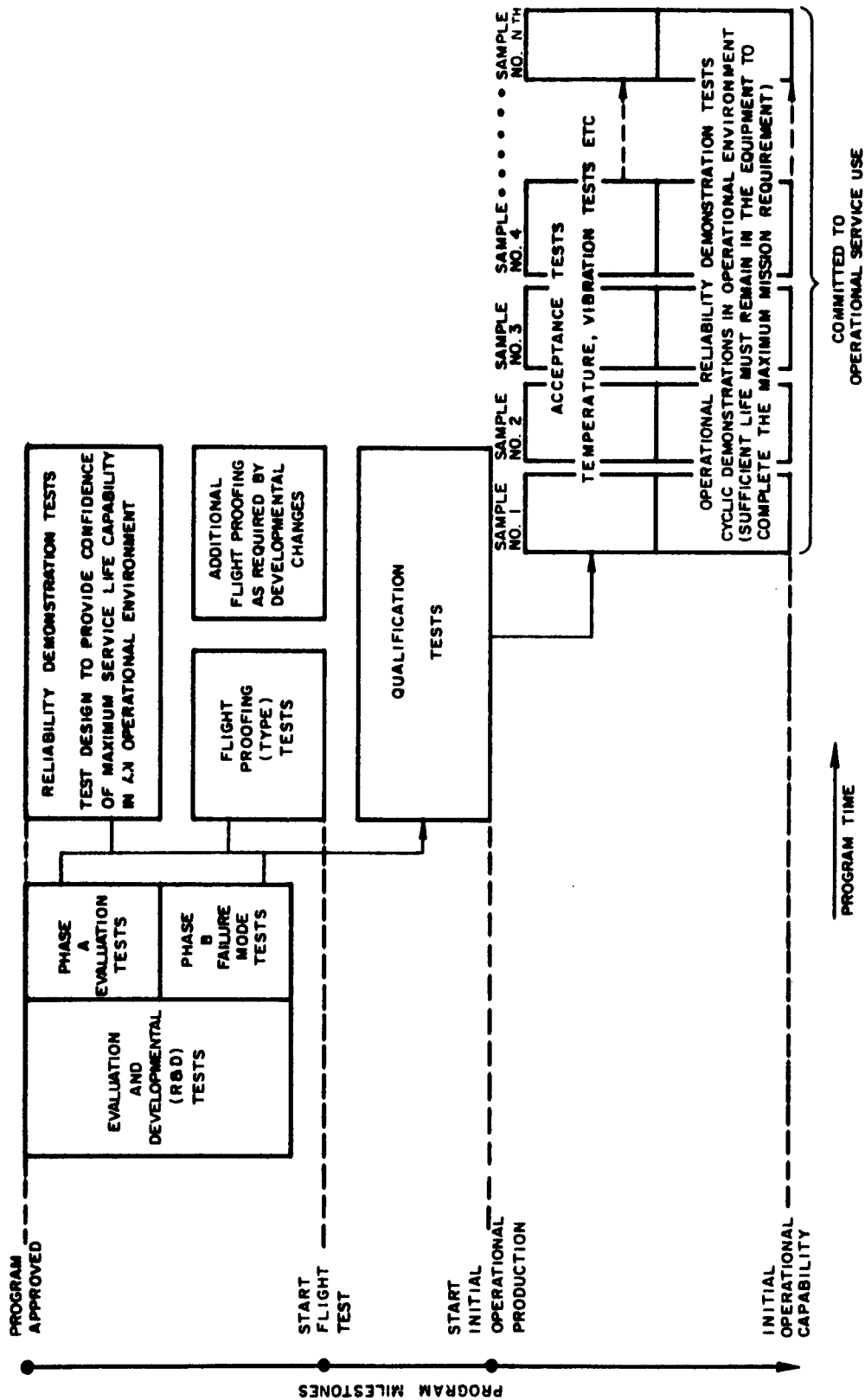


Figure 1. Environmental Testing Schedules in Relation to Program Milestones

Table 1
KIND OF EQUIPMENTS USED RELATIVE TO TEST AND END CONDITION

Type of Test	Kind of Equipment		Condition of Equipment
Evaluation and Development	Prototype		Non-operational, expended
Flight Proofing	First Production Model		Operational, can be operational
Qualification	Pre-Production Model		Non-operational, expended
Acceptance	Production Model		Operational
Demonstration			
*Wearout	Pre-Production/Production Model		Non-operational, expended
**Non-Wearout	Production Model		Operational

*Test is a function of maximum life cycle or stress level. If this sample size is statistically significant, a mathematical confidence can be attached to these tests.

**Test is a function of program mission. Realistic simulation of environmental requirements will provide confidence (faith) in a mission success.

evaluation of improved design as a final step before the production of initial operational hardware. Formal evidence that Phase B was accomplished successfully is provided by the Qualification Tests.

This test effort should indicate significant modes of failure, including the effects of valid stress levels, combinations and sequences of environments, and the determination of Mean-Time-to-Failure (MTTF) under simulated environments. All stress levels from normal ambient to extreme must be considered and applied. These results are particularly important in making modifications later in the program if in-service stress levels change or are found to have been erroneous or incorrectly estimated. The MTTF tests provide data which permit reliability estimates that are valid in proportion to the degree of realism in simulating the in-service environment; and also provide the basis for the Reliability Demonstration Tests. These R and D Tests also yield information on early wear-out types of failure, and provide the usually unavailable failure-rate data for equipments; thus also providing needed operational repair, maintenance and logistic information.

B. Flight Proofing (Type) Tests

These tests, together with the Qualification Tests, usually fulfill the environmental qualification requirements for R and D equipment. In general the tests are based on environmental stress-strain safety margins rather than on obtaining statistical operating life data. The equipment is subjected to increasing levels of environmental stress. If no failures occur under the conditions imposed the design is considered adequate. The safety margins used are above the expected in-service levels to allow for the variability of in-service conditions and the individual characteristics of the equipment. The test conditions should not, however, be so severe as to exceed reasonable safety margins or to excite unrealistic or improbable modes of failure. All equipment used in flight proofing tests is considered expended and may not be used in the field.

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C. Qualification Tests

The Qualification and Flight Proofing Tests constitute the required environmental qualification tests for all equipment. The Qualification Tests demonstrate the readiness of the design for the start of initial operational production. However, the final design and other improvements may be made as a result of this test phase. Although similar to the Flight Proof Tests, the Qualification Tests are more advanced in relation to stress-strain safety margins; and are more comprehensive because they are more completely oriented to all of the in-service environmental conditions.

D. Acceptance Tests

Environmental Acceptance Tests are performed at the factory on each item of operational equipment to improve and/or control functional reliability by revealing defects in workmanship and permitting their correction prior to operational deployment or use. Test levels applied should be comparable to in-service levels anticipated and are held well within design limitations. Test durations should be of sufficient length to produce initial failures, but not so long as to permit wear to be a function of the failure. These tests are designed to permit the equipment reliability to be advanced beyond the "debugging" or high initial failure rate period of its life cycle failure rate curve (See Figure 2). Acceptance tests are conducted with flyable, operational equipment.

E. Reliability Demonstration Test

The validity of the Reliability Demonstration Test in environmental testing is based on the premise that controlled environmental testing will induce failures similar to those which would occur during in-service operation. These tests use failure rate measurements, in terms of Mean-Time-to-Failure, to demonstrate a specified level of confidence for attaining a pre-established numerical value of reliability. The Demonstration Tests may be commenced any time after the start of Evaluation Testing and must be conducted under simulated environmental conditions and in accordance with the required Acceptance Test procedures. Close simulation of environmental stresses is necessary because part and equipment

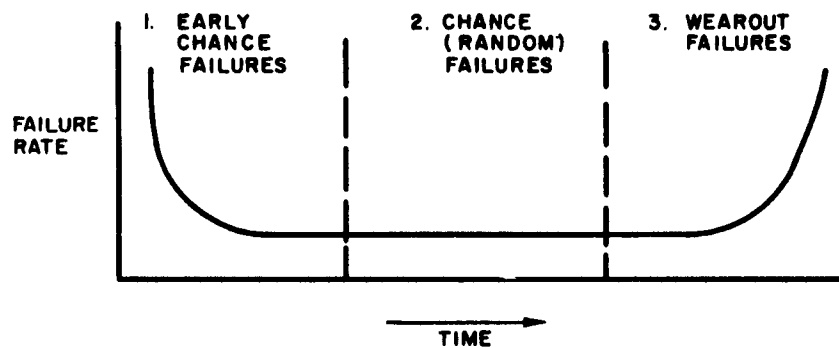


Figure 2. Failure Rate in Relation to Operating Life Cycle

failure rates and failure modes are highly sensitive to these stresses. Failure rates in some areas (e.g., as a function of temperature) have been determined for many types of parts from previous test and operational experience. However, the effects of other types of stresses (e.g., vibration, accoustics, or radiation on some electronic parts) have not yet been clearly defined.

Design of the Reliability Demonstration Test is started with the determination of an environment-time profile that represents the in-service use of the equipment. Equipment operating modes during in-service use must be studied in detail and synchronized with the environment-time profile. Operation in the in-service environment must include prelaunch, launch, and powered and orbital flight conditions. The design, the nature, the procedures, and the requirements for the test must be clearly stated.

Reliability Demonstration Tests include two kinds of environmental testing:

1. Wearout Testing is a function of the maximum service life cycle in the operational environment. On the life cycle failure rate chart (Figure 2) this kind of testing extends into the third phase of failure rate types. Equipment tested is considered expended and may not be committed to operational use.
2. Non-Wearout Testing is a function of mission environment and real time requirements. This test effort must not extend past the mid-point of the second type of failure rate (chance or random failure) shown in Figure 2. Operational equipment is used for this test and is then committed to flight or in-service use. Reliability Demonstration Test requirements for such equipment may be fulfilled as part of the Acceptance Test procedures. It is essential, however, to determine the maximum number of cycles of operation to prevent these testing efforts from adversely affecting the reliability of equipment which will be committed to operational use. This determination is made during Phase B of the Evaluation and Development testing. The design of the Reliability Demonstration Test is considered critical to the operational life and functional performance of the equipment and/or subsystem.

III. SAMPLE SIZE GUIDE REQUIREMENTS

The factors which determine the sample size requirements for environmental testing are identical with those used to define and formulate the over-all environmental testing effort (see Introduction). Sample size requirements for various tests in programs having a small number of units (less than 50) are often arbitrary, and at present are being based on typical experience in space environments accumulated only during the past six years. Potentially firm requirements for such programs must be varied according to the high- or low-risk nature of the program, the reliability level desired, the complexity of the equipment, the flight or operational schedule, and the amount of funds available. Sample size requirements for programs having 50 units or more (e. g. , ATLAS, TITAN, MINUTEMAN ICBM's) can be established by applying Standard Sampling procedures and Techniques outlined in existing military specifications.* An additional important factor to be considered in arriving at the sample size requirements for a program is the repeatability of a test on a piece of equipment. Repeatability of the test cycle may compensate for a reduced sample size.

A guide for sample size allocation is given in Table 2. The guide sample sizes indicated, however, are minimal and are not to be considered rigid. Definition of the final environmental test program and determination of sample size requirements for each specific program must be based on a full and individual consideration of all of the program factors, and the particular specifications, objectives, and high- or low-risk nature of the specific program mission.

*MIL-STD-105B	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective
DOD-HDBK-H-106	Multi-level Continuous Sampling Procedures and Tables for Inspection by Attributes
DOD-HDBK-H-108	Sampling Procedures and Tables for Life and Reliability Testing (Based on Exponential Distribution)

Table 2
SUGGESTED MINIMUM SAMPLE SIZE GUIDE REQUIREMENTS FOR ENVIRONMENTAL TESTING

Flight Units (a)	Evaluation Test (b)	Types of Environmental Testing				Operational Reliability (f) Demonstration Test (e)
		Non-operational Reliability Tests (g)	Qualification Test	Flight Proofing Test	Acceptance Test (e)	
2-5	1(c)	1(c)	0	1(d)	All Units	All Units
5-10	1(c)	2(c)	0	2(d)	All Units	All Units
11-20	2	2(c)	1	2(d)	All Units	All Units
21-30	4	4(c)	2	2(d)	All Units	All Units
31-50	6	6(c)	3	2(d)	All Units	All Units
> 50	6	6(c)	5(d)	2(d)	All Units or Random Sampling Plan	All Units or Random Sampling Plan

- (a) One distinctive design.
- (b) Failure mode tests conducted to determine marginability caused by wearout from: (1) increased stress-level and (2) increased mission time duration at flight level (MTTF measurements). Equipment expended.
- (c) May be used in Qualification and Flight Proofing Tests if repair and quality control requirements are satisfied.
- (d) Plus one spare.
- (e) All units are operational and are committed to flight or in-service use unless adversely affected by this test.
- (f) Operational Reliability Demonstration Tests may be conducted on operational hardware following the acceptance test. This is a procedural requirement for low-risk programs.
- (g) Non-operational Reliability Tests may be conducted after the start of evaluation testing but prior to committing IOC production. These tests are designed to provide confidence for attainment of maximum service life capability in an operational environment.

IV. SUMMARY

The environmental test and sample size guide requirements discussed in this report are considered minimal for an acceptable integrated reliability program effort. Any curtailment of environmental testing or reduction of the sample sizes suggested in Table I will reduce considerably the probability that the equipment reliability requirements will be attained. If the program is an R and D effort using a limited number of units to demonstrate the feasibility of a specific system or mission, the minimal effort may not be possible with the time and funds available. If the environmental test effort must be abbreviated, however, even greater care must be taken in designing the test program to assure maximum benefit from each test phase and to reduce redundant or back-up testing to a minimum.

Aerospace Corporation, El Segundo, California. RELIABILITY PROGRAM ENVIRONMENTAL TESTING AND SAMPLE SIZE GUIDE. by F. P. Klein. 16 November 1962. [] p. (Report TDR-169(3303)TN-1; SSD-TDR-62-181) (Contract AF 04(695)-169) Unclassified report Environmental testing is a critical function in the evaluation and improvement of reliability of missile and space vehicles. When equipment and/or a subsystem operate successfully in the laboratory or factory, but fail to function satisfactorily in flight or in the field, the cause can often be attributed to incomplete or incorrect environmental test or simulation during the test program. This report considers environmental testing required for equipment and/or subsystems based on a balance of factors determining the high- or low-risk nature of a specific mission. It also considers determination of sample size requirements as an extension of over-all environmental testing.	UNCLASSIFIED
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