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Technical Memorandum 33-575

Accelerated Life Testing of Spacecraft Subsystems

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PREFACE

The work described in this report was performed by the Project Engineering Division of the Jet Propulsion Laboratory as one task of a NASA Research and Technology Operating Plan (RTOP) on Reliability Modeling and Assessment Techniques.

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ABSTRACT

This report presents the results of a study performed to establish the rationale and requirements for conducting accelerated life tests on electronic subsystems of spacecraft. A method for applying data on the reliability and temperature sensitivity of the parts contained in a subsystem to the selection of accelerated life test parameters is described. Additional considerations affecting the formulation of test requirements are identified, and practical limitations of accelerated aging are described.

I. Introduction

A. Statement of The Problem

Since the inception of the space program, spacecraft life requirements have increased many fold. Missions lasting a few hours or days have been replaced by missions lasting up to two and three years. Projections for future missions contain spacecraft lifetime requirements of ten years or more.

Life testing spacecraft assemblies and subsystems for missions of the past was performed utilizing a real time, mission operations profile simulation. Life tests performed in this manner and completed prior to launch provided the system designers the opportunity to utilize the information generated by each test.

Future space missions may be faced with the need to develop spacecraft having operating lifetimes up to 10 years or even longer. Typical hardware development times are on the order of three years. With the rapidly evolving technology in electronics parts there are significant pressures to use the latest state-of-the-art components to achieve improved performance through increased reliability while simultaneously providing a savings in weight and volume. The evaluation and demonstration of system reliability under these conditions offers several challenges in the following areas:

1. The selection of piece-parts with high reliability.
2. The development of subsystem and system designs that optimize reliability through redundancy considerations.

3. The demonstration and evaluation of both design reliability and flight hardware quality. This activity in turn has the following subsets.

   a) The demonstration and evaluation of piece-part long life reliability.

   b) The demonstration and evaluation of subsystem* and system long life reliability.

It is from item 3b) that this study evolved. The typical problem may be restated as follows. In a time period of a few years demonstrate that sophisticated electronics subsystems, which may be new in design and include state-of-the-art components, possess reliability characteristics that are consistent with the operating life needs of missions lasting 8 or 10 years. Short of total demonstration it is desired to evaluate the long life reliability of the subject hardware and identify its life limiting characteristics.

A constraint is assumed which is typical of the planetary spacecraft programs. That is, that the total number of systems and subsystems of flight design which are actually fabricated is small; typically 3 to 6 and almost certainly less than 10 of any given electronics assembly. Because of the small quantities the cost of individual units is high. This tends to preclude the development of any statistically valid empirical data on subsystem reliability.

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* In this report the term "subsystem" refers to a collection of components designed to perform a major function. A radio is a subsystem. The term "subsystem" is used interchangeably with "assembly" but should be distinguished from a part (such as a resistor) and a system (such as a spacecraft).

B. Study Objective

It was the objective of this study to develop test rational and requirements for performing accelerated life tests on spacecraft assemblies or subsystems. (This type of testing is considered separate from related accelerated life tests of piece-parts. The distinction is that subsystem level tests are intended to evaluate subsystem design characteristics and parts application conditions rather than to evaluate parts characteristics).

The study focused primarily on electronic assemblies as opposed to hardware items performing only mechanical or structural functions.

C. Summary of Conclusions

1. No single approach or applied stress can be employed to uniformly accelerate all life related failure mechanisms. Since many failure mechanisms exist in a complex electronics subsystem, any accelerated life test will reflect compromises between undertesting some failure mechanisms and over-testing others.

2. The accelerating stress found most applicable at the subsystem level is increased temperature* which accelerates those mechanisms which are chemical and/or physical in nature (e.g., corrosion, diffusion, ion migration). However, temperature by no means accelerates all mechanisms and in certain cases may even anneal degradation caused by other stresses. Nevertheless, temperature provides the most useful accelerator and is the subject of much of the remainder of this report.

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* The application of heat accelerates the degradation processes, but the effects are evaluated and test control is achieved through measurement of temperature. "Temperature" is used in this context throughout this report.

3. A second aspect of accelerated ageing concerns those failure mechanisms associated with subsystem operation. Included in this category are mechanisms which depend on the presence of a voltage or current, or are related to cyclic and switching operations. The transient conditions may generally be accelerated by adjusting the operational profile of the subsystem as it is subjected to the life test, while acceleration of the voltage or current dependent mechanisms is limited by subsystem operational constraints.

4. The recommended approach makes use of available reliability and temperature sensitivity data on the subsystem's part population. This information contributes to the selection of test temperature and duration. In addition these data contribute to the evaluation of test results, particularly the interpretation of overtest and undertest for various part types.

5. Failure analysis plays a significant role in any subsystem life test program. As each failure occurs during an accelerated life test an examination must be conducted to determine the cause, and an assessment must be made of the likelihood of such a failure occuring during the mission.

6. A life test program developed in the context of the problem described above requires a set of hardware dedicated to providing life related information. The hardware will be in test for a significant period of time and will be degraded by the tests to an extent that other uses will probably be precluded.

7. The generation of detailed test requirements for a given electronic subsystem requires consideration of several factors:

a) The operating environment of the subsystem and the sensitivity of the subsystem to its environment.

b) The operating modes and sequencing of the subsystem's operation.

c) The types and characteristics of the piece-parts used in the subsystem. (A method for collecting and compiling this data has been developed in this study and is described in following sections.)

d) The means by which degradation of a subsystem's performance may be monitored.

e) The design life of the subsystem.

f) The available test time.

II. APPROACH

The approach taken in this study was to develop a statement of accelerated life test objectives and then review the contributions to be made toward satisfying these objectives by various considerations.

A primary contribution to the selection of accelerated life test parameters was the existing data base on piece-part reliabilities and temperature sensitivities. This data base was assessed and a methodology developed wherein data on the part population of a subsystem could be compiled, evaluated, and applied to the selection of test parameters for a test to be conducted on the subsystem. In addition, a review of part failure mechanisms provided general insight into the ageing processes of concern.

Attention was given to the programmatic constraints encountered in a typical JPL spacecraft program in an effort to develop conclusions and recommendations which would contribute to the formulation of reasonable and practical test programs for future projects. These considerations served to identify factors which in practice offer very real constraints or limitations on results which may be achieved. These constraints are in turn reflected in the statement of test objectives.

Finally, a basic rationale or methodology for developing a subsystem accelerated life test program was established.

III. Life Test Objectives and Constraints

A statement of life test objectives has been developed and is stated below. Once again it should be noted that the context for this particular statement of objective is that of the typical planetary spacecraft program. Military or commercial programs may have a somewhat different problem in which case the corresponding test objective would be somewhat different.

Accelerated Subsystem Life Test Objective: Develop "life related information" about the capabilities of assemblies/subsystems to perform functionally for their design life.

"Life related information" is information about the subsystem's performance as a function of time. More specifically, the anticipated information includes the following:

- Parts application information. (Thermal, mechanical, or electrical conditions to which a part is subjected in the subsystem may be beyond a part's operational capability due to a design error. These conditions should be detected by observation of the subsystem's eventual degradation or failure and analysis of the cause.)

- Information about chemical and physical processes which can occur in the subsystem and contribute to degradation and/or failure over time.

- Information about degradation due to fatigue or wear which may result from cyclic stressing operations.

The test should produce information about system design characteristics and weaknesses and systematic fabrication errors rather than information on either random workmanship quality or piece-parts reliability.

It is further noted that a life test satisfying the above objectives is not a pass or fail test. Being a design evaluation type of test suggests that the "best" test is the one that produces the most "life related information".

The above statement of test objective has evolved largely from a consideration of the constraints which have been assumed. These constraints include:

- Limited number of test items of a given design.
- Maximum effective test time available is significantly less than a mission duration which produces the need for accelerated testing.
- Limited ability to duplicate degradation or failure as it will occur in a mission.

IV. Accelerated Life Test Considerations

A. Failure Mechanisms

The mechanisms of interest in the study are those processes which cause degradation over relatively long time periods and which eventually lead to total or partial failure of a subsystem. There are many mechanisms which fall in this category. A partial listing of life related failure mechanisms is given in Table 1 for the purpose of indicating the variety of processes which may be involved.

As the subsystem ages degradation may occur and failures such as opens, shorts, and changes in electrical characteristics may develop. The actual occurance of a functional failure in a subsystem is dependent on the rate of degradation and the tolerance of the subsystem to the accumulated degradation.

No attempt has been made to study these mechanisms in detail or evaluate their applicability to any particular subsystem; however, further description and characterization of failure mechanisms may be found in references 2 through 6.

The rates at which degradation occurs is dependent on a number of parameters which are discussed below. It is noted here that the concept of accelerated life testing of an electronic subsystem involves increasing the rate of degradation, preferably in a controlled manner such that results can be interpreted with regard to mission conditions.

TABLE I

TYPICAL LIFE RELATED FAILURE MECHANISMS*

Oxidation	Material Diffusion
Precipitation	Surface Ionization
Evaporation	Creep
Chemical Corrosion	Surface Wearout
Electrolytic Corrosion	Dielectric Breakdown
Crystallization	Ion Migration
Fatigue (Mechanical and Thermal)	Polymerization
Carbonization	
Outgassing	
Surface Contamination	

* Material taken from Reference 1.

Since many failure mechanisms are involved, with varying degrees of sensitivity to temperature, and since many opportunities exist for these mechanisms to occur, it is not possible to reproduce all aspects of ageing.

B. Ageing Accelerators

The rates at which degradation takes place are a function of several parameters. Table II lists various factors which affect the rate of degradation or parameter change due to the types of mechanisms listed in Table I. The items are listed in three categories. Environmental factors can be controlled in testing to bring about increase or decrease in ageing rates. Some control of electrical currents and voltages may be possible; however, it is limited by the operational characteristics of the subsystem. Materials properties inherent in the test article cannot be controlled in the life test. Where materials properties are significant one would expect to discover related failures in an accelerated life test (i.e., we depend on the test to detect these problems).

It is judged that two parameters provide potential for practical acceleration of the ageing of a complex electronics subsystem: temperature and operational cycling. The vacuum environment is of importance for considerations of outgassing, surface contamination, and heat transfer mechanisms, but is not useful as an ageing tool. In certain cases the absence of vacuum would preclude the simulation of mission conditions. Charged particle

TABLE II

FACTORS AFFECTING RATES OF DAMAGE ACCUMULATION

<u>Environmentally Related</u>

- Temperature
- Charged Particle Radiation
- Vacuum

<u>Design and Operation Related</u>

- Electric Potential
- Electric Current
- Mechanical Stress
- Operational Cycling and Sequencing

<u>Materials Properties</u>

- Impurities in Materials
- Contamination of Surfaces
- Compatibility of Adjacent Materials

radiation is not viewed as a practical alternative at this time for reasons of limited knowledge of effects and limited implementation capability. Of the factors which affect reaction rates, the control of temperature and operational mode appear to be the only practically available means for accelerating degradation. Much of this study was concerned with the effects of temperature on ageing and the question of how best to select a temperature (and associated time) to be used for an accelerated life test.

C. The Use of Available Parts Data

There are two basic reasons for reviewing the technology and data base which have developed in the parts reliability physics and failure analysis activities. First, it is in this area that the fundamentals of failure mechanisms have been studied, and it is assumed that in general the mechanisms of part failures are essentially the same as subsystem failures. Secondly, a knowledge of the reliability, failure mechanisms, and temperature dependancy of failure mechanisms for the parts contained in a given subsystem appears to be useful for developing life test requirements for that subsystem.

For many electronic parts types failure rate data as a function of temperature has been compiled. (See for example reference 7). For many newer part types such data are not available, especially the temperature-effects information. For some of these newer part types analytical models have been developed for predicting failure rates (references 8 and 9). In the absence of an empirical data base it may be necessary to use predictive models. For the following discussion it is assumed that usable data exist for the various part types.

The compilation and presentation of data on the parts in a given electronic subsystem according to the following scheme is recommended as one step to be taken in establishing accelerated life test requirements for that subsystem. This technique provides a method for considering the temperature and time test parameters as influenced by those part failure mechanisms which are temperature related.

Let λ_{im} = failure rate of part type i at mission temperature, T_m

λ_{it} = failure rate of part type i at test temperature, T_t

Then, define

$\alpha_i = \dfrac{\lambda_{it}}{\lambda_{im}}$ = acceleration factor for part type i when tested at temperature T_t.

Figure 1 presents all the part acceleration factors for a hypothetical subsystem as a function of the quantity of each part type. An example using an actual spacecraft subsystem is given in the Appendix. Typically, a significant spread will be found in the degree to which the ageing of the various parts can be accelerated, (e.g., for a test temperature $55^{o}C^{*}$ above mission temperature, the α_i typically will range from 1.0 to 30 or 50).

One can now begin to interpret the overtest/undertest compromises to be encountered. As an example, if one were to test under the conditions of Figure 1 for a time period of 1/5th the mission duration then parts having an acceleration factor of 5 would receive the equivalent of one mission's degradation (represented by the dashed arrow). Parts falling to the right of the arrow would in principle be overtested and parts falling to the left would be undertested where the basis of comparison is one equivalent mission.

Presenting the parts' temperature sensitivity information as in Figure 1 allows several observations to be made. First, the effect of changing test temperature is seen to expand or compress the abscissa scale (e.g., as test temperature T_t is lowered toward mission temperature T_m the acceleration factors α_i will converge to 1). Secondly, the changing

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* $55^{o}C$ is only an example in this discussion but appears reasonable in light of typical Mariner experience. This value is limited by the range over which the subsystem remains functional.

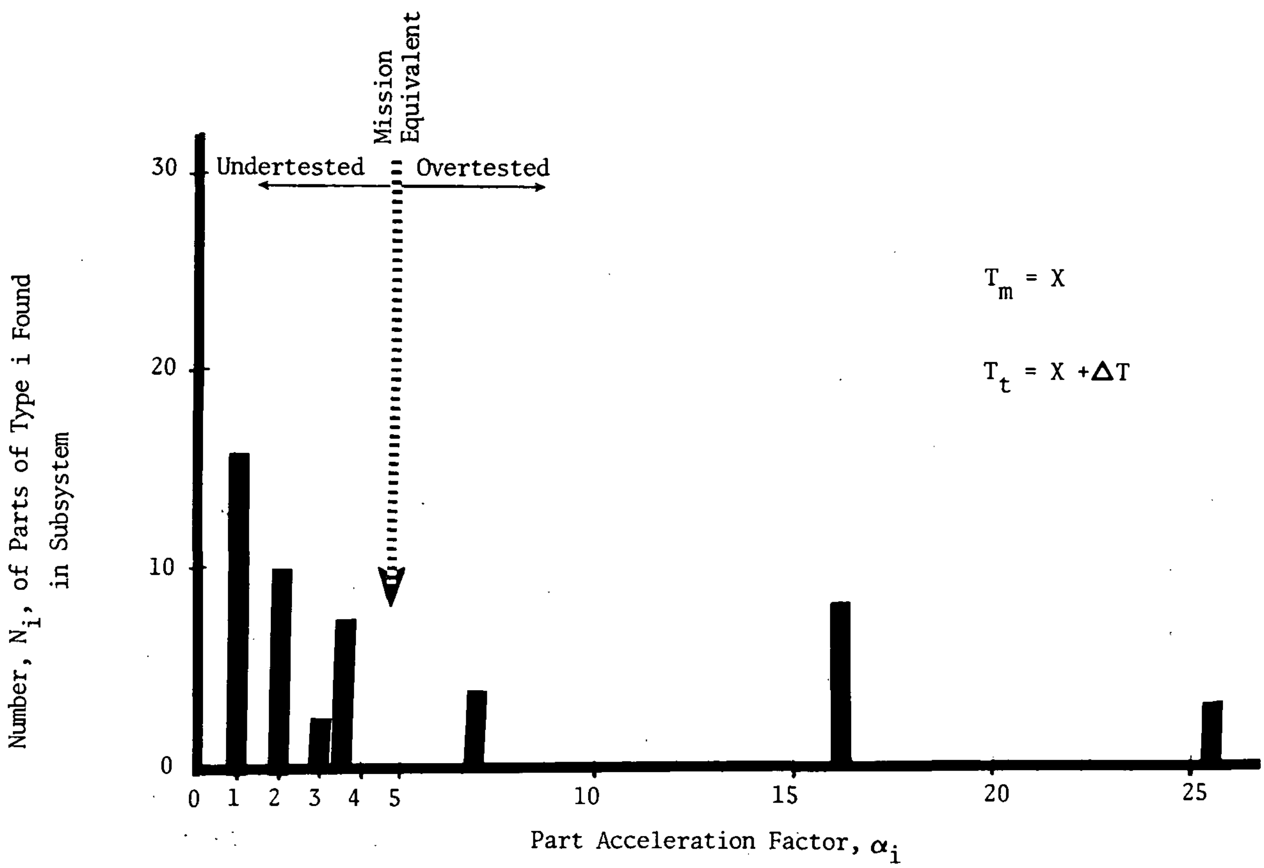

Figure 1. Acceleration Factors Found in Subsystem (Conceptual)

of test duration is seen to shift the location of the dashed arrow which marks one mission equivalent. As test time lengthens the arrow shifts left, as test time shortens the arrow shifts right.

Figure 1 may be used to qualitatively assess the overtest/undertest situation. In a sense, the "optimum" test appears to occur when the arrow falls such that the total deviation (overtest and undertest) from one mission equivalent is minimized. This occurs when the arrow falls at the mean A of the distribution, where

$$A = \frac{\sum_{i=1}^{n} \alpha_i N_i}{N} = \text{"optimum" acceleration factor for test} = \frac{\text{Mission Duration}}{\text{"Optimum" Test Duration}}$$

and $N = \sum_{i=1}^{n} N_i$ = Total number of parts.

n = Number of part types.

The consideration of some additional information can enhance the usefulness of the data presented in Figure 1. The Figure 1 data may be interpreted as if one had a collection of loose parts in a box and the box was to be tested for some time at some temperature to age the parts. Additional information can be included to bias the selection of a test duration.

The Figure 1 data may be modified by consideration of a) predicted failure rates for each part type under mission conditions and, b) a measure of functional importance or criticality for the various part types. Briefly, the use of a weighting based on the failure rate of various part types suggests that those part types which are less reliable should influence the selection of test conditions more than the reliable parts. Similarly, a weighting of part type criticality (or importance to mission success) suggests that parts which play important functional roles should influence the selection of test conditions more than parts having minor roles.

The consideration of these additional factors results in a weighted description of the parts data. Figure 2 presents a hypothetical modification of the Figure 1 data. Under the weighted conditions an optimum test point could again be selected. The new test duration might be more or less than the unweighted optimum would suggest, depending on which part types were more or less reliable and which were more or less critical.

The above discussion suggests that data exists on characteristics of the parts in an electronic subsystem and that this data should be compiled and should influence the selection of accelerated life test conditions for that subsystem. However, there are limitations which should be noted in both the availability and the quality of parts data.

First, for many of the newer part types limited information on failure rates and temperature effects is available. To proceed with the suggested methodology <u>estimates</u> of these parameters will have to be made. Secondly, where the temperature effect on failure rate has been compiled

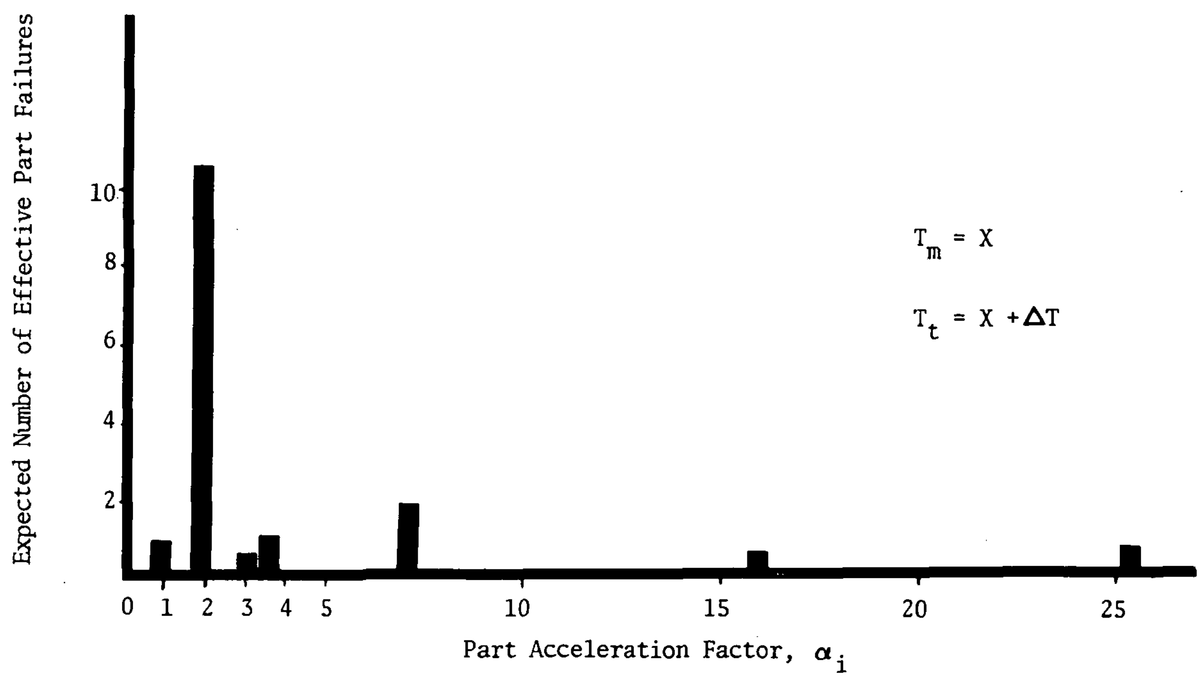

Figure 2. Weighted Parts Data (Conceptual)

the data were collected in accelerated tests. The question of whether or not these tests created valid or true acceleration has not generally been answered. The difficulty is that even at the part level little data exists on the long life reliability (e.g., 10 years) of parts under mission conditions.

It must also be recognized that a complete review of all available data on the parts within a subsystem does not completely define accelerated life test requirements for that subsystem. Other factors, some of which are discussed further below, include the temperature range over which the subsystem can properly function, the operational cycle or duty cycle of various circuits within the subsystem, special consideration of low α and high α parts which cannot be well tested in the "optimum" test discussed above, and possibly the various costs associated with the test. Cost considerations which cannot be overlooked include costs of parts, repair, failure analysis, test facilities, and operational support during the life test. These additional factors have not been quantitatively evaluated because of their dependence on a specific application, but they deserve consideration beyond that given to parts characteristics as defined above.

D. The Role of Failure Analysis

An information producing test consistent with the above statement of test objective requires that the hardware be exercised under controlled conditions and its performance evaluated as a function of time. When performance becomes unacceptable the analysis of the degradation or failure and the identification of the cause produces the desired information. Thus, failure analysis plays a major role in an accelerated life test program on subsystems.

Besides identifying failures and the causes, the analysis must predict or estimate whether or not each failure represents a potential mission problem. In support of this analysis it is essential that the operational and environmental history of the test item be well known.

As indicated above, any useful accelerated test will subject some components or parts to overtest conditions. Failures under these conditions are somewhat expected and must be identified and separated from other failures occuring due to actual design errors. Failure analysis is relied on to make the distinction between these test induced failures and actual design weaknesses.

E. Test Specification and Procedure Considerations

In the context of a planetary spacecraft program as described above, the specification of accelerated life test requirements has a primary objective of assuring that the life related information being developed consists of good quality data. Since the test is aimed at evaluating hardware and is somewhat developmental in nature (as opposed to a pass/fail type test) the specification should contain quality assurance provisions for the test article, test implementation controls (facility, instrumentation, operational procedures), and minimum standards for documentation and records keeping. The technical requirements for subsystem temperature, test duration and test article operations will also be defined in the specification but should be individually tailored for each subsystem. The following paragraphs discuss several considerations which need to be addressed in an accelerated life test specification.

Hardware Quality Requirements: The test article subjected to the life test program should be as representative of flight design and flight quality as possible (within the constraints of hardware availability, schedules, etc.).

Prerequisite Test Requirements: To assure that the test article is exposed to environmental stresses at least as severe as the flight article, and also to assure that random workmanship defects and infant mortality type weakness are not present, the test article should be subjected to some form of an acceptance test program prior to beginning the life test. This testing may consist of either the flight acceptance or design qualification type tests typical of spacecraft programs, depending on how the overall test program is defined.

Test Article Operations: The functional modes through which the hardware is operated while in test should reflect the various mission modes and should also allow thorough exercising and evaluation of all aspects of the subsystem's performance. This portion of the specification must be developed by the cognizant subsystem design engineer.

Provision should also be made in the operational sequence for periodic evaluation of performance and measurements of accrued degradation (when practically feasible).

The concept of "dynamic mission equivalence" (DME) testing appears to have merit for use in formulating subsystem operations requirements for the test (reference 10). This concept reproduces the cyclic and transient operations of the subsystem and effectively accelerates the test by abbreviating steady-state operational periods. The use of this approach will provide insight into the life characteristics which are related to mechanical and thermal fatigue, mechanical wearout, switching transients, and other life limiting mechanism dependent on cyclic type operations.

Records Keeping: To enhance the evaluation of degradation or failure causes, it is essential that accurate records be kept of the test article's operational and environmental history.

Test Temperature: Test temperature should be selected after reviewing a) the parts acceleration factors as described above, (See also the Appendix), b) the upper temperature limit for functional operation (both design requirement and actual), and c) the available test time. In general the intent should be to perform the test at as high a temperature as possible while maintaining the functional performance within tolerances. In addition, care should be taken in the selection of the test temperature to preclude the introduction of invalid (test induced) failure mechanisms.

Test Duration: Test duration should be selected after reviewing a) the part acceleration factors characterizing the subsystem, b) the selected test temperature, and c) the time between test article availability and the time at which additional information is of little value, for example launch.

Other Environmental Requirements: The need for controls on other environments, particularly vacuum, needs to be addressed on a subsystem-by-subsystem basis.

Policy for Handling Failures: In the event of degradation or failure prior to termination of the test, the policies for interupting the test, conducting failure evaluation (including tear down and repair), and resumption of the test need to be defined. These policies may require on-site interpretation since these decisions will be dependent on the nature of the problem and the time at which it occurs.

Documentation and Reporting: Provisions for reporting test status and accomplishments should be included. A final assessment of each subsystem's expected life capability and an evaluation of design characteristics and/or components most likely to limit the subsystem's life, is recommended.

V. Conclusions and Recommendations

This study developed a set of guidelines for the definition of an accelerated subsystem life test program. Any life test program appearing to be reasonable in the context of schedule and resources typical of a planetary spacecraft program has been found to have limitations. Nevertheless, the evaluation of spacecraft capabilities by conducting an accelerated life test program on subsystems is considered necessary for long duration missions. This study served to provide the basic rationale for defining such an evalaution program.

A primary conclusion is reflected in the statement of test objective for an accelerated life test on an electronic subsystem. The information producing aspect or developmental nature of an accelerated life test is considered to reflect a test objective which can realistically be pursued. A test satisfying this objective falls short of total demonstration that the subsystem has the required life capability. However, once this objective is accepted, then the test techniques evolved will produce qualitative and quantitative information on the long life capability and limitations of the subsystem.

The benefits of conducting an accelerated life test on subsystems are derived from the exercising of the subsystem design in its flight configuration causing interactions between parts, materials, circuits, and local environments. The impact of these interactions as a function of time is usually not amenable to design analysis. It is the evaluation of the life related strengths and weaknesses of these "system" characteristics that forms the basic justification for the test.

Several limitations of accelerated life test have been identified in preceding sections. The basis for these limitations rests on the fact that accelerated ageing cannot be made to duplicate real life ageing. Any test conducted under accelerated ageing conditions therefore requires compromises of conflicting goals.

Of the parameters affecting the ageing processes, only temperature and functional operation of the test article are recommended for use in implementing and controlling an accelerated life test. The upper bound on temperature is constrained by the range over which the subsystem remains functional and by the introduction of unrealistic failure mechanisms when the latter can be identified. Functional operation of the subsystem should provide simulation of mission operations as well as allow thorough exercising of all modes and the monitoring of functional performance degradation.

The role of failure analysis is primary in an accelerated life test program for spacecraft subsystems. The basic information return results from the analysis of degradation or failure which has been promoted under controlled conditions. The failure analysis is relied on to identify the cause of failure and determine the extent to which such a failure represents a life related design weakness.

The effect of other environments on the long life reliability of a subsystem has been considered only briefly. One which deserves further attention is the charged particle radiation environment associated with both the radioisotope thermoelectric generators (RTG's) considered for use on long life outer planets spacecraft and the natural space radiation environments. The extent to which these environments degrade performance and interact with the long life effects considered in this study is not well known and deserves further evaluation.

Finally, although slightly beyond the scope of this study, it seems appropriate to place the accelerated life testing of spacecraft subsystems in the broader context of the total long life reliability problem. Given a long life mission for which a spacecraft is to be developed, there will be activities in several areas which should be closely related and coordinated. These activities include parts qualification, parts screening, parts design and fabrication analyses, system reliability analysis, quality assurance, subsystem testing, failure analysis, and others. Of obvious significance to this study is the relation between the parts testing program and the subsystem testing program. Each activity should be structured so as to complement the other. In addition, where reliability models are developed, some interplay should take place between the parts and subsystem testing activities and the analytical modeling. Analytical models can shape test requirements and test results can influence model development.

It is recommended that any program faced with the need for long life capability as addressed in this study provide suitable organizational structure to enhance the coordination of the many life related activities.

A related recommendation pertains to the parts test program. Continued growth in understanding of the basic physics of failure at the parts level is required. Data developed in parts test programs can be utilized in the formulation of subsystem test requirements.

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Appendix

Example Compilation of Parts Data for Typical Spacecraft Subsystem

The MM'71 Television Subsystem was selected to exemplify a way parts data may be used to assist in the development of an accelerated life test specification. In this example parts acceleration factors and reliability data were taken from two sources; MIL-HDBK-217A, (for discrete parts data), and Porter and Finke's integrated circuit reliability model, reference 8 (for microcircuits). Weighting factors were constructed using estimates of the criticality of each part (defined by considering the relative importance of each subsystem function supported by each part), and its probability of failure (using the exponential distribution and failure rates from the above noted sources).

As used in this example, acceleration factors and weighting factors were determined for each part type in accordance with the following definitions and assumptions:

Part Acceleration Factor $= \alpha_i = \dfrac{\lambda_{i,T}}{\lambda_{i,M}}$ where

$\lambda_{i,T}$ = the failure rate of part type i at the candidate accelerated life test temperature, and

$\lambda_{i,M}$ = the failure rate of the same part type at its expected mission temperature.

Weighting Factor = $w_i = n_i(1-e^{-\lambda_{i,M} t})$ where

t = mission duration, in hours; (10,000 hours assumed for this example), and

n_i = "the Effective Quantity" of parts of type i found in the subsystem.

Effective Quantity = $n_i = \sum_{j=1}^{K} P_j f_{i,j}$ where

P_j = a measure of the relative importance of the jth function on a scale of 0 to 1,

$f_{i,j}$ = number of critical* parts of type i supporting function j.

Table A-1 contains a compilation of the T.V. parts data and calculations used in the following two figures. Figure A-1 is a histogram showing actual parts quantities versus acceleration factors. Judging from the information presented in this figure, and a desire to minimize both undertesting and overtesting, an accelerated subsystem life test duration approximately equal to the mission duration divided by the mean acceleration factor (or $\frac{\text{mission duration}}{2.77}$ = .36 mission durations) might be appropriate.

To see the impact of evaluating each parts' relative importance and probability of failure during a mission, a mission duration of 10,000 hours (approximating the MM'71 mission) was assumed, and the

* The number of critical parts of type i is defined to be the total quantity of type i supporting the function minus the number of parts which serve in redundant capacity.

resultant data displayed on Figure A-2. On this histogram the bulk of the data is more densely distributed and shifted towards typically lower acceleration factors than the data displayed on Figure A-1. Again judging from the information presented in the histogram and the same undertest/overtest desires noted above, an accelerated test duration approximately equal to $(\frac{1}{1.56}) \cdot$ (mission duration) = .64 mission durations would be found desirable. Although the use of the weighted data results in the selection of a longer test duration than the unweighted data (in the example), performing the test based on the weighted data should produce the most valuable information on those characteristics of the subsystem deemed most critical in contributing to the total success of the mission.

As a supplemental note, it should be recognized that the choice of using the MM'71 T.V. subsystem as an example encountered some unique (and in some ways undesirable) considerations. Primarily, the upper bound selection of 55°C for an accelerated test temperature reflects a temperature constraint not usually found on other MM'71 subsystems. (75°C is more often found as a subsystem upper bound temperature, in design qualification test.) Consequently, the achievable degradation in this example is typically less than that achievable in a subsystem capable of being tested at higher levels, where the same baseline mission temperature exists.

It should also be recognized that the use of weighted data does not imply that long test durations would always be suggested (in comparison to durations suggested by the use of unweighted data). Other subsystem examples may show an effect opposite to the one shown in this example, where the application of weighting results in the formulation of a shorter test duration than that suggested on the basis of unweighted data.

Finally, the reliability data associated with each part type in this example was accrued from sources that generally indicate reliability levels several orders of magnitude higher than values typically associated with Hi-Rel. parts used in Mariner Programs. To get the most accurate picture in histograms employing weights, actual reliability values should be used.

TABLE A-1

MM'71 T. V. SUBSYSTEM PARTS DATA EXAMPLE

Part Type	Part Number	Real Quantity	Effective Quantity	Failure Rate[1]	Probability of Failure [2]	Weighting Factor [3]	Acceleration Factor [4]
Capacitors							
Mica	CEM	2	2	.22	.022	.044	1.54
Ceramic	CKR	216	210	.01	.001	.197	3.30
GP	CYFR	48	46	.01	.001	.046	4.70
Mica Dip.	HRDM	9	9	.22	.022	.195	1.54
Paper	P323Z	1	1	.21	.021	.021	1.48
Film	05PK	10	10	.0016	.00016	.0016	2.10
Teflon	05T4	8	8	.0016	.00016	.0013	2.10
Tant. Foil	16K	23	22	.380	.037	.820	2.20
Tant.	29F	4	4	.380	.037	.149	2.20
Tant. Solid	350D	157	146	1.1	.104	15.21	1.90
Diodes							
Ref., G.P.	1N755A	4	3	2.06	.186	.559	1.10
Ref., G.P.	USR1172	29	29	2.06	.186	5.40	1.10
Ref., G.P.	1N972A	4	3	2.06	.186	.559	1.10
Ref., G.P.	1N3033B	2	2	2.06	.186	.372	1.10
Sig. & Comp.	1N4447	269	240	.374	.0367	8.81	1.73
Ref. Prec.	1N4572A	22	22	2.06	.186	4.69	1.10
Ref. Prec.	1N4772A	6	5	2.06	.186	.930	1.10
Zener	1N748A	4	4	2.06	.186	.745	1.10
Ref., G.P.	1N751A	3	3	2.06	.186	.559	1.10
Ref., G.P.	1N756A	2	2	2.06	.186	.372	1.10
Light Sensor	T1XL09	4	4	(Not Identifiable)			
Rect., F.R.	UTR3320	101	99	.374	.0367	3.63	1.73

TABLE A-1 (Contd)

MM'71 T. V. SUBSYSTEM PARTS DATA EXAMPLE

Part Type	Part Number	Real Quantity	Effective Quantity	Failure Rate[1]	Probability of Failure[2]	Weighting Factor[3]	Acceleration Factor[4]
Diodes - Cont.							
Rect., F.R.	UTR3360	22	22	.374	.0367	.807	1.73
Zener	1N3827A	3	3	2.06	.186	.559	1.10
Zener	UTR62	8	8	2.06	.186	1.49	1.10
Microcircuits							
	M1101A	24	21	8.46	.571	12.0	1.39
	M1102A	1	0	8.46	.571	0.00	1.39
	M1709H	7	6	10.07	.635	3.81	1.66
	M1731Q	5	4	10.07	.635	2.54	1.66
	M1156Q	3	2	8.46	.571	1.14	1.39
	M1416Q	7	7	8.46	.571	4.00	1.39
	M1424Q	16	15	8.46	.571	8.56	1.39
	M1455Q	2	2	7.39	.522	1.04	1.45
	M1480Q	58	51	10.07	.635	32.4	1.66
	M1410Q	8	7	8.46	.571	4.00	1.39
Resistor							
W.W.	AGS-1	25	25	.019	.002	.047	1.20
W.W.	AGS-3	24	24	.019	.002	.045	1.20
Fixed Carb.	BB	102	102	.0035	.00035	.036	4.57
Fixed Carb.	CB	697	627	.0035	.00035	.219	4.57
Fixed Carb.	EB	6	6	.0035	.00035	.002	4.57
Fixed Carb.	GB	16	16	.0035	.00035	.006	4.57
Fixed Carb.	HB	11	11	.0035	.00035	.004	4.57
Comp.	MG710	4	4	(Not Identifiable)			
Carbon Film	HV1000	4	4	(Not Identifiable)			

TABLE A-1 (Contd)

MM'71 T. V. SUBSYSTEM PARTS DATA EXAMPLE

Part Type	Part Number	Real Quantity	Effective Quantity	Failure Rate[1]	Probability of Failure [2]	Weighting Factor [3]	Acceleration Factor [4]
Resistor - Cont.							
SW, Precision	6HM1	1	1	(Not Identifiable)			
Metal Film	451	139	139	.017	.0017	.236	1.47
Metal Film	462	216	206	.017	.0017	.350	1.47
Metal Film	465	5	5	.017	.0017	.008	1.47
Metal Film	470	4	4	.017	.0017	.007	1.47
Metal Film	475	3	3	.017	.0017	.005	1.47
XFMR							
S.P.	PT1854	4	4	.210	.021	.083	1.0
Power	16592	1	1	.210	.021	.021	1.0
Power	16593	1	1	.210	.021	.021	1.0
Power	16594	1	1	.210	.021	.021	1.0
Power	16595	1	1	.210	.021	.021	1.0
Power	16596	1	1	.210	.021	.021	1.0
Power	16597	2	2	.210	.021	.021	1.0
Vid. Pfl.	D10015769	4	4	.210	.021	.021	1.0
XSTR							
Med. Power	2N2219A	4	4	.180	.018	.071	1.72
Med. Power	2N2222A	43	33	.180	.018	.589	1.72
Med. Power	2N2369A	6	6	.180	.018	.107	1.72
Chopper	2N2432	2	2	.820	.079	.157	1.40
Med. Power	2N2484	32	32	.820	.079	2.52	1.40
Med. Power	2N2605	3	3	.820	.079	.236	1.40
Med. Power	2N2658	16	15	.820	.079	1.18	1.40
Power	2N2880	7	7	.820	.079	.550	1.40

TABLE A-1 (Contd)

MM'71 T. V. SUBSYSTEM PARTS DATA EXAMPLE

Part Type	Part Number	Real Quantity	Effective Quantity	Failure Rate[1]	Probability of Failure [2]	Weighting Factor [3]	Acceleration Factor [4]
XSTR - Cont.							
Med. Power	2N2905A	4	4	.365	.036	.143	1.90
Med. Power	2N2907A	25	24	.365	.036	.860	1.90
Dual.	2N2920	18	18	.820	.079	1.42	1.40
Chopper	2N2945A	2	2	.820	.079	.157	1.40
Dual PNP	2N3350	30	30	(Not Identifiable)			
Med. Power	2N3496	11	10	.180	.018	.178	1.72
Med. Power	2N3501	15	14	.180	.018	.250	1.72
Med. Power	2N3637	2	2	.180	.018	.036	1.72
Med. FET	2N3954	14	14	(Not Identifiable)			
Med. FET	2N3969	2	2	(Not Identifiable)			
Med. FET	2N4093	18	18	(Not Identifiable)			
Med. FET	2N4393	2	2	(Not Identifiable)			
Photo	LS600	4	1	(Not Identifiable)			
Power	SDT8805	1	1	.820	.079	.079	1.49
Med. Power	2N2905A	4	4	.365	.036	.143	1.90
Med. Power	SDT3304	7	7	2.50	.221	1.55	1.8.

Notes:

1) In failures/million hours at 20°C.

2) For a 10,000 hour mission.

3) Calculated by multiplying the effective quantity by the probability of failure.

4) For a test temperature of 55°C.

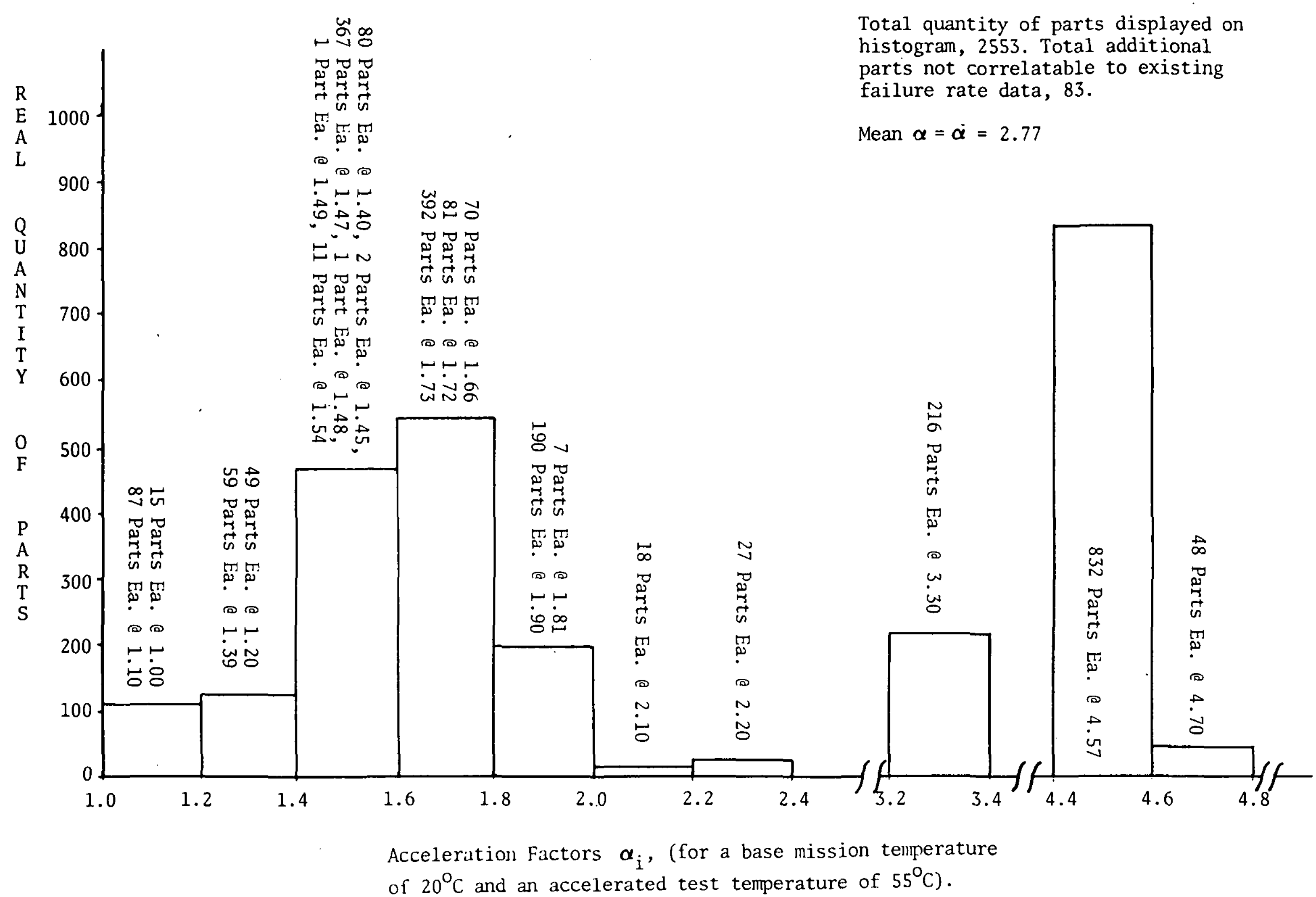
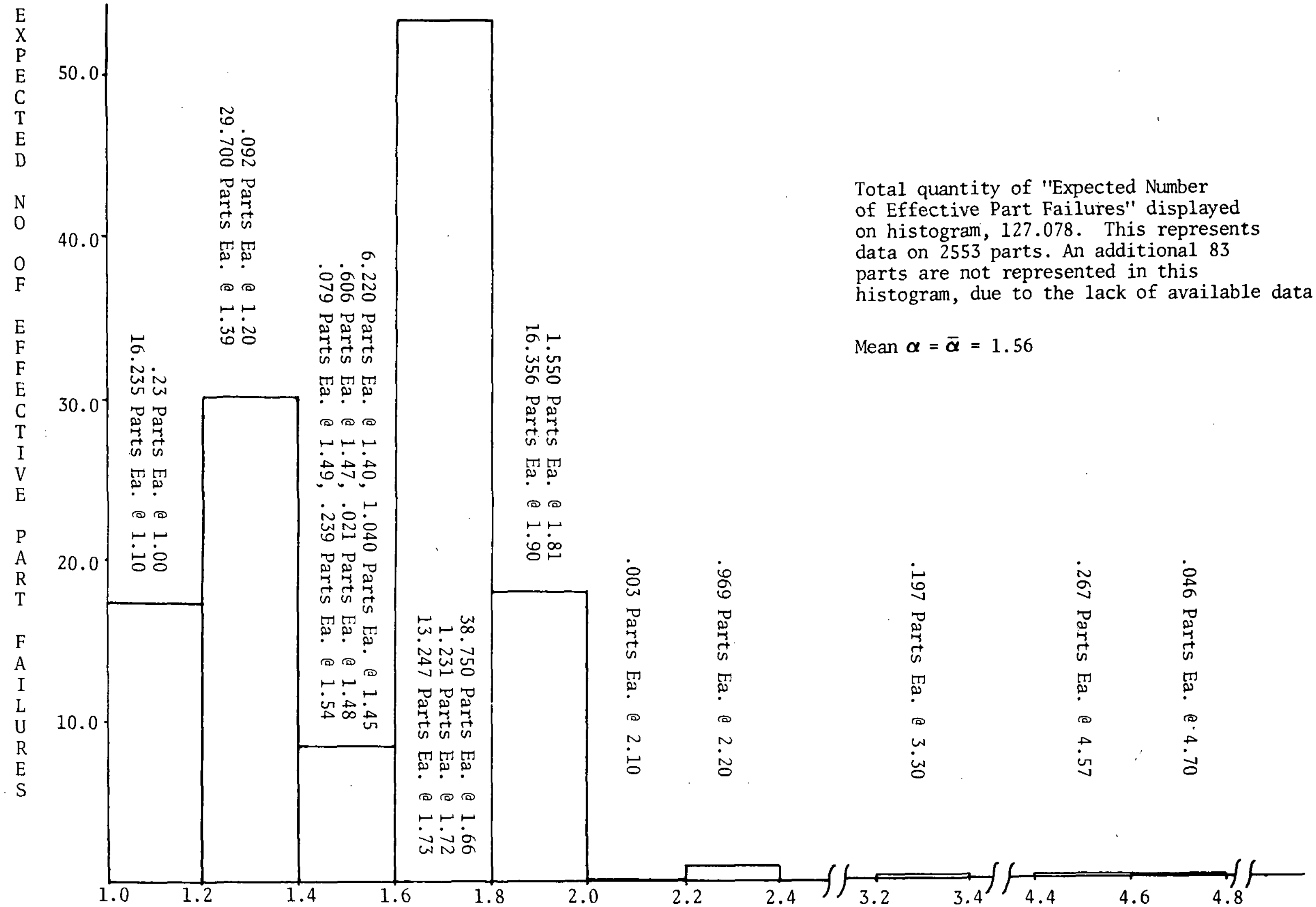


Figure A-1. MM'71 T.V. Subsystem Histogram Example: Real Parts Quantities vs. Acceleration Factors



Acceleration Factors α_i, (for a base mission temperature of $20^{o}C$ and an accelerated test temperature of $55^{o}C$).

Figure A-2: MM'71 T.V. Subsystem Histogram Example: Expected Parts Performance vs. Acceleration Factors