JPL PUBLICATION 83-76

NASA Flight Electronics Environmental Stress Screening Survey

Compiled by
Edward J. Marian

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FOREWORD

Considerable testing is required on all NASA flight programs to provide assurance that the mission objectives will be achieved. Testing is accomplished on NASA flight hardware at all levels ranging from individual parts to total systems. During the course of testing, failures are noted that are attributed to, among other things, workmanship/manufacturing flaws, and parts and design deficiencies.

Some of the earlier space programs that were the forerunners for "screening" programs for environmental exposure were the unmanned spacecraft programs and, later, the manned spacecraft programs such as Apollo. Component-level screening for various types of latent failures at the various NASA centers was (and still is) accomplished through the environmental acceptance-testing process.

More recently, industry has become sensitive to environmental-stress screening of electronic hardware because of Government initiatives being exercised in the procurement cycle. In general, industry tends to view screening as a "screen" and not a test. The Institute of Environmental Sciences (IES) Industry/Government Committee on Environmental Stress Screening of Electronic Hardware (ESSEH) has defined screening as follows (see Reference 1):

> "A process or combination of processes for the purpose of identifying and eliminating defective, abnormal, or marginal parts and manufacturing defects."

A two-year effort by the IES ESSEH committees culminated in a set of guidelines for environmental-stress screening that was presented in an industry/government workshop sponsored by the IES in 1981 at San Jose, California (see Reference 1).

Industry's interests in screening relate primarily to production quantities, and the data base developed as the basis for the IES ESSEH guidelines document utilizes data gathered from production projects. A wide variety of parts used in these production units are also used in NASA flight electronic equipment, and it would seem reasonable to expect similar types of latent failures to be present in this NASA equipment. It also seems reasonable to apply this industrial base of experience to NASA flight electronic equipment.

This document utilizes the IES ESSEH data augmented by other available sources of similiar information in conjunction with NASA centers' data and presents this information in a form that may be useful to all NASA centers in planning and developing effective environmental-stress screens. Specifically, this document presents information relative to thermal and vibration screens as the most effective for surfacing latent failures in electronic equipment at the component level.

ACKNOWLEDGEMENT

Appreciation is expressed to those individuals at JPL, JSC, MSFC, GSFC, LaRC, LeRC, NASA Office of Chief Engineer, and others for their contributions in the reviews and interviews conducted in the data gathering and preparation of this document. Material as noted in this document is attributed to the Institute of Environmental Sciences, and is reprinted from the ESSEH Environmental Stress Screening Guidelines Document, copyright 1981, Institute of Environmental Sciences, 940 East Northwest Highway, Mt. Prospect, Illinois, 60056, and reprinted by permission of the copyright owner.

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ABSTRACT

This document utilizes NASA centers' data in conjunction with the IES ESSEH data augmented by other available sources of similiar information and presents this information in a form that may be useful to all NASA centers in planning and developing effective environmental-stress screens. Specifically, this document presents information relative to thermal and vibration screens as the most effective for surfacing latent failures in electronic equipment at the component level.

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1.0 INTRODUCTION

Many surveys and studies have been conducted investigating environmental-stress screening. In most cases test data were gathered from a variety of sources from both government and industry. The data covered many different projects involving electronic hardware being produced in relatively large quantities. These data are then correlated, analyzed, and used as the basis for developing general screens for specific types of electronic equipment. These screens are generally designed to precipitate latent workmanship defects and manufacturing flaws. Such generally used parameters as levels, duration, and number of cycles are independent of mission profiles, and are applied in the production sequence prior to the hardware acceptance test.

The surveys and other literature sources used in the preparation of this document are listed in Section 5.0, References. As part of the task in preparation of this document, NASA has been actively involved in the IES ESSEH committees/survey. The data from the IES survey represent more state-of-the-art technology for electronic equipment and are more indicative of current trends than earlier surveys.

Under the auspices of the IES, a technical committee was established in 1979 to develop a guideline document which could be used as a standard by the industry. This group has devoted two years to the collection, review and evaluation of the different screens currently used in the industry. Actual screening data on many programs were obtained from various disciplines of industry. An extensive literature search of published documents on the subject was conducted, yielding valuable insight into the heritage of many of the screens currently used. The final report covering guidelines for parts and assemblies was presented at the September 1981 2nd National Conference and Workshop of the ESSEH sponsored by the IES.

The resulting guidelines from this industry study are, by necessity, general in nature. This industry committee considered all end uses of electronic equipment. In this respect, the industry study was very broad in scope when compared to the NASA objective of developing an effective screen for flight projects. NASA flight projects generally involve small quantities of a given component (in many cases a single component per project) while the IES industry data are based on high-volume production units. However, many of the guidelines developed under the industry study are relevant to the NASA hardware. The industry guidelines have been developed from information and statistics on state-of-the-art hardware.

2.0 BACKGROUND

2.1 General

A review of recent literature, surveys, and screening programs associated with environmental-stress screening of electronic hardware combined with data obtained from a survey of the major NASA centers form the data base for recommendations included in this document.

Quality assurance tests carry many labels, such as flight acceptance, workmanship, and delivery test, with a common purpose - to reveal weaknesses or defects in the equipment as a result of errors or excessive variability in the manufacturing process. These tests are not intended to detect design weaknesses or to demonstrate design adequacy. The survey of major NASA centers indicates that the quality assurance tests are for the most part labeled "acceptance testing." All NASA centers surveyed accomplish acceptance testing as part of their overall test program. Environmental-stress screening per se within NASA received wider attention in the midsixties for the Apollo program (see Reference 2 - Apollo experience report). It was found that the Apollo environment was so benign that acceptance tests designed to simulate the actual flight environment were, in many cases, not severe enough to precipitate latent defects in the equipment. These defects were escaping to higher levels of assembly, where repair is much more costly, or appearing in flight with consequent dangers to mission objectives and astronaut safety.

An extensive amount of experimental effort was expended to develop minimum vibration and thermal-cycling acceptance tests for the Apollo program (see Reference 2), which were applied to all electronic equipment at the component or "black-box" level of assembly. The exposure levels employed in environmental-stress screening were unrelated to the expected use environment whereas historically, acceptance testing has involved the application of environmental exposures intended to simulate the flight environment. The purpose of the acceptance test has been to ensure that the tested hardware is capable of surviving and performing to specification in that environment. The survey conducted for the Apollo program (see Reference 2) indicates that thermal-vacuum testing was more effective than temperature cycling in precipitating latent failures at the component level. (It should be noted that respondents to the IES survey (see Reference 1) did not report on thermal-vacuum testing.) The Apollo program required both thermal (cycling) and thermal-vacuum testing.

The survey of the NASA centers consisted of a series of meetings with the appropriate individuals from the various centers. Information was gathered from JSC, GSFC, JPL, MSFC, and LeRC. The information consisted of documents, briefings and letters describing the particular center's approach to screening. In almost all cases, the NASA centers perform acceptance testing at the component level. The primary purpose of these acceptance tests is to precipitate latent failures that exist because of both manufacturing flaws and workmanship defects in parts. Included in these acceptance tests are temperature-cycling and/or thermal-vacuum testing, and random-vibration exposure. A considerable amount of testing is accomplished on NASA flight electronic hardware at all levels of assembly ranging from individual piece parts to total systems.

During the course of testing, failures are noted that are attributed to workmanship, marginal designs, and marginal parts. These are also the more common causes referred to most often by industry. Table 1 summarizes the NASA survey for environmental-stress screening as accomplished by each center.

The most recent industry/government survey was conducted by the IES ESSEH committee (see Reference 1) and represents more state-of-the-art electronic equipment than previous surveys. The results of the IES ESSEH survey indicate that temperature-cycling, random-vibration, and high-temperature screens were reported as the most effective (see Figure 1). Other surveys and applicable documents reviewed (see Section 5.0) also conclude that thermal-cycling and random-vibration screens are the most effective environmental screens for precipitating latent defects. The types of latent defects uncovered by these screens are summarized in each of the surveys reviewed. The IES ESSEH survey listing is shown in Table 2 as typical for more current electronic equipment, and Table 3 shows the results of the earlier Apollo experience.

In general, industry employs environmental-stress screening on high-volume production programs of complex hardware. The mathematical models developed for these kinds of programs indicate that environmental-stress screening can be cost-effective. These models may be extended to a single system such as is the case for many NASA Flight projects; however, it is not evident based on

Table 1. Summary of NASA Surveys for Stress Screening

Topic	GSFC	MSFC	JSC	Le RC	JPL
THERMAL					
Thermal Cycle	1 - 6 cycles	1 - 8 cycles	1 1/2 - 5 cycles	3 - 10 cycles	1 cycle
Temperature Range	± 10°C margin of mission level	50 to -47°C	40 to 0°C	79 to -25°C	55 to 0°C
Temperature Rate of Change	----------------------	5°C/min.	3 - 5°C/min.	5°C/min.	5°C/hr
Power ON vs. Power OFF	(NOT SPECIFICALLY ADDRESSED IN THE SURVEY - NEEDS CENTER INTERACTION)				
VIBRATION					
General Approach and Policy	1. Random vibration for spacecraft, thermal vacuum for component test. 2. Stress screening or confidence testing is different from flight acceptance test.	1. Accept. test based on project requirement and min. screening level. 2. Accept. test to screen workmanship and quality defects.	1. Verify manufacturing flaws and workmanship defects by environmental acceptance test. 2. Acceptance test is screening test. 3. Qual. level is 1.3 times accept. level (grms).	1. Acceptance test to detect defects.	1. Adequate qual. test has been completed prior to acceptance test. 2. Acceptance test to detect material and workmanship defects before flight.
Test Method	1. Shock exposure 2. Random exposure 3. Temperature cycling 4. Thermal vacuum	1. Random vibration 2. Temperature cycle	1. Random vibration 2. Temperature 3. Thermal vacuum test	1. Sine swept and random combined 2. Temperature cycle	1. Random vibration 2. Thermal vacuum test 3. Sine swept

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Table 1 (Continued) Summary of NASA Surveys for Stress Screening

Topic	GSFC	MSFC	JSC	Le RC	JPL
Test Level	1. Shock 200 - 4000 Hz 130g (max) Note: shock level is the acceptance shock requirement 2. Random 4.1 ∿ 5.9 grms 20 - 400 Hz 0.1 g^2/Hz peak 3. Acceptance random 16.7 grms 20 - 2000 Hz 0.18 g^2/Hz peak	1. Random 20 - 2000 Hz 5 ∿ 8 grms 0.03 ∿ 5 g^2/Hz	1. Random 5.4 ∿ 12 grms 20 - 2000 Hz 0.02 ∿ 0.10 g^2/Hz	1. Sine swept 1.6 ∿ 2.2g peak 50-100 or 10-100 Hz 2. Random 8 grms 20 - 2000 Hz 0.062 ∿ 0.134 g^2/Hz peak	1. Random 5.1 ∿ 6.8 grms 20 - 2000 Hz 0.035 ∿ 0.038 g^2/Hz peak 2. Sine swept 3 grms 5 - 1000 Hz
Axis	1. 2 axes for screening 2. 3 axes for acceptance	3 axes	3 axes	3 axes	3 axes
Duration	7.5 to 8 min/axis for screening 1 min for acceptance	3 ∿ 5 min/axis	1/2 ∿ 1 min/axis	1 min/axis	1 min/axis
Test Sequence	Shock first and random exposure "Alligator" test	1. Thermal and vibration used separately	1. Thermal and vibration used separately	1. Thermal and vibration when used separately 2. Sine and random combined	1. Thermal and vibration when used separately 2. Applying sine swept and random vibration singularly
Reliability Improvement	1. PIND test for component part 2. Significant improvement in the failure rate after screening	Not addressed	1. Parts are 100% screened and burned-in 2. Less than 1% failure after screening	1. PIND test component part 2. Not addressed for unit failure rate	1. All component parts subjected to shock vibration and thermal qual. requirements. 2. Significant improvement
Related Program or Project	MMS	Shuttle	Shuttle Apollo	Centaur	Viking, Voyager, Galileo

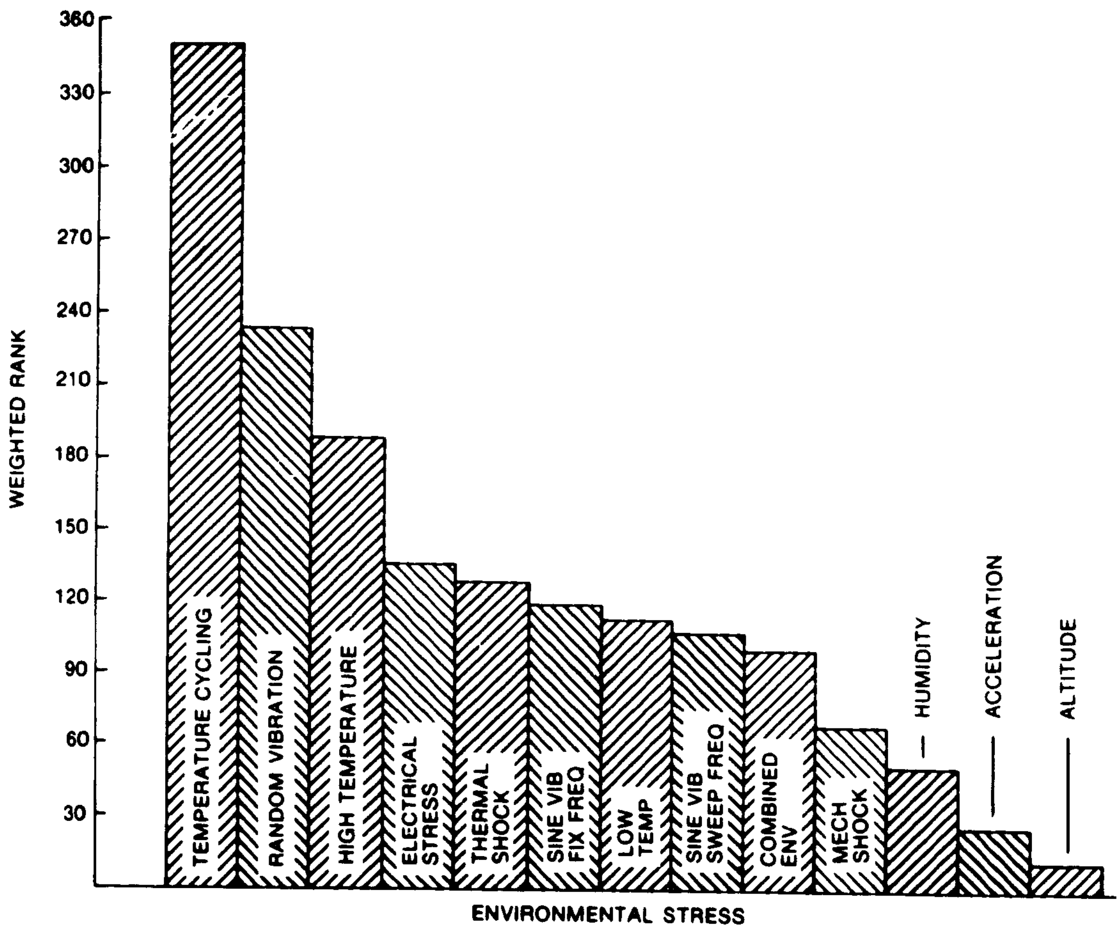

Figure 1. Effectiveness of Environmental Screens. (Ref. 1)

Table 2. Actual Causes of Failure by Screening Environment — ESSEH Study (All Assembly Levels). (Ref. 1)

THERMAL CYCLING ONLY	VIBRATION ONLY	BOTH THERMAL CYCLING AND VIBRATION
Drift	Particle contamination	Solder joints
PC board opens, shorts	Chafed, pinched wires	Loose hardware
Harness termination	Crystals, internal	Defective components
Part incorrectly installed	Mixer assemblies, internal	Fasteners
Wrong part	Adjacent boards rubbing	
Hermetic seal failure	Two parts shorting	
Contamination, chemical	Loose wire	
	Part not bonded down	
	Part came loose	

Table 3. Actual Causes of Failures by Screening Environment — Apollo Experience*.

THERMAL CYCLING ONLY	VIBRATION ONLY	BOTH THERMAL CYCLING AND VIBRATION
Material between relay contacts (C)	Wind-up mechanism misalignment	Contamination
Premature time delay	Defective module (C)	Lead broken
Broken or nicked wire (C)	Chip on rf contact	Relay contamination
Damaged Terminal	Connector backed off	
Broken wire (C)	Uncured epoxy	
Damaged wire insulation	Wire improperly soldered (C)	
Broken resistor	Dewetted solder joint	
Gear binding	No solder on joint (C)	
Damaged transistor	Intermittently open capacitor (C)	
Poor lead routing	Potting defect-glass fractured	
Improper resistor selection	Open relay coil (C)	
Bad splice (C)	Improper connector pin	
Bad crimp (C)	Intermittent relay	
Broken wire in potting		

(C) - Candidate failure mechanisms for detection with either vibration or thermal cycling.

* Source:
NASA TN D-8271 APOLLO Experience Report Environmental Acceptance Testing, Charles H.M. Laubach, Lyndon B. Johnson Space Center, Houston, Texas 77058, June 1976.

the industry data that this would necessarily be cost-effective. Each NASA project would need to be reviewed on its own merits to determine the cost-effectiveness aspect. (See Reference 3.0)

2.2 Thermal

The NASA survey data for thermal considerations as shown in Table 1 is summarized in Figures 2 through 4. Figure 2 shows that the temperature range typically applied to projects varies from a ΔT of $60^{\circ}C$ to a ΔT of $100^{\circ}C$. Figure 3 shows a thermal cycling variation from 1 to as many as 10 cycles. Figure 4 shows a comparison of rate of change of temperature with $5^{\circ}C/min$ being the most widely used. It should be pointed out that the project missions are considerably different from one another (i.e., interplanetary versus earth orbiting) and as such it is reasonable for a wide variation to occur. The past NASA experience record (see Reference 4) reflects that since 1975 NASA is achieving a high overall mission effectiveness, which could lead one to conclude that the screens presently being employed at the various NASA centers to date appear adequate. However, in the future, the concern is related principally to today's state-of-the-art electronics (i.e., LSI, VLSI) and packaging coupled with the long design life expected for future spacecraft and the impact on future missions of latent failures which could result in high life-cycle costs due to increased replenishment requirements.

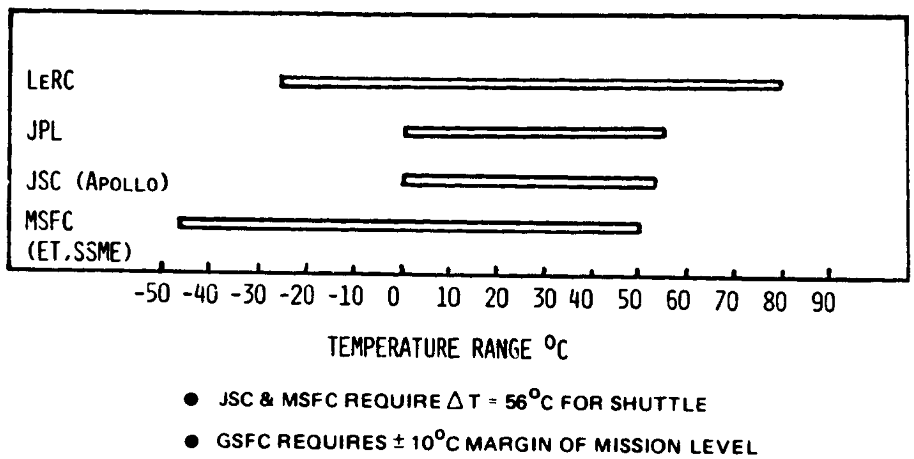

Figure 2. Temperature Range - NASA Installations

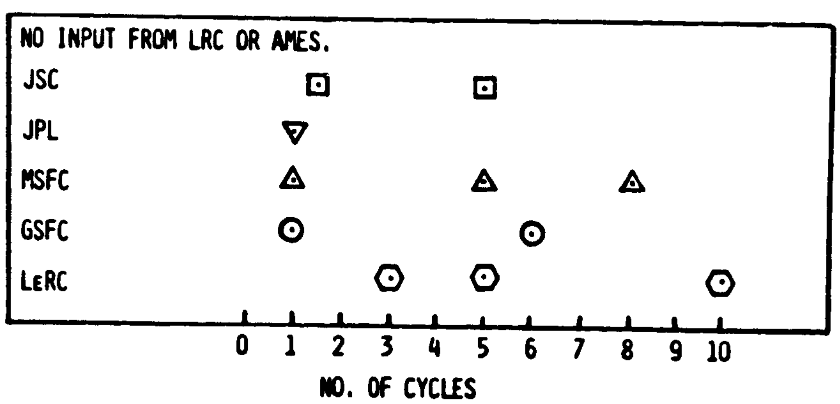

Figure 3. Typical Thermal Cycling Practices for NASA Installations

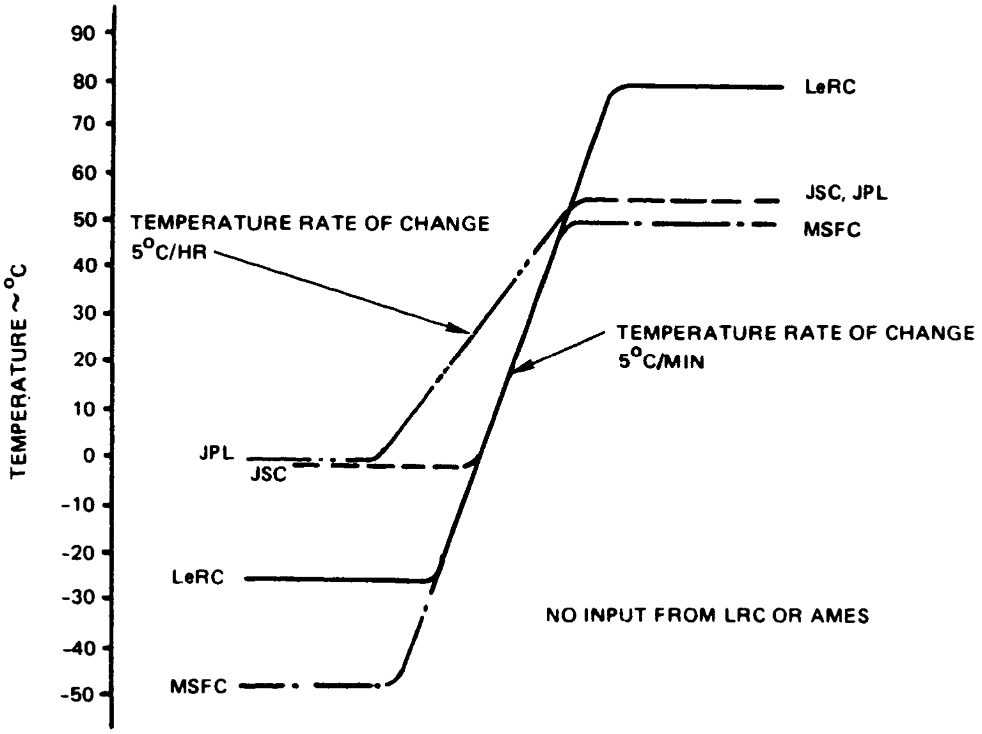

Figure 4. Typical Temperature Ranges and Rates of Change Used by NASA Installations

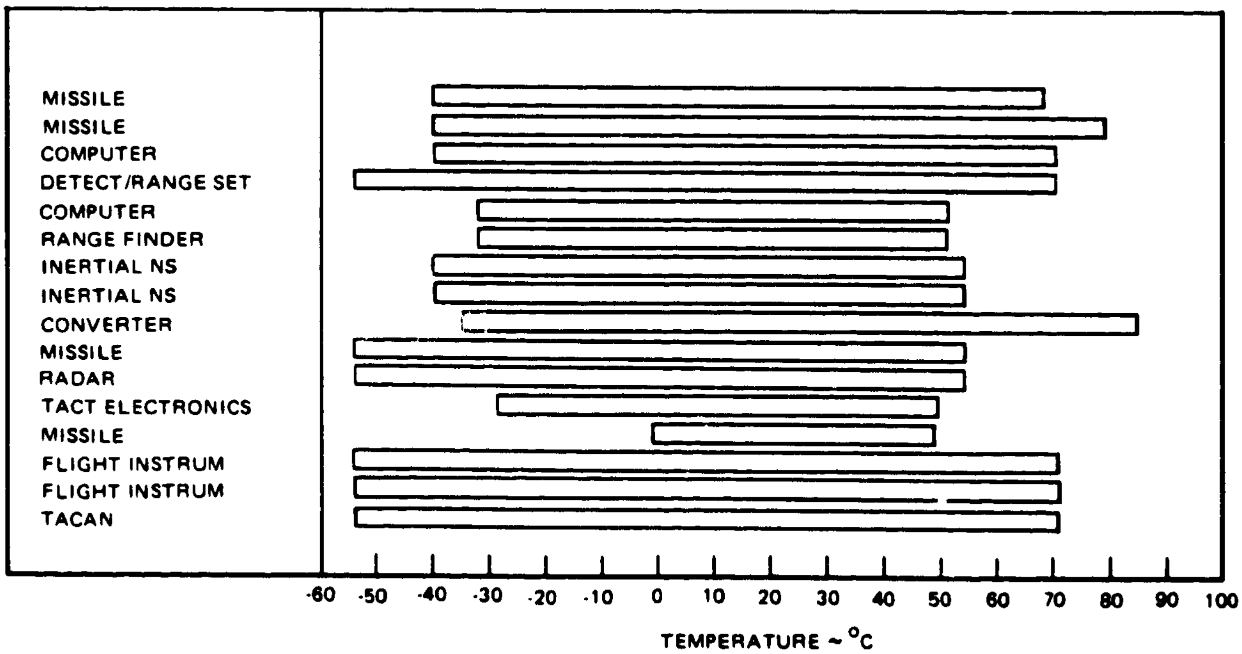

Figure 5. Component Level Screening - Temperature Range. (Ref. 1)

Therefore, the industry data base as shown in the IES ESSEH survey might be reviewed for future missions that incorporate more advanced electronics.

The IES ESSEH survey data (see Reference 1) for thermal considerations is shown in Figures 5 through 7. Figure 5 shows that the temperature ranges as applied to specific equipment items vary from a ΔT of $50^{o}C$ to a ΔT of $140^{o}C$. Figure 6 shows the typical profile used for thermal cycling and Figure 7 shows the percent fallout of latent defects versus number of thermal cycles applied.

The survey shown in the Navy manufacturing screening program (Reference 5) refers to data on electronic equipment that provides a correlation between equipment complexity (i.e., number of parts within the component) and number of thermal cycles. The IES ESSEH survey attempted a similiar effort and that data showed there was no correlation between number of parts in a component versus number of thermal cycles applied and number of failures.

2.3 Vibration

Table 4 and Figure 8 summarize the NASA centers' random-vibration characteristics and power spectral densities (PSD) utilized for acceptance testing. The data correlates to the NASA survey shown in Table 1. The PSD level in g^2/Hz varies from approximately .02 to .07. The frequency range for the flat portion of the spectrum ranges from approximately 80 Hz to 800 Hz. The time durations for the applied random-vibration environment varied from 1 minute per axis to 3 minutes per axis with 1 minute being used by most NASA

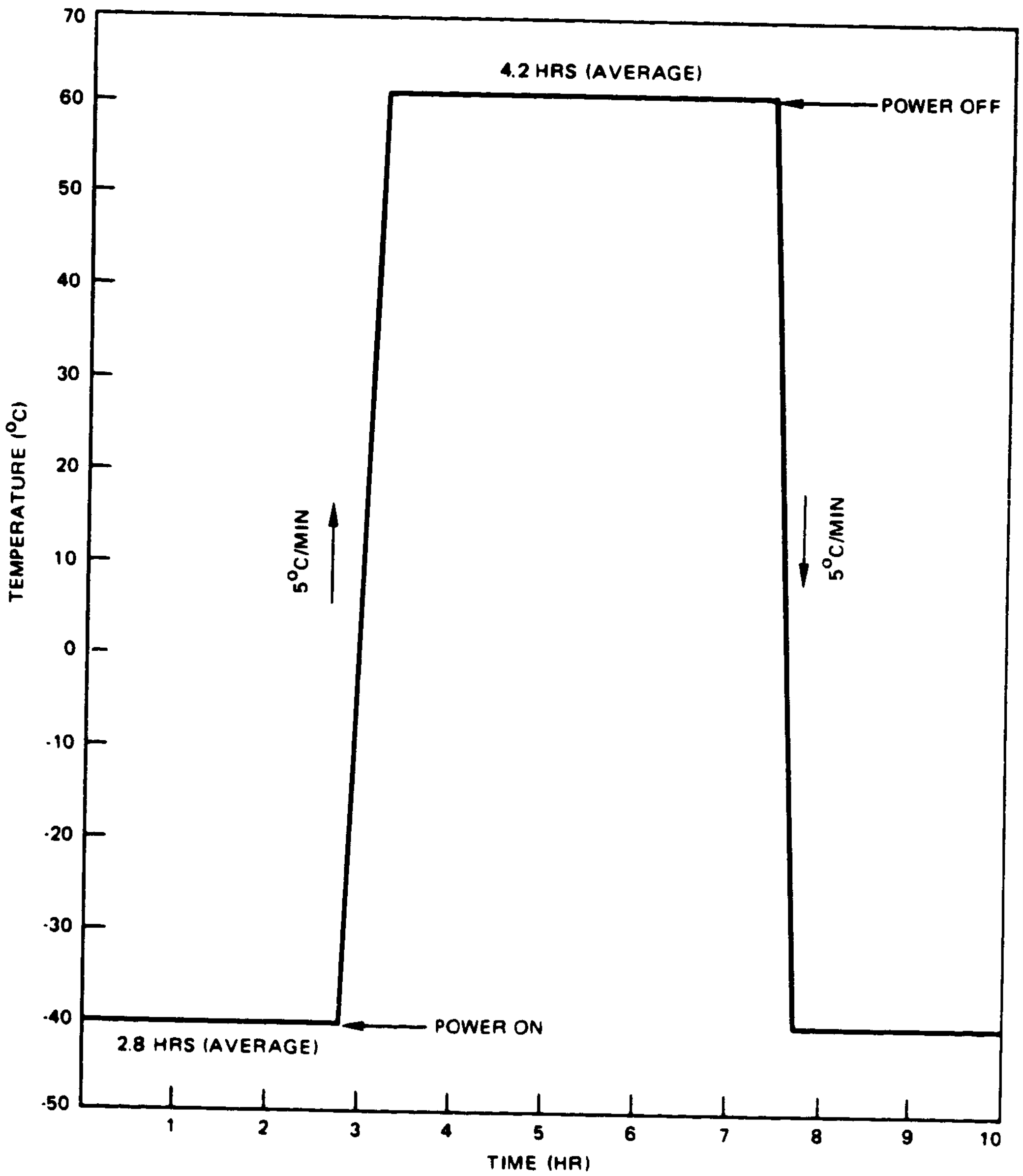

Figure 6. Typical Temperature Profile for Component Level Thermal Cycling. (Ref. 1)

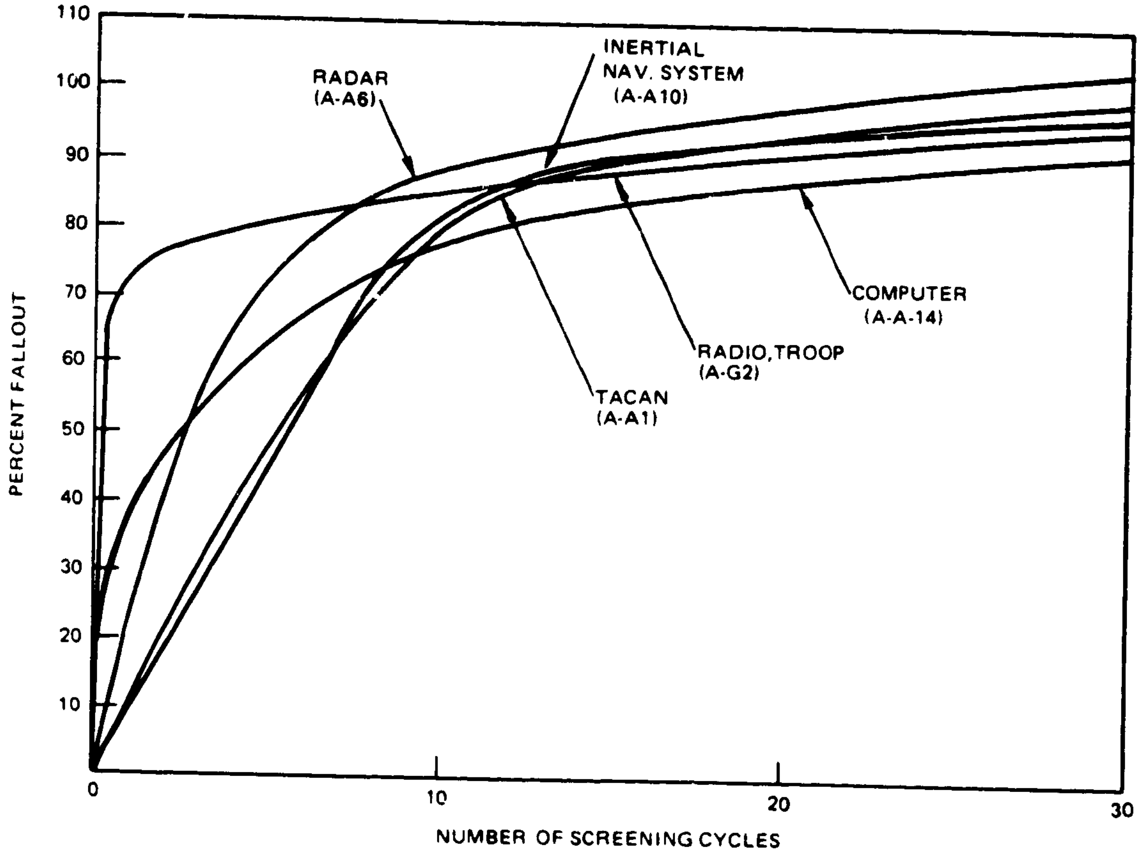

Figure 7. Percent Fallout vs Number of Screening Cycles Increased for Component Level Screening. (Ref. 1)

Table 4. TYPICAL VIBRATION ACCEPTANCE SPECIFICATIONS FOR NASA INSTALLATIONS

NASA CENTER	PROJECT	OVERALL G-RMS	FREQUENCY RANGE	VIBRATION DURATION TIME (MIN.)	NUMBERS OF AXES	REMARKS
JPL	GALILEO	6.6	20-2000	1	3	
MSFC	SHUTTLE	5.0	20-2000	3	3	
JSC	SHUTTLE APOLLO	6.1	20-2000	1	3	
GSFC	RIU	16.7	20-2000	1	3	
LEWIS	CENTAUR	8.0	20-2000	1	3	SINE SWEPT AND RANDOM COMBINED
NO INPUT FROM LRC OR AMES.						

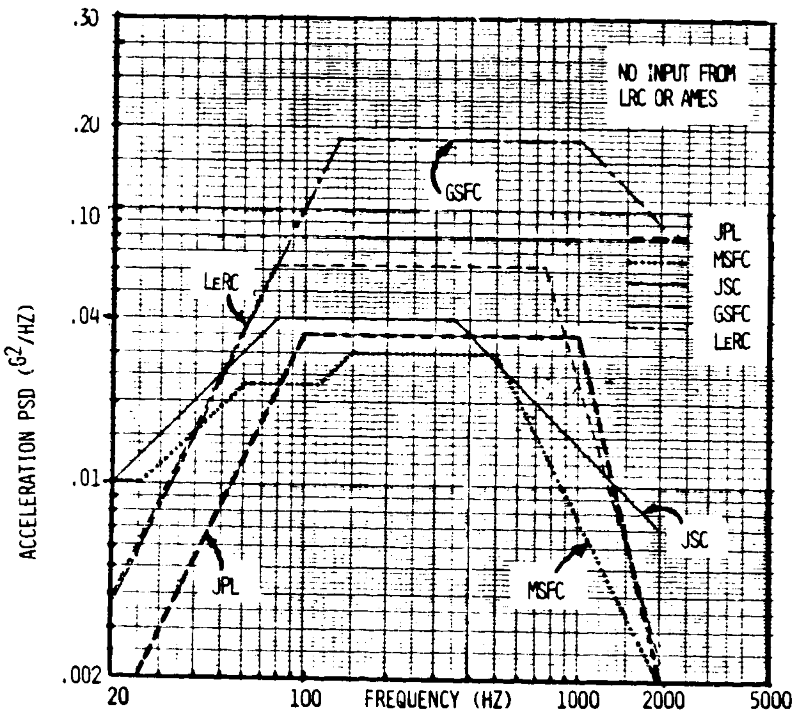

Figure 8. Typical Acceleration Spectra for Random Vibration for NASA Installations

centers. Figure 9 shows the Apollo random-vibration screen applied to component level electronic equipment. The same spectrum is used in the Navy screening program (see Reference 5).

The Grumman Report (see Reference 6) on Investigation to Determine Effective Equipment Environmental Acceptance Test Methods shows results of vibration-testing experiments in precipitating latent defects in electronic equipment.

Figure 10 shows the typical curve of percent fallout of failures for an applied random-vibration spectrum of 6 g's rms. The shapes of the various curves for different kinds of implanted latent defects shown in the Reference 6 report for random-vibration excitation are similar to those shown in Figure 7 from the IES survey in that the "knee" of the curve occurs at around 5 to 10 minutes. Both surveys indicate that random vibration is effective in precipitating latent defects in electronic equipment at a level of about .04 g^2/Hz.

The IES ESSEH survey data (Reference 1) for random vibration PSDs showed a wide variation (.01 to 0.1 g^2/Hz) with the majority of the spectrums similar to the NAVMAT P-9492 spectrum (see Reference 5), as shown in Figure 9.

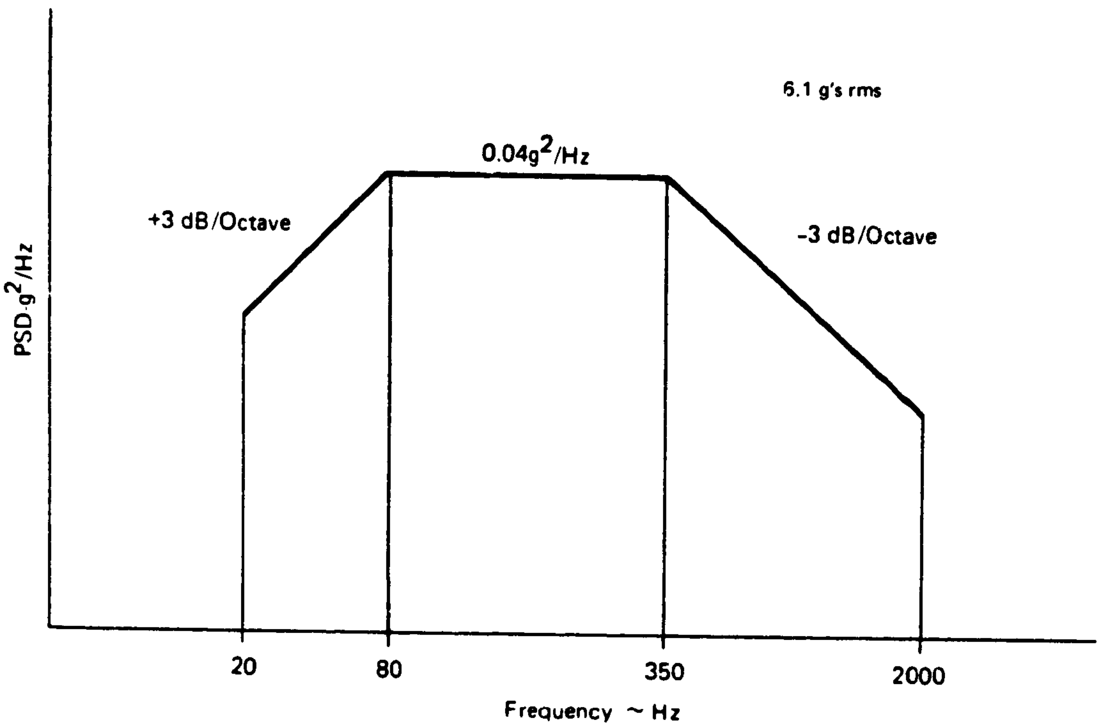

Figure 9. Random-Vibration Spectrum. (Ref. 2)

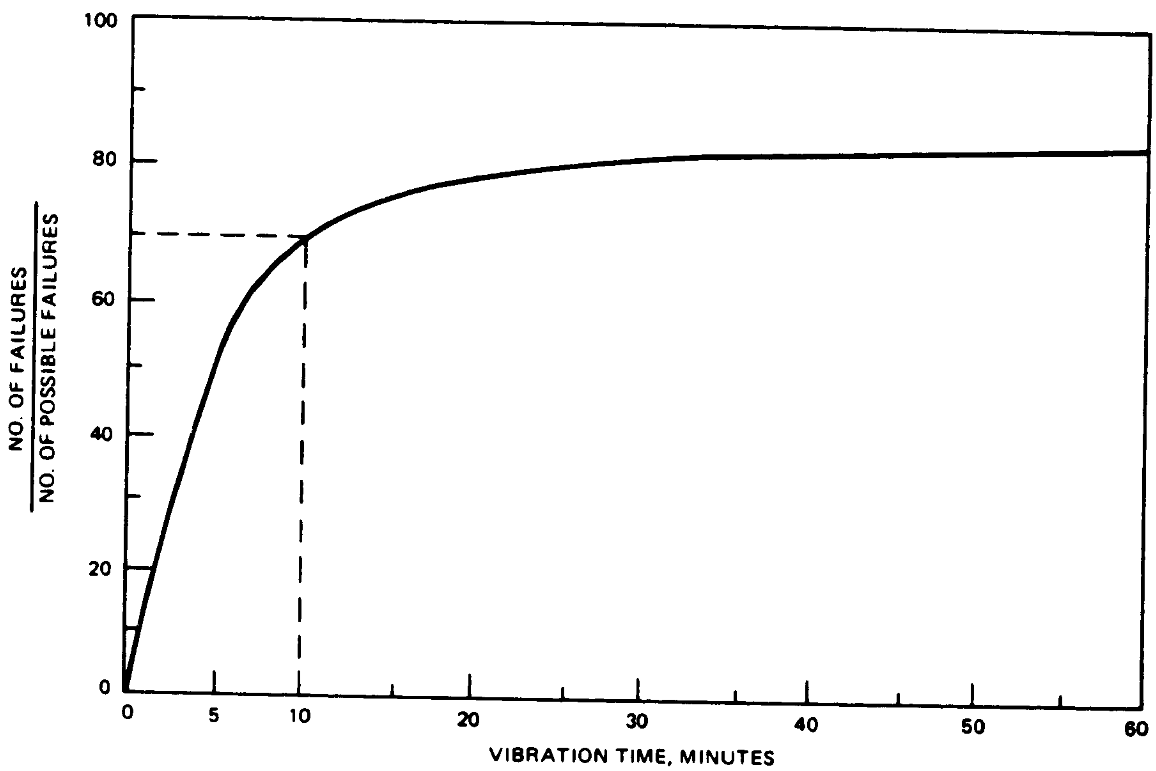

Figure 10. Percent Fallout as Vibration Time Increases for Component Level Screening. (Ref. 6)

3.0 RECOMMENDATIONS

3.1 General

Based on available data from both government and industry (see Section 3.0 and References in Section 5.0), it seems reasonable that screening tests for NASA flight electronic equipment components include thermal cycling and random vibration. The purpose of these tests should be to discover latent failures due to manufacturing flaws and defects in both parts and workmanship in order to permit corrective action prior to integrating the component into the next level of assembly where discovery of these latent defects would incur more cost for correction.

The suggested environmental-stress screening information provided in this document may be helpful in developing minimum requirements for thermal and random vibration. The data shown in Figures 7 and 10 have been replotted on one page (Figure 11) to make the point that the industry experience for catching 70% of the potential latent manufacturing and workmanship defects suggests 7 thermal cycles and a vibration time of 10 minutes as a benchmark. These suggested exposures (or those selected within the limits indicated) for environmental-stress screening may be less or more severe than those required to simulate the flight environment. If they are more severe, they should be considered as possible minimum acceptance requirements and govern the resultant specification.

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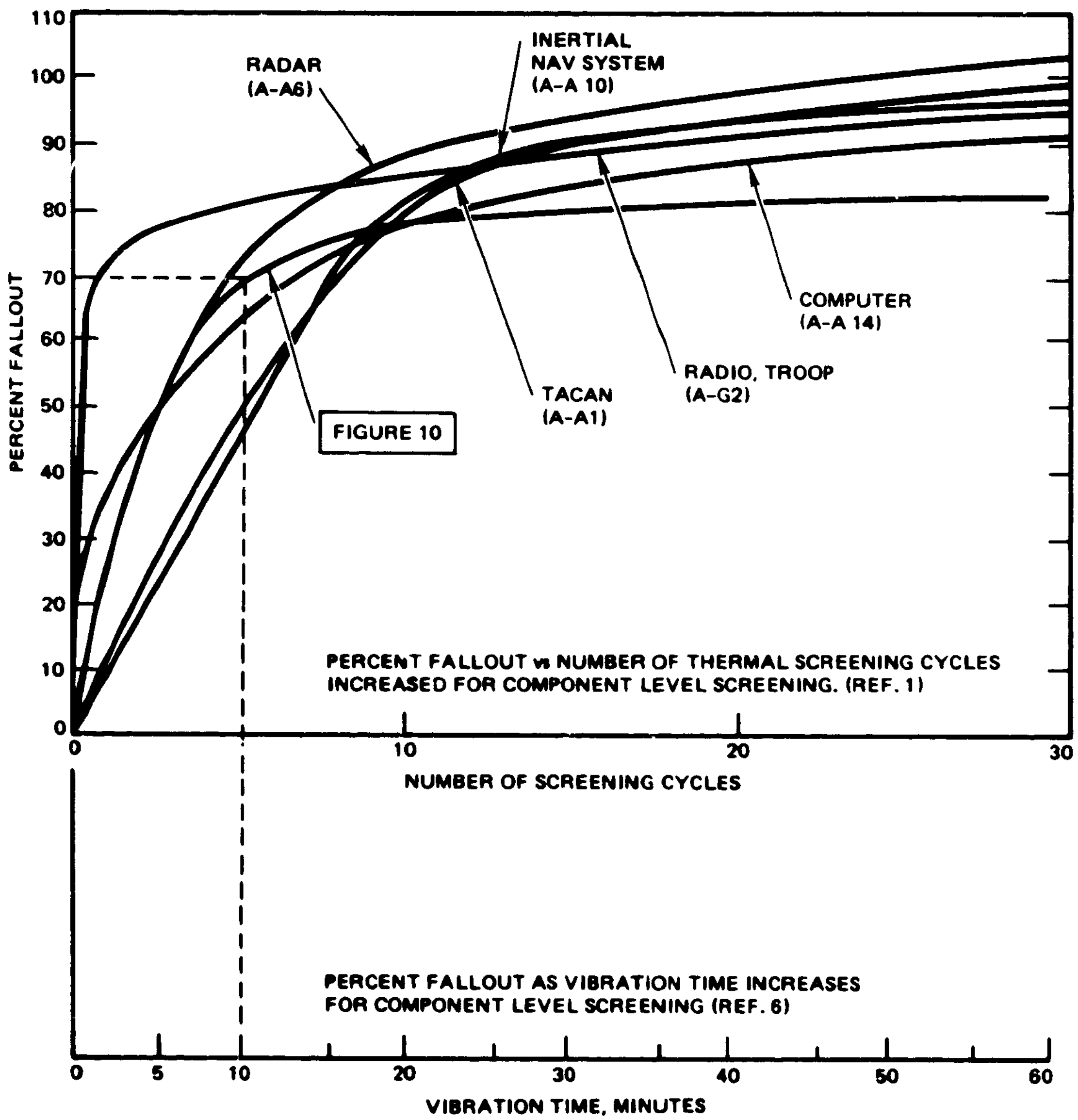

Figure 11. Composite of Figures 7 and 10

Figure 7 in Section 2.2 shows the % fallout of latent defects versus number of thermal cycles applied. The empirical data for thermal cycling indicates that the more thermal cycles applied the higher percent of the number of possible failures will be found. Again, 5 to 10 thermal cycles might be considered appropriate based on this data. The data for temperature extremes and associated rate of change of temperature indicates -50°C to +50°C and 5°/min may be appropriate.

Figure 10 in Section 2.3 shows the % failure versus duration for a random-vibration spectrum of 6 g rms. Empirical data indicates that the longer the duration the higher percent of the number of possible failures will be found. Again, 5 to 10 minutes might be considered appropriate based on this data. These time durations are in excess of those used by the NASA centers. However, selection of higher screening levels based on mission requirements may justify shorter screening durations. The vibration levels and durations should be used in each of three orthogonal axes, unless there is strong evidence that responses are essentially nonexistent in a particular axis, then a lesser number of axes might be appropriate.

The recommendations for both thermal and vibration considerations are general and provide a reference for planning project stress screening requirements. As an example, The Shuttle Program has developed a NASA handbook for the Shuttle's unique needs and would not necessarily utilize recommendations from this document.

3.2 Thermal

Recommendations for thermal considerations are provided in Table 5. As suggested in Section 3.0, these recommendations may provide a basis for planning and establishing specific project environmental-stress screening requirements as appropriate.

3.3 Vibration

Based on the finding of this survey (see References 1, 2, and 6) as described in Section 2.1, a random-vibration screen appears to be the most effective vibration screen for the component (black-box) level. Figure 12 provides an envelope of the flat portion of the power spectral densities (PSD) most commonly used as reported in . e surveys and documents (see References) reviewed.

Levels outside of this envelope were reported and were generally related to project or mission unique requirements. This may be true in many future NASA projects, and selected random-vibration levels may not be within the suggested envelope.

TABLE 5. THERMAL CONSIDERATIONS

Temperature Cycling:	o Figure 7 provides a summary of % failures vs. no. thermal cycles. This information in conjunction with the curves shown in ref. 6 should prove helpful in determining thermal cycling requirements.
Temperature Range:	o As shown in Section 2.2 the temperature range varied widely from within the NASA community as well as within industry. A suggested minimum range from the IES survey is about a ΔT of 100°C. The high and low ends should be selected based on Project requirements.
Temperature Rate of Change:	o Most programs surveyed utilized 5°C/min. The variation went from approximately 1°C/min to 10°C/min. The general consensus was that a faster rate of change provided the best screening. However, this is not clearly substantiated. o Figure 6 (reproduced from the IES survey, ref. 1) shows a typical temperature profile for component level screening where the temperature is the test chamber temperature and the duration was an average of those programs surveyed.
Equipment Operation:	o The results from the surveys reviewed suggest that the equipment be operated (power-on) during thermal cycling. References 1 and 5 provide suggestions and rationale for when turn-on should occur and possible on-off cycling in addition.
Failure Criteria:	o If the screen is applied as a true screen (per IES definition) then a pass/fail criterion is not necessary. However, where the "screen" is a part of the acceptance test a retest requirement may be appropriate upon determination of the particular failure.

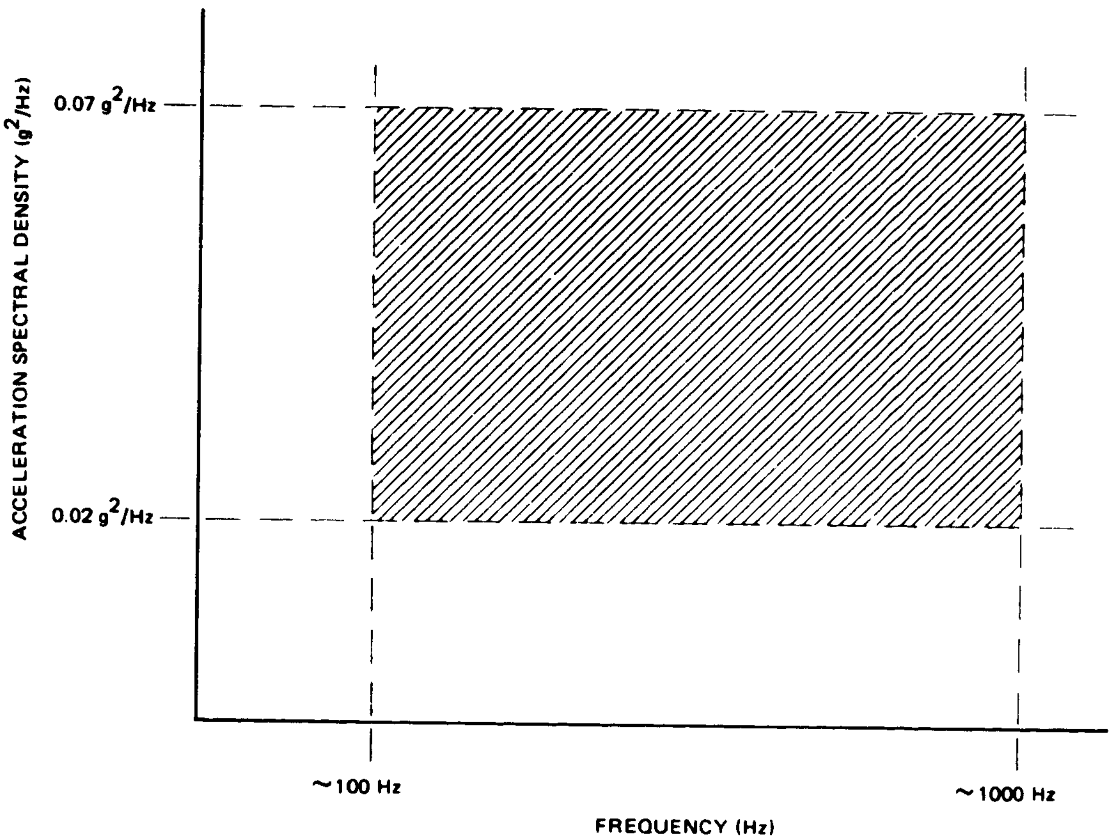

Figure 12. Recommended Envelope For Random-Vibration Acceleration Spectra. (Ref. 1)

4.0 DEFINITIONS

Because there is such a wide range in opinion and definition of stress screening, the following definitions are provided for clarification. Exception may be taken to these definitions, but for the purpose of clarification, they represent the flavor of the terms used in this document.

4.1 Acceptance Tests

Acceptance tests are the required formal tests conducted to demonstrate acceptability of an item for delivery. They are intended to demonstrate performance to operational requirements and to act as quality-control screens to detect deficiencies of workmanship, material, and quality.

4.2 Component

A component is a functional unit that is viewed as an entity for purposes of analysis, manufacturing, maintenance, or record keeping as stand-alone, or is an element in a system or subsystem. Equivalent terms include, but are not limited to: black box, line replaceable unit (LRU), unit, and assembly.

4.3 Screening

A process or combination of processes for the purpose of identifying and eliminating defective, abnormal, or marginal parts and manufacturing defects.

4.4 System

A system is an assembly of two or more functionally related subsystems.

4.5 Subsystem

A subsystem is an assembly of two or more functionally related components.

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