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13. ABSTRACT *(Maximum 200 words)*

This TOP presents guidance procedures for the planning and conduct of Environmental Stress Screening (ESS) tests. ESS is a process where hardware is exposed to one or more environments in a serial fashion to accelerate the discovery of design, workmanship, or part flaws inherent in electrical, optical, or mechanical equipment. Emphasis is placed on temperature cycling and random vibration test environments to include instructions for the conduct of thermal and vibration surveys.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

Test Operations Procedure (TOP) 5-1-033 30 September 1997
AD No.

STRESS LEVEL TESTING OF MISSILE AND ROCKET SYSTEMS DURING DEVELOPMENT TESTS (ENVIRONMENTAL STRESS SCREENING)

1. SCOPE.

a. This TOP provides guidance for planning and conducting an Environmental Stress Screening (ESS) program on missiles, missile components, and other support equipment. Use of this procedure will accelerate the discovery of design, workmanship, and part flaws inherent in electrical, optical, and mechanical assemblies, i.e., to find the flaws before equipment is fielded.

b. The ESS process can be performed at any stage in the acquisition cycle - development, preproduction, or production. This TOP focuses on the application of ESS to development hardware.

c. There is no provision in this TOP for testing piece parts such as integrated circuits, semiconductors, etc. It is assumed that all piece parts have been stress screened by the manufacturer or that a good production line process control program is in place. Thus, this TOP will focus on the application of the screening environment to cards, modules, assemblies, units, and systems.

d. Lastly, only the stresses induced by temperature cycling and random vibration will be discussed. Information about other stress tests such as burn-in, power-on power-off cycling, and temperature shock can be found in the literature (AFWL-TR-80-3086[a*]).

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Climatic Chamber	The climatic chamber must be capable of providing air temperatures between -65 °C and 100 °C (-85 °F and 212 °F), a temperature rate change of at least 30 °C (55 °F) per minute, and a chamber airflow rate of at least 4.6 m/s (15 ft/s). The chamber should be appropriately sized to contain the test item, and it should have a blower which swirls the discharge to provide turbulent airflow. This greatly enhances the transfer of heat to all parts of the test item. Two chambers may be used, one hot and one cold, in order to obtain the required temperature rate of change. In this case, a cart or dolly may be required to facilitate the transfer between chambers. Additional chamber design information can be found in Quart[1].
Vibration Facility	The vibration facility must be capable of providing the necessary force to stimulate the test item over a minimum frequency band of 10 to 2000 Hz. This is accomplished with a vibration exciter which can be of any type, including electrodynamic, hydraulic, pneumatic, mechanical, or any combination of these. Six degree of freedom machines (combination of pneumatic actuators and other mechanical devices) have recently appeared on the market and can be used to facilitate vibration testing. The test item is usually attached to a vibration fixture which in turn is attached to the vibration exciter. The vibration fixture shall be designed to transmit the vibrational energy equally to all components or assemblies being tested. The vibration signal or test specification must be provided by a broadband random noise generator or a random vibration control system. The vibration environment must be measured or monitored with some sort of data acquisition system. This usually consists of one or more of the following: accelerometers, strain gages, velocity or displacement transducers, signal conditioning equipment, recording system (magnetic disk or tape), and associated cabling. The data acquisition system should provide a flat response over the frequency range of interest to within ±10 percent. Lastly, a data processing and analysis system is required which allows the screen designer to playback and plot or display the transducer signals in the form of acceleration spectral densities for vibration analysis. A dual channel, Fast Fourier Transform (FFT) analyzer would satisfy this requirement.

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[*] Superscript letters/numbers correspond with those in Appendix D, References.

Item	Requirement
Equipment Monitoring Station	Power will be applied to the test item at some point during ESS in order to monitor test item status. This may require continuous monitoring, stimulation or status checking equipment to be specially designed and fabricated for the test item. The test item may require an access point to be built in so that status can be monitored with existing equipment.

2.2 Instrumentation.

Devices For Measuring	Measurement Accuracy**
Transducers (accelerometers, velocity or displacement devices, strain gages, thermocouples, flow rate sensors)	±10%
Vibration Control System	±6 dB tolerance bands over the required frequency range
FFT Analyzer	±10%
Temperature Control System	±3 °C
Temperature Logger/Recorder	±3 °C

3. REQUIRED TEST CONDITIONS.

3.1 Test Planning.

a. ESS is a process. The hardware is exposed to one or more environments in a serial fashion, and its condition is evaluated before, during, and after exposure to those environments. ESS in the development cycle is an evolving process which strives to reduce workmanship and part flaws so that the hardware design can be performance tested in the field. The screen designer must periodically evaluate the screen effectiveness to ensure the inherent flaws are being removed from the equipment. The performance of ESS during development testing is an experimental process. First of all, the hardware may contain, one of a kind, custom made parts. It should be recognized that these parts may not lend themselves to being mass produced and so substitutions could be made throughout the manufacturing process. Second, the suppliers and vendors of components and piece parts may change during the process. Third, part substitutions may occur because of schedule conflicts; i.e., the part may not be readily available. Lastly, the hardware design usually is not fixed at this point. Changes may occur daily depending on the maturity of the design. Note that poor equipment performance is the main driver of design changes. All of these factors make it difficult to track failures and evaluate screen effectiveness.

b. The hardware level of assembly must be determined by the screen designer. ESS can be conducted on module, unit, or system levels. Either one, two, or all three levels can be selected for testing. It is recommended to conduct stress screening as early as possible in the manufacturing process, i.e., at the lowest level of assembly. Cost is the driving factor here, and it usually increases with the complexity of the hardware. Inherent flaws will be

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** Measurement accuracy is not critical here.

precipitated and repairs will be made more quickly on a Printed Wire Assembly (PWA) than on a complete guidance system. The best advice is to know your hardware. What are its weak and strong points? Will it be beneficial to test at the module, unit, or system level of assembly or do you need to test at all three levels?

c. ESS removes defects introduced by the manufacturing process - fabrication, assembly, handling, and item operation. These flaws can be created through poor workmanship, bad parts, or improper design.

(1) Workmanship quality is a function of having experienced personnel fabricating the hardware.

(2) Parts may not be properly screened by the vendor due to poor quality control procedures.

(3) Designers may specify improper parts resulting in performance deficiencies. Redesign may be required.

d. The screen designer needs to know the test item. Any past ESS program experience with similar type items provides valuable information regarding the type of failures to be surfaced. Flaws found in similar programs tend to be repeated in new development programs. Typical flaws found by ESS are:

(1) Broken or damaged parts

(2) Incorrect installation of parts

(3) Bad solder connections, voids, and creep

(4) Loose contacts, relays, wire terminations, PWB's

(5) Chaffing and pinching of wires

(6) Improper crimping or mating

(7) Chemical contamination

(8) Hermetic seal failure

(9) Component parameter drifting

(10) Printed Circuit Board (PCB) etching causing shorts or opens

(11) Open plated - through hole

e. The most difficult defect to uncover is the intermittent failure, also known as "no trouble found" or "cannot replicate". The assembly operates perfectly at ambient conditions, but when a stress is applied, it may or may not work resulting in unpredictable equipment behavior. The intermittent failure is "in transition" to a hard failure, and usually the test item is not being appropriately stressed. Intermittent failures are difficult to detect without continuous on-line monitoring of the assembly. This may not be practical to do because of cost, proper equipment not being available, or because no monitoring points have been built into the equipment. It is recommended that the screen designer require on-line monitoring equipment, in order to eliminate the possibility of releasing flawed hardware.

3.2 Test Preparation.

The performance of ESS as defined in this document consists of thermal testing, random vibration testing, and continuous status monitoring of the test item. The recommended test conditions are described below for each environment and listed in Table 1.

a. Thermal Screen. The thermal environment stimulates many failure mechanisms due to the expansion and contraction of materials having different thermal conductivities. The screen designer should conduct a thermal survey of the test assembly (or thermal mass model if assemblies are scarce) in order to understand the response of the assembly to temperature change. See Appendix C for thermal survey procedures. The information obtained from the thermal survey can be used to select the four parameters which define a thermal screen. These are:

(1) Temperature

(a) Constant high temperature testing of assemblies is often performed when the test item is known to be susceptible to hot environments. The temperature is raised to some predetermined extreme value and allowed to remain there for an extended period of time (4-12 hours).

(b) A better test method utilizes temperature cycling from low to high to low temperature, e.g., -54 to 71 to -54 °C, at a specified rate of change (see Table 1). The screen designer must choose the optimum temperatures which stress the hardware to quickly surface all test item flaws. Defects are found faster when temperature cycling is used rather than "burning in" at high temperature.

(2) Number of Cycles. The number of temperature cycles performed can influence schedule, cost, and failure rates. The Institute of Environmental Sciences guidelines state that failures normally occur within 12 cycles in a properly designed screen. Experience has shown that there is a certain number of cycles at which no payback is provided (usually beyond 16). The screen designer must determine if the benefit of performing extra cycles is worth the cost.

(3) Temperature Rate of Change. The rate of change should be quick but not too rapid. The test item thermal response must be known (either by experience or measurement) so that the proper rate of change is selected. The important point is to ensure that all parts of the assembly attain the desired temperature, i.e., a uniform temperature distribution is achieved. Uniform temperatures can be obtained with turbulent airflow of about 4.6 m/s (15 ft/s) in the chamber. One also might be limited by the chamber thermal dynamics and the test item size. Kallis, et. al.3 have conducted studies to determine the optimum temperature rate of change to surface flaws in PWA's, modules, assemblies and units. The recommended temperature rate of change for PWA screens is 20 to 30 °C/min (35 to 55 °F/min) and for all other items is 10 to 15 °C/min (20 to 30 °F/min).

(4) Dwell Time. How long should the temperature be held at the extreme end of the temperature ramp? Once again, the thermal response time of the hardware needs to be known so that all piece parts of the test item can be exposed to the extreme temperature, i.e., thermal stability is achieved.

Table 1. Recommended Screen Conditions.

Screen Type and Parameter	Assemblies	System or Unit
Thermal Cycling Screen		
Temperature Extremes	-54 °C to 85 °C (-65 to 185 °F)	-54 °C to 71 °C (-65 to 160 °F)
Rate of Change	20 to 30 °C/min (35 to 55 °F/min)	10 to 15 °C/min (20 to 30 °F/min)
Dwell Time	Until Stabilization	Until Stabilization
No. of Cycles	12	12
Continuous Monitoring	Yes	Yes
Random Vibration Screen		
Test Level	6 grms	6 grms
Spectrum Shape	NAVMAT P-9492	NAVMAT P-9492
Test Duration and Axes (Serially/Simultaneously)	10 min/axis	10 min/axis
Frequency Bandwidth	20-2000 Hz	20-2000 Hz
Continuous Monitoring	Yes	Yes

b. Vibration Screen. Vibration screening can be accomplished using either sinusoidal or random vibration. Random vibration is the preferred method of stimulation. What truly matters is the way the test item responds to the excitation and that all parts of the test item are exposed to the same levels. Historically, the vibration specification is defined as an input spectrum, i.e., the applied signal is controlled at the vibration table to test fixture interface. The test item response needs to be characterized and understood by the screen designer. This is accomplished by performing a vibration survey as described in Appendix B. Once the test item has been characterized, the vibration screen parameters below can be wisely specified.

(1) Test Level and Spectrum Shape. If no other data exist the 6 grms spectrum specified in NAVMAT P-9492[4] can be used as the starting point of the vibration screen. Realize that this spectrum can be unnecessarily damaging to good hardware if it is applied arbitrarily. Thus, it is a good idea to conduct a vibration survey to collect test item dynamic response data. The survey data can be used to tailor the NAVMAT or any other spectrum as described in Curtis and McKain[5] and in Appendix B.

(2) Test Duration. Typical vibration screen durations range from 5 to 10 minutes per axis. A 10 minute duration is recommended for a properly tailored screen developed from vibration survey data. If the risk is high that good equipment might be damaged by excessive levels, then a 5-minute duration may be more appropriate. The exact duration depends upon the prior experiences with similar test items and the fidelity of the vibration survey data.

(3) Instrumentation Requirements. Very little instrumentation is required assuming that the test item has been characterized by a vibration survey. An accelerometer is required to control the shaker table to the desired vibration spectrum. It is recommended that an in-axis response accelerometer be strategically located on the test item so that comparisons to survey data can be made. It might be physically impossible or time consuming to mount a response accelerometer, in which case, vibration survey data is of the utmost importance.

c. Monitoring Test Item Status. Operational status of the test item must be known before and after application of ESS. One has to know that the test item properly functions before testing begins. Continuous on-line monitoring of the test item is recommended in order to find failures and to know where in the sequence these failures occur. This may be cost prohibitive. The alternative is to perform functional checks after the completion of the thermal cycle screen and the vibration screen. The risk is to continue screening an item that may have failed during the first cycle.

4. TEST PROCEDURES.

4.1 General.

The recommended ESS sequence is shown in Figure 1. The first climatic test may be omitted if previous ESS experience has shown the test to be ineffective with similar hardware; that is, the number of flaws to be precipitated do not increase when the first climatic test is performed. As a minimum, the random vibration test must be performed followed by the temperature cycle test.

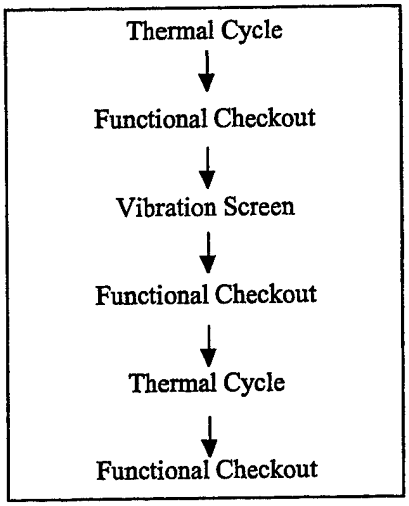


Figure 1. Stress Screen Sequence.

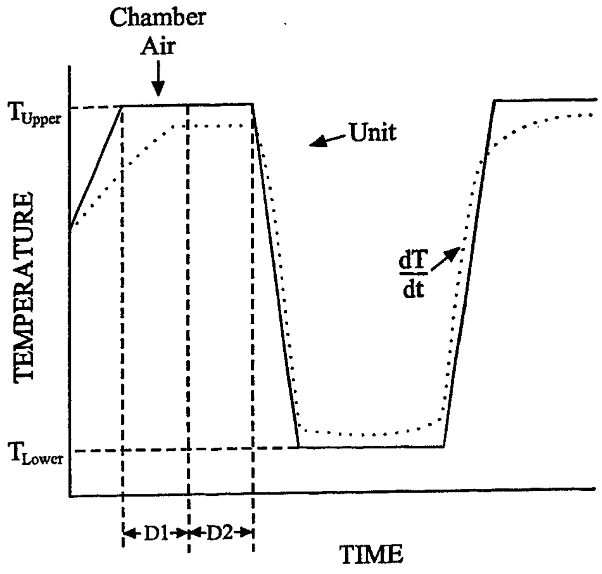
4.2 Operation and Inspection.

The test item must be in good working condition before proceeding with ESS. Visual inspection and operational tests will determine the status of the unit. Operational procedures must be documented and provided to the tester by the hardware developer. Review and approval by the procuring agency will ensure that all test item functions are properly exercised. Also, any provisions for continuous monitoring of the test item status, if different from the operational test equipment, must be identified at this time. Inspect the test item for any signs of physical damage that may have occurred during transportation to the test facility. Record the visual inspection and operational test results.

4.3 Temperature Cycle Tests.

4.3.1 Instrumentation. Place the test item inside the temperature conditioning chamber. Install the necessary temperature measuring devices (thermocouples) on the test item and in the chamber. Test item orientation and thermocouple locations should have previously been determined by the thermal survey described in Appendix C. Verify operation of the chamber and the data acquisition equipment. Note, temperature measuring instrumentation may be omitted if the conditioning chamber and test item dynamics have been carefully characterized during the thermal survey. Instrumentation, at this point, only serves to validate the test item response measured during the thermal survey.

4.3.2 Conduct of Test. A typical thermal cycle profile is shown in Figure 2. Start temperature conditioning by raising the temperature to the high temperature limit within the required period of time, i.e., at the specified temperature rate of change. Hold the chamber temperature until stabilization occurs. Stabilization has occurred when the temperature of the slowest responding element of the test item is within 3°C (5°F) of the specified temperature extreme. Once stabilized, lower the chamber temperature at the specified rate to the lowest temperature limit. Again, hold until stabilization occurs. Repeat the above for the required number of cycles or until test item fails.



D1 = Dwell Time to Stabilization (0.5 to 1.5 hrs)
D2 = Dwell Time to Soak Units (5 to 15 minutes)
$\frac{dT}{dt}$ = Ramp Rate of 10 to 15 °C/min (20 30 °F/min)
T_{Upper} = 71 °C to 85 °C(160 °F to 185 °F)
T_{Lower} = -41 °C to -54 °C (-40 °F to -65 °F)

Figure 2. Typical Temperature Cycle For Units/Assemblies.

4.3.3 Monitoring. It is recommended that test item performance be continuously monitored or spot checked. This spot check should be conducted at the predicted failure point in the cycle or the most severe stress point in the cycle. Observe and record test item performance data. Stop the test if the test item fails to perform properly. When a failure occurs record the cycle number, time in the cycle, and type of failure information. Return the test item to the developer for failure analysis and repair.

4.3.4 Unmonitored Equipment. If it is impossible to monitor test item status during the thermal cycle, conduct a full operational test upon conclusion of the last cycle. Record the results.

4.3.5 Rescreening. The extent of the repairs, modifications, rework and reassembly, and the amount of life remaining in the test item should be evaluated in order to decide where in the cycle to continue testing. In general, resume testing at the beginning of the cycle where the failure occurred. If the failure occurred within the last two cycles or it is unknown when failure occurred, then at least six thermal cycles should be completed to ensure that the test item is indeed repaired. As a rule of thumb, the design life of the test item is consumed within five temperature cycle tests.

4.3.6 Test Completion. Upon successful completion of all thermal cycles, perform a full operational test if not already done so. Also, visually inspect the test item for physical damage. Record the results and proceed to the vibration test.

4.4 Vibration Test.

4.4.1 Vibration Fixture. Install the fixture onto the vibration exciter table to perform the first axis of vibration. Install the vibration transducers (accelerometers) onto the fixture and perform a calibration run at full test level to verify that all instrumentation and test equipment work properly and that the required test levels are attained. A typical vibration test spectrum is provided in Figure 3. Install the test item into the vibration fixture. Instrument the test item with accelerometers, strain gages, etc., and verify that all transducers are correctly wired to the recording equipment. The vibration fixture and test item transducer locations should have previously been determined during the test item vibration survey performed per the instructions of Appendix B.

4.4.2 Test Conduct. Expose the test item to the specified vibration level and duration. Monitor all acceleration response channels during the test and watch for any drastic change in signal content or level. Failures such as broken or loose bolts/parts may be observed in this manner. If no failures occur, then reorient the test item and/or fixture into one of the remaining axes and repeat the process outlined above. Repeat the above until all axes have been completed.

4.4.3 Monitoring. Continuous monitoring of the test item status is recommended in order to guard against intermittent failure. If monitoring is impossible, conduct a performance test upon conclusion of all vibration testing. Stop all testing when a failure occurs. Record the time and axis when the failure occurred and the type of failure.

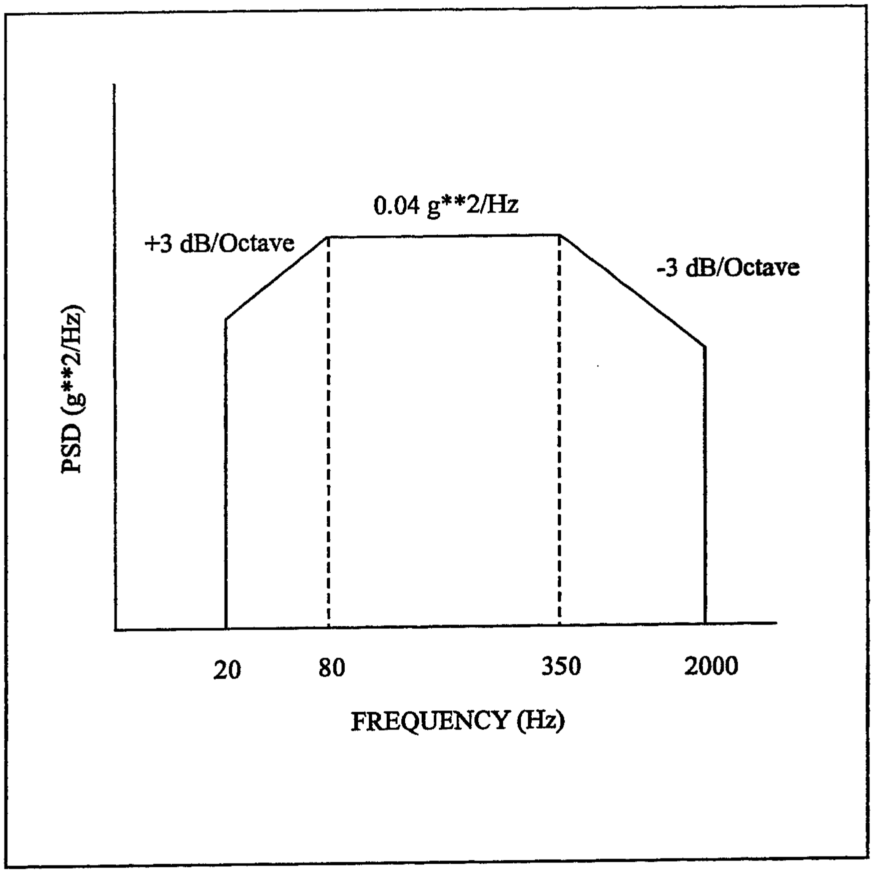


Figure 3. Stress Screening Random Vibration Spectrum Suggested by NAVMAT P-9492.

4.4.4 Rescreening. The degree of disassembly and the type of repairs to the hardware should be assessed when trying to determine where to begin retesting. In general, the following rules can be applied:

a. Complete the remaining test time or 5 minutes, whichever is greater, whenever failure occurs during a monitored vibration screen.

b. Perform a full test level vibration screen for 50 percent of the test time when the hardware status is nonmonitored and the time of failure cannot be identified.

c. Repeat the vibration screen at 3 dB below test level for 50 percent of the time when more than one repair is required, i.e., when more than one retest per axis is required. This protects the hardware from being overstressed so that its useful life will be conserved.

d. The vibration exposure time per axis should never exceed 5 times the original duration. Again, the operational life of the hardware should not be consumed by the vibration exposure. If it does, the risk of continuing with fatigued, worn-out equipment exists and may jeopardize the whole development program.

4.4.5 Test Completion. Perform a full operational test of the hardware and record the performance data upon completion of all vibration testing. Inspect the test item for signs of any physical damage and record the results. Proceed to the final climatic test of the ESS sequence (Fig. 1).

4.5 Final Temperature Cycle Test.

Repeat the procedures of paragraph 4.3. Note the vibration test may have significantly fatigued the test item such that the item might fail after a short time in service. The final climatic test is needed to uncover those weakened connections and components. Keep this in mind when performing a failure analysis during this phase. If a failure does occur, resume testing at the beginning of the cycle in which the failure was detected.

4.6 ESS Tailoring.

The ESS process should result in the removal of most test item flaws. The screen must be designed to remove a certain percentage of those flaws, for example more than 99 percent (see DOD-HDBK-344[5] for details). Tailoring of the test specifications may be required in order to attain the specified flaw removal fraction. It is recommended that the test item and its response to the test stimuli be re-evaluated for the following cases.

a. No Flaws Precipitated. The test levels and durations may be suspect. It is likely that the hardware is not being appropriately stressed and thus, no failures occur. Test item design levels and stress screening levels should be re-evaluated and adjusted as necessary.

b. Too Many flaws. The test item is being tested to extremely high levels which results in an overstressed condition and too many failures. The screen designer should re-evaluate the test levels and durations.

c. Modified or Redesigned Hardware. The hardware may need to be redesigned or modified due to a bad design. The hardware may not have been correctly designed to withstand the intended operational environment, let alone the screening stresses. Modifications to the hardware may also require adjustment of the ESS specifications.

4.7 Failure Analysis and Corrective Action.

4.7.1 The root cause of all failures must be investigated. The test item shall be returned to the manufacturer for disassembly and analysis. Good record keeping practices will make the investigation more efficient and effective. Use all recorded data to evaluate the failure.

4.7.2 Once the problem is located, take corrective action quickly so that the problem is not propagated in future hardware. Corrective action can take the form of changes to the screen levels and durations, identification of defective parts or bad supplier of parts, improvements in the manufacturing process, and refinement of the testing process.

5. DATA REQUIRED.

5.1 Failure Analysis Data.

The complexity of the test program and test item will determine the type of data to be recorded. It is recommended that failure data be recorded in a computer data base so that the program history can be recalled and used by the screen designer on a future ESS program. The failure information to be recorded in the data base is summarized as follows:

a. Type of Failure. Classify failures into one of these categories:

(1) Part defect - failure due to a basic weakness or flaw in a part.

(2) Manufacturing defect - failure due to workmanship or the manufacturing process.

(3) Design failure - failure due to a design deficiency.

(4) Externally induced failure - failure due to external influences such as status monitoring equipment, test facility equipment or test personnel.

(5) Dependent failure - failure caused by the independent failure of another associated part.

(6) Software failure - failure due to an error in a computer program.

(7) Unknown cause failure - failure which cannot be classified into any of the above categories.

b. Time of Failure. Record test date and time of failure.

c. Type of Test Failed. Record the type of test the hardware failed. Note the cycle number and where in the thermal cycle failure occurred. Note which axis and when a vibration induced failure occurred.

d. Reason For Failure. This is the "first look" reason for failure and will have to be expanded upon when failure analysis is completed.

e. Failed Component and Location. Component type and location of the component need to be recorded. This information could lead to a part/vendor problem if the number of occurrences is too high.

f. Vendors' Names. The complexity of the test item will dictate the number of vendors. Record the name of the vendor who manufactured the failed part.

g. Level of Assembly. Determine and record the test item level of assembly (PWA, unit, module, or system).

h. Item Identification. Name, serial number, model number, etc., of the test item shall be recorded.

5.2 Environmental Test Data.

Data to be collected and recorded during the climatic and vibration tests are listed below. These are test specific and as such may be used to verify test conditions.

a. Test date.

b. Chamber and test item temperature versus time plots.

c. Power Spectral Density (PSD) plots of selected accelerometer data.

d. Name and model numbers of test facility equipment.

e. Photographs of test setups.

f. Test specifications used.

g. Any deviations from the test specifications.

h. Results of visual inspections.

i. Operational test results.

6. PRESENTATION OF DATA.

The ESS process needs to be monitored as a check on the effectiveness of the screen. When a failure occurs, it is important to note the conditions of failure, i.e., when, what, and how item failed. This information must be analyzed to determine if the proper stress screening parameters have been selected. The parameters may need to be adjusted if failures of good items are induced because the levels are too high. Several iterations of the test parameters may be required in order to obtain an effective stress screening program. Tabulation of the data provides an easy method for viewing the whole ESS process, an example of which is shown in Table 2.

Table 2. Example of a Data Collection Sheet.

Item Identification	Flight Termination Receiver, Model 21A, SN21
Level of Assembly	Unit
Failure Type	Workmanship - Bad Solder Connection
Time of Failure	1015, 18 August 1996
Type Test Failed	Random Vibration - 3 minutes into X-axis
Reason For Failure	Loss of signal due to bad solder connection
Failed Component & Location	Filter Oscillator in center of card No.1
Vendor's Name	Smith Electronics Company

The quality control chart in Figure 4 is one way to evaluate the screen effectiveness. The control chart utilizes the Chi Square statistic to determine the upper and lower control limit values. The control limits of Table 3 are based on a 10 percent probability that a good point will lie outside of the upper and lower control limit lines.

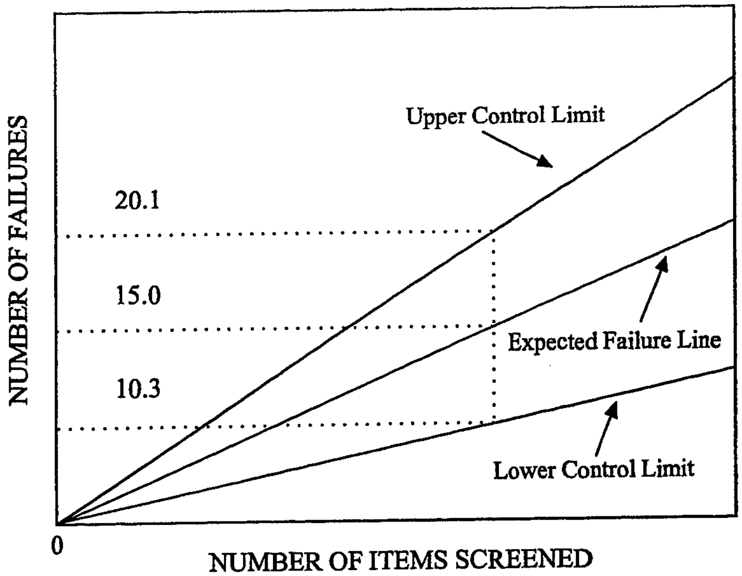


Figure 4. Typical Control Chart.

Table 3. Recommended Control Limits (Adapted from Reference 2).

Failures	Upper*	Lower	Failures	Upper	Lower
5	8.0	2.4	80	91.7	68.8
10	14.2	6.2	85	97.0	73.4
15	20.1	10.3	90	102.3	78.1
20	25.9	14.5	95	108.7	82.7
25	31.6	18.8	100	113.0	87.4
30	37.2	23.2	105	118.3	92.1
35	42.8	27.4	110	123.6	96.8
40	48.3	32.1	115	128.9	101.5
45	53.8	36.6	120	134.2	106.2
50	59.3	41.2	125	139.5	110.9
55	64.7	45.7	130	144.8	115.6
60	70.1	50.3	135	150.1	120.3
65	75.5	54.9	140	155.4	125.0
70	80.9	59.5	145	160.6	129.8
75	86.3	64.1	150	165.9	134.5

*Limits are based on the Chi-Square Distribution of 0.10 and 0.90 intervals.

APPENDIX A. BACKGROUND.

1. HISTORY OF ESS.

ESS is not a new technology. The first application began in the 1950's when the Advisory Group for the Reliability of Electronic Equipment (AGREE) published a reliability test document. Electronic instruments with vacuum tube technology were "burned in" to increase product reliability. The equipment was turned on and allowed to operate for a specified number of hours or it was cycled by powering the equipment on and off.

In the late 1970's, the Navy initiated the random vibration era in ESS with the Navy Manufacturing Screening Program NAVMAT P-9492[4] publication. Up until this time most vibration tests were conducted using sine vibration input. The appearance of digital vibration control computers facilitated the change to random vibration input.

In the 1980's, the Institute of Environmental Sciences became very active in this arena by publishing two ESS guideline documents. Each one built upon previous documents and industry practices. More guidance is provided in the newest document (reference 2) but the general principles remain the same. Thermal cycling and random vibration testing are still the major stressing environments.

2. TODAY'S ESS.

Today, ESS has gained popularity with both government and industry program offices. ESS is a process. The objective of which is to subject hardware to accelerated environmental stresses, forcing hidden defects introduced during the manufacturing process to become observable failures. These defects must be found before they become failures in the field. Note that the stress levels are accelerated but should never exceed the hardware design limits.

3. ESS DURING DEVELOPMENT TESTING.

ESS is normally a production line tool but it can be effectively used in design and development programs. In development programs, ESS is viewed as an experimental process in which information is collected on the quantity and type of potential defects. First hand experience is gained with the hardware which can be extrapolated to the production line assuming the design, parts, and suppliers remain relatively the same. The primary reason to perform ESS during the development phase is to improve the probability of performing successful system level demonstration tests. These tests will not be delayed because of latent part defects or poor workmanship. Thus, the hardware design can be truly field tested to determine if operational goals are met. Conducting ESS will help ensure bad parts and workmanship failures will not delay the production milestone decision. Industry experience has shown that 90 percent of all defects are due to nondesign problems (see Table A-1). Consequently, the hardware has a better chance to succeed when screening is performed during the development phase.

4. LEVEL OF ASSEMBLY.

There are four levels of assembly:

a. Parts (integrated circuits, semiconductors, etc.)

b. Modules (PWA's and cards)

c. Units (black boxes, line replaceable units [LRU's], etc.)

d. Systems

Table A-1. Failure Analysis Results of Unscreened Development Items.

60% Workmanship
30% Parts
10% Design

The screen designer needs to understand the hardware in order to determine the level of assembly to screen. One must know how many parts, PWA's, cards, or units are present in the unit under test. Industry experience has shown that the number of flaws in an assembly is related to the complexity of the hardware, i.e., the more pieces there are the more defects built into the unit.

5. SCREEN SELECTION AND DESIGN.

Screening can be performed at more than one level of assembly. It is recommended that screening be performed at the lowest level of assembly because the complexity of a system level test magnifies the cost and time required to perform failure analysis and corrective action. It is suggested that ESS be performed at the black box or unit level and also at the system level. The amount of testing has to be balanced with cost, schedules, and equipment availability. Another suggestion is to limit the test article weight to 50 or 60 lbs. This makes the item easy to handle and the small size improves vibration response characteristics. If the unit is too large, applying the vibration force to all parts equally is virtually impossible.

Table A-2 shows the type of defects caused by the different environments. Type of failure knowledge and hardware knowledge will help the screen designer develop an ESS program.

Table A-2. Screening Environments vs. Typical Failure Mechanisms.

	Screening Environment		
	Thermal Cycling	Vibration	Thermal and/or Vibration
TYPE OF FAILURE	Component parameter drift. PCB opens/shorts. Component incorrectly installed. Wrong component. Hermetic seal failure. Chemical contamination. Defective harness termination. Improper crimp.	Particle contamination. Chafed, pinched wires. Defective crystals. Mixer assemblies. Adjacent boards rubbing. Two components shorting. Loose wire. Poorly bonded component. Inadequately secured high mass parts. Mechanical flaw.	Defective solder joints. Loose hardware. Defective components. Fasteners. Broken component. PCB etch defective.

6. OPERATIONAL VS. NON-OPERATIONAL.

The screen designer needs to determine whether or not to apply power to the hardware during the screen. The power-on situation increases the amount of stress experienced by the equipment. Also, the test item temperature usually lags the chamber temperature due to different material properties and nonuniform airflow. Thus, the heat transfer rate or rate of temperature change is different for each component or unit on the assembly. Placing operating hardware into a chamber complicates the heat transfer mechanism and must be taken into consideration when determining test specifications. It is recommended to apply power to the hardware whenever possible. As an alternative to continuous operation of the hardware, the power may be turned off during the hot to cold portion of the thermal cycle to facilitate the cycle by relieving the extra heat load on the chamber. The unit should be powered upon reaching temperature stabilization.

7. MONITORING OF HARDWARE STATUS.

Whenever possible, monitor hardware status whether it's continuous or scheduled at various intervals (preferably the predicted place for failure to occur). Continuous monitoring gives the tester the ability to determine which environment caused the item to fail. Knowing the point of failure can reduce test costs and save test item life when multiple retests are required. Also, performing on-line continuous monitoring virtually eliminates the problem of intermittent failures. Intermittents are also known as "no trouble found", "cannot duplicate" and "false removal". The intermittent failure is a defect which is transitioning to a hard observable failure. Proper ESS levels will stress the hardware and accelerate the transition. Continuous on-line monitoring ensures that no hardware containing intermittent flaws will be released into the field.

APPENDIX B. VIBRATION SURVEY.

1. GENERAL.

It is the test item internal component responses which precipitates flaws. The vibration survey measures the response of the test item to an arbitrary, nondestructive input. The survey may also reveal that the chosen test spectrum may need to be tailored to levels which appropriately stimulate the test item. Thus, the goal of the survey is to develop an efficient, effective screen that is appropriate for the item under test.

2. CONSIDERATIONS.

a. Hardware. The vibration facility must have test equipment capable of attaining the screen levels. The same equipment should be used to perform the survey as well as conduct the vibration screen, otherwise, errors may be introduced. This especially pertains to the vibration fixture. If the screen fixture is designed to test more than one item at a time, then the survey fixture should be identical if not the same one. The fixture/attachment arrangement shall provide a uniform, broadband response over the volume of the test item. The survey should be performed with actual test items position at each location of the fixture. Representative hardware is acceptable but it should precisely model the test item in order to eliminate any variation between representative and actual hardware. Also, the survey will be conducted at low enough levels to preclude any damage or fatigue to test items.

b. Survey Specifications. The survey level shall be between 6 and 10 dB below the anticipated vibration screen level. The vibration spectrum shape should be based on prior knowledge with similar items. If no prior knowledge exists, a flat spectrum from 20-2000 Hz at a 0.001 g^2/Hz level may be substituted.

c. Survey Axes. The survey shall be conducted in each of the three axis orientations. Acceleration data shall be collected in all three axes for a single axis run. Prior knowledge with similar hardware may eliminate the need for surveys in all three axes. This decision should not be made arbitrarily. The ability to provide excitation in simultaneously two or three axes simultaneously may exist at the chosen test facility, in which case response measurements could be obtained in one or two vibration runs.

d. Instrumentation. Accelerometers shall be mounted internally on the test item and shall measure the input to a particular component not its response. Accelerometers should be small, lightweight sensors so as to not influence the test item dynamic response characteristics. This is especially important for mounting sensors in the center of large circuit cards as large displacements could be induced. The number and location of the accelerometer mounting points is determined by the complexity of the test hardware. It is not reasonable to instrument every junction point of a complete missile. The survey engineer should strive to obtain a representative response for a majority of the anticipated failure locations. This should be able to be accomplished at approximately 20 locations with 20 triaxial accelerometers. Triaxial measurement is not always required or always possible. Off-axis sensors located near a single axis accelerometer may be used to extrapolate the response of the other two axes. Again, common sense and ease of data manipulation are factors which determine quantity of sensor locations.

e. Data Acquisition. All vibration survey data shall be stored in some manner for future processing. This can be accomplished with analog or digital tape recorders. The data to be collected includes not only accelerometer data but any other test documentation to include handwritten logs, photographs, etc.

3. SURVEY TEST PROCEDURE.

A short vibration survey test procedure is described below. The procedure is not all inclusive and should be tailored to the practices of the individual test facility for the particular test item. It is assumed that single axis electrodynamic exciters are available.

a. Install appropriate accelerometers on the test item in the proper locations and orientations. Document with video or photographs.

b. Install vibration fixture and fixture control accelerometer to the vibration exciter.

c. Program the vibration control computer with the test specification.

d. Install test item onto vibration fixture. Torque all bolts to specified values.

e. Perform an end to end check of the data acquisition system to include accelerometers, cables, signal conditioning equipment, vibration control system, tape recorders (data storage device). Check system calibration.

f. Run vibration test in first axis and record all data.

g. Verify data recorded are valid.

h. Repeat steps a through h for other axes and other accelerometer response groupings, if required.

i. Analyze recorded data to obtain PSD plots.

4. VIBRATION SURVEY EVALUATION.

a. The vibration survey data are evaluated to determine if the vibration screen baseline specification needs to be tailored. Is the vibration fixture providing a uniform input to the test item such that all critical or potential failure areas are sufficiently stimulated? If this is not the case, modifications may be required to the vibration fixture, to the vibration levels and/or to the shape of the input vibration curve to improve test item response.

b. The determination of the vibration stress screen parameters is an iterative process. Too many or not enough flaws may be precipitated and so tailoring of the vibration parameters may be required. Tailoring can occur even after the vibration survey has been performed, i.e., the equipment may have already transitioned from development into the production phase.

5. METHOD FOR TAILORING LEVELS AND SPECTRUM SHAPE.

a. Curtis and McKain[5] have developed a method for determining levels and adjusting the spectrum shape using vibration survey data. Remember, that it is the responses within the item near the immediate vicinity of the flaw which affects it into a failure, regardless of the vibration input. Thus, it is important to tailor the vibration input spectrum via the vibration survey data.

b. A brief description of the procedure is provided below. This method requires acceleration measurements to be taken from at least 20 locations and assumes these locations are where anticipated failures will occur. See references 2 and 5 for further details.

(1) Compute the PSD for each accelerometer location.

(2) Calculate the SUM-PSD for each measurement location. The SUM-PSD is the arithmetic sum of the three orthogonal accelerometer PSD values at a particular location.

(3) Calculate the mean of the SUM-PSD's.

(4) Calculate the grms versus frequency for each SUM-PSD and the mean SUM-PSD.

(5) Tabulate grms values from 20 Hz up to 100, 300, 500, 1000, 1500, and 2000 Hz for each SUM-PSD and the mean SUM-PSD.

(6) Tabulate grms versus cutoff frequency for the 90th and 50th percentiles. If there are 20 measurements, the 90th and 50th percentiles are the second and eleventh from the highest value at each cutoff frequency.

(7) Scale up the mean SUM-PSD by the reduction factor (6-10 dB) used in the vibration survey and compare to Figure B-1. For an adequate screen the value should lie within the darkened area of the curve.

(8) Scale up the 50 percent, 90 percent, and the mean grms values by the survey reduction factor. Compare the mean grms to Figure B-2. The 90 and 50 percent values should be within 3 to 6 dB of the mean value for an adequate screen.

(9) Scale overall level, notch and/or boost the input spectrum as needed to obtain a reasonable match of the mean SUM-PSD and the grms values to Figures B-1 and B-2, respectively.

(10) This is the tailored screen. If time and resources permit, rerun the vibration survey at full level to verify that the desired responses are obtained.

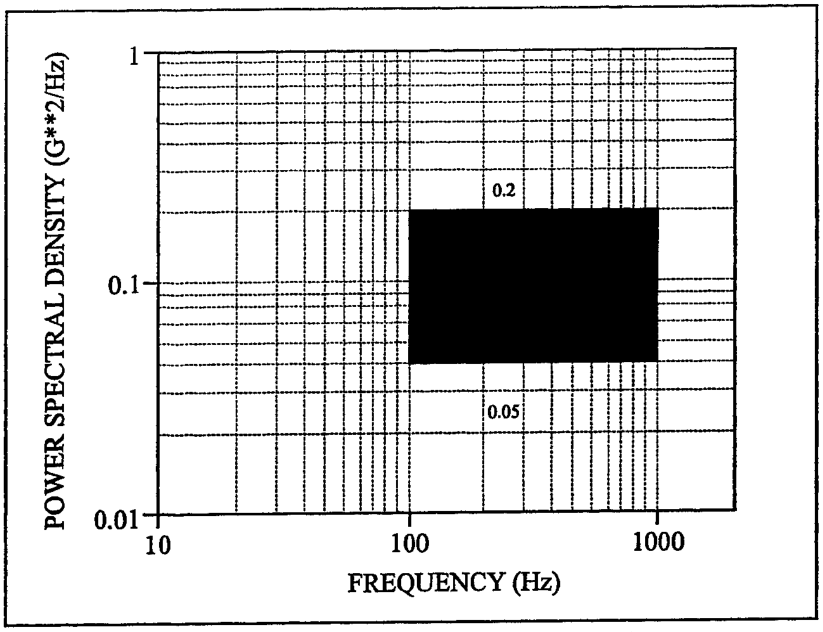


Figure B-1. Range of Mean Response SUM-PSD.

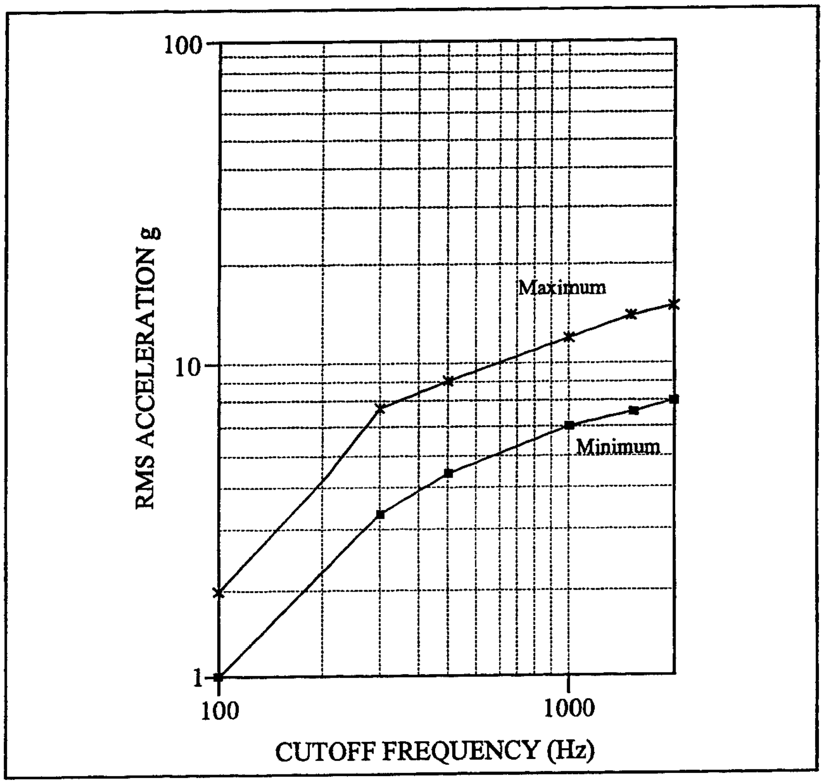


Figure B-2. RMS Acceleration vs Frequency Range For Mean SUM-ASD.

APPENDIX C. THERMAL SURVEY.

1. GENERAL.

It is important to correctly characterize the thermal response of the test item before conducting a thermal screen. The thermal survey evaluates the temperature histories of various components as they respond to changes in air temperature. Temperature cycling test parameters such as temperature extremes, temperature rate of change, dwell times at temperature extremes, and the number of cycles are determined from the thermal survey data. Additionally, test methods other than air circulation may have to be devised in order to obtain temperatures which adequately stress the components. These could include strategically located heater strips, radiant heaters, cold plates, etc.

2. THERMAL ANALYSIS.

Perform a thermal analysis using computer simulation to determine critical thermal stress locations and an estimate of their thermal response. Estimates of component temperature histories, thermal resistances, and thermal capacitances as a function of a changing heat transfer medium should be the result of the analysis. This information will identify components with the slowest response time, reveal the optimum temperature rate of change, and disclose the dwell time required to reach stabilization temperatures.

3. CONSIDERATIONS.

a. Facilities. The ideal survey is performed using temperature chambers and real test items that are planned to be used in the thermal screen. This may not be possible so using a thermal model of the test item is acceptable when the item is not available. The same is true of the test chamber. Try to replicate the thermal screen conditions as closely as possible.

b. Instrumentation. Thermocouples or other temperature sensing devices shall be installed at the locations identified in the thermal analysis. Flow rate sensors should be mounted inside the chamber near the test item. Flow rates inside the test item may need to be measured if the item is actively cooled or heated during item operation.

c. Data Acquisition. All instrumentation should be logged to a computer or other recording device for further data manipulation. Temperature time histories shall be plotted for thermal response evaluation.

4. SURVEY TEST PROCEDURE.

a. The test item shall be instrumented with thermocouples and placed into the temperature conditioning chamber. Location and setup inside the chamber shall replicate the thermal screen conditions as closely as possible.

b. Set up flow rate sensors inside the chamber to measure airflow rates near the test item.

c. Verify data recording device operation and check calibration of all sensors.

d. Run thermal cycling test. Run for at least three cycles to obtain system stabilization.

e. Plot temperature time histories for data analysis.

5. THERMAL SURVEY EVALUATION.

Compare the thermal survey data to that obtained with the computer simulation analysis performed in paragraph 2. If agreement is not evident, then repeat the thermal survey using different temperature cycling parameters. Perhaps the dwell time or temperature extreme values will have to be increased. A good computer simulation should result in one or two iterations of the temperature cycling parameters. The survey is complete when the selected parameters adequately stress the components in order to effectively accelerate the time it takes for flaws to surface.

APPENDIX D. REFERENCES.

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c. Robert E. Schmidt, Douglas L. Vossler, and Donald B. Russell, Making ESS a Dynamic Process Using the Procedures of DOD-HDBK-344, Proceedings of the Institute of Environmental Sciences, May 1992.

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