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STRESS SCREENING OF ELECTRONIC HARDWARE

Hughes Aircraft Company

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This report presents the results of a study to develop quantitative and qualitative techniques for planning, monitoring and evaluating stress screening programs during electronic equipment development and production. A screening and debugging optimization (SDO) model developed on a prior study, RADC-TR-78-55, was revised to include current thermal cycling and vibration screening experience and an adaptive feature was added to allow stress screening program changes based on screening results. Guidelines

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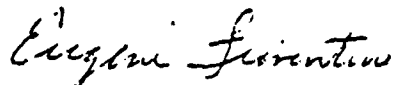
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EVALUATION

1. The objective of this study was to develop methodologies and techniques for planning, monitoring and evaluating stress screening programs during electronic equipment development and production.

2. The study objectives have been successfully achieved. Both qualitative and quantitative guidelines have been developed for tailoring screening procedures to specific hardware development and production programs. A methodology for screen selection and placement and for monitoring the screening process through use of adaptive procedures has also been developed. In addition, a previously developed stress screening model has been simplified and updated to include more recent stress screening experience. The model establishes a quantitative basis for planning and control. All of the major variables and inputs required for planning and evaluating screening programs are addressed through use of the model. Application of the techniques should greatly enhance the stress screening practitioner's capability to plan and conduct screening programs in a cost-effective manner.

3. Use of the techniques and methodology contained in the report should hopefully foster the development of a broader data base for estimation of model parameters and input variables. Users are encouraged to provide feedback of information on their application experience and results.

EUGENE FIORENTINO
Project Engineer

This study was conducted to develop quantitative and qualitative techniques for planning, monitoring and evaluating stress screening programs. The effort included investigation of technical and economic factors leading to the adoption of a screening program and identifying factors which influence the selection of particular screens and placement of screens at various assembly levels.

A product of this study effort is a set of three computer programs (comprising the Stress Screening Model) which are intended to aid the stress screening practitioner in selecting screens, setting screening parameters and adjusting screens on the basis of observed results. The function of the Stress Screening Model (SSM) is to exercise some mathematical routines designed to find an optimum set of screens to achieve the desired, (user-input) results, subject to the user-indicated constraints.

If the quantity and type of latent defects present in equipment during each level of manufacture were known and the ability of the various stress screens to precipitate those defects into hard, detectable failures was also known, the planning of stress screening programs would be greatly simplified. Actually, the nature and magnitude of defects present are unknown and changing with time; screening strengths are not well understood and appear to be hardware dependent. Much stress screening has been done in the past several years and general patterns are beginning to emerge. Screening appears to be cost-effective. Temperature cycling and random vibration are commonly used screens and appear to be effective screens. Temperature cycle screening effectiveness appears to increase with wider temperature range and greater rates of change. Random, or broadband, vibration appears more effective than single or swept frequency vibration. Constant temperature burn-in, power cycling, and low level single frequency vibration screens do not appear to be generally effective. These patterns form an industry consensus on stress screening effectiveness.

The Martin-Marietta temperature cycling curves (Ref. 7) and the Grumman vibration curves (Ref. 8) are combined into NAVMAT P-9492 and are generally representative of the industry consensus. Screening strength equations developed previously by Hughes were modified to reflect the Martin/Grumman data and further adjusted to satisfy other stress screening results. The screening strength equations should not be interpreted as scientifically derived equations of general applicability but rather as useful tools to serve as a quantitative basis for planning and controlling a stress screening program. Use of the stress screening equations in conjunction with the screen selection and placement guidelines will provide a sound planning basis.

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Careful review of stress screening results will enable the proper adjustment of the screening strength equations to match the items being screened through use of the SSM adaptive feature.

The SSM is easy to use but this should not be interpreted as meaning that planning, monitoring and evaluating a stress screening program is simple. Rather, it is the intent of the authors to provide a model which accepts all the major variables as user inputs, when available, but which can be meaningfully used when some input data is not available. The SSM contains default values for all but two user inputs and while considerable data gathering and analysis was necessary to establish the default values, they must be considered applicable only to the source from which they were derived. Each user should establish his own set of input variables applicable to his production processes and hardware item characteristics to make best use of the SSM and to have the most confidence in the results.

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'1. INTRODUCTION AND SUMMARY.

1.1 Introduction. The use of environmental stress screening of electronic hardware during development and production has increased significantly in the past few years among many military electronic equipment manufacturers. The basic intent of stress screening is to detect latent defects, by subjecting test items to specific conditions of environmental stress, so that such defects can be degraded to a detectable level. "Latent defects", as used here, represent weaknesses in parts, workmanship and to some extent design, which result in much higher failure rates than what may be indicated by predicted inherent failure rate values. Electronic equipment delivered to the field often contain latent defects traceable to the production process. Such defects result in abnormally high failure rates and excessive repair costs in the field. Early stress screening of modules and assemblies, during production, is a widely accepted, effective means of alleviating the problem. Screening programs may be, however, costly to perform and may not be fully effective, perhaps even detrimental, if improperly applied and controlled. The technology base, in addition, for screening test selection, effectiveness measurement, and cost control, is largely under developed.

Stress screening programs should be designed to precipitate and detect latent defects early in the production cycle when it is most cost-effective to do so. Early stress screening can increase the likelihood of the completed equipment passing final acceptance and reliability demonstration tests and may eliminate or reduce the need for costly burn-in or reliability growth programs at the system level. Early life stress screening of modules and subassemblies, therefore, can offer a cost-effective means of enhancing equipment reliability and reducing production and field support costs.

Due to the varied nature of military electronics equipment and their associated design, development and production program elements, it is difficult to "standardize" on a particular screening approach. A tailoring of the screening process to the unique elements of a given program is, therefore, required. Screening tests such as temperature cycling and random vibration appear to be the most effective tests. However, exposure levels, number of cycles, and test durations differ widely among users. Other, perhaps less costly, tests such as sinusoidal vibration, power cycled burn-in at ambient and temperature soak are also used, but, in general, their effectiveness is believed to be less than the former tests. Precise information of the effectiveness of the various available screening tests is not currently known. Screening tests therefore should be selected based upon estimates of cost and test effectiveness, early development program data and on equipment design, manufacturing, material and process variables, which at least, narrow consideration to the most

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cost-effective choices. The screening process then should be continuously monitored and test results analyzed so that changes in the process can be made, as required, to optimize the cost-effectiveness of the screening program.

A survey of the current literature has shown that although the use of stress screening is on the increase, there is little general guidance as to how to best plan, monitor and control a stress screening program. The Institute of Environmental Sciences (IES), a professional organization of engineers and scientists, currently has a national program underway to develop a guideline document for Environmental Stress Screening of Electronic Hardware. Results of this effort were published in a guidelines document (Ref. 12).

Hughes Aircraft Company is also preparing a Stress Screening Guidelines document for internal use which is expected to be released in 1982.

1.1.1 Objective and Scope of Study. The objective of this study was to develop quantitative and qualitative techniques for planning, monitoring and evaluating stress screening programs during electronic equipment development and production. The work effort investigated methodologies for test selection and control which provide assurance that reliability growth is achieved in a cost-effective manner throughout the development and production process. The work performed was concerned primarily with the cost-effectiveness of stress screening at levels of assembly above the part level, i.e., assembly/module, unit/group and equipment/system. Part level screening considerations were included in the study only to the extent that the quality grade of components used influences the initial quantity of latent defects and therefore the planning of the stress screening program.

1.2 Summary of Study

1.2.1 Study Approach. The basis of stress screening is the elimination of latent defects at a point in the production process when it is least costly to do so. Figure 1.1 depicts a typical production process where parts and printed circuit boards (PCB) or wired chassis comprise assemblies; then manufactured assemblies, purchased assemblies and associated wiring comprise units; and finally the units, other equipment and intercabling make up the completed system. Latent defects are introduced at each stage in the process and, if not eliminated, propagate through to field use. The cost of repair increases with increasing levels of assembly, being $1 to $5 at the part level and perhaps as high as $1000 at the system level. Field repair cost estimates have been quoted as high as $15,000. For economic reasons alone, it is desireable to eliminate latent defects at the lowest possible level of assembly and certainly prior to field use.

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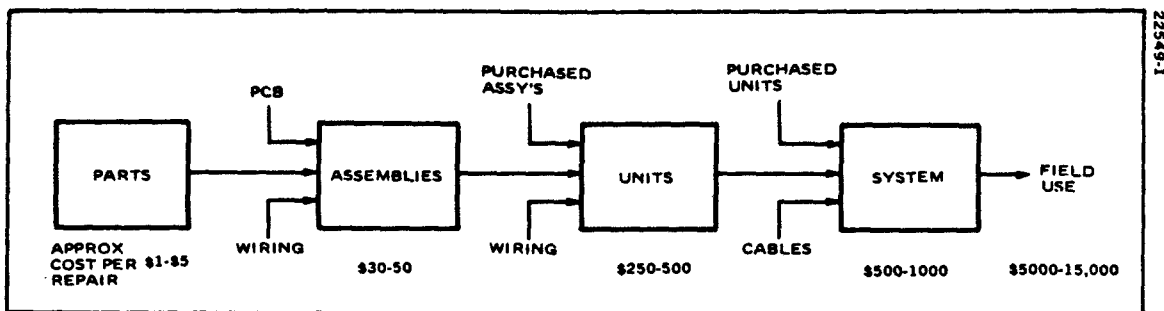
Figure 1.1. A Typical Production Process. Finding defects at the lowest level of manufacture is most cost effective.

Latent defects can be transformed into patent, or hard, defects through the application of environmental stresses such as elevated temperature operation, temperature cycling or vibration.

The probability that a stress screen will transform a latent defect into a hard failure (given that there is a latent defect present) and that failure will be detected by the screen is called "screening strength". Screening strength varies with the screen parameters, (e.g., the strength of a temperature cycle screen increases with increases in temperature extremes, temperature rate of change and number of cycles). But there is a cost associated with application of a stress screen and that cost varies with screening strength. There are then many possible combinations of screening strengths and screening costs at each level of assembly and the objective is to find the lowest cost set of screens that produces the desired results. A computer program is available to perform this "optimization" function and is discussed below.

1.2.2 The SDO Model. A prior study (Ref. 1) conducted by Hughes for RADC resulted in development of a Screening and Debugging Optimization (SDO) model which provides an optimum set of stress screens based on model inputs of estimated number of initial and process-induced defects and estimated screening costs. The model contains empirical screening strength equations for five stress screen types (constant temperature, constant power, cycled power, cycle temperature, and vibration) in which the screening strength is a function of screening parameters such as temperature extremes, number of cycles, rate of change of temperature, and screen duration. Since there are a very large number of combinations of stress screens and screen costs at each level of

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assembly, e.g., at assembly/module, unit/group, and equipment/system levels, the SDO model utilizes a dynamic programming algorithm to find the optimum solution to either,

> 1) the set of screens which achieve a predetermined reduction of latent defects for the least cost, or

> 2) the set of screens which achieve the maximum reduction of latent defects for a fixed cost.

The SDO model was retained for this study because of its optimization capability. However, many changes were made to the model during the course of this study, as indicated below.

Previous SDO Model	Model Changes
1) Screening strength equations do not reflect recent stress screening experience.	More current equations were substituted for existing equations.
2) Vibration screening strength equation is only for single frequency vibration.	Equations were added for random vibration and swept-sine vibration. A new equation for single frequency vibration was substituted.
3) Model is difficult to use. Many user inputs are required.	Use of the model was simplified by:
	a. Minimizing user input requirements.
	b. Providing clear instructions for model use.
	c. Providing examples to aid the user.
	d. Making the model interactive for use on time-share terminals.
	e. Including user prompter and assist instructions.
	f. Output formats were improved to facilitate user understanding.
4) The solution of the optimum set of screens	The dynamic programming algorithm was altered to a

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determined by the model was, occassionally, un-realistic (e.g. 5 different screens might be required sequentially at the same level of assembly).	contrained optimization solution to provide an optimum set of screens consistent with current practice.
5) Running of the model can be costly (much core is required and CPU time can become significant for large systems).	Unnecessary precision was eliminated. Instructions were reduced.
6) SDO model does not have "adaptive screening" capability.	Adaptive feature was added to allow an adjustment of stress screen parameters on the basis of results observed.
	Screening strength and initial fraction defective estimates can be derived from observed results using the chance-defective exponential (CDE) model.

1.2.3 _Screening Strength Equations_. Screening strength equations were developed for random vibration, swept-sine vibration, single frequency vibration, temperature cycling, and constant temperature. The first three equations (those for vibration) were developed from the results of the vibration screening experiments conducted by Kube and Hirschberger (Ref. 8). Experiments conducted by Edgerton (Ref. 5) and Baker (Ref. 6) did not produce sufficient vibration induced latent defect precipitation to enable model development. No other controlled experiments with the effectiveness of vibration were identified by the literature search. The development of the vibration screening strength equations is described in detail in Appendix A. Figures 1.2, 1.3, and 1.4 show screening strength versus time for the three vibration types.

The temperature cycling screening strength equation is derived from the curves on page 6 of NAVMAT P-9492 (Ref. 9). It was assumed that the curves represented results primarily from AGREE testing of avionics equipment and represent -54 deg. C to +55 deg. C temperature extremes and a 5 deg. C/minute rate of change. The constant temperature screening strength equation is derived from the temperature cycling equation. Figures 1.5 and 1.6 show screening strengths for the temperature related equations. The derivation is described in Appendix A.

1.2.4 _Adaptive Screening_. Since the stress screening equations are empirically derived, they are only rough quantitative
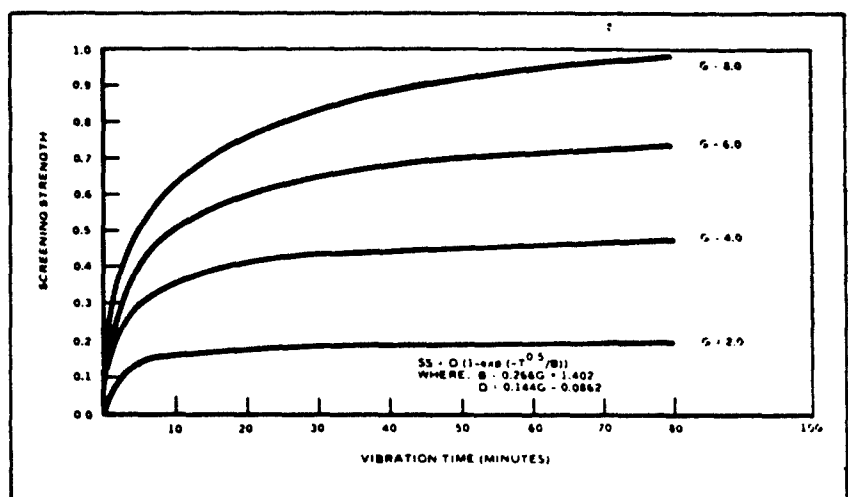
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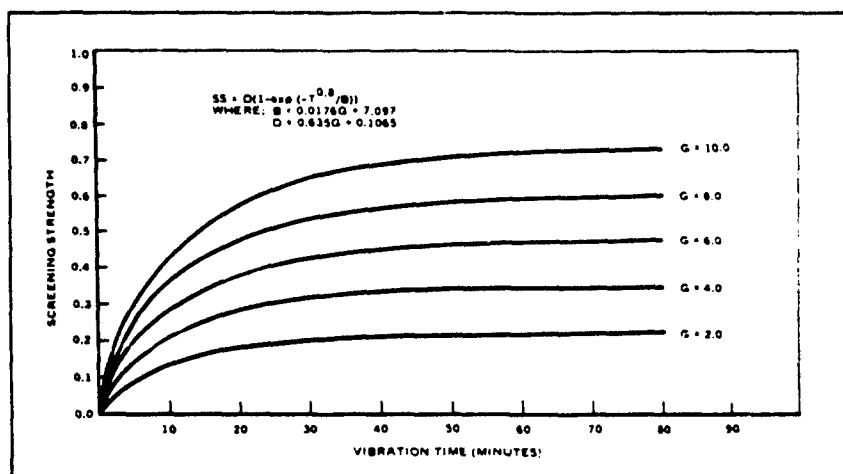
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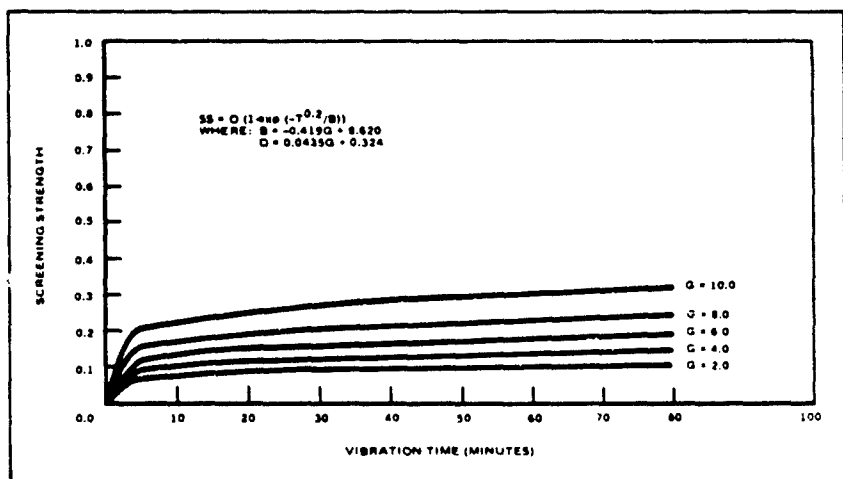
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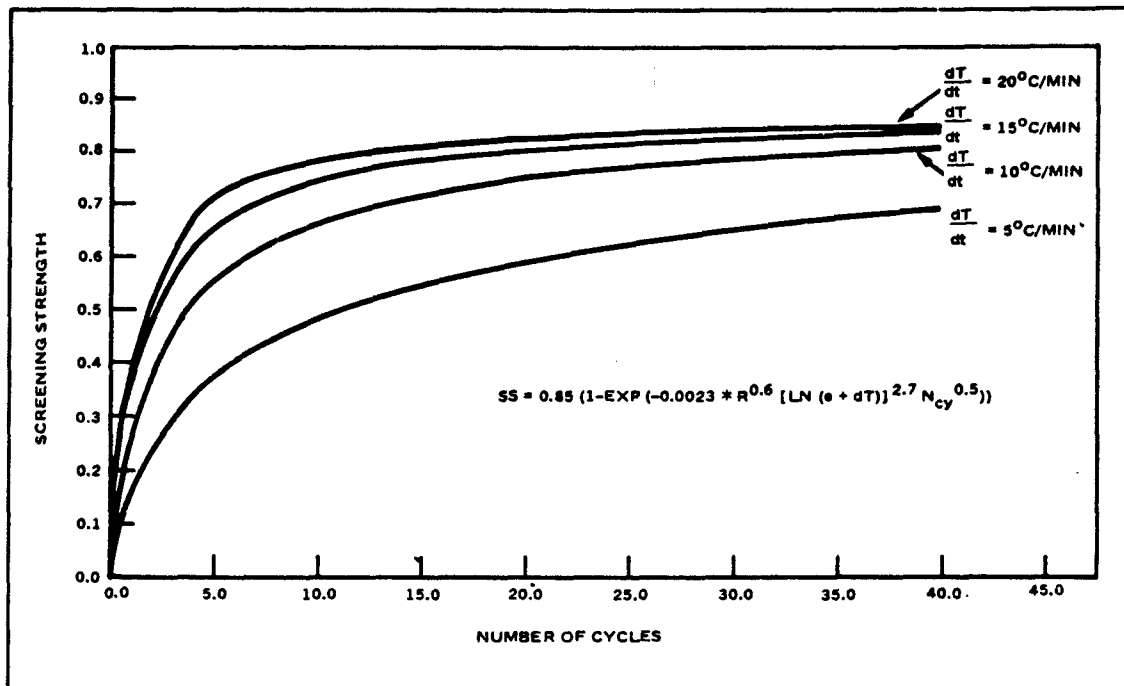
Figure 1.5. Screening Strength for a Temperature Cycling Screen (R = 100)

The equation shown in the figure:

$$SS = 0.85 \left(1-EXP\left(-0.0023 * R^{0.6} \left[LN\left(e + dT\right)\right]^{2.7} N_{cy}^{0.5}\right)\right)$$
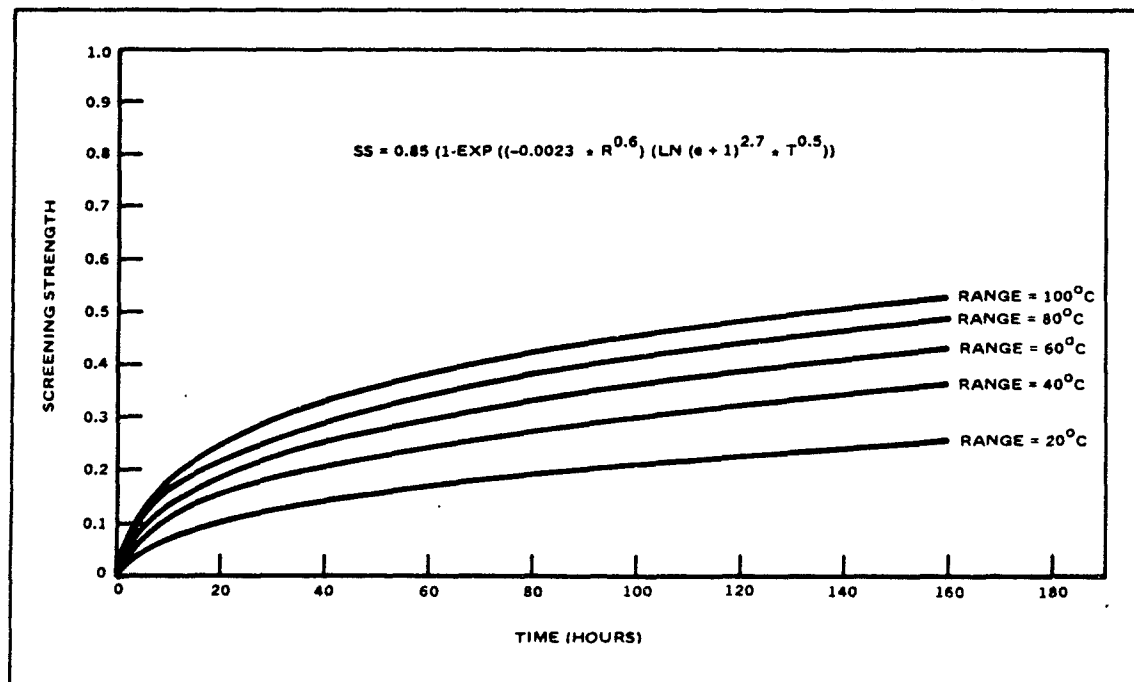
Figure 1.6. Screening Strength for a Constant Temperature Screen

The equation shown in the figure:

$$SS = 0.85 \left(1-EXP\left(\left(-0.0023 * R^{0.6}\right)\left(LN\left(e + 1\right)^{2.7} * T^{0.5}\right)\right)\right)$$

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approximations of the screens' ability to precipitate latent defects. Screening strength is also thought to depend on other factors such as equipment type, construction, size, part composition and degree of design and production maturity. Therefore, the equations are useful in establishing a starting point and serve as a basis for planning a screening program. As actual screening results become available they can be compared with the expected results as determined by the screening strength equations. If the actual results fall outside the 99 percent bounds on the expected results, the actual data can be entered into the model which will automatically adjust the "equipment-related" constants of the stress screening equations, thereby adapting the equations to the specific hardware characteristics. The 99 percent bounds are based on a statistical test of the hypothesis that the planned values are correct (with a probability of 1 - .99 = .01 of rejecting the hypothesis when it is true).

1.3 Summary of Industry Surveys

1.3.1 Surveys Previously Conducted and Reviewed for this Study. Three surveys previously conducted on the subject of stress screening were reviewed and the results of each are summarized in the following paragraphs.

The results of the three surveys show marked similarity because there are common respondents to the surveys reporting on the same experiences. Much of the experience data reported shows striking similarity in stress screens used, screening parameters (e.g., temperature extremes, temperature rates of change, vibration levels) and in opinions as to which screens are most effective. This is attributed to the fact that much of the reported screening experience is the result of contractually required MIL-STD-781B AGREE testing, primarily on avionics "black boxes".

1.3.2 Martin-Marietta Survey (Ref. 7). This survey of twenty-six sources primarily reporting on AGREE testing experience indicate the following beliefs.

NOTE: This survey represents experience and opinions of about ten years ago and a large amount of stress screening experience, apart from AGREE testing, has been accumulated since then.

a. 6-10 thermal cycles are required for the elimination of incipient defects. As more complex the screened item becomes (i.e., by part count), more cycles are required.

b. More than 10 cycles are required if screening is done at the assembly level, and unscreened parts are used. 16-25 cycles have been used.

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c.   A temperature range of -54 deg. C to 55 deg. C is most commonly used. (AGREE temperature range for avionics). Best screening is provided by using the maximum safe temperature range and rate of change.

d.   Temperature cycling of soundly designed hardware does not degrade the hardware.

e.   Application of power during temperature cycling with continuous performance monitoring is recommended. Turning off power during the cool-down cycle allows a more rapid temperature rate of change and allows parts to reach the low temperature extreme.

f.   Failure-free cycles are sometimes used. The report recommends one failure-free cycle.

g.   Implementing temperature cycling is most compatible with printed circuit board (PCB) construction and least compatible with large, complex potted cordwood modules.

h.   Augmenting "black box" temperature cycling with additional cycling at the PCB level should be considered.

i.   An approximation of the types of failures detected in mature hardware by temperature cycling is:

      Design-related   5%
      Manufacturing-related   33%
      Part-related   62%

j.   Temperature cycling is an effective screen, with the screening strength dependent on the temperature range, temperature rate of change and number of cycles. Temperature soaks and low-level vibration are not effective screens.

1.3.3 McDonnell Aircraft Company Survey (Ref. 11). This survey was conducted during 1979-1980 of thirty-three avionic equipment manufacturers to determine the industry practice and opinions current at that time in the conduct of environmental screening. A summary of the survey results follows.

a.   The primary environmental stress screen used is a thermal cycle, with a high temperature limit of 55 deg. C or 71 deg. C most common and a low temperature limit of -55 deg. C most common, reflecting the test limits of MIL-STD-781B.

b.   Temperature cycle durations of six to eight hours are most common and probably reflect convenience in adapting to the 24-hour day rather than for screening effectiveness purposes.

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c. Four to ten temperature cycles is most common, with the last cycle being failure free.

d. The most common temperature rate of change is 3 to 5 deg. C/minute.

e. Vibration during temperature cycling was limited to MIL-STD-781B requirements (i.e., 2.2g, sinusoidal, 10 minutes/hour). Some random vibration was used as a screen, separate from the temperature cycling, using levels of 3 to 6.2g RMS for durations of 5 to 10 minutes in 2 or 3 axes.

f. There was no concensus on when random vibration should be done when applied with temperature cycling (i.e., before, after, or in-between temperature cycling).

g. The distribution of the types of failures detected as a result of temperature cycling is:

Design-related	8%
Manufacturing-related	30%
Part-related	46%
Other	15%

The above percentages are mean values with large variances, reflecting varying degrees of production maturity. Soldering defects were the most common manufacturing related defect.

h. Factors influencing the design of a screen for a new production item were:

Factor	Percent of Respondents
1) Previous experience on similar equipment	91
2) Customer desires	67
3) Equipment characteristics	67
4) Reliability requirements	64
5) Use environment	58
6) Existing environmental facilities	48
7) Test operating cost	36

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i.   About 40% of the respondents reported that the screen had been changed after the start of production and the majority (80%) of the changes were to increase the screen (more temperature cycles, added burn-in, added random vibration, increased vibration level) as a result of poor reliability resulting from the initial screen.

1.3.4 Institute of Environmental Sciences (IES) Survey (Ref. 12). This survey was conducted during 1980-1981 by an IES-sponsored National Committee to develop an environmental stress screening guidelines document. The survey resulted in receipt of 85 detailed responses from 14 sources and over 50% of the responses were for avionics applications. Salient findings of the survey are as follows:

a.   Thermal cycling and vibration were the most common stress screening environments used at the module, unit and system levels. Survey respondents also believe that thermal cycling and vibration are the most effective stress screens.

b.   Equipment reliability can be improved by 25 to 90% by means of environmental stress screening. The range of reliability improvement varied widely depending on equipment type, screening environment and the levels of assembly at which screening was performed.

c.   Thermal cycling was found to be a more effective screening environment for electronics than vibration, by a factor of 3 or 4 to 1. Random vibration is more effective than swept sine, and swept sine is more effective than fixed sine.

d.   Both thermal cycling and vibration are needed for optimum screening effectiveness. It is inconclusive that it is more effective to perform thermal cycling or vibration in any specific sequence but there appears to be a synergistic effect of using both the environments.

e.   Module-level temperature cycling is generally 20 to 40 thermal cycles, with a temperature rate of change of 5 deg. C/minute most common, and no power applied to the module. There is no significant payoff to extend the number of cycles beyond 40. Increasing the temperature rate of change produces more effective screening. Application of power to the module during the screen does not increase screening effectiveness.

f.   Units and system level screening profiles used reflect the strong influence of MIL-STD-781B in temperature range and rate of change. 8 to 12 thermal cycles, with power applied, were most common.

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g. Some cases were noted where degradation was introduced in equipment at high levels (i.e., 6gRMS) of random vibration. There is also an indication that lower levels of random vibration can be as effective as higher levels in some applications.

1.3.5 Survey Consensus. Thermal cycling and vibration are thought to be the effective environmental stress screens for precipitating latent defects. A large part of the reported stress screening experience data is a result of contractually required AGREE tests in accordance with MIL-STD-781B, test levels E and F, for avionics equipment. The AGREE requirements have obviously strongly influenced the survey respondents with regard to temperature cycling and vibration. This, at least partly, explains the commonality in stress screening practice. Most screening experience is at the unit, or "black box", level and a range of 4 to 12 thermal cycles is believed to be sufficient to screen out latent defects. There is some belief that the more complex the unit (i.e., in part count), more thermal cycles are needed, although this belief is not universally accepted. The most common temperature range over which thermal cycling is done is -54 deg. C to +55 deg. C, again reflecting the influence of MIL-STD-781B. There is a common belief that greater temperature ranges provide more effective screening, provided that the temperature limits are within the safe operating limits of the unit being screened. The most common temperature rate of change appears to be 5 deg. C/minute and there is general agreement that higher rates of change provide more effective screening. Temperature cycling at the unit level is most often accomplished with power applied and close monitoring of performance at both temperature extremes is recommended. Power is turned off during the cool down cycle. Application of power during temperature cycling at the module level does not appear to increase the effectiveness of unpowered screening. There does not appear to be a clear consensus on the use of failure-free cycles. While the practice of requiring the last cycle to be failure-free is used by some and supported by others, there is another group who believe that a failure-free requirement should be included with other acceptance criteria and kept separate from the stress screening process.

Random vibration is considered to be the most effective vibration screening process, followed by swept frequency sinusoidal vibration (swept sine) and fixed frequency sinusoidal vibration (fixed sine).

Fixed sine vibration at low levels (e.g., 2.2g) is almost universally believed to ineffective as a workmanship screen. Random vibration at levels of 3-6gRMS, for 5-10 minutes (per axis), and applying to 2 or 3 axes is currently thought to be the most effective screen. However, the application of random vibration is relatively new and the survey results were mostly reports of AGREE testing, using 2.2g fixed sine vibration. Vibration at the module level is not currently thought to be effective.

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Screens other than temperature cycling and vibration (e.g., temperature soak, power ON-OFF cycling) are not considered to be effective screens. Combining screens, such as performing temperature cycling and vibration on the same unit simultaneously or sequentially is considered to be effective. Opinions are mixed, however, on whether simultaneous screening is more effective or has the same effectiveness as sequential screening. There is also no agreement on the most effective sequence of combined screens, i.e., vibrate before or after temperature cycle.

Table 1.1 summarizes the key issues of the three surveys.

TABLE 1.1   SUMMARY OF THREE PREVIOUS SURVEYS.

Topic	Martin-Marietta Survey (Ref. 7)	McDonnell Air-craft Company Survey (Ref. 11)	IES Survey (Ref. 12)
Thermal Cycle Screening	6-10 cycles. More cycles are required for more complex units & when done at lower assembly levels.	4 and 10 cycles most common. No. of cycles used varies widely (2 to 70 cycles).	8-12 cycles, independent of unit part count. 20-40 cycles for module level temp. cycling.
Temperature Range	$-54°C$ to $+55°C$ most common. (influence of AGREE testing.) Maximum safe range is most effective.	$-54°C$ to $+55°C$ or $+71°C$ (influence of AGREE testing)	Not stated, but stress screening cycles strongly influenced by AGREE testing profiles.
Temperature Rate of Change	$1°F$ to $40°F$/min. with higher rates more effective.	$3°C$ to $5°C$/min.	$5°C$/minute. Higher rates (15-20 C/min.) at module level more effective.
Power ON vs. OFF	ON, with close monitoring of performance. OFF during cool-down portion.	Not stated, but expected to follow AGREE profile. (ON, except during cool-down portion.	ON, for Unit and System-Level. Functional testing at both extremes. OFF, for module-level.

TABLE 1.1   SUMMARY OF THREE PREVIOUS SURVEYS.

Topic	Martin-Marietta Survey (Ref. 7)	McDonnell Air- craft Company Survey (Ref. 11)	IFS Survey (Ref. 12)
Failure-Free Cycles	0-2 cycles FF. 1 FF cycle recommended.	Varies greatly, 0 to 22 FF cycles 1 FF cycles is most common.	Should be made part of accept- ance criteria, separate from stress screening.
Random Vibration	Not addressed	3-6.7gRMS, 5-10 minutes per axis, 2 or 3 axes.	Various Levels. Many are using NAVMAT P-9492, 6gRMS. Recom- mends tailoring to item being screened. Not effective at module-level.
Degradation	Temperature cycling does not degrade soundly designed hard- ware.	Not addressed.	Cases noted where high levels of random vibration (6g RMS) cause degradation.

TABLE 1.1   SUMMARY OF THREE PREVIOUS SURVEYS.

Topic	Martin-Marietta Survey (Ref. 7)	McDonnell Aircraft Company Survey (Ref. 11)	IES Survey (Ref. 12)
Distribution of Defects: Part-related Manufacturing-related Design-related Other	 62% 33% 5% -	 46% 30% 8% 15%	Not addressed
Effectiveness of screens other than temperature cycling and random vibration	Low Level (2g) Fixed Sine Vibration and temperature soak are not effective screens.	Low level (2g) Fixed Sine Vibration not effective. Opinion mixed on effectiveness of temperature soak	All screens other than temperature cycling and vibration are less effective substitutes.
Combined Temperature Cycling and Random Vibration	Not addressed, except that AGREE vibration is not an effective screen.	Majority think combining the screens is more effective than applying singly.	Combined testing is no more effective than applying screens singly. Using both temp. cycling and vibration singly is necessary and a synergistic effect is gained.

TABLE 1.1   SUMMARY OF THREE PREVIOUS SURVEYS.

Topic	Martin-Marietta Survey (Ref. 7)	McDonnell Air-craft Company Survey (Ref. 11)	IES Survey (Ref. 12)
Sequence of Temperature Cycling and Vibration, when used singly.	Not addressed.	Respondents indicated various combinations, vibration before, after and in-between temp. cycling, with no concensus opinion on which is most effective.	No preferred sequence. Applying either screen before and after the other screen shows additional fall-out.
Reliability Improvement through Stress Screening	Not specifically addressed, but there is general agreement that temp. cycling eliminates incipient defects (and it can be inferred that reliability will thereby improve)	Not specifically addressed, but there is general agreement that temp. cycling eliminates incipient defects (and it can be inferred that reliability will thereby improve)	Equipment relia-bility can be improved by 25-90% through stress screening.

2.   PLANNING A STRESS SCREENING PROGRAM.

2.1   Introduction.   The ultimate success of a stress screening program is strongly dependent on the care taken in planning and understanding the limitations of stress screening. The planning of a stress screening program involves a number of considerations which are addressed below.   Two important considerations should be kept foremost in mind in the process of planning a stress screening program:

- The quantitative aspects of stress screening, i.e., the expected number of latent defects and the ability of a specific screen to precipitate those defects, cannot be analytically determined, and any models purporting to do so must be recognized as approximation methods based on past experience.

- Past experience may provide some guidance in stress screen selection in cases of similar equipment composition and construction and degree of production maturity. However, there are usually other factors involved (e.g., reliability improvement fixes may have been incorporated simultaneously with the start of stress screening) which may obscure the true source of improvement.

Other factors to consider are:

- What are the objectives of a stress screening program? (e.g., achieve a quantitative reliability goal, maximize reliability, reduce production costs, reduce warranty costs, minimize life cycle costs?)

- What are viable alternative stress screens for achieving objectives (which screens applied at which levels produce the desired results?)

- What are the costs associated with each of the alternative approaches? (consider both nonrecurring and recurring costs)

- How does one know if the screening program is going according to plan (data gathering, analysis, decision criteria)?

- How can a stress screening program be changed to achieve more cost effective screening?

- What are things that can go wrong, what early indications are there and what should be done to correct them?

● How to and why keep management attention on benefits being derived from stress screening?

2.2 Developing a Stress Screening Plan

2.2.1 Establishing an Objective. The most common objective in establishing a stress screening program is to improve field reliability by eliminating latent defects in the factory prior to delivery. This objective includes motivation through warranty considerations as well as motivation to improve poor field reliability. Other objectives to consider are:

a. Meeting a contractual reliability demonstration requirement.

b. Achieving and maintaining a high field reliability level.

c. Assuring cost effectiveness in a Reliability Improvement Warranty (RIW) contract.

d. Reducing production costs.

e. Reducing field costs of operations and maintenance (O&M)

The cost of failing a reliability demonstration is high enough to negate most compromises. The amount of screening planned should be consistent with the specified MTBF and test decision risks. The same approach should be considered on a reliability improvement warranty (RIW) contract. It should be noted that more screening is not always better and the improvement per unit of time decreases with time.

Achieving and maintaining a high field reliability requires careful evaluation of problems which could adversely affect reliability levels and an understanding of how such problems can be eliminated or controlled.

2.2.2 Determining if a Stress Screening Program is Appropriate. The current popularity of stress screening might lead one to believe that it is a panacea for solving problems of low field reliability, high production rework costs and slipping production schedules. Unfortunately, there are many other causes of such problems and no simple solution exists for correcting (or preventing) them. The value of stress screening, i.e., the knowledge of what potential technical or economic benefits are derivable from stress screening, should be understood before a decision is made to apply it. Generally, on high volume production programs of complex hardware the cost-effectiveness of stress screening should be considered. It is not so obvious that

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stress screening is cost-effective, or otherwise beneficial, on a single system, advanced development model, where the production phase is remote and the non-recurring costs for stress screening facilities and test equipment are not insignificant.

The construction and complexity of the development item are important considerations. A breadboard or brassboard model which has little resemblance to a future production model should not be screened for manufacturing/workmanship defects. A development model which is expected to undergo extensive productization changes falls in the same category. Pre-production models embodying new designs are prime candidates for stress screening in a development phase because the types of defects to be expected in production can be identified and a production stress screening program can be effectively planned.

To determine if a stress screening program is appropriate, consider the following:

- Does the reduced field maintenance cost justify the screening program cost?

- Is stress screening necessary for eliminating excessive latent defects?

- Is stress screening necessary to achieve a technical (e.g., reliability) requirement?

- Will stress screening (in a development phase) provide valuable information for planning the production stress screening program?

- Will stress screening save money in production (through reduced rework costs)?

- Is the improved production schedule resulting from stress screening worth the cost of screening?

- Does the goodwill derived from delivering latent defect-free products balance the cost of stress screening?

2.2.2.1 Field Maintenance Cost Savings through Stress Screening. Field maintenance costs resulting from latent defects can be calculated by multiplying the number of latent defects present by the average cost per field repair. Figure 2.1 is a simplified production flow process of an unscreened unit. Assume the unit has $N=10,000$ parts, of which $p=.001$ fraction defective, resulting in the introduction of 10 latent defective parts. Further, assume 20 workmanship defects are introduced at the assembly level and 10 more at the unit level. The normal assembly and unit operational testing is assumed to have screening strengths of

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0.20 at the assembly level and 0.40 at the unit level. Then, only 6 latent defects are precipitated at the assembly level (0.20 x 30 defects) and 14 at the unit level. Since a total of 40 defects were introduced in the process and 20 were precipitated, a balance of 20 remain to fail in subsequent field use.
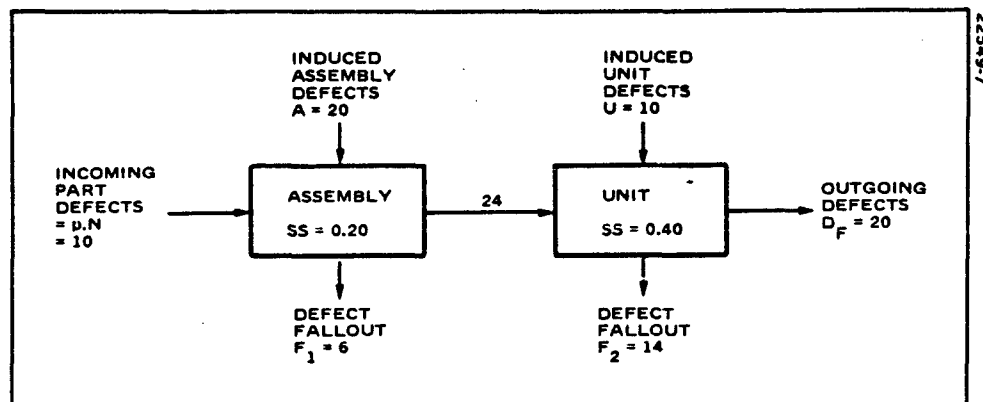
Figure 2.1. Latent Defect Flow for Process Without Stress Screening

Figure 2.2 shows the same unit with stress screening at both the assembly and unit levels and screening strengths of 0.70 are assumed. The same number of latent defects are introduced (40) but because of the increased screening strength, 34 defects are precipitated, leaving only 6 defects to be found in field use. The reduction of 20-6=14 defects saves $140,000 in maintenance costs (at $10,000 per repair). If the cost of doing the screening is less than the discounted value of $140,000, the screening has been cost-effective.
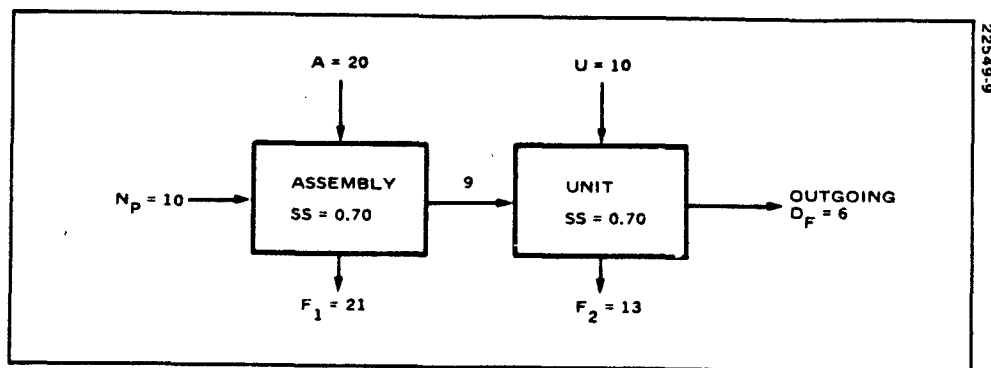
Figure 2.2. Latent Defect Flow for Process with Stress Screening

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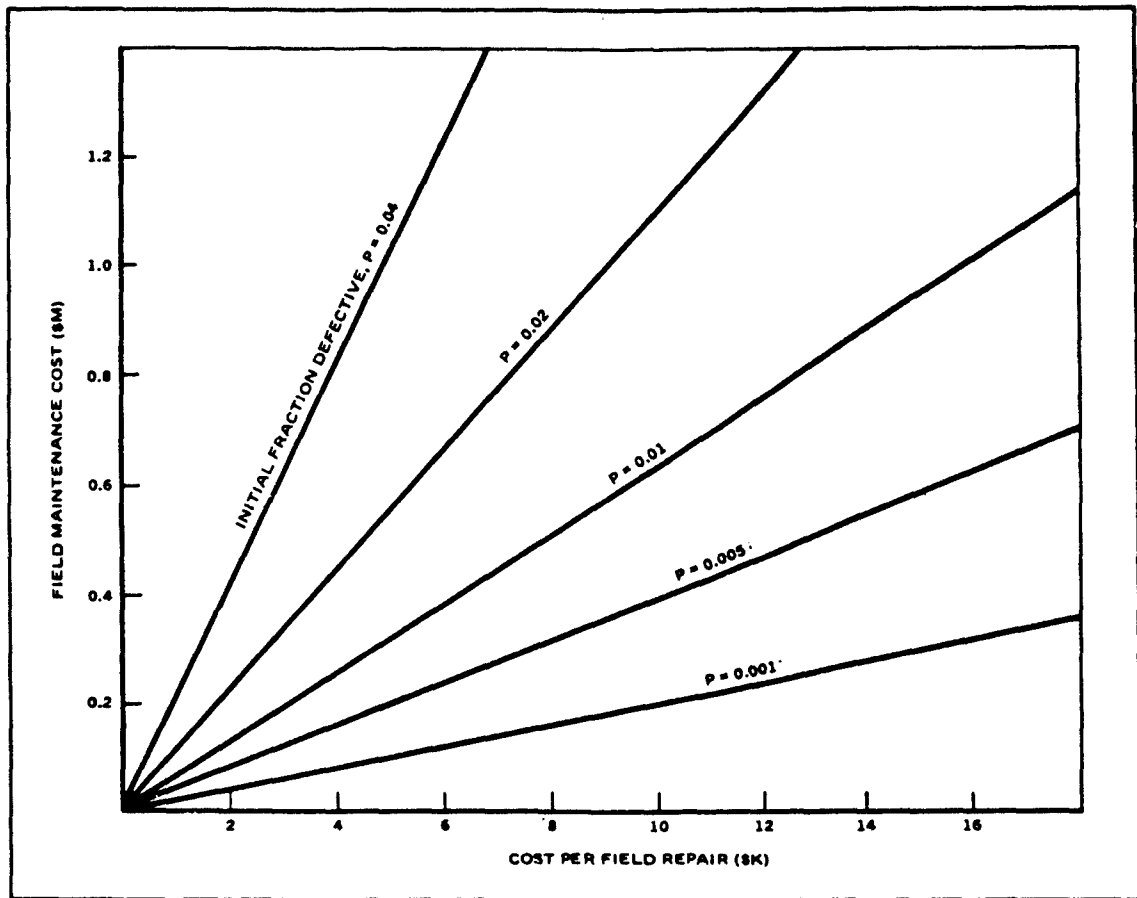
Figure 2.3.   Field Maintenance Costs for Repairs Resulting From Latent Defects

Figure 2.3 shows that, for this example, at $10,000 per field repair a total of $200,000 will be spent in maintenance as a result of the 20 latent defects (p=.001). The figure shows costs rise rapidly as the initial fraction defective increases.

2.2.2.2 Using Stress Screening to Achieve a Reliability Requirement. It is generally believed that large part populations are comprised of two subpopulations, viz., "good" parts with a low failure rate, λg, and "bad" parts with a high failure rate, λb. It is further believed, and empirical and experimental evidence supports, that the good subpopulation dominates. The fraction of good parts in the population may be from 0.9 to 0.999, depending on the part type and quality grade. There is increasing evidence (ref. 19) that failures occurring during the life of equipment are latent defectives precipitated to hard failures through the application of the normal field usage stresses over a period of time. The continuously decreasing subpopulation of bad (latent defective) parts results in an equipment life characteristic of a decreasing failure rate.

If the expected instantaneous failure rate of an equipment is the summation of the failure rates of the good and bad (defective) parts,

$$\lambda_{equipment} = (N-D)\,\lambda_g + Dk\lambda_g \qquad (2-1)$$

where, N = total part population

D = number of defective parts

λ_g = good part failure rate

$k\,\lambda_g$ = defective part failure rate

and if estimates of λg and k can be made, then the number of latent defects that corresponds to a desired equipment failure rate can be determined by solving (2-1) for D,

$$D = \frac{\lambda_{equipment} - N\lambda_g}{\lambda_g(k-1)} \qquad (2-2)$$

Equation 2-2 addresses only latent defective parts and thereby excludes latent workmanship defects, which can be included by expanding equation 2-1,

$$\lambda_{equipment} = (N-D)\lambda_g + Dk_1\lambda_g + (M-C)\lambda_c + Ck_2\lambda_c \qquad (2-3)$$

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where,   M = total number of electrical connections

        C = number of latent defective connections

     λ_c = good connection failure rate

   $k_2\lambda_c$ = defective connection failure rate 2

Equation 2-3 can be used in planning and monitoring a stress screening program for determining the necessary reduction in the initial number of defective parts and the number of latent defective connections that yield a value of λ equipment that corresponds to the desired equipment failure rate. At the conclusion of stress screening, there are still some residual latent defects. As these latent defects are precipitated by field use, the reliability will improve because the latent defects are replaced (with high probability) with good parts. See Appendix E for a theoretical discussion of long term field reliability improvement through latent defect elimination. Figures 2.4, 2.5 and 2.6 show this reliability improvement for systems of 2,000, 10,000, and 20,000 parts and initial fraction defective rates of .001, .005, and .01. The figures represent systems of three different part counts, and undergo a natural screening of latent defects (no stress screening) in which the good part failure rate is 10^{-7} and the bad part failure rate is 2×10^{-4}. The curves in Figures 2.4, 2.5, and 2.6 were derived from a simulation program which simulates failures of good and bad parts and keeps track of cummulative MTBF as the number of failures due to bad parts decreases with time.

2.2.2.3 Manufacturing Cost Savings through Stress Screening. Consider the production model shown in Figure 2.7. The figure shows a moderately large production operation involving 100,000 parts. This may represent a single, large system of that many parts or multiple systems whose total part count is 100,000. Assume that, without stress screening, the natural screening strengths of the assembly, unit and system levels are 0.2, 0.4 and 0.6, respectively. If the incoming part defect rate is 0.5 percent and induced workmanship defect rates (as a fraction of the number of parts) are as shown in the figure, a total of 850 latent defects are introduced into the process and 672 of them are precipitated, detected and removed in the process, with the balance of 178 remaining to be discovered in field use.

    If stress screening is employed at the assembly and unit levels, each with screening strengths of 0.70, the resulting defect fallout at each level is as shown in Figure 2.8.

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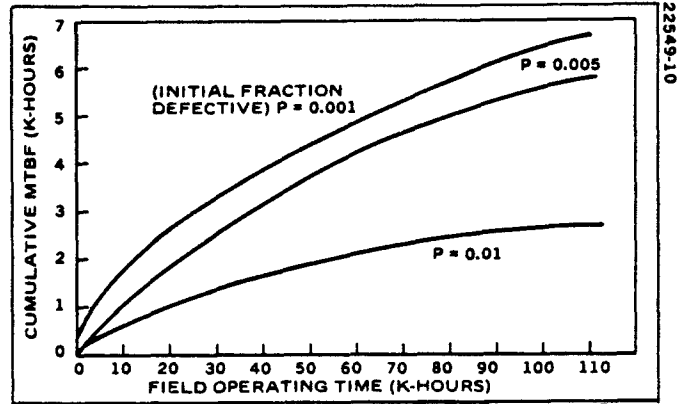
Figure 2.4. Field MTBF Improvement Through Natural Latent Defect Fallout (2000 Part System)
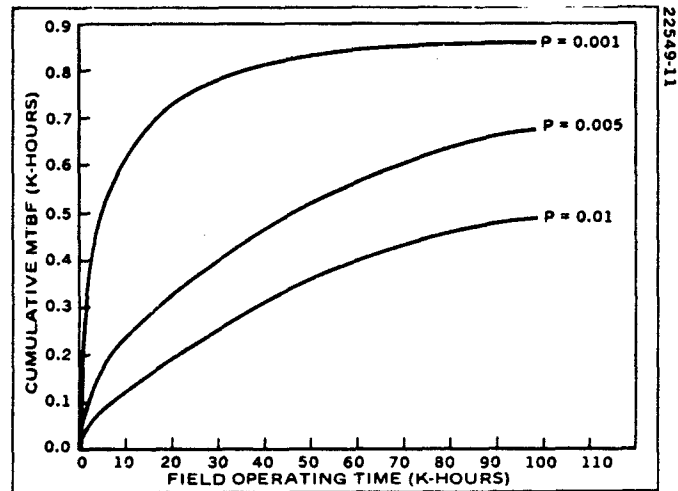
Figure 2.5. Field MTBF Improvement Through Natural Latent Defect Fallout (10,000 Part System)
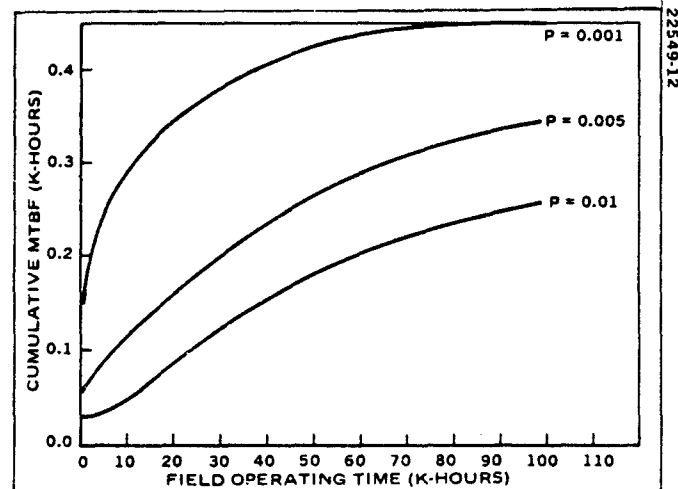
Figure 2.6. Field MTBF Improvement Through Natural Latend Defect Fallout (20,000 Part System)

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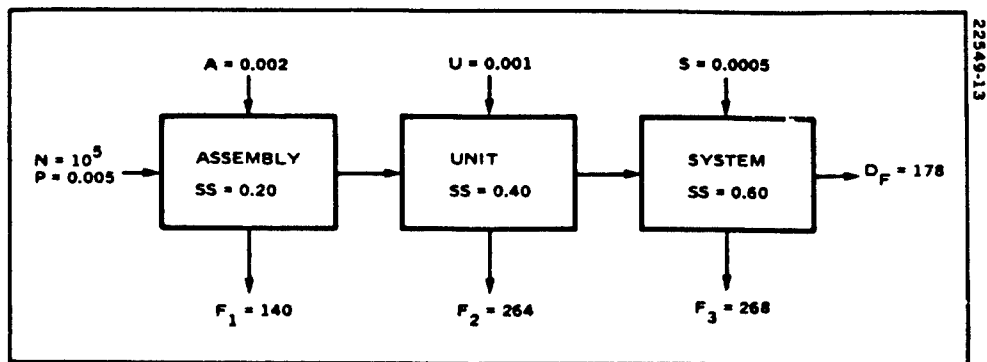
Figure 2.7. Production Flow Model Without Stress Screening
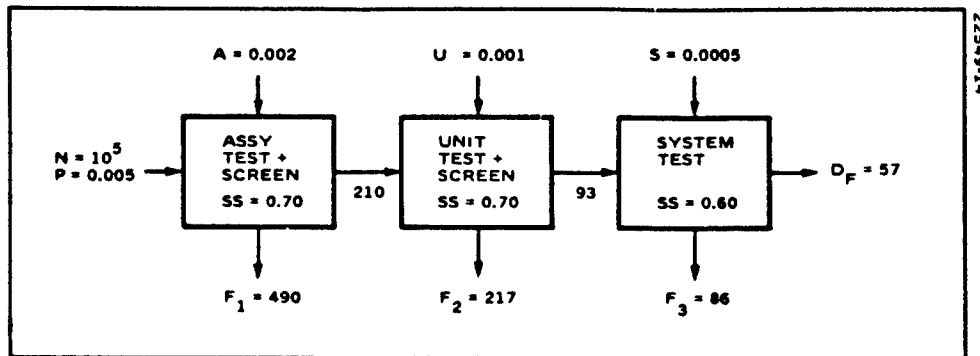
Figure 2.8. Production Flow Model With Stress Screening

The figure shows that there is significant increase in the number of defects precipitated at the assembly level, a moderate decrease at the unit level and a significant decrease at the system level.

The cost analysis of the effect of the stress screening for this example is shown in Table 2.1.

The table shows that the total manufacturing cost of repair without stress screening is $354.2K and the cost of repair with stress screening is $175.6. This indicates that if the cost of screening is less than $178.6K, a manufacturing cost savings results. (Also, the reduction in number of latent defects escaping to field use from 178 to 57 results in a potentially significant field maintenance cost savings).

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Table 2.1   Manufacturing Stress Screening Cost Analysis Example.

	Assembly Level		Unit Level		System Level	
	W/O SS	W/SS	W/O SS	W/SS	W/O SS	W/SS
Number of Defects Precipitated	140	490	264	217	268	86
Cost per Repair	$50	$50	$300	$300	$1,000	$1,000
Repair Cost ($K)	7.0	24.5	79.2	65.1	268.0	86.0

Since the cost per repair estimates are expected to vary with type and complexity of hardware, Figure 2.9 shows the total assembly repair costs (per 1000 assemblies) as a function of cost per assembly repair. Figure 2.10 shows the total unit repair costs (per 100 units) as a function of cost per unit repair. Total cost is the product of cost per repair and expected number of repairs. The expected number of repairs is determined by the expected fraction of assemblies defective as a function of the initial part fraction defective, number of parts per assembly and number of assemblies per unit, explained in paragraph 2.2.3, below. Both figures show the repair costs incurred if all latent defects entering that level are precipitated, detected and eliminated at that level, which is unlikely since screening strengths are not expected to approach 100 percent. Some latent defects will escape to subsequent stages where repair costs are higher. Therefore, the repair costs shown represent the lowest cost to eliminate latent defects entering that level.

2.2.3   The Role of Part Level Screens

2.2.3.1   Part Failures in Field Use. The major portion of failures that occur in field use appears to be part failures as compared to workmanship failures, although during early life the split between part and workmanship failures is about equal. Figure 2.11 shows the changing distribution in failure types with time for a system development program. The early portion of the figure represents the later development stages and the later portion represents the final field testing stages.

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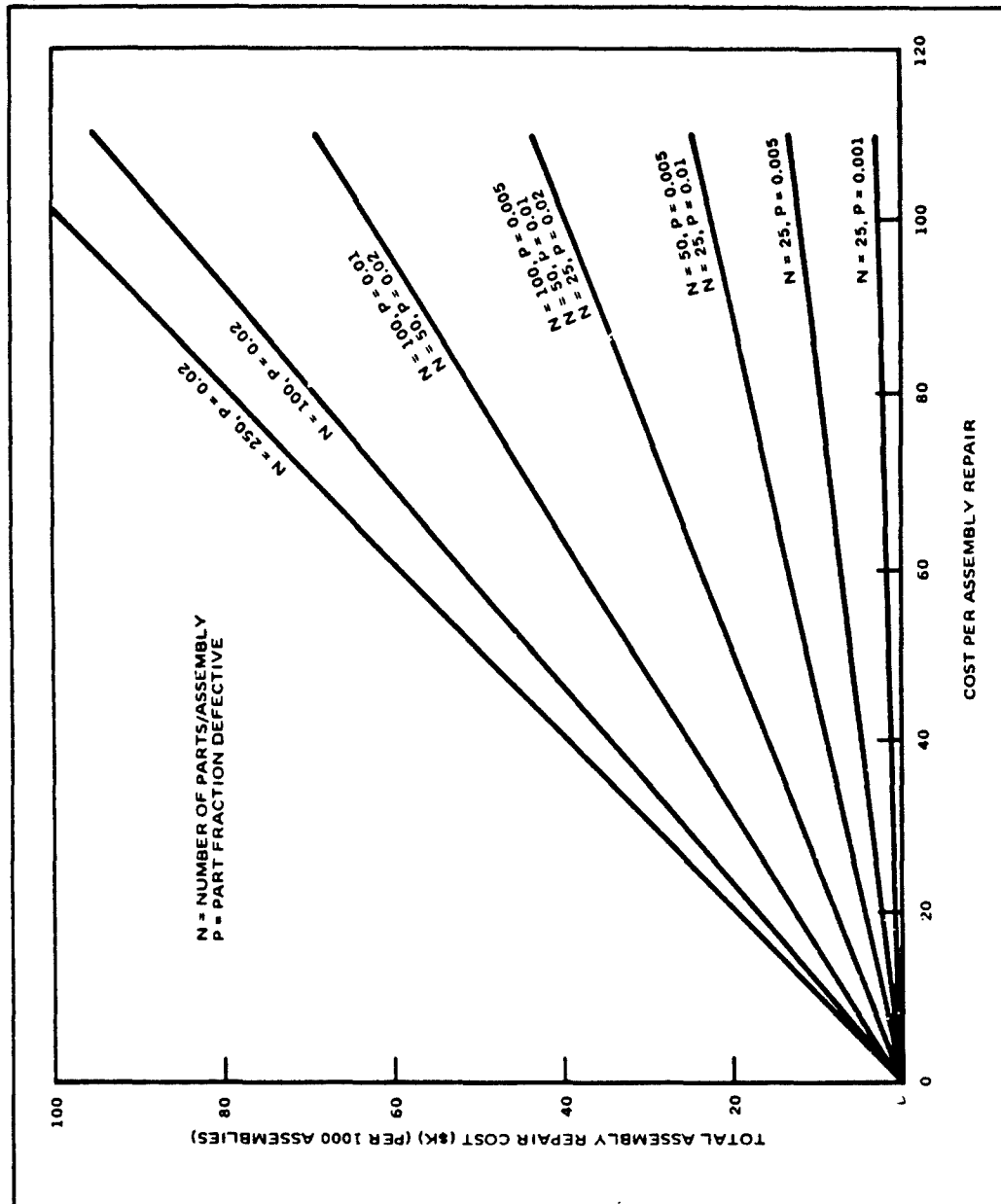
Figure 2.9. Assembly Repair Cost Analysis

COST PER ASSEMBLY REPAIR

TOTAL ASSEMBLY REPAIR COST (\$K) (PER 1000 ASSEMBLIES)

N = NUMBER OF PARTS/ASSEMBLY
P = PART FRACTION DEFECTIVE

N = 250, P = 0.02
N = 100, P = 0.02
N = 100, P = 0.01
N = 50, P = 0.02
N = 100, P = 0.005
N = 50, P = 0.01
N = 25, P = 0.02
N = 50, P = 0.005
N = 25, P = 0.01
N = 25, P = 0.005
N = 25, P = 0.001

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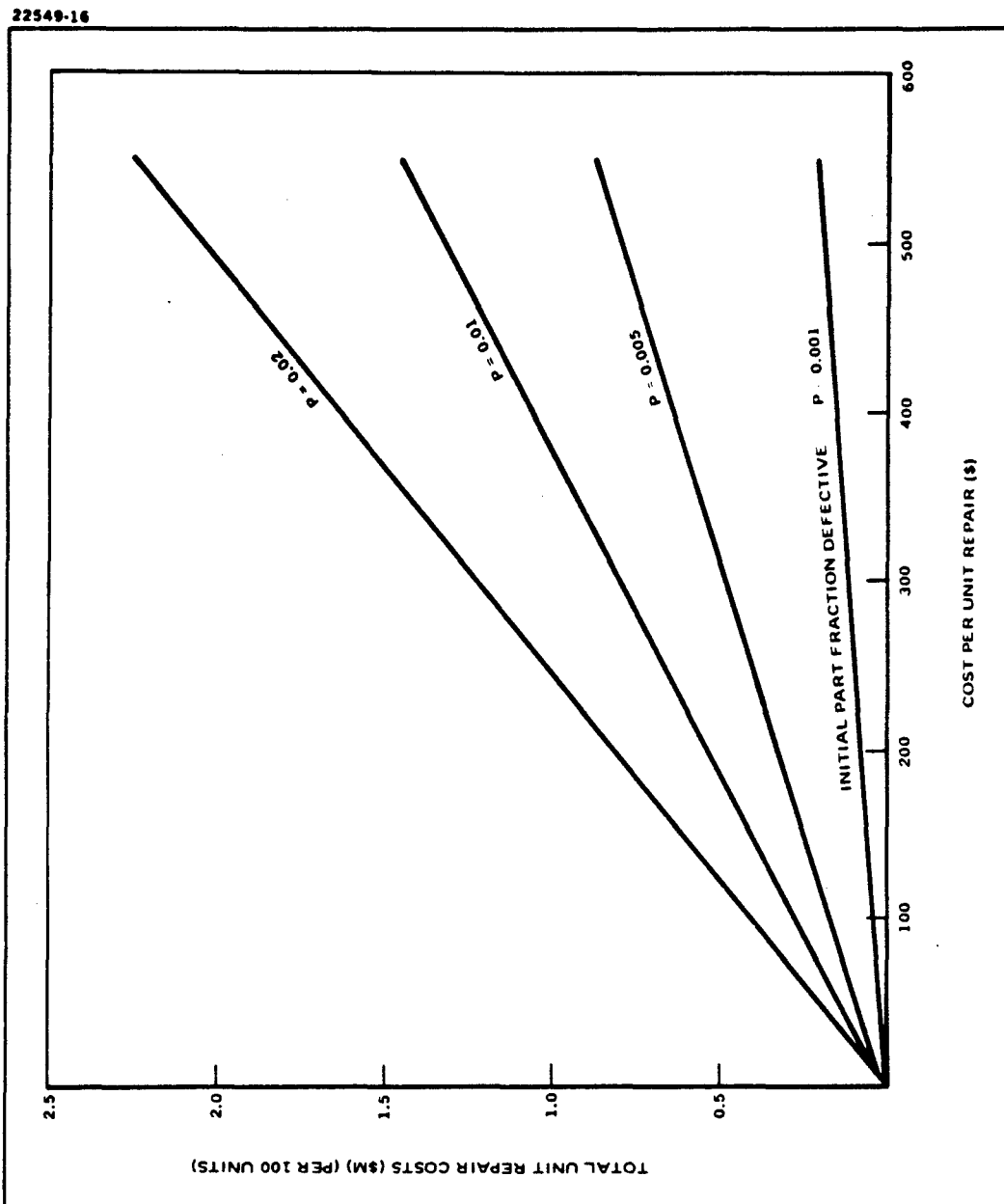
Figure 2.10. Unit Repair Cost Analysis

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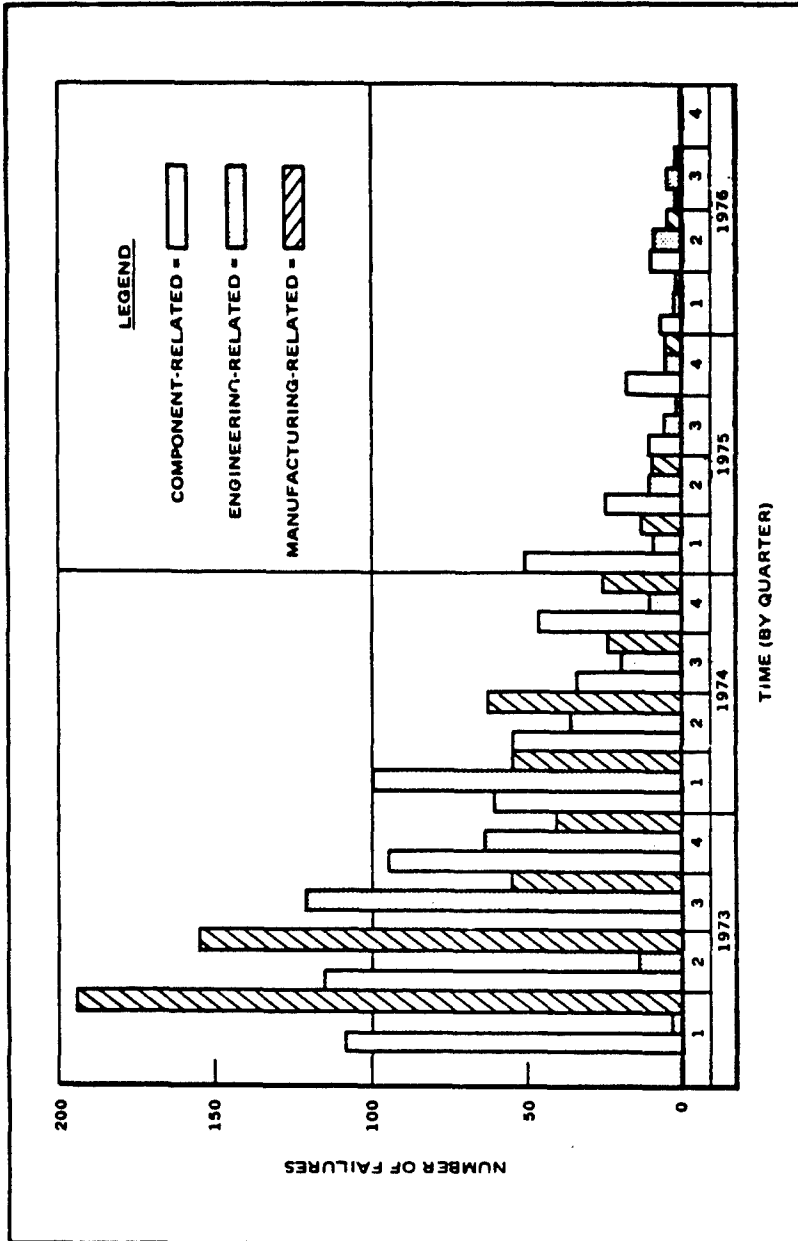
Figure 2.11. Distribution of Failures by Classification and By Time for a Radar Development Project

Design-related failures are a small fraction of the total number of failures in mature production systems. During development, however, the distribution is quite different as indicated by Figure 2-12. The figure shows the distribution of defects for three recent, large scale (25,000 to 47,000 parts/system) development programs over 2-3 years of field operation.

Part failures during production results in rework costs as described earlier. If parts are procured without screening and subjected to sample receiving inspection, the fraction defective may range from .01 to .20, depending on part type and quality grade. Even if the fraction defective is as low as .01 and the parts are installed on assemblies averaging, say, 50 parts, then about 40 percent of all assemblies produced will be defective (only one defective part can make an assembly defective). Figure 2.13 shows the expected fraction of assemblies defective as a function of number of parts per assembly and part fraction defective.

2.2.3.2 Relationship of Part Fraction Defective to Quality Grade. The failure rate of different populations of microcircuits, operating under identical conditions, can vary over an order of magnitude, depending on quality grade (Class S versus C-1). Yet, the major differences between the Class S die and the class C-1 die are the visual inspection acceptance criteria, level of process controls, and part-level screens and electrical tests to which the dice are subjected. Since screens and tests do not make devices more reliable (they improve lot quality by eliminating some latent defective parts), a "good" class C-1 die is as "good" as a class S die. Perhaps this can be extended to "good" class D-1 die as well. Therefore, it can be postulated that difference in failure rate of populations due solely to quality grade is a direct measure of the difference in fraction defective of those populations.

For example, consider a class S, hermetic flatpack MSI device of, say, 40 gates operating with T_j=25 deg. C in a benign ground environment. A failure rate of 0.0032x10^{-6} failures per hour is calculated. Let 5,000 of such devices be used in an end item expected to operate 50,000 hours. The expected number of device failures during the end item life is less than 1. For this application, this device can be considered "good" and if the population exhibited its calculated failure rate by having 0, 1, or even 2 failures, the population might be considered to be free of latent defectives. If a class C-1 device were used on the end item instead of the class S device, an additional 20 failures could be expected to occur during the same end item life, due solely to the difference in quality grade. Perhaps the additional 20 failures represent latent defectives in the population. If the class S parts were operated with T_j=100 deg. C instead of 25 C deg. the increase in failure rate would result in an additional two failures during the 50,000 hours. This may indicate that the
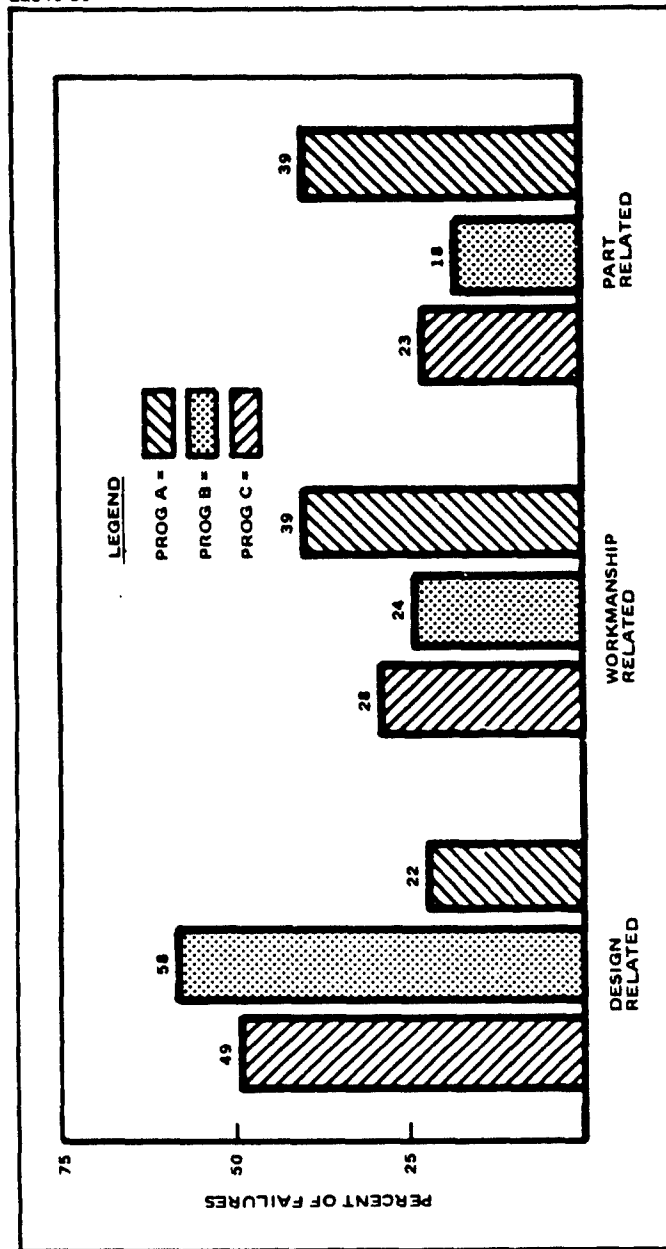
Figure 2.12. Distribution of Failures by Type for Three Recent Development Programs

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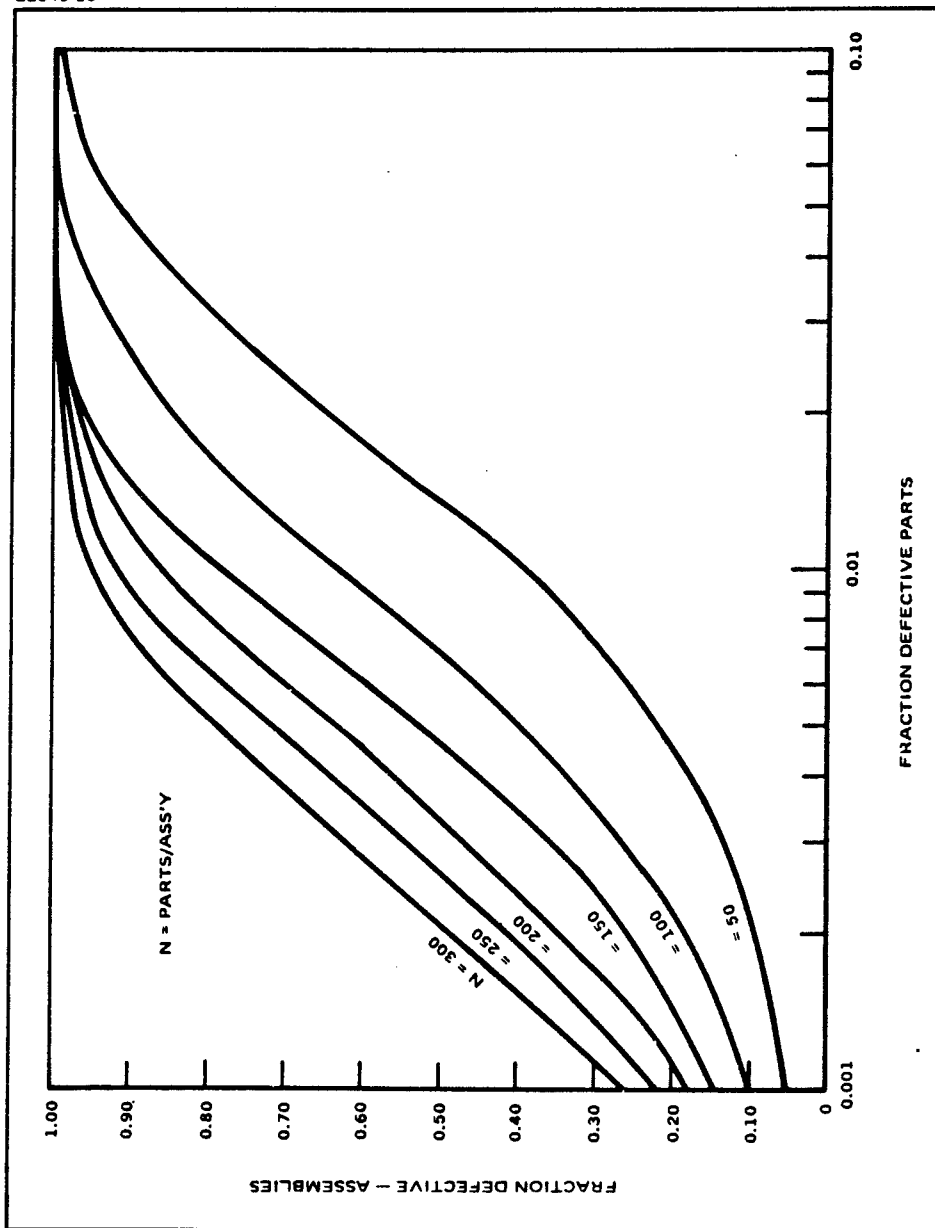
Figure 2.13. Fraction of Defective Assemblies as a Function of Initial Part Fraction Defective

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class S lot contains latent defectives that were precipitated by the increased operating temperature. There can be no precise definition for a latent defective part because the inherent flaw which makes a part defective can range from a minor flaw (which may not be subjected to sufficient stress to cause degradation of the flaw to a hard failure) to a major flaw which requires only a slight stress. One view is that if a part fails during the life of the end item in which it resides it is, by definition, a latent defective part (excluding wearout failures). A device population containing a small fraction of defectives whose flaws range uniformly from minor to major would exhibit a decreasing failure rate until it reached a limiting population fraction defective,

$$p^* = \frac{p}{k(1-p) + p} \qquad (2-5)$$

k = ratio of defective part failure rate to good part failure rate

See Appendix E for a discussion of the limiting fraction defective. References 19 and 21 also discuss the decreasing failure rate characteristic relationship to defectives.

2.2.3.3 <u>Incoming Receiving Inspection and Test</u>. Microelectronic devices procured to the quality requirements of MIL-STD-883 receive 100% final electrical testing by the part manufacturer but, nevertheless, typically about 1 percent, and as much as 4 percent of the parts will not pass a similar electrical test performed at receiving inspection. There are several possible reasons for this, including:

- the seller's and buyer's tests are different

- seller testing errors

- buyer testing errors

- device damage or degradation in handling and transportation

- inspection and sorting errors

To determine what fraction of incoming microcircuit test rejects are actually defective, one manufacturer performed a retest of 525 rejects from a population of 75,981 devices tested. Results indicate that about 50% of the rejects are defective. Results are summarized in Table 2.2. Other studies indicate that without receiving inspection test, 60% of the defectives will be detected at the printed circuit board test, 10% will be detected at higher levels and 30% will not be detected (device applications not manifesting the defect).

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TABLE 2.2 Results of Retesting Incoming Receiving Test
Microcircuit Rejects

| Supplier | # of Lots | Total Qty. | Rejects | | Verified (See Note) | | |
			Total	%	Pass	Fail	% Fail
A	25	8525	100	1.17	62	32	0.38
B	8	8435	22	.26	15	7	0.08
C	17	21826	166	.76	120	46	0.21
D	30	27295	144	.53	35	102	0.37
E	22	9471	96	1.01	31	63	0.67
F	2	429	6	1.40	4	2	0.47
TOTALS	104	75,981	534	0.70	267	258	0.34

NOTE: 525 of the 534 rejects were retested. Percent
failed shown in last column is the percent of
the total quantity tested.

Table 2.3 shows recent experience with receiving inspection test-
ing. The results in Table 2.3 for microcircuits show a slight
increase in percent rejects over the figures in Table 2.2 due
primarily to increased testing at elevated temperature (0.97% vs.
0.70%).

Table 2.3   Recent Receiving Inspection Test Results.

Part Type	Quantity	Average Quality	Rejects	Percent Rejected
Microcircuits	1,419,581	B-1	13,779	0.97
Discrete Semiconductors	343,000	TX	2,008	0.59
Passives	1,296,200	ER-M	8,539	0.66

The implication of the data in tables 2.2 and 2.3 is that
populations of parts, even high quality parts contain defectives
and if incoming receiving test is not performed then the estimate
of the initial fraction defective (PDEF) must be appropriately
adjusted when using the Stress Screening Model.

2.2.4   Manufacturing Process Defects

2.2.4.1 Sources of Defects. Both patent and latent defects are introduced during the fabrication, assembly and test processes of equipment in manufacture. The patent defects pass through the various assembly stages until detected by a test of sufficient thoroughness and all but the most subtle are detected and eliminated prior to shipment.   Patent defects include the following:

- Parts

    - Broken or damaged in handling

    - Wrong part installed

    - Correct part installed incorrectly

    - Part failed due to EOS/ESD

    - Missing part

- Interconnections

    - Incorrect wire termination

    - Open wire due to handling damage

    - Wire short to ground due to misrouting or insulation damage

    - Missing wire

    - Open etch on PWB

    - Open plated-through hole

    - Shorted etch (solder bridge, loose wire strand)

Latent defects cannot be detected until they are transformed to patent defects through stress and time and stress screening is intended to effect this transformation. Latent defects include the following:

- Parts

    - Latent material or process defects

    - Partial damage through EOS/ESD

    - Partial physical damage in handling

- Partial damage during soldering (excessive heat)

- Interconnections

  - Cold solder

  - Inadequate/excessive solder

  - Broken wire strands

  - Insulation damage

  - Loose screw termination (lugs)

  - Improper crimp

  - Unseated connector contact

  - Cracked etch

  - Contact contamination

  - Loose conductive debris

2.2.4.2 Distribution of Defects. The quantity and distribution of manufacturing process defects are dependent on three basic factors;

- Density. Equipment with high part and/or wiring density is more susceptible to induced process defects due to smaller error margins and increased rework difficulty.

- Maturity. New production requires time to identify and correct planning and process problems, train personnel, etc. Maturity rate is dependent on volume and time. Low volume over a long time period has a low maturity rate.

- Process Control. Even with good process controls, low maturity and high density may result in suffi-cient process induced latent defects to justify stress screening. Maturity, with good process con-trol, may eliminate the need for stress screening.

Because each manufacturer's production process is unique in terms of product types, technology, skills, and management and worker attitudes towards process control, there can be no single set of guidelines for process defect elimination with general ap-plicability. Each manufacturer must examine his own conditions to determine the magnitude and nature of process induced defects and decide the appropriate, perhaps cost-effective, course for their elimination.

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Table 2.4 shows a typical distribution of interconnection defects for printed wiring assemblies in early production, showing a 70/30 relationship of solder/etch defects and an overall defect rate of 0.2% defects per part. The table shows the defects that were detected without stress screening at the first opportunity (first assembly test).

Table 2.4 Interconnection Defects Detected at First Test for Early Production PWAs.

PWA Type	Qty.	Average Parts Per Assy.	Average IC's Per Assy.	Defects Detected				Defects Per Assy.	Defects Per Part
				Solder	Etch	Other	Total		
Digital	8,160	85.73	41.33	1,343	638	7	1,988	0.244	0.0028
Analog	3,839	172.2	15.00	450	152	2	604	0.157	0.0009
TOTALS	11,999	113.4	32.91	1,793	790	9	2,592	0.216	0.0019

If it is assumed that the number of PWA interconnection defects per part increases linearly with an increasing percentage of integrated circuits, a reasonable assumption because IC's have more solder connections per part and solder defects dominate, then the data in Table 2.4 for digital and analog assemblies can be used to derive the linear relationship,

$$y = mx + b$$

$$m = \frac{\Delta \text{ in defects/part}}{\Delta \text{ in fraction IC's}}$$

$$= \frac{.0028 - .0009}{.4821 - .0871} = .0048$$

$$y - .0028 = .0048(x - .4821)$$

$$y = .0048 x + .00049$$

where y is the interconnection defects per part and x is the IC fraction. The bounding values are .00049 when the PWA contains no ICs and .0053 when all parts are ICs.

Table 2.5 shows the distribution of part defects over a one-year period for multiple projects in various stages of maturity.

Table 2.5. Part Defects Detected at First Test for Production PWAs.

PWA Type	Qty.	Parts Per Ass'y.	ICs Per Assy.	Defects Detected			Defects Per Assy.	Defects Per Part
				Broken	Defective	Other		
Digital	41,879	108	35	876	14,426	15,532	0.736	0.00682
Analog	39,831	208	10	1,391	17,288	21,152	1.321	0.0048
Totals	81,710	157	23	2,267	31,714	36,684	0.865	0.0055

Using the same methodology as above, the defects per part as a function of the fraction of ICs is,

$$y = .00743x + .00444$$

where y is the part defects per part and x is the IC fraction. A review was made of unit wiring defects covering a one-year period. Results are shown in Table 2.6.

Table 2.6. Results of First Opportunity Wire Testing of Unit Wiring.

Time Period	Qty. Wires Tested	Qty. Wiring Defects	Fraction Defects	Defect Type	
				Cont.	Leak
Jun-Dec 1980	1,175,663	12,183	.0104	8,517	3,666
Jan-July 1981	1,104,211	11,830	.0107	7,584	4,246
Total	2,279,874	24,013	.0105	16,101	7,912

Tables 2.2 through 2.6 represent a relatively small sample of the nature and magnitude of defects to be expected in the manufacturing process and are provided only to allow the SSM user to establish starting points for part and workmanship defect values (PDEF and ADEF) where better information is not available.

2.2.5 Screen Selection and Placement

2.2.5.1 General Industry Consensus on Screen Selection and Placement. Because the origin of environmental stress screening was in AGREE testing, specifically temperature cycling and vibration of avionics "black boxes", the current general industry consensus is that temperature cycling is the most effective

stress screen, followed by random vibration (Ref. 12). The vibration used in AGREE testing done in the past was single frequency and relatively low level (2.2g). In search of more effective screens, the Grumman experiments (Ref. 8) indicated that random vibration was more effective than either swept-sine or single frequency sine vibration. The results of thermal cycling in eliminating parts and workmanship defects (primarily during AGREE testing) were collected and summarized by Martin-Marietta (Ref. 7). The results of the two studies (Ref. 7, 8) were combined into NAVMAT P-9492 (Ref. 9) to serve as a starting-point guideline document.

At the module/assembly level, thermal cycling is believed to be an effective screen for both part and workmanship defects. The rate of change of temperature is thought to be an important parameter, with higher rate of change being more effective. Between 20 and 40 temperature cycles are generally recommended. There are two opposing schools of thought on whether power should be applied or not during the thermal cycling. There also is no general agreement on the effectiveness of vibration at the module/ assembly level. Experiments conducted at Hughes (Ref. 5, 6) indicated that vibration was not effective for printed wiring assemblies (PWAs). Ref. 20 states that PWAs can be effectively screened with broadband random vibration for certain defects.

At higher levels of assembly, i.e., units, groups, thermal cycling and random vibration are effective screens. Less thermal cycles are thought to be necessary at these levels, varying from 4 to 12 cycles. Power on is generally accepted as more effective and an increasing number of practitioners are recommending a performance verification test (PVT) at each temperature extreme. One report states that 80% of all defects detected during stress screening were found during PVT at the low temperature extreme. Several practitioners using random vibration at these levels cite power on and continuous monitoring as essential to detect intermittents. Low level single frequency vibration is widely accepted as being an ineffective screen.

There is some disagreement on the effectiveness of some screens at certain levels of assembly, the source of which may lie in differences in hardware type, construction, part content and degree of design and production maturity. Also, the definitions for the various levels of assembly (subassembly, assembly, module, unit, group, etc.) are not clear descriptions of the items they represent.

2.2.5.2 Technical and Economic Factors to Consider in Selection and Placement of Screens

2.2.5.2.1 Factors to Consider in Assembly Level Screen Selection. Assembly level screens are intended to accomplish two things,

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1) precipitate latent defects which have escaped the part manufacturer's screens and receiving inspection tests, and

2) precipitate workmanship defects introduced in the process of assembly manufacture.

The types of latent part defects expected to be present depends on several factors, including,

1) types of parts comprising the assembly (i.e., microcircuits, discrete semiconductors, passive parts, low population parts, microwave parts, etc.)

2) quality grade of the parts

3) extent to which the parts were previously screened (e.g., receiving inspection tests and screens)

4) testability of the parts (e.g., microprocessor and other LSI devices are difficult to test completely and therefore precipitated defects may go undetected).

Table 2.7 is a summary of the expected types of defects for common part types. The table may be used to assist in the determination of the most effective screen to be selected based on the types of components that comprise the assembly to be screened. If, for example, the assembly consisted mostly of passive components, the table indicates that temperature cycling is the most effective screen, followed closely by burn-in. In this case, the choice of temperature cycling or burn-in should probably be made on a cost basis. Ref. 7 provides detailed breakdowns of typical failure modes and mechanisms for each major part type.

The types of latent workmanship defects expected to be present also depends on several factors, including,

1) assembly type (i.e., PWA or hard wired assembly)

2) assembly complexity (e.g., number of printed wiring layers, PTH density, metallization spacing, number of parts, wiring density, technology type)

3) type of parts used (flat pack vs DIP, hybrids vs discretes)

4) wire termination type (hand solder, wave solder, wire wrap, crimp)

5) design and production maturity.

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Table 2.7. Distribution of Screening Methods for Various Classes of Parts. (Ref. 7)

General Screening Method	Percent Failure Modes Screened				
	Passive Components	Discrete Semiconductors	Monolithic ICs	Hybrid ICs	All Parts
Mechanical Shock	0	2.6	0	1.4	10.0
Particle Impact (PIND)	0	7.9	0	5.1	3.3
Random Vibration	10.4	7.9	15.6	10.9	11.0
Burn-In	63.6	36.8	35.6	43.5	51.9
Temperature Cycling	70.1	31.6	24.4	38.4	48.6
Temperature Soak	7.8	31.6	28.9	30.4	22.9
Temperature Shock	13.0	13.2	0	3.6	2.4
Power Cycling (ON/OFF)	13.0	13.2	0	3.6	7.1
High Pot.	2.6	0	0	0	1.0
Short Term Overload	39.0	0	0	0	14.3

The recommended method for estimating the expected quantity and type of latent assembly workmanship defects is to use experience data on assemblies of similar characteristics produced under similar conditions. Table 2.8 provides a brief listing of typical latent defect categories applicable to the assembly level and the types of screens thought to be effective in precipitating the defects. Table 2.8 may be used to assist in the selection of a screen type based on knowledge of prior workmanship defect types present in similar assemblies. The table indicates that vibration screens are effective for loose contacts, debris, loose hardware and mechanical flaws while thermal screens are not effective. Also, thermal screens are effective for defects relating to improperly installed parts, wire insulation, improper crimp and contamination while vibration screens are not effective. For other types of workmanship defects identified in the table, both thermal and vibration screens are effective.

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Table 2.8. Assembly Level Defect Types Precipitated
by Thermal and Vibration Screens

Defect Type Detected	Thermal Screens	Vibration Screens
Defective part	X	X
Broken part	X	X
Improperly inst. part	X	
Solder connection	X	X
PCB etch	X	X
Loose contact		X
Wire Insulation	X	
Loose wire termination	X	X
Improper crimp	X	
Contamination	X	
Debris		X
Loose hardware		X
Mechanical flaw		X

If a thermal screen (temperature cycling or constant temperature burn-in) is selected for the assembly level, the following screen parameters must be determined:

1) <u>Maximum temperature</u> - The maximum temperature to which the assembly will be exposed should not exceed the lowest of the maximum ratings of all the parts and materials comprising the assembly. Non-operating ratings for parts are higher than the operating ratings.

2) <u>Minimum temperature</u> - The minimum temperature to which the assembly will be exposed should not exceed the highest of the minimum ratings of all the parts and materials comprising the assembly.

NOTE: 1) and 2), above, must be carefully selected to assure that maximum screening effectiveness is achieved. Exceeding the maximum ratings may result in damage to non-defective parts or materials which is contrary to the principle of stress screening. If the operating temperature for a power-on screen cannot be readily determined analytically, a thermal survey of the item to be screened should be performed to determine the maximum and minimum screening temperatures.

3) <u>Temperature rate of change</u> - Screening effectiveness increases with increasing temperature rate of change. The maximum rate of change is dependent on the thermal chamber characteristics and the thermal mass of the items to be screened.

4) <u>Dwell at temperature extremes</u> - During a temperature cycle it is sometimes necessary to maintain the chamber temperature constant once it has reached the maximum (or minimum) temperature, sometimes referred to as dwell. Dwell may be required to allow the item being screened to achieve the chamber temperature. The item thermal lag depends on thermal mass and most PWAs have a low thermal mass. Figure 2.14 shows the part case temperatures tracking the chamber temperature very closely, therefore eliminating the need for dwell. PWAs with more mass may require some dwell or dwell may be required if a PVT or a vibration screen is to be imposed at a temperature extreme.

5) <u>Number of Cycles</u> - Ref. 12 recommends 20 to 40 thermal cycles for the assembly level. If the SSM is used, the number of cycles is determined by the required screening strength. (See Section 4).

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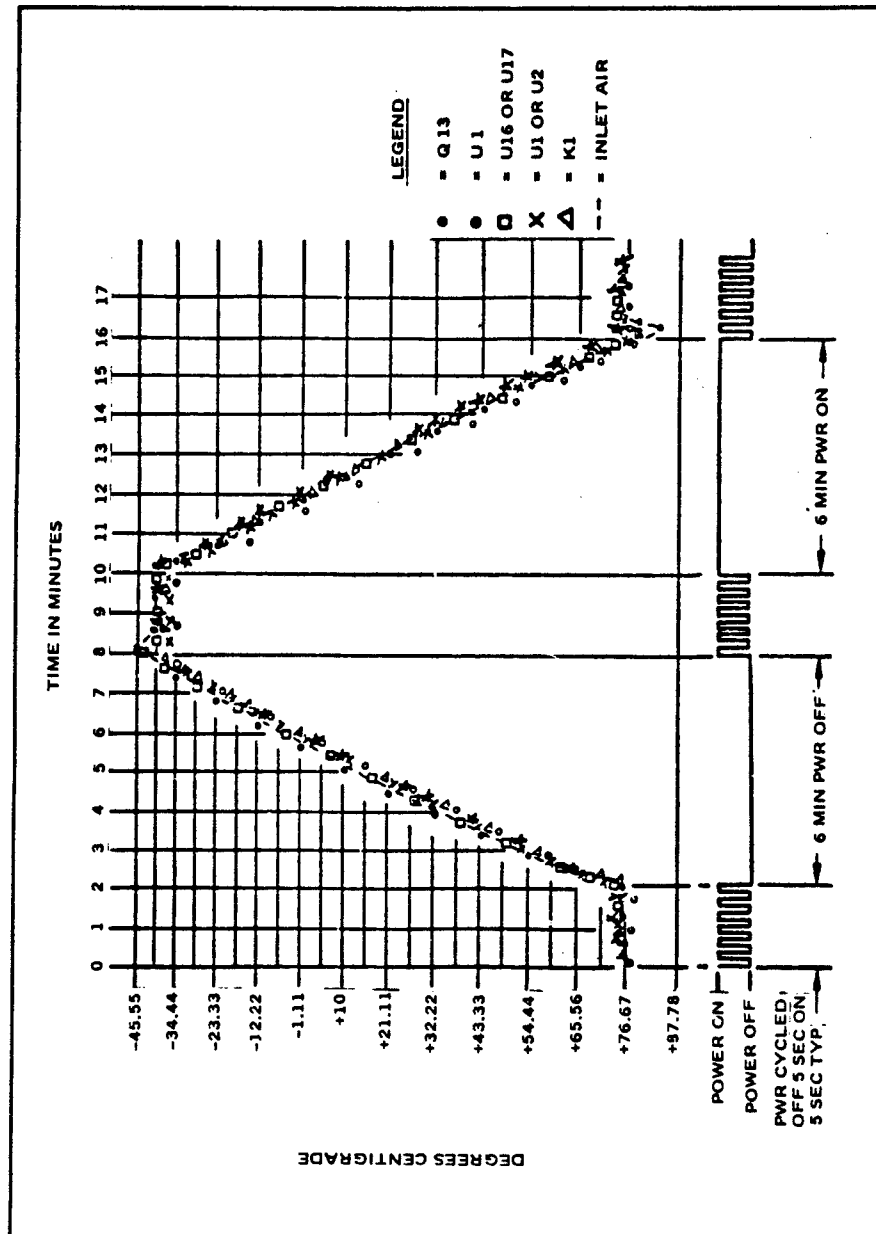
Figure 2.14. Card Thermal Survey. Part temperatures track the chamber temperature very closely. (Ref 5)

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The determination of whether or not to apply power to assemblies being screened and whether or not to perform a functional test during the screen requires consideration of the following factors;

1) <u>Predominant type of defect present</u> - If the predominant type of defect is expected to be a weak interconnection which is transformed to an open circuit by the screen, (cold solder joint, weak wire bond) then a post-screen test will detect the open circuit and power-on is not required.

If, on the other hand, the predominant type of defect is expected to be of an intermittent nature, then power-on with continuous performance monitoring is necessary.

2) <u>Economics</u> - A fixture and associated test equipment to house assemblies, apply power, provide stimuli, and monitor assembly performance can be costly. The tradeoff of fixture and test equipment cost and potential benefits may prove difficult.

If a vibration screen is selected for the assembly level, the type of vibration (i.e., random, swept-sine or fixed-sine) must be selected and the following two parameters must be determined.

1) <u>Vibration level</u> - Ref. 9, 12 and 20 recommend random vibration and suggest a level of 2 .04-.045 g /Hz provided that the assembly can withstand that level without damage. If the assembly dynamic response characteristics to the vibration excitation are not known, a careful vibration survey should be conducted to properly establish the acceleration spectrum and level. Ref. 20 provides a procedure for conducting a vibration survey. Ref 12 suggests use of swept-sine as a second choice if random vibration cannot be performed. Single frequency vibration at the assembly level is considered as ineffective.

2) <u>Vibration duration</u> - Ref. 9 and 12 suggest 10 minutes per each of three axes. The need for multiaxis excitation may vary from one assembly to another and therefore it is desireable to determine fallout per axis during initial screens to allow screen adjustments.

Some other factors to consider in determining the desireability of a PWA vibration screen are the PWA size and stiffness. Larger PWAs will flex more and precipitate such latent defects as cracked etch, cold solder and embedded conductive debris. Smaller PWA, particularly if conformally coated, are stiff and not amenable to vibration screening.

2.2.5.2.2 <u>Factors to Consider in Unit Level Screen Selection</u>. It is the intent of assembly level screens to precipitate latent part escapes and assembly workmanship defects. Unit level screens are then intended to precipitate unit workmanship defects and assembly level escapes. Unit level defect types vary with unit construction but typically include interconnection defects such as,

1) PWA Connector (loose, bent, cracked or contaminated contacts, cracked connector)

2) Backplane Wiring (loose connections; bent pins, damaged wire insulation, debris in wiring)

3) Unit Input/Output Connectors (loose or cracked pins, damaged connector, excessive, inadequate or no solder on wire terminations, inadequate wire stress relief)

4) Intra-Unit Cabling (Improperly assembled coax connectors; damaged insulation).

Units may also contain wired assemblies integral to the unit and not previously screened such as Power Control and BIT Panels, and purchased assemblies such as modular low voltage power supplies. The latent defects associated with those assemblies should be considered in the selection of screens.

Thermal screens are more effective than vibration screens in precipitating latent defective parts. Thermal cycling and vibration screens are both effective in precipitating latent workmanship defects although one screen may be more effective than the other for certain defect types. The unit composition and knowledge of prior screening will dictate the expected types of defects and aid in screen selection.

If a thermal screen is selected, the same process as described for the assembly must be followed. Differences are outlined below.

1) Units have greater thermal mass and therefore the higher temperature rates of change may be more difficult to achieve. A dwell at temperature extremes is probably required.

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2) Power-on screening is usually easily accomplished
    and widely recommended. A functional test (PVT) at
    temperature extremes has been shown in several
    cases to be effective in detecting defects not
    detectable at room ambient temperature. As stated
    previously, one project reported finding 80 percent
    of the total defects during PVT at low temperature.

3) Less temperature cycles appear to be required at
    the unit level. A range of 4 to 12 cycles is
    common.

If a vibration screen is selected, it is very important
that competent engineering personnel evaluate the unit to be
vibrated to determine the appropriate vibration type, level of
excitation and whether or not a vibration survey should be per-
formed. There is some evidence that for large, massive units,
low levels of vibration are effective screens.

2.2.5.3 Pre- and Post-Screen Testing Considerations. If an item
is subjected to an unpowered screen, testing subsequent to the
screen may reveal part or workmanship defects requiring correc-
tion. If the item was not tested prior to entering the screen it
cannot be determined, even if a detailed failure analysis were
performed, if the defects found were precipitated by the screen
or were present in the item before the screen. If all the neces-
sary information relating to the effectiveness of the screen were
known, i.e., the average number of latent defects entering the
screen and the average screening strength in precipitating those
defects, it would not be necessary to know the condition of the
item prior to screening. However, stress screening has not yet
advanced to the point where quantity and type of latent defects
can be accurately predicted and screening strengths calculated
and therefore some degree of experimentation is necessary to
precisely derive reasonable defect rate and screening strength
estimates. Testing before entering a screen establishes a
baseline upon which post-screen testing results can be used to
measure the screening strength. The pre-screen testing should be
done immediately before the screen to eliminate the uncertainty
of latent defect introduction during such processes as cleaning,
conformal coating, handling and storage which may follow the ini-
tial item testing.

Once the screening effectiveness has been established
the value of both pre-screen and post-screen testing has
diminished and it may prove cost effective to perform only post-
screen testing. When major perturbations take place, such as
production line changes, fabrication/assembly process changes,
personnel changes or alterations to the stress screening process,
it may be advisable to reinstitute pre-screen testing until the
process has stabilized.

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For long term production programs, the normal learning curves result in process improvements and the quantity and distribution of latent defects is expected to change accordingly. There will be a predominance of workmanship and manufacturing process related defects in early production and component related defects dominate mature production. Stress screens have a different degree of effectiveness for different defect types and therefore screens that may have been effective during early productions should be periodically re-evaluated to assure their continued effectiveness.

2.2.6 Planning a Stress Screening Program for the Development Phase

2.2.6.1 Characteristics of a Development Phase.

A development phase may consist of a very advanced development in which a technical concept is being validated and the hardware used in the validation bears little resemblance to the production hardware. At the other extreme, a development phase may be late engineering development and the hardware is intended to be production prototype. Most often, a development phase will be somewhere in between the above extremes. When a high volume production program follows development, there may be a productization or production engineering phase (PEP) in which major hardware design changes are made to enhance producibility. Also, suppliers/vendors used in development may change for production. In short, if a stress screening program is considered for a development phase primarily for the purpose of gaining information for planning the production phase stress screening program, consider the amount of hardware changes expected and the relevancy of development phase screening results.

2.2.6.2 Pro's and Con's of Stress Screening in a Development Phase.

As mentioned in the previous paragraph, one good reason for stress screening development hardware is to gain information about the nature and magnitude of latent defects in complex hardware items. This knowledge is valuable in planning how to cope with the problem in production. If a reliability demonstration test is required during development when a large number of latent defects are present in the hardware, a stress screening program may be the best way to reduce the number of defects and give a high probability of passing the test. On the other hand, the benefits to be derived from stress screening in development may not be worth the cost of implementation. During development there are many design related problems. About one-half of all failures are design or engineering-related. Also, there are many manufacturing related problems but may have no relationship to production problems because the development hardware may have been fabricated in an engineering model shop, from engineering sketches, with soft tooling, etc. Manufacturing-related problems are about 30% of the total. Only one of five confirmed failures in development is component related and many of these failures

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are a result of low quality part substitution for long-lead hi-rel parts. The hectic integration and checkout activity and the lack of disciplined electrostatic discharge/ electrical overstress (ESD/EOS) controls results in a predominance of electrical overstress failures. The combination of the above (numerous design and fabrication problems and electrical overstress failures) may tend to overshadow the latent defects during development and make stress screening of questionable value.

2.2.6.3 Relationship of Stress Screening and Reliability Growth. Reliability growth is achieved through the process of eliminating correctable defects. All design problems and some workmanship and component problems are correctable. When the proper corrective action is taken on correctable problems, the resultant hardware failures will not recur and the hardware manifests an improved MTBF, called reliability growth. Reliability growth in development can be enhanced through stress screening by precipitation of latent defects (early in the growth process). The latent defects eliminated through stress screening will not occur as random failures during later stages of the growth process.

2.2.7 Planning a Stress Screening Program for the Production Phase

2.2.7.1 Using Development Phase Results to Guide Production Phase Planning. As was pointed out in the preceding paragraph, determination of the effectiveness of stress screening in a development phase is difficult because latent defect failures are masked by a predominance of other failure types. Therefore, it is probably unrealistic to expect that accurate screening parameters can be derived for production phase screening from development phase screening results. However, valuable information can be gathered for the development phase which can be used to guide the planning for production. The most valuable information is:

1) Identification of hardware items (parts, assemblies, units, equipments, ...) which exhibited known or potential latent defects.

2) Identification of suppliers/vendors whose products show potential latent defect problems.

3) Assessment of the effectiveness of corrective actions taken to eliminate latent defects.

4) Known defective items, eliminated from production, the substitutes for which may require qualification testing and stress screening to assure the absence of latent defects.

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5) The cost and schedule estimating factors for stress screening during development, and their applicability to production.

2.2.7.2 Initial Production Phase Start-up Problems. Typical start-up problems to be expected include the following:

1) Production personnel unfamiliarity with stress screening requirements.

2) Facilities and test equipment unavailable for stress screening.

3) Production planning errors result in incorrect screening and stress screening omissions.

4) Required stress screening data is not recorded or recorded incorrectly.

5) Schedule priorities preempt stress screening priorities.

6) Loss of failed parts preclude a sufficiently thorough analysis.

7) Excessive lag time from screened item failure to repair, making timely analysis of screening results difficult.

8) Factory test equipment breakdowns.

It is optimistic to state that all of the above problems can be avoided through careful planning but it is nevertheless correct to state that careful planning is the only hope to minimize them. The planning requires that all organizational activities in manufacturing involved in the stress screening be made aware of their roles and responsibilities at a time early enough that they are able to plan their functions and acquire the necessary resources to execute their responsibilities.

2.2.7.3 Planning for Subcontractor/Supplier Stress Screening. If it is determined that certain subcontractor/supplier items will require stress screening, the first decision to be made is whether the items are to be screened at the subcontractor's/ supplier's facility or screened by the prime contractor, either at receiving inspection/test or at a higher level of assembly. There are several benefits to screening at the subcontractor's/ supplier's facility,

1) Subcontractor/supplier concern for yield at screening, translated to profits, may force process improvements to minimize latent defects.

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2) Screening at receiving inspection/test requires return of defectives to the subcontractor/supplier, and may result in shortages and concomitant schedule slips.

3) Special stress screening facilities and test equipment do not have to be acquired/supported/ operated by the prime contractor.

Few benefits of stress screening of a subcontractor/supplier item by the prime contractor can be identified.

To assure that the subcontractor/supplier is able to perform the required stress screening, it is important that the requirements are made known at an early enough time to allow him to acquire the necessary capability, or alternatively, arrange for an external laboratory to plan to perform to the requirements. This early planning is required to assure that the subcontractor/supplier is contractually required to perform the specified stress screening and record and report the results.

2.3 Contractual Considerations in Stress Screening

2.3.1 General Considerations. There are two views on stress screening that relate to contractual considerations. One view is that a stress screen or stress screening program is similar to a formal qualification or acceptance test, requiring contractual terms, formal test plans, procedures and reports. Contractually required failure free periods are appended to screens in this view and strong considerations are being given to coupling incentives to screening results. The second view is that stress screening is just another step in the production process to be applied selectively and temporarily as an effective method of eliminating latent defects and achieving cost savings and/or schedule improvement in the process.

It is not surprising that the first view is widely held by consumers while the second view is more common among producers. Consumers are primarily concerned with elimination of latent defects prior to acceptance to avoid the high cost of field repairs and to improve operational readiness. The producers primary concern is to optimize the production process by eliminating latent defects at the lowest possible assembly level, thereby effecting cost savings and avoiding schedule delays. If the producers process does not satisfy the consumers objectives, contractual terms must be executed to enhance the process.

2.3.2 Contractual Flexibility to Permit Stress Screening Program Adaptability. In early production, a number of unknowns preclude adoption of optimum stress screening. Some of the more significant unknowns are:

1)   residual design deficiencies

2)   manufacturing planning errors

3)   worker training

4)   new suppliers

5)   latent defects in new part lots

6)   new process capability

7)   stress screening effectiveness

8)   testability (for defect detection)

The stress screening program, even if carefully planned, may produce unexpected results which should be addressed though modification of the screens. The principle of adaptive screening is to adjust the screens on the basis of observed screening results so that the screens are always most cost-effective. Contract terms should be flexible enough to permit a modification of screens or screen parameters when such modification is shown to be beneficial to the consumer.

In long term production the quantity and distribution of latent defects changes with time and therefore contract terms should contain provisions for periodically reassessing the individual screens and the overall screening program. The overriding criterion for change should be the most cost-effective achievement of consumer objectives while remaining consistent with the optimum production process.

2.3.3   Failure Free Cycles. While currently used in some stress screening programs and apparently gaining in popularity, all that can be meaningfully said about failure free cycles is that some small measure of confidence is gained that the product is not totally devoid of merit. End-items being screened, say units, typically have inherent MTBFs of 500-5000 hours. Failure-free periods may range from 1-10 percent of the inherent MTBFs. Figure 2.15 shows the probability of passing a failure free period in 1, 2, or 3 tries as a function of the True MTBF-to-Inherent MTBF ratio. The figure clearly shows that items with low ratios (indicating many remaining latent defects) have a good chance of passing a failure free period. For example, an item which has only 1/10 of its specified MTBF has a 75 percent chance of passing a failure free period in 3 or less attempts.

2.3.4   Incentives Associated with Stress Screening. Many commercial products exhibit extremely good "field" reliability without having been contractually required to perform stress screening. For commercial producers, the producers objective

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stated in 2.3.1 is modified to include in the process optimization the least repair cost during the warranty period. Significant losses that might accrue through excess field repairs resulting from latent defect escapes must be avoided. Some commercial manufacturers employ forms of stress screening to precipitate latent defects while others concentrate more on process control and worker training and motivation.
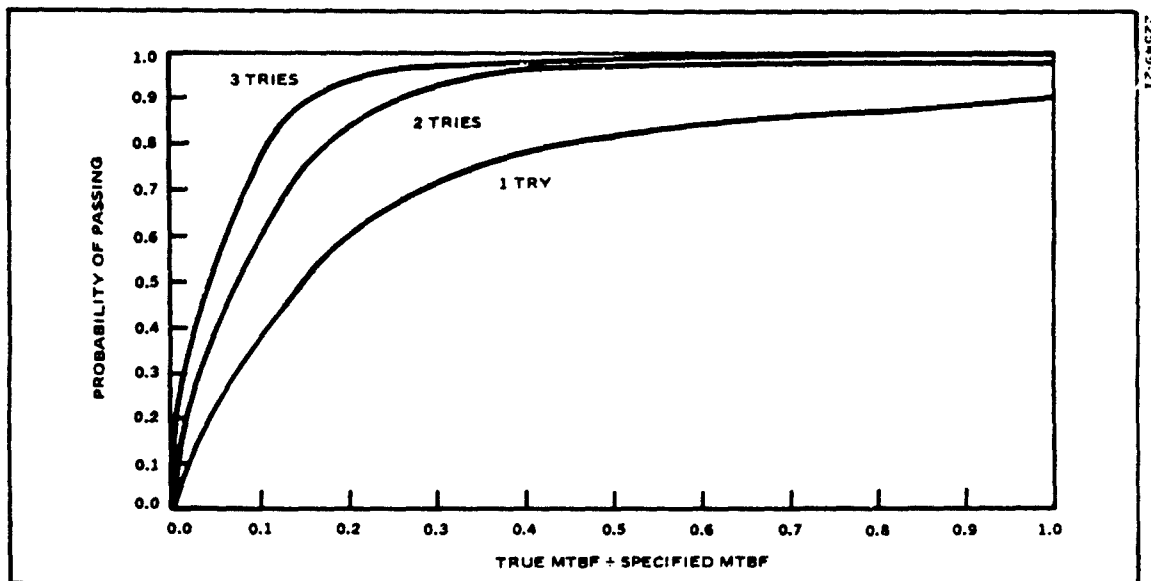
Figure 2.15. Probability of Passing a Failure Free Period of Duration 0.1 x Specified MTBF

The producers concern for potential losses (which may be stronger than his concern for potential gains) resulting from excessive maintenance in early fielding may be the necessary motivation for delivery of defect-free products, be it through stress screening or other means. The further pursuit of warranties, RIW contracts, guaranteed reliability, full contractor maintenance, etc., seems strongly justified.

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3. DATA COLLECTION, ANALYSIS AND REPORTING

3.1 <u>Data Collection</u>. A stress screening program conducted during a development or early production phase will be concurrent with many other activities such as reliability improvements through design changes, quality improvements through manufacturing process changes, and supplier corrective action programs. The simultaneous activities will, collectively, result in a product improvement the credit for which may be difficult to assign. To gain assurance that the stress screening measures taken to improve reliability (or just to precipitate latent defects) are cost effective, it is important that the proper data be gathered and analyzed. This is particularly true if an adaptive stress screening program, where screening results are compared with pre-determined criteria, is employed. Data other than screening results is important for use in conjunction with the analysis of screening data, and includes,

- Qualification test results

- Supplier acceptance test results

- Part receiving inspection/test results

- Failure history

- Item inspection and test records.

3.1.1 <u>Data Collection Requirements for Stress Screening Program</u>. The determination of the specific data elements to be collected during a stress screening program can be made on the basis of the program objectives. Simple stress screening programs require little data other than the number of defects precipitated by the screen(s). When adaptive stress screening is conducted, considerably more data is required. The principle of adaptive stress screening is the change of the stress screens applied, on the basis of observed results, to achieve the most cost-effective elimination of latent defects. Therefore, adaptive stress screening requires data related to the effectiveness of the applied screens and the actual costs incurred.

The effectiveness of a stress screen can be measured by its screening strength, i.e., the probability that, given that a latent defect is present, the stress screen will transform the latent defect into a patent, or hard, defect and that defect will be detected by the screen. However, only the total number of defects found as a result of the screen is observable, which is insufficient to determine screening strength. The expected number of latent defects , F, precipitated by a screen is,

$$F = D \ \times \ \text{Screening Strength}$$

or the product of the screening strength and the number of latent defects entering the screen. The true values of D and screening strength are unknown. Further, the observed number of defects may not be totally comprised of precipitated latent defects but may include patent defects which have escaped prior screens. Another complicating, yet important, factor is that screening strength is a combination of the ability of the screen to raise a latent defect to a detectable level and the ability of the screen to detect it. The probability that a patent defect will be detected by the test to which the item being screened is subjected is called probability of detection, Pd, or detection efficiency. The value for Pd varies with the equipment complexity and the thoroughness of the test. Modern equipment comprised of microprocessors, large memory devices and other LSI devices may contain patent defects so subtle that only the most thorough of tests will detect them. The screening strength equations in the SSM are derived from screening experience with less complex equipment and therefore the screening strengths can be expected to be somewhat reduced for modern, complex equipments. Because there are many unknowns (e.g., initial part fraction defective, number of manufacturing defects introduced at each stage of assembly, the effectiveness of screens to precipitate the various types of latent defects, and the ability of equipment tests to detect precipitated flaws) in the art of stress screening, it is important to collect as much meaningful data as possible during the screening process so that analyses of the data may be helpful in developing better estimates for the unknowns. Some of the essential data elements are,

1) Defect data: Number of defects observed, time-to-failure or cycle-of-failure, failure classification (part, design, workmanship) and failure cause (to assist in discriminating between latent and patent defects and in determining corrective actions).

2) Screen Parameter Data: Recording of chamber temperature and the temperature of the item being screened during temperature cycling and constant temperature screens are important, at least initially, to ascertain that the chosen screen is actually being applied. For vibration screens, the vibration input and test item response are needed.

3) Cost data: Data related to the cost of conducting the screens and the cost of repairs due to precipitated latent defects, including, chamber/facility usage hours; labor hours; labor classifications.

Ref. 17 provides an extensive discussion of data collection during production with emphasis on the aspects of environmental stress screening.

3.1.2 The Role of Failure Analysis in Determining Screening Effectiveness.
The effectiveness of a screen can be measured by the number of latent defects that are precipitated by the screen (fallout) and the number of latent defects precipitated at subsequent screens. The fallout at one level of screening is insufficient as a measure of effectiveness because the number of latent defects entering the screen is unknown. A comparison of fallout at successive screens provides a basis for estimating the initial quantity of latent defects and, therefore, effectiveness.

The total number of failures occurring during a screen (or detected at a post-screen test) are not all precipitated latent defects. Some are patent defect escapes from lower level testing. Examples of such patent defects would be manufacturing errors such as missing components, improperly installed components and wiring errors which were not detected at prior test/inspection levels. A failure analysis of the "fallout" data is necessary to segregate the manufacturing errors from the true part and workmanship defects and to further segregate the screen-induced defects (precipitated latents) from the patent escapes. In some cases a detailed failure analysis, including part autopsy, may be required to distinguish latents from patents and should be done if economically justifiable. Analysis in conjunction with test thoroughness investigation will help in establishing the assembly level at which the defect was introduced.

3.1.3 Analysis of Stress Screening Data.

3.1.3.1 Data Analysis for Monitoring the Stress Screening Program.
Since a stress screening program is established for the purpose of precipitating latent defects and thereby improving early field reliability and, perhaps, saving production costs in the process, it is highly desireable, if not absolutely necessary, to gather and analyze stress screening data to determine if latent defects are being precipitated at the expected rate. An extensive review of stress screening literature conducted during the course of this study confirms that data collection and analysis is the most neglected aspect of stress screening. Inasmuch as it is widely recognized that estimating the number of latent defects present is, at best, difficult and there is considerable uncertainty about the ability of various stress screens to precipitate those defects, the importance of carefully examining the initial screening results cannot be over-emphasized.

The SSM can be used to assist in the analysis of data. The model calculates the expected fallout F, of any screen i by,

$$F = (D_i + ADEF_i) \cdot SS_i \cdot$$

where D_i = number of latent defects entering the screen at the ith assembly level

$ADEF_i$ = number of latent workmanship defects introduced at the ith assembly level

SS_i = screening strength of the ith screen

The SSM also calculates a probability interval, i.e., upper and lower bounds on the expected fallout. A .99 probability interval is computed by the model unless a different interval is requested by the user. See Appendix B for a theoretical discussion of the probability interval calculation. If the actual number of defects precipitated by the screen is within the desired probability interval, it can be concluded that the stress screening is proceeding as ex' ected. If, on the other hand, the actual fallout lies outside the interval, an analysis of the data is indicated. The fallout data may either exceed the upper bound or fall short of the lower bound. When the upper bound is exceeded, four possibilities exist:

1) the screening strength may be greater than calculated by the model,

2) the estimate of the initial part fraction (PDEF) may be low,

3) the estimates of induced assembly defects (ADEF) may be low, or

4) the fallout may include patent defects that escaped detection in prior process steps.

To be able to determine which of the four possibilities is most likely, a thorough analysis of the actual fallout data is required. If the fallout data is predominantly part defects as compared to assembly defects, possibility 2) seems likely. Conversely, if assembly defects predominate, possibility 3) seems more likely. If the part and assembly defects are in the expected proportion but high, possibilities 1) or 4) may be selected. the same type of reasoning can be applied when the actual fallout falls short of the lower bound.

3.1.3.2 **Data Analysis for Evaluating the Stress Screening Program.** Stress screening programs may be costly to implement, and are justified by the resulting subsequent savings. Caution should be exercised to avoid commiting to a fixed stress screening regimen for a long production run on the basis of the initial cost-effectiveness analysis and early screening results. Time may bring about changes that impact on the cost-effectiveness of screening, such as changes in the magnitude and distribution of latent defects, cost of conducting screens, cost of repairs, and improved estimates of screening strengths. The SSM, with its optimization feature, can be used to determine a new set of

screens or revised screening parameters that are more cost effective. Refer to the examples in Section 4.0 to see how the SSM can be used for this purpose.

The data analyses required for cost-effectiveness evaluation are,

1) revised estimates of part and assembly defects

2) adjusted equipment-related parameters of screening equations (using the adaptive feature),

3) revised estimates of screening cost (at this point, the fixed cost is sunk cost and may be excluded from the analysis),

4) revised estimates of repair costs at each level of assembly.

Data analysis during a production screening program serves another vital purpose besides determining the cost-effectiveness of the screening. Proper analysis of fallout data aids in identification of "correctable" defects which, if corrective action is taken to eliminate their source/cause, will not recur in subsequent production items. Elimination of correctable defects results in reduced fallout and lower production costs, which may indicate a need to alter the screens. Sufficient elimination of correctable defects may result in no further need for screening.

3.1.3.3 <u>Using the Chance Defective Exponential (CDE) Model to Evaluate Stress Screening Results.</u> Ref. 11 provides a method of temperature cycle screening data analysis which gives estimates of screening strength, initial fraction defective and constant failure rate. Figure 3.1 is an extract from Ref. 11 showing a sample histogram plot of unit average failure rate per temperature cycle. The per cycle data is used to develop maximum likelihood estimates (MLE), for parameters a_0, a_1 and a_2 using a constrained optimization computer program developed by McDonnell Aircraft Company.

The parameters of the CDE model (a_0, a_1, and a_2) are directly related to key unknowns (initial fraction defective, screening strength, latent defective fallout rate) vital to planning, monitoring and evaluating stress screening programs. Therefore, the CDE model is considered to have potential as an analytical tool for evaluating a screening program. The parameters are;

a_0 = $N\lambda$ g, where N is the total number of parts in the item(s) subjected to stress screening

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and λg is the failure rate of good parts, i.e., parts without latent defects. a_0 then provides a measure of failure rate of the good parts subjected to the screen.

a_1 = Np, where p is the fraction of the part population that is latent defective. a_1 is then a measure of the total number of latent defective parts entering the screen.

a_2 = $k \lambda g$, where k is the ratio of the failure rate of latent defective parts to the good parts. a_2 is then a measure of the rate at which latent defectives precipitate into patent defects under the conditions of the stress screen, and therefore is a measure of the screening strength.

Obtaining estimates of a_0, a_1, and a_2, from actual screening fallout data allows the estimation of the vital screening program parameters. Since $a_0 = N\lambda g$, an estimate of a_0 provides an estimate of λg because N is known. Similarly, since a_1, = Np, an estimate of a_1 provides an estimate of p (fraction defective). Finally, an estimate of a_2 provides an estimate of k since an estimate for λg is derived from a_0.
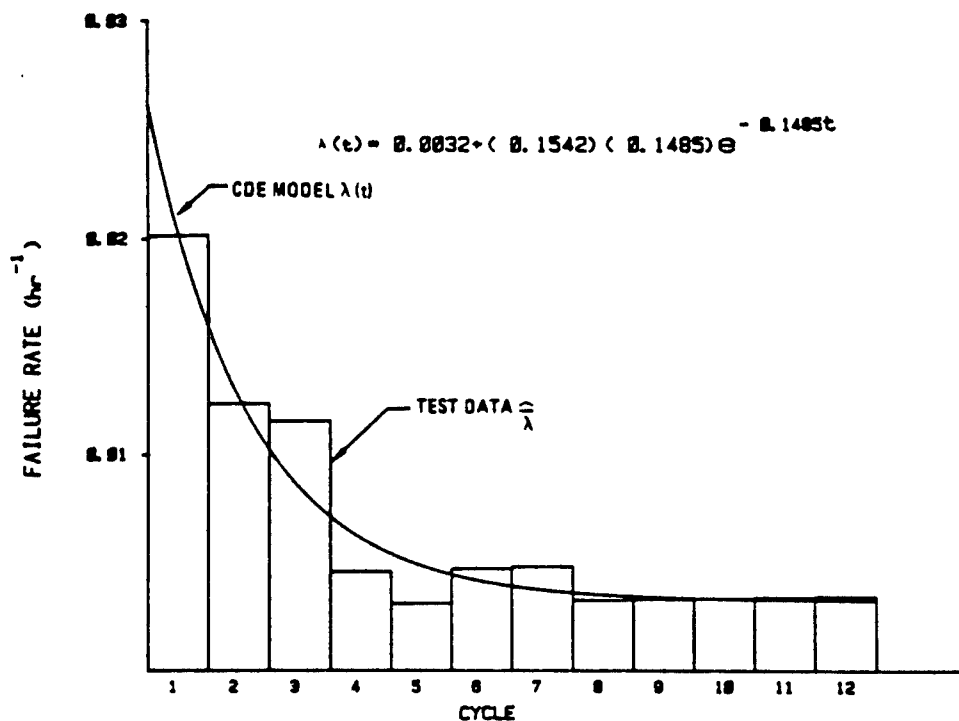
Figure 3.1. Temperature Cycling Data Fitted to the Chance Defective Exponential Model (Ref 11)

3.2 Reporting of Results

3.2.1 Purpose of Reporting Results. Timely reporting of the results of stress screening to cognizant management personnel is important to provide the necessary visibility regarding progress toward achieving the stress screening program objectives (achievement of a reliability requirement, manufacturing cost savings, field maintenance cost savings, or combinations thereof). Timely and accurate reporting allows decisions to be made regarding changes to the stress screening program for improved effectiveness or enhanced cost savings. Reporting also serves as a forcing function on the important tasks of stress screening data collection and analysis.

3.2.2 Reporting Methods. There are three basic methods of reporting results to management,

1) Periodic verbal reporting with visual aids,

2) Periodic written reports, ranging from informal, internal correspondence to formal, contractually required reports, and

3) Computer generated reports, either in hard copy form or image form on graphics terminals.

The verbal reporting method is most common and has the advantage of facilitating a question/answer exchange for report clarification. The disadvantage of this method is that it is more time consuming than the preparation of an informal report but this may be justified by the more effective information transfer. The verbal reporting is most desireable at the beginning of the stress screening program when there is the highest degree of uncertainty and highest management interest. As the stress screening program initial adjustments are effected and screening results are consistent with expectations, reporting should transfer to informal internal correspondence (e.g., weekly reports) and, perhaps, a formal monthly or bi-monthly report to the customer. The third reporting method is most efficient and is applicable during any phase of the stress screening program.

3.2.3 Report Content. The content of the reports should be tailored to the specific objectives of the stress screening program. If the primary objective is to achieve a reliability requirement, a reliability projection based on screening results is most appropriate. Cost data is always an appropriate reporting element and may include planned versus actual screening costs, manufacturing costs, or field maintenance costs. Below are some other typical reporting elements:

● Assemblies screened to date (total number of)

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- Assemblies passed screen without failure
- Assembly workmanship defects expected
- Upper and Lower Bounds
- Assemblies with 1, 2, ... defects
- Parts on assemblies screened
- Part defects detected
- Part defects expected
- Upper and Lower Bounds
- Assembly workmanship defects detected
- (Repeat of above for units, systems)
- Assembly yield
- Assembly repair costs
- Unit repair costs
- System repair costs
- Estimated part fraction defective
- Correctable failures
- Corrective action status

4. THE STRESS SCREENING MODEL (SSM)

4.1. Description of the Model. The SSM is a modified version of the Screening and Debugging Optimization (SDO) Model (Ref. 1), the changes to which are described in paragraph 1.2 of this report. A simplified flow diagram depicting the stress screening process is shown in Figure 4.1 below. The figure shows (INCOMING) the total number of parts and number of defective parts entering a screening process. At level 1, some workmanship defects (ADEF) are introduced and the screen at level 1 has some screening strength (SS) which acts on the incoming part and workmanship defects to produce an expected fallout of part defects (PRT) and workmanship defects (WKM). The total number of defects entering a level minus the fallout is the number of residual defects passed on to the next level (DEF PASSED). After passing through the three screening levels, there are still some defective parts remaining (DEF P REM) and some workmanship defects remaining (DEF W REM), resulting in some instantaneous outgoing MTBF value. At each level there is an expected fallout and because of random variations in defect quantities and screening strengths, a probability interval with upper and lower bounds (UPPR BND, LOWR BND) is computed for monitoring purposes.
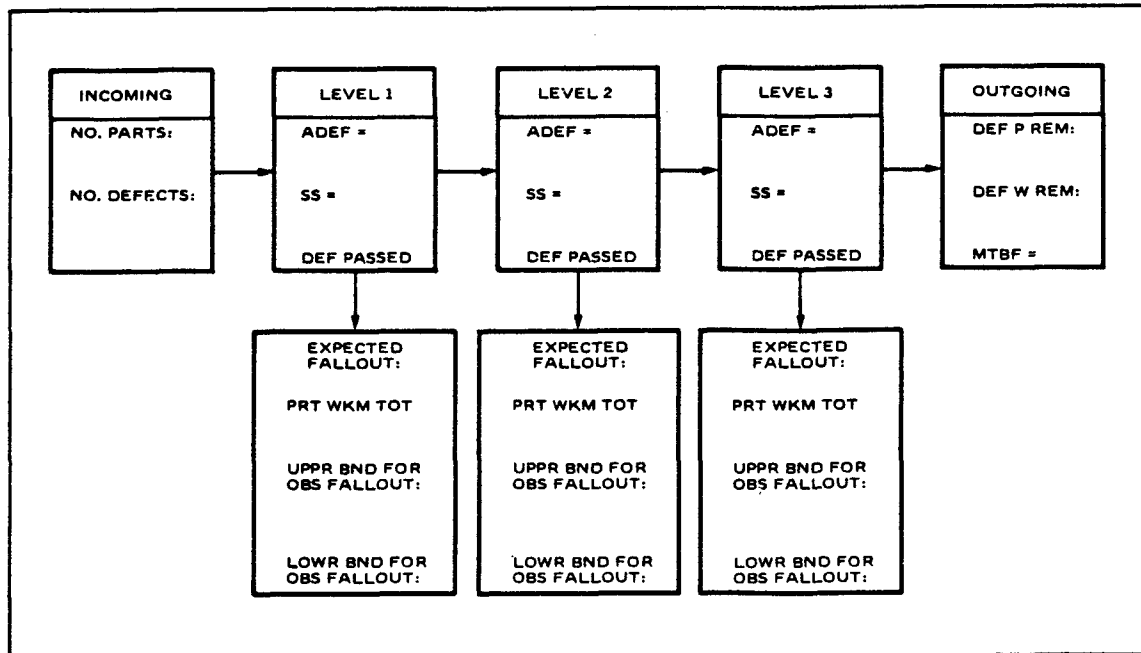
Figure 4.1. Stress Screening Model Representation of the Production Flow Process

4.1.1 Model Options. The SSM has three options, as follows:

1) **MTBF Option (Option A).** The SSM provides an optimum set of stress screens to precipitate the required number of latent defects to achieve a desired instantaneous MTBF at the termination of the screening.

2) **Cost Option (Option B).** The SSM provides a set of screens to precipitate the maximum number of latent defects for a fixed cost.

3) **Trade-off Option (Option C).** The SSM provides the capability to evaluate existing screens and to identify equivalent screens for trade-off purposes.

4.1.2 The MTBF Option. In this option, the user must input the desired MTBF of the item(s) to be screened and must also input the total number of parts comprising the item(s) and the expected number of latent defects. User input requirements and model default values are described in paragraph 1.5 below. The MTBF value must be a series MTBF (i.e., the sum of the failure rate of all parts subjected to the stress screen). The model may be used for a single system or for multiple systems. The total number of parts and MTBF must be adjusted accordingly. The model assumes that the MTBF is comprised of the reliability characteristics of good parts, with a failure rate λg, and latent defective parts, with a failure rate $k\lambda g$, good connections with a failure rate λc and defective connections with a failure rate $k\lambda c$, as follows:

$$MTBF = [(N-D)\lambda_g + Dk_1\lambda_g \ (M-C)\lambda_c + Ck_2\lambda_c]^{-1} \qquad (4-1)$$

where N = Total number of parts

        D = Number of latent defective parts

        k_1 = Defective part failure rate multiplier

        M = Total number of connections

        C = Number of latent workmanship (connections) defects

        k_2 = Defective connection failure rate multiplier

The SSM uses equation (4-1) to determine the optimum set of screens that result in an MTBF equal to or greater than the desired MTBF.

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4.1.3   The Cost Option. In this option, the user must input a fixed cost amount for which the SSM will identify a set of stress screens removing the largest number of defects.

4.1.4   The Trade-off Option. In those cases where a stress screening program has already been defined, the user may want to compare the overall cost and composite screening strength of the pre-defined screens with the optimum screens selected by the SSM. In this option, the user inputs the stress screen types and screen parameters and the SSM will compute the total cost and composite screening strength. This option also allows the determination of equivalent screens, i.e., if a given screen has some undesirable characteristics, an alternate screen of equivalent strength can be determined.

4.1.5   Description of User Inputs to SSM and Model Defaults. Table 4.1 lists the SSM data requirements and default values. The model prompts the user for the necessary data for the option chosen.

A ceiling cost (CREQD) for the screening program is necessary only for Option B. The model optimizes removal of the largest number of latent defects while staying under the ceiling cost.

The total number of parts, the failure rate of good parts, the failure rate of good connections, and the fraction of parts which are defective are necessary for all options. Defaults are available for all but the number of parts. Expected latent defects are discussed in Paragraph 4.1.6 below.

The screen sequence is entered by use of the screen numbers as indicated below:

Screen No.	Screen
1	Constant Temperature
2	Cycled Temperature
3	Random Vibration
4	Sine Sweep Vibration
5	Sine Fixed Vibration

Model defaults are:

Level 1   Cycled Temperature (1)

Level 2   Random Vibration   (3)

Level 3   Constant Temperature (2)

TABLE 4-1. STRESS SCREENING MODEL USER INPUT DATA REQUIREMENTS
&
MODEL INPUT VALUES

Data Requirements	All	Option A	B	C	Program Symbol	Input Format	Units	Model Default Value
1. Desired Series MTBF	X				FRP	Integer	Hours	None,"(User Input Req.)
2. Cost Budget			X		CREQD	Real	Dollars	None
3. Total Part Population	X				NPARTS	Integer		None
4. Failure rate of good parts	X				XLAMP1	Real	Failures/hour	$1. \times 10^{-7}$
5. Failure Rate of Good Connections	X				XLAMO1	Real	Failures/hour	1×10^{-10}
6. Fraction of Parts Latent Defective	X				PDEF	Real	Fraction of total parts	.001
7. Screen Sequence	X				ISCR	Integer		ISCR(1)=2 ISCR(2)=3 ISCR(3)=1
8. Screen Parameters a) Constant Temp	*							
i) Temperature	X				AMAX 11	Real	°C	70° C
ii) Time	X				AMAX 12	Real	Hours	48 hours

* If a particular screen is used.

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TABLE 4-1. STRESS SCREENING MODEL USER INPUT DATA REQUIREMENTS
&
MODEL INPUT VALUES

Data Requirements	All	Option A	Option B	Option C	Program Symbol	Input Format	Units	Model Default Value
b) Temp. Cycling								
i) Upper Temp.	X				AMAX 12	Real	°C	71° C
ii) Lower Temp.	X				AMAX 22	Real	°C	-54° C
iii) Rate of Change	X				AMAX 23	Real	°C/Min.	10° C/Min.
iv) No. of cycles	X				AMAX 24	Real	No. Cycles	20
C) Random Vibration								
i) g-level		X			AMAX 31	Real	g's	6 g
ii) Time		X			AMAX 32	Real	Minutes	10 Min.
d) Sine-Sweep Vib								
i) g-level			X		AMAX 41	Real	g's	6 g
ii) Time			X		AMAX 42	Real	Minutes	10 Min.
e) Sine-Fixed Vib								
i) g-level				X	AMAX 51	Real	g's	6 g
ii) Time				X	AMAX 52	Real	Minutes	10 Min.
9. Fixed Test Cost	X				A1	Real	Dollars	$0.00
10. Variable Test Cost	X				B1	Real	Dollars/hr	$30/hour
11. Repair Cost	X				B3	Real	Dollars	Level 1 = $45, Level 2 = $300, Level 3 = $990
12. Assembly Defects	X				ADEF	Real	Fraction of total	ADEF(1)= .002, ADEF(2)= .001, ADEP(3)= .0005

** If using to analyze fallout data.

TABLE 4-1. STRESS SCREENING MODEL USER INPUT DATA REQUIREMENTS

MODEL INPUT VALUES

Data Requirements	All	Option A	B	C	Program Symbol	Input Format	Units	Model Default Value
13. Number of Dropouts at each level **	X				AFALL or if analyzing parts & workmanship separately) APFALL AWFALL	Integer		None
14. Probability for probability interval.		X		X	PER	REal		0.99
15. No. of Faults Detected (Fallout)	X				NMF	REal		None
16. Times to Failure	X				T	REal		None

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The SSM prompts the user for the test parameters in the chosen test. Table 4.2 identifies the parameters for each test.

TABLE 4.2   TEST PARAMETER CROSS REFERENCE

	TEST PARAMETER			
	No. 1	No. 2	No. 3	No. 4
1. Constant Temperature	Temp. Extreme (^{o}C)	Test Time (Hrs.)	-	-
2. Cycled Temperature	Upper Temp. (^{o}C)	Lower Temp. (^{o}C)	Temp. Rate Change (^{o}C/Min.)	Number Cycles
3. Random Vibration	Vibration G-level (g's)	Test Time (Min)	-	-
4. Sine Sweep	Vibration G-level (g's)	Test Time (Min)	-	-
5. Sine Fixed Vibration	Vibration G-level (g's)	Test Time (Min)	-	-

In Options A and B (MTBF and Cost) the user chooses all but the last parameter for all desired screens. An upper limit for a range is chosen for the final parameter. The model examines a grid of 5 points on each range. It then finds the optimal set of time and/or cycle parameters.

In Option C (Tradeoff) all parameters are fixed at user inputs. The model computes test strengths, costs, fallouts, etc.

When the screen equivalency capability is utilized only two screens are considered. All parameters in the given screen are fixed by the user. All but one selected parameter are fixed in the desired screen. The model finds the value for the

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variable parameter. This value yields a strength for the desired test equal to the strength for the given test. If this value cannot be achieved, a message is written and the user may enter new parameters.

The basic cost equation for each test is of a linear nature where:

test cost = fixed cost + (variable cost x test duration).

The default used for fixed cost in the SSM is zero due to the assumption that test equipment, etc. are already available to the user. For assembly and unit levels the actual time on test is multiplied by 15% since it was found in a previous study (RADC-TR-78-55) that this yields an approximation of actual labor hours. If the user wishes to alter the 15% constant its location is given in Appendix F.

Test duration is a test parameter in all but temperature cycling screens. The time required to reach the temperature extremes is computed by using the temperature rate of change parameter. It was found that the function

$$t_d = 4/dT \qquad\qquad (4-2)$$

where t_d = dwell time
dT = temperature rate of change (in oC/minute)

with units adjusted to yield hours, gave a good approximation of dwell time. Thus, test duration for temperature cycling is expressed.

$$d = 2N_{cyc} (t_t + t_d) \qquad\qquad (4-3)$$

where   d   =   test duration

N_{cyc} =   number of cycles

t_t =   temperature transition time (minimum

temperature to maximum temperature)

t_d =   dwell time

In all cases test duration is computed in hours and the input or default variable cost is in dollars per hour. If the user does not input a variable test cost the default of $30/hour per hour is used.

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The average cost to repair a defect found at each level may be input. The default repair costs are \$45 at level 1, \$300 at level 2, and \$990 at level 3.

Total costs at each level are given by the linear equation;

$$C_i = C_{Ti} + F_i \cdot C_R \qquad (4\text{-}4)$$

where C_i = Total cost at level i

C_{Ti} = Test cost at level i

F_i = Number of latent defects precipitated (fallout) at level i

C_R = Cost to repair at level i (one repair per defect)

Workmanship defects introduced at each assembly level (ADEF (i), i=1, 2, 3)) are entered as a fraction of the number of parts.

If the SSM is being used to analyze fallout data this data can be entered for each screening level. The model examines the number of defects detected at each level to determine if it is consistent with the expected number. Parts and workmanship fallout can be analyzed separately at each level or a total can be used.

A probability value (PER) can be entered to change the 0.99 probability interval about expected fallout automatically assumed by the model. A smaller probability yields a narrower interval. That is, if the expected mean is the true mean, the band which contains 80% of the actual fallout is narrower than the band which contains 99%. It is suggested that the probability interval not be made too narrow (PER not less than .80). An overly narrow interval may frequently result in instructions to change the screen when a change is not required. If the planned mean is the true mean, then (1-PER) is the fraction of the time actual fallout will still be outside the interval. That is, (1-PER) of the time instructions will be given to change the screen even though no change is needed.

4.1.6 Determining the Initial Fraction Latent Defectives. An incoming lot of parts contains three subpopulations, viz.,

o parts that are "good", i.e., free of defects and are expected to survive the useful life of the end item of

which they are a part, given that they are not
subjected to stress beyond their ratings,

- parts that are "bad", i.e., containing a patent defect
which precludes them from achieving their specified
performance, and,

- parts that are "marginal", i.e., containing a latent
defect which when initially tested appear to be "good"
parts but when subjected to normal operating stresses
and time will transform to "bad" parts.

If an electrical test is performed on a received lot of
parts, the fallout from the test is expected to be all or most of
the "bad" parts. The "marginal" parts are not expected to fail
unless the operating stresses applied during the test and the
test duration are sufficient to transform the "marginal" part to
a "bad" part.

There is expected to be a good correlation between the
quality grade of parts used and the initial quantity of "bad" and
"marginal" parts. That is, higher quality grade parts are expec-
ted to have fewer "bad" and "marginal" parts. This is par-
ticularly true for microcircuits because the processing and final
test and inspection requirements on the part supplier increase in
severity for increasing quality grades, which serves to reduce
the quantity of marginal parts and preclude delivery of bad
parts.

Table 4.3, Initial Fraction Latent Defective Parts, is in-
tended to provide the user with default values in those cases
where better information is not available. The table contains
values for type of equipment and quality level. The type of
equipment is characterized by percentage of microcircuits,

number of microcircuits x 100
   total number of parts

Quality levels range from 1 to 8 and indicate the general quality
grade of the equipment in terms of the various microcircuit, dis-
crete semiconductor and passive part quality grades. The table
values are derived through direct application of the values
of MIL-HDBK-217C, Notice 1, for a typical part mix.

Table 4.4 provides a sampling of generic equipment types
of recent vintage to aid the user in estimating the percentage of
microcircuits that an equipment or system might contain if it can
be related to one of the generic equipments.

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TABLE 4.3   INITIAL FRACTION LATENT DEFECTIVE PARTS

Part Type	Quality Grades							
Microcircuits	S	B	B-1	B-2	C	C-1	D	D-1
Semiconductors	JTXV	JTX	Mixed	JAN/JTX	JAN	Mix. JAN/Non-Mil	Non-Mil	Plastic
Passives	S	R	P	M/P	M	L/M	L	Com'l
Level	1	2	3	4	5	6	7	8
Percent Microcircuits								
100	.00086	.00173	.00520	.01120	.01378	.02240	.03015	.06030
90	.00101	.00229	.00683	.01427	.01935	.03442	.04871	.09084
80	.00116	.00284	.00846	.01735	.02492	.04644	.06726	.12138
70	.00130	.00340	.01009	.02042	.03048	.05846	.08582	.15192
60	.00145	.00395	.01172	.02349	.03605	.07048	.10437	.18246
50	.00160	.00451	.01335	.02657	.04162	.08250	.12293	.21300
40	.00175	.00506	.01498	.02964	.04719	.09452	.14148	.24354
30	.00190	.00562	.01661	.03271	.05276	.10654	.16044	.27408
20	.00204	.00617	.01824	.03578	.05832	.11856	.17859	.30462
10	.00219	.00673	.01987	.03886	.06389	.13058	.19715	.33516
0	.00234	.00728	.02150	.04193	.06946	.14260	.21570	.36570

4.2   Using the Model.

4.2.1   General Instructions for User. The Stress Screening Model consists of three programs designed to run interactively on a terminal.

> NOTICE: The third program, "Adapt", must be link-edited to the single precision IMSL library in order to run in its present form. See Step 5 of Section 4.2.2.

If a user has access to the IBM 370 TSO system (or equivalent) refer to paragraph 4.2.2. If not, the following general instructions describe the use of the Stress Screening Model.

TABLE 4.4   PARTS MIX FOR SAMPLE GENERIC EQUIPMENTS

GENERIC EQUIPMENT TYPE	PERCENT MICROCIRCUITS	QUANTITY OF PARTS				
		MICROCIRCUITS	DISCRETE SEMICONDUCTORS	PASSIVES	LOW POPU- LATION	TOTAL
SHIPBOARD DISPLAY CONSOLE	54.3	4228	1528	1889	137	7782
MILITARIZED LARGE COMPUTER	44.0	4598	428	5063	354	10,443
MILITARIZED MINI COMPUTER	39.0	814	23	1180	71	2,088
SHIPBOARD INTERFACE UNIT	37.8	4785	1016	5556	1300	12,657
RADAR OPERATIONS VAN	35.5	5361	1051	8294	388	15,094
RADAR VIDEO PROCESSOR	34.4	3206	385	4837	896	9324
SUBMARINE DISPLAY CONSOLE	32.2	5963	1807	10,270	450	18,490
TORPEDO GUIDANCE AND CONTROL	31.9	6806	1483	12,653	412	21,354
SHIPBOARD INTERFACE UNIT	29.4	7787	2367	15,126	1200	26,480
AIRBORNE COMMUNICATIONS TERMINAL	24.7	3864	1352	9752	705	15,673
SHIPBOARD SEARCH RADAR	19.2	3713	2381	10,522	2700	19,316
COMPUTER PERIPHERAL (MAG TAPE UNIT)	18.6	214	194	737	4	1149
SHIPBOARD SEARCH RADAR	16.2	2420	1794	10,139	571	14,924
AIR DEFENSE DISPLAY CONSOLE	16.0	1685	1074	6637	1104	10,500
GROUND MOBILE RADAR	14.9	878	798	3882	344	5902
SUBMARINE INTERFACE UNIT	8.6	515	2657	2484	354	6010
TOTALS		56,837	20,338	109,021	10,990	197,186

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The three FORTRAN IV programs (PREFIX, SD01, and ADAPT) comprise the SSM and together require nine working data sets for operation. These data sets should be "card image" (i.e., record length of 80 characters) with appropriate blocking (consult your installation requirements) and should be assigned FORTRAN IV data set reference numbers 2, 4, 8, 9, 10, 11, 12, 13, and 17. While the names assigned to these data sets are irrelevant to the operation of the programs, the naming conventions used in paragraph 4.2.2 are recommended. They are consistent with the data sets in a previous version of the SSM (RADC-TR-78-55).

The next step is to assemble the required input data using Table 4.1 as a guide. Having allocated the working data sets, the next step is to run the programs PREFIX, SD01, and ADAPT, in that order. The programs will prompt the user for all input data which has been assembled.

4.2.2 IBM 370 TSO User Instructions. Figure 4.2 is a simplified flow diagram of the SSM. The following instructions describe the five steps necessary for initial use of the SSM.

Step 1. Using the program listings in Appendix F, create PREFIX.SDO.LOAD, SD01.LOAD, and ADAPT.LOAD. Recall that ADAPT.OBJ should be link-edited to the single precision IMSL library when forming ADAPT.LOAD. ADAPT.OBJ is the object program compiled from the source program ADAPT.FORT.

Step 2. Create the empty data sets PROGRM.DATA, PD.DATA, F.DATA, R.DATA, AB.DATA, LIMITS.DATA, OPS.DATA, FTIME.DATA, and ADAPT.DATA. The user is not required to enter data directly into these files. All data is entered interactively. The data files are reused each time the model is executed. Thus, once they are created, they may be ignored by the user. They are only used to transfer data from one program to the next.

Step 3. Assemble required data. Using Table 4.1 as a guide, determine user-unique values, default values, etc. Also see the examples which follow.

Step 4. Execute the CLIST:


```
000010 FREEALL
000012 ALLOC FI(FT02F001) DA(ADAPT.DATA)
000020 ALLOC FI(FT04F001) DA(PROGRM.DATA)
000030 ALLOC FI(FT11F001) DA(PD.DATA)
000040 ALLOC FI(FT08F001) DA(F.DATA)
000050 ALLOC FI(FT09F001) DA(R.DATA)
000060 ALLOC FI(FT10F001) DA(AB.DATA)
000070 ALLOC FI(FT12F001) DA(LIMITS.DATA)
000080 ALLOC FI(FT13F001) DA(OPS.DATA)
000085 ALLOC FI(FT17F001) DA(FTIME.DATA)
```
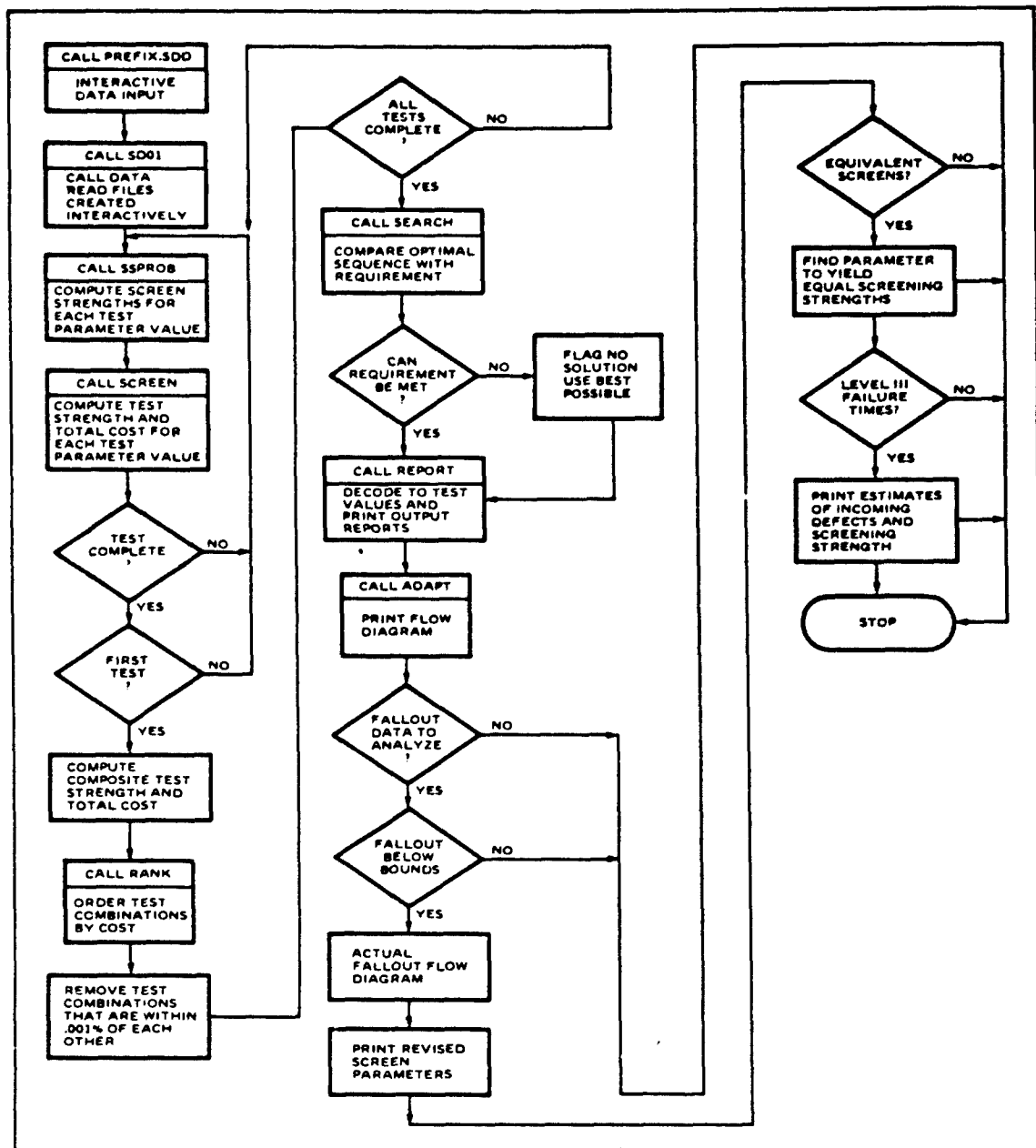
Figure 4.2. Flow Diagram of the Stress Screening Model

```
000090 CALL PREFIX.SDO.LOAD(TEMPNAME)
000100 CALL SDO1.LOAD(TEMPNAME)
000105 CALL ADAPT.LOAD(TEMPNAME)
000110 END
```

Step 5. Enter data as prompted. Once data is input, the optimization and flow chart output will be printed without further action from the user. If there is actual fallout data to be analyzed, the user will be prompted. If equivalent screens are to be found, the parameters will be called for.

For subsequent use, only steps 3, 4, and 5 will be necessary for use of the model since the load modules and data sets are on file. The examples which follow illustrate some of the possible options.

Two proprietary routines are used in the model. If IMSL is not already available the user may wish to contact

International Mathematical and Statistical
        Libraries, Inc.
Sixth Floor - NBC Building
7500 Bellaire Boulevard
Houston, Texas   77036

Telephone (713) 772-1927
Telex 79-1923 IMSL INC HOU.

The IMSL routine MDCH is used in the computation of the bounds for actual fallout in this program. As stated previously, ADAPT.OBJ needs to be link-edited to the single precision IMSL library in order to run in its present form.

The use of MDCH is as follows:

CALL MDCH(CS, DF, P, IER)

where

CS = input value for which the probability is computed. CS must be greater than or equal to zero.

DF = input value containing number of degrees of freedom of the chi-squared distribution. DF must be greater than or equal to .5 and less than or equal to 200,000.

 P = output value containing probability.

IER = error parameter. Terminal error = 128 + N. N=1 indicates that CS or DF was specified incorrectly.

Warning error = 32 + N. N=2 indicates that the normal PDF would have produced an underflow.

MDCH computes the probability P that a random variable X which follows the chi-squared distribution with continuous parameter DF, is less than or equal to CS.

Any chi-squared routine with similar input and output parameters could be substituted if access to the IMSL library is not available.

The two lines -

CALL MDCH (X1,B(I),P,IER)   BOUN 300

CALL MDCH (X1,B1,P1,IER)   BOUN 360

found in ADAPT.FORT would be the only program lines changed if a different library routine is used.

A Newton-Raphson root-finding technique is used to obtain the degrees of freedom since no available routine could do that directly.

The IMSL Routine ZXSSQ is used for the least squares fit of failure times to the CDE model. Parameters a_1 and a_2 of the CDE model are estimated. Fairly extensive rewriting will be necessary if a different curve-fitting routine is to be used. However, if times to failure for level III are not to be analyzed, ZXSSQ is not needed. The line calling ZXSSQ (OPT 200 in ADAPT) may be removed in this case.

4.3   Examples of SSM Use

4.3.1   MTBF Option Examples

4.3.1.1   Planning a Stress Screening Program to Achieve a Certain
           MTBF, without Pre-established Screens. The user in this
           example specifies an MTBF of 1200 hours and selects the
           model default screens at the assembly, unit and system
           levels. The least cost Thermal cycling screen at the
           assembly level and random vibration screen at the unit
           level to achieve the desired MTBF is determined by the
           SSM. A screen at the system level is determined not
           necessary to achieve the 1200 hour MTBF value.

            ******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

       IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

       OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
        RELIABILITY REQUIREMENT

       OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

       OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS

       DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
       ENTER ZERO)
    ?
    1200

       TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
    ?
    5000

       FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
    ?
    0 0
        PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
    ?   ,
    0

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```
*********TEST AND PARAMETER SELECTION*********


        FOLLOWING  ARE THE AVAILABLE SCREENS :

        1.  CONSTANT TEMPERATURE
        2.  CYCLED TEMPERATURE
        3.  RANDOM VIBRATION
        4.  SINE SWEEP VIBRATION
        5.  SINE FIXED VIBRATION



        DEFAULTS ARE:
              LEVEL 1          LEVEL 2          LEVEL 3
          TEMP. CYCLING        RAN.VIB       CONST. TEMP.
              (2)               (3)             (1)



        IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:
    ?
    0
```

********LEVEL 1********

TEMPERATURE CYCLING, LEVEL 1
THE DEFAULT VALUES ARE:
LOWER TEMP=-54 DEG C
UPPER TEMP=71 DEG C
TEMP. RATE OF CHANGE=5 DEG C/MIN
RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0

VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

********LEVEL 2********

RANDOM VIBRATION, LEVEL 2
THE DEFAULT VALUES ARE:
G-LEVEL=6 G
RANGE OF TIME TO BE INVESTIGATED=0 TO 10 MIN.
IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0

VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

```
*********LEVEL 3*********


     CONSTANT TEMPERATURE, LEVEL 3
     THE DEFAULT VALUES ARE:
     TEMPERATURE=70 DEG C
     TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS
     IF YOU WISH THE DEFAULT VALUES, ENTER ZERO, IF NOT,ENTER 1:
?
0


     ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

     IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

     FIXED TEST COST IN DOLLARS=
?
0
     VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

     AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

     ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
0



     IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1
```

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PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
5000	3	5.	0.0	1200.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	10.
2	5.
3	3.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

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```
                 TEST   DESCRIPTION
                      PARAMETER VALUE
     TEST SEQUENCE     TYPE  NO. 1  NO. 2  NO. 3  NO. 4  TOTAL COST($)

----------------------------------------------------------------

     LEVEL  NO.  1          '                                   450.
        TEST  NO.  2   CYT   71.00  -54.00   5.00   5.00        450.
     LEVEL  NO.  2                                             1955.
        TEST  NO.  3   RVIB   6.00    7.50    0.0    0.0       1955.
     LEVEL  NO.  3                                                0.
        TEST  NO.  1   CT     0.0     0.0     0.0    0.0          0.

----------------------------------------------------------------

     TOTAL COST                                        $      2404.

                                                       ------------
                                                       ------------




               INSTANTANEOUS MTBF FOR REMAINING
                   FLAWS AT END OF SCREENING


                              WORKMANSHIP
     PARTS :     5.      6.      7.      8.      9.     10.     11.
     -------------------------------------------------------------
        0. :   1956.   1955.   1955.   1955.   1954.   1954.   1954.
        0. :   1956.   1955.   1955.   1955.   1954.   1954.   1954.
        1. :   1586.   1586.   1586.   1586.   1585.   1585.   1585.
        2. :   1204.   1204.   1204.   1204.   1204.   1204.   1204.
        3. :    971.    971.    971.    970.    970.    970.    970.
        4. :    813.    813.    813.    813.    813.    813.    813.
        5. :    699.    699.    699.    699.    699.    699.    699.




     IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
     IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
     ENTER ONE:
?
1

     ENTER PROBABILITY DESIRED:
?
.8
```

STRESS SCREENING FLOW DIAGRAM

```
-------------    -------------    -------------    -------------    -------------
: INCOMING :     : LEVEL 1 :      : LEVEL 2 :      : LEVEL 3 :      : OUTGOING :
-------------    -------------    -------------    -------------    -------------
:#PARTS:   :     :ADEF=     :     :ADEF=     :     :ADEF=     :     :DEF P REM:!
:    5000!  :    :     10.!  :    :      5.!  :    :      3.!  :    :       2.!
:          :--> :          :--> :          :--> :          :--> :          :
:#DEFECTS: :     :TS=       :     :TS=       :     :TS=       :     :DEF U REM:!
:      5.! :     :   0.403! :     :   0.466! :     :   0.0   :     :       8.!
:          :     :          :     :          :     :          :     :          :
:          :     :DEF PASSED:     :DEF PASSED:     :DEF PASSED:     :MTBF:     :
:          :     :      9.! :     :      7.! :     :     10.! :     :    1204.!
:          :     :          :     :          :     :          :     :          :
-------------    -------------    -------------    -------------    -------------
                      :               :               :
                      :               :               :
                      V               V               V
                 -----------------   -----------------   -----------------
                 :               : : :               : : :               :
                 :   EXPECTED    : : :   EXPECTED    : : :   EXPECTED    :
                 :   FALLOUT:    : : :   FALLOUT:    : : :   FALLOUT:    :
                 :               : : :               : : :               :
                 : PRT UKM TOT:  : : : PRT UKM TOT:  : : : PRT UKM TOT:  :
                 : 2.  4.  6.!  : : : 1.  6.  7.!  : : : 0.  0.  0.!  :
                 :               : : :               : : :               :
                 :UPPR BND FOR:  : : :UPPR BND FOR:  : : :UPPR BND FOR:  :
                 :OBS FALLOUT:!  : : :OBS FALLOUT:!  : : :OBS FALLOUT:!  :
                 :               : : :               : : :               :
                 : 5.  8. 10.!  : : : 3.  9. 11.!  : : : 0.  0.  0.!  :
                 :               : : :               : : :               :
                 :LOWR BND FOR:  : : :LOWR BND FOR:  : : :LOWR BND FOR:  :
                 :OBS FALLOUT:!  : : :OBS FALLOUT:!  : : :OBS FALLOUT:!  :
                 :               : : :               : : :               :
                 : 0.  1.  2.!  : : : 0.  2.  2.!  : : : 0.  0.  0.!  :
                 :               : : :               : : :               :
                 -----------------   -----------------   -----------------
```

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INTERVAL MTBF

```
------------------
  TIME  :  MTBF
------------------
  2000. :  1219.
  4000. :  1233.
  6000. :  1247.
  8000. :  1261.
 10000. :  1275.
 12000. :  1288.
 14000. :  1302.
 16000. :  1314.
 18000. :  1327.
 20000. :  1339.
```

IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?

1
IF YOU HAVE SEPARATE FALLOUT FOR PARTS AND WORKMANSHIP ENTER ONE
IF YOU HAVE TOTAL FALLOUT ONLY AT EACH LEVEL, ENTER ZERO:
?
1
ENTER, IN ORDER, ACTUAL FALLOUT:
DUE TO   (A) PARTS   (B) WORKMANSHIP, AS PROMPTED:
FOR LEVEL 1:
?
1 0
FOR LEVEL 2:
?
1 4
FOR LEVEL 3:
?
0 0

STRESS SCREENING RESULTS:

```
-------------    -------------    -------------    -------------    -------------
: INCOMING :    : LEVEL 1 :    : LEVEL 2 :    : LEVEL 3 :    : OUTGOING :
-------------    -------------    -------------    -------------    -------------
:#PARTS:   :    :ADEF=     :    :ADEF=     :    :ADEF=     :    :DEF P REM:
:     5000:    :      10.:    :       5.:    :       3.:    :        3.:
:         :-->:          :-->:          :-->:          :-->:          :
:#DEFECTS: :    :TS=       :    :TS=       :    :TS=       :    :DEF U REM:
:       5.:    :    0.067:    :    0.466:    :     0.0  :    :       10.:
:         :    :          :    :          :    :          :    :          :
:         :    :DEF PASSED:    :DEF PASSED:    :DEF PASSED:    :MTBF:     :
:         :    :      14.:    :      10.:    :      13.:    :     900.:
:         :    :          :    :          :    :          :    :          :
-------------    -------------    -------------    -------------    -------------
                      :              :              :
                      :              :              :
                      V              V              V
          -------------    -------------    -------------
          :          :    :          :    :          :
          : EXPECTED :    : EXPECTED :    : EXPECTED :
          : FALLOUT: :    : FALLOUT: :    : FALLOUT: :
          :          :    :          :    :          :
          : PRT UKN TOT:  : PRT UKN TOT:  : PRT UKN TOT:
          : 0.  1.  1.:   : 2.  7.  9.:   : 0.  0.  0.:
          :          :    :          :    :          :
          :UPPR BND FOR:  :UPPR BND FOR:  :UPPR BND FOR:
          :OBS FALLOUT::  :OBS FALLOUT::  :OBS FALLOUT::
          :          :    :          :    :          :
          : 0.  3.  3.:   : 5. 11. 14.:   : 0.  0.  0.:
          :          :    :          :    :          :
          :LOWR BND FOR:  :LOWR BND FOR:  :LOWR BND FOR:
          :OBS FALLOUT::  :OBS FALLOUT::  :OBS FALLOUT::
          :          :    :          :    :          :
          : 0.  0.  0.:   : 0.  3.  4.:   : 0.  0.  0.:
          :          :    :          :    :          :
          -------------    -------------    -------------
```

INCREASE NUMBER OF CYCLES ON LEVEL 1 TO   40.00

4.3.1.2 <u>Planning a Stress Screen Program to Achieve a Certain MTBF,</u> <u>with Pre-established Screens</u>. In this example the user is constrained to apply a pre-established screen (perhaps required by contract) at the Unit level. The SSM determines the minimum number of thermal cycles necessary to achieve the desired MTBF.


```
******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
RELIABILITY REQUIREMENT

OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS



DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
ENTER ZERO)
?
900

TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
5000

FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1. CONSTANT TEMPERATURE
2. TEMPERATURE CYCLING
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
3
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
4

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER G LEVEL AND TIME IN MINUTES
?
6 7.5

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER G LEVEL AND TIME IN MINUTES
?
0 60

TEST STRENGTH FOR GIVEN SCREEN= 0.4658

PARAMETER FOR DESIRED VIBRATION SCREEN=   5.8

IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
0

    IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
    IF NOT, ENTER ZERO:
?
0
READY

TEMPERATURE CYCLING, LEVEL 2
THE DEFAULT VALUES ARE:
LOWER TEMP=-54 DEG C
UPPER TEMP=71 DEG C
TEMP. RATE OF CHANGE=5 DEG C/MIN
RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
1

ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
UPPER TEMP.,LOWER TEMP.,TEMP. RATE OF CHANGE, NO. OF CYCLES:
(TEMPERATURE RANGE MUST BE WITHIN -55 TO +75 DEG C
AND RATE OF CHANGE BETWEEN 1 AND 20 DEG C/MIN)
?
75 -40 5 24

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
10000
VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
.002

********TEST AND PARAMETER SELECTION********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

DEFAULTS ARE:

LEVEL 1	LEVEL 2	LEVEL 3
TEMP. CYCLING	RAN.VIB	CONST. TEMP.
(2)	(3)	(1)

    IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:
?
1

    ENTER YOUR SCREEN SEQUENCE AS PROMPTED USING NUMBERS FROM ABOVE LISTING:
    IF YOU DO NOT WISH TO SCREEN AT A PARTICULAR LEVEL, ENTER ZERO:
FOR LEVEL 1 THE SCREEN NUMBER DESIRED IS:
?
0
FOR LEVEL 2 THE SCREEN NUMBER DESIRED IS:
?
2
FOR LEVEL 3 THE SCREEN NUMBER DESIRED IS:
?
0

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TEST DESCRIPTION
PARAMETER VALUE

TEST SEQUENCE	TYPE	NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						0.
TEST NO. 1		0.0	0.0	0.0	0.0	0.
LEVEL NO. 2						12071.
TEST NO. 2	CYT	75.00	-40.00	5.00	6.00	12071.
LEVEL NO. 3						0.
TEST NO. 1		0.0	0.0	0.0	0.0	0.

| TOTAL COST | | | | | $ | 12071. |

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

PARTS	WORKMANSHIP 3.	4.	5.	6.	7.	8.	9.
0.	1957.	1956.	1956.	1955.	1955.	1955.	1954.
1.	1436.	1436.	1435.	1435.	1435.	1435.	1435.
2.	1116.	1115.	1115.	1115.	1115.	1115.	1115.
3.	912.	912.	912.	912.	912.	912.	912.
4.	771.	771.	771.	771.	771.	771.	771.
5.	668.	668.	668.	668.	668.	668.	668.
6.	590.	590.	590.	590.	589.	589.	589.

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IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
5000	3	5.	0.0	900.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	0.
2	10.
3	0.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

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INTERVAL MTBF

```
--------------------
  TIME  :  MTBF
--------------------
  2000. :   944.
  4000. :   976.
  6000. :  1007.
  8000. :  1037.
 10000. :  1066.
 12000. :  1094.
 14000. :  1122.
 16000. :  1148.
 18000. :  1174.
 20000. :  1199.
```

```
      IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
0
IF YOU WISH TO ANALYZE EQUIVALENT SCREENS  ENTER ONE
 IF NOT ENTER ZERO:
?
0
READY
```

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:
?
0

STRESS SCREENING FLOW DIAGRAM

```
-------------    -------------    -------------    -------------    -------------
: INCOMING :    : LEVEL 1 :      : LEVEL 2 :      : LEVEL 3 :      : OUTGOING :
-------------    -------------    -------------    -------------    -------------
:#PARTS:    :    :ADEF=     :     :ADEF=     :     :ADEF=     :     :DEF P REM:
:     5000:    :          0.:    :          10.:   :          0.:   :          3.:
:        :-->:  :          :-->: :          :-->:  :          :-->: :          :
:#DEFECTS: :    :TS=       :     :TS=       :     :TS=       :     :DEF U REM:
:       5.:    :       0.0 :    :       0.415:    :       0.0 :    :          6.:
:        :    :          :     :          :     :          :     :          :
:        :    :DEF PASSED:     :DEF PASSED:     :DEF PASSED:     :MTBF:     :
:        :    :          5.:   :          9.:   :          9.:   :       912.:
:        :    :          :     :          :     :          :     :          :
-------------    -------------    -------------    -------------    -------------
                     :               :               :
                     :               :               :
                     V               V               V
               ---------------  ---------------  ---------------
               :             :  :             :  :             :
               :  EXPECTED   :  :  EXPECTED   :  :  EXPECTED   :
               :  FALLOUT:   :  :  FALLOUT:   :  :  FALLOUT:   :
               :             :  :             :  :             :
               : PRT UKN TOT:  : PRT UKN TOT:  : PRT UKN TOT:
               : 0.  0.  0.:  : 2.  4.  6.:  : 0.  0.  0.:
               :             :  :             :  :             :
               :UPPR BND FOR:  :UPPR BND FOR:  :UPPR BND FOR:
               :OBS FALLOUT::  :OBS FALLOUT::  :OBS FALLOUT::
               :             :  :             :  :             :
               : 0.  0.  0.:  : 7. 11. 14.:  : 0.  0.  0.:
               :             :  :             :  :             :
               :LOWR BND FOR:  :LOWR BND FOR:  :LOWR BND FOR:
               :OBS FALLOUT::  :OBS FALLOUT::  :OBS FALLOUT::
               :             :  :             :  :             :
               : 0.  0.  0.:  : 0.  0.  0.:  : 0.  0.  0.:
               :             :  :             :  :             :
               ---------------  ---------------  ---------------
```

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```
********TEST AND PARAMETER SELECTION********


       FOLLOWING  ARE THE AVAILABLE SCREENS :

       1.   CONSTANT TEMPERATURE
       2.   CYCLED TEMPERATURE
       3.   RANDOM VIBRATION
       4.   SINE SWEEP VIBRATION
       5.   SINE FIXED VIBRATION



       DEFAULTS ARE:
            LEVEL 1            LEVEL 2            LEVEL 3
          TEMP. CYCLING        RAN.VIB         CONST. TEMP.
             (2)                (3)                (1)




       IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:
    ?
    0
```

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4.3.1.3   Planning a Stress Screening Program to Achieve a Certain
           MTBF, No Solution. In this example, the desired MTBF can-
           not be achieved by stress screening alone. The SSM de-
           termines that maximum strength screens will not precipi-
           tate enough latent defects to achieve the desired MTBF.
           Other measures are required, such as reducing the incoming
           part fraction defective (by using higher quality grade
           parts or performing incoming receiving screening) or by
           reducing the workmanship defects induced at one or more
           stages. The SSM prints out the best possible solution
           for the conditions given.

              ******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

        IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

        OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
        RELIABILITY REQUIREMENT

        OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

        OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS

        DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
        ENTER ZERO)
    ?
    1300

        TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
    ?
    8000

        FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
    ?
    0 0
         PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
    ?
    0

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RANDOM VIBRATION, LEVEL 2
THE DEFAULT VALUES ARE:
G-LEVEL=6 G
RANGE OF TIME TO BE INVESTIGATED=0 TO 10 MIN.
IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
1

ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
G LEVEL, TIME IN MIN:
(G LEVEL MUST BE BETWEEN .6 AND 7.5)
?
6 40

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0

VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

********LEVEL 1********

TEMPERATURE CYCLING, LEVEL 1
THE DEFAULT VALUES ARE:
LOWER TEMP=-54 DEG C
UPPER TEMP=71 DEG C
TEMP. RATE OF CHANGE=5 DEG C/MIN
RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0

VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CRE8D	MTBF
8000	3	8.	0.0	1300.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	16.
2	8.
3	4.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

REQUIREMENT CANNOT BE MET

CONSTANT TEMPERATURE, LEVEL 3
THE DEFAULT VALUES ARE:
TEMPERATURE=70 DEG C
TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS
IF YOU WISH THE DEFAULT VALUES, ENTER ZERO, IF NOT,ENTER 1:
?
1

ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
TEMP IN DEG C, TIME IN HRS:
(TEMP MUST BE LESS THAN +75 DEG C)
?
70 96

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0

VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

STRESS SCREENING FLOW DIAGRAM

INCOMING	LEVEL 1	LEVEL 2	LEVEL 3	OUTGOING
#PARTS: 8000	ADEF= 16.	ADEF= 8.	ADEF= 4.	DEF P REM: 1.
#DEFECTS: 8.	TS= 0.615	TS= 0.683	TS= 6.314	DEF W REM: 6.
	DEF PASSED 9.	DEF PASSED 5.	DEF PASSED 6.	MTBF: 1051.

```
        :              :              :
        :              :              :
        V              V              V
```

EXPECTED FALLOUT:	EXPECTED FALLOUT:	EXPECTED FALLOUT:
PRT UKN TOT 4. 11. 15.	PRT UKN TOT 2. 10. 12.	PRT UKN TOT 0. 3. 3.
UPPR BND FOR OBS FALLOUT:	UPPR BND FOR OBS FALLOUT:	UPPR BND FOR OBS FALLOUT:
11. 21. 26.	7. 20. 22.	0. 9. 9.
LOWR BND FOR OBS FALLOUT:	LOWR BND FOR OBS FALLOUT:	LOWR BND FOR OBS FALLOUT:
0. 2. 5.	0. 2. 3.	0. 0. 0.

```
                    T E S T   D E S C R I P T I O N
                           PARAMETER VALUE
        TEST SEQUENCE      TYPE  NO. 1  NO. 2  NO. 3  NO. 4  TOTAL COST($)

    ------------------------------------------------------------------------


        LEVEL  NO.  1                                              1375.
            TEST  NO.  2   CYT   71.00 -54.00   5.00  20.00        1375.
        LEVEL  NO.  2                                              3557.
            TEST  NO.  3   RVIB   6.00  40.00   0.0    0.0         3557.
        LEVEL  NO.  3                                              5824.
            TEST  NO.  1   CT    70.00  96.00   0.0    0.0         5824.

    ------------------------------------------------------------------------

        TOTAL COST                                         $      10756.


                                                    ---------------
                                                    ---------------




                     INSTANTANEOUS MTBF FOR REMAINING
                        FLAWS AT END OF SCREENING


                              WORKMANSHIP
        PARTS :     3.      4.      5.      6.      7.      8.       9.
    ------------------------------------------------------------------------
         0. :     1223.   1223.   1223.   1223.   1223.   1222.    1222.
         0. :     1223.   1223.   1223.   1223.   1223.   1222.    1222.
         0. :     1223.   1223.   1223.   1223.   1223.   1222.    1222.
         1. :     1051.   1051.   1051.   1051.   1051.   1051.    1050.
         2. :      869.    869.    860.    868.    868.    868.     868.
         3. :      740.    740.    740.    740.    740.    740.     740.
         4. :      645.    645.    645.    645.    645.    645.     644.




        IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
        IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
        ENTER ONE:
    ?
    0



                                   104
```

```
        IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
0
IF YOU WISH TO ANALYZE EQUIVALENT SCREENS  ENTER ONE
 IF NOT ENTER ZERO:
?
1


FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1.  CONSTANT TEMPERATURE
2.  TEMPERATURE CYCLING
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION



ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
1
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
2

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER ABSOLUTE VALUE OF DIFFERENCE BETWEEN TEMP IN DEG C AND 25 DEG C
 AND TIME IN HOURS
?
45 96

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
100 3 0

TEST STRENGTH FOR GIVEN SCREEN= 0.3143


PARAMETER IN DESIRED TEMP CYCLING SCREEN=       8.0
```

INTERVAL MTBF

```
-------------------
TIME  :  MTBF
-------------------
 2000. :  1054.
 4000. :  1057.
 6000. :  1060.
 8000. :  1063.
10000. :  1065.
12000. :  1068.
14000. :  1071.
16000. :  1073.
18000. :  1076.
20000. :  1078.
```

4.3.2   Cost Option Example

In this example, the user desires a set of screens which precipitate the maximum number of latent defects for a fixed dollar amount of $40,000.


```
******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
 RELIABILITY REQUIREMENT

OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS



DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
ENTER ZERO)
?
0

COST BUDGET(OPTION B ONLY,FOR OPTION A OR C ENTER ZERO)
?
40000

TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
7000

FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1. CONSTANT TEMPERATURE
2. TEMPERATURE CYCLING
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
2
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
2

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
125 5 20

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
100 3 0

TEST STRENGTH FOR GIVEN SCREEN= 0.6145

PARAMETER IN DESIRED TEMP CYCLING SCREEN=   61.6

TEMPERATURE CYCLING, LEVEL 1
THE DEFAULT VALUES ARE:
LOWER TEMP=-54 DEG C
UPPER TEMP=71 DEG C
TEMP. RATE OF CHANGE=5 DEG C/MIN
RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
10000
VARIABLE TEST COST IN DOLLARS PER HOUR=
?
40
AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

********TEST AND PARAMETER SELECTION********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

DEFAULTS ARE:

LEVEL 1	LEVEL 2	LEVEL 3
TEMP. CYCLING	RAN.VIB	CONST. TEMP.
(2)	(3)	(1)

IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:
?
0

```
********LEVEL 3********


    CONSTANT TEMPERATURE, LEVEL 3
    THE DEFAULT VALUES ARE:
    TEMPERATURE=70 DEG C
    TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS
    IF YOU WISH THE DEFAULT VALUES, ENTER ZERO, IF NOT,ENTER 1:
?
0


    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
10000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
50
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
1000
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

********LEVEL 2********

RANDOM VIBRATION, LEVEL 2
THE DEFAULT VALUES ARE:
G-LEVEL=6 G
RANGE OF TIME TO BE INVESTIGATED=0 TO 10 MIN.
IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
10000
VARIABLE TEST COST IN DOLLARS PER HOUR=
?
50

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
500
ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

```
                  T E S T   D E S C R I P T I O N
                        PARAMETER VALUE
      TEST SEQUENCE      TYPE  NO. 1  NO. 2  NO. 3  NO. 4  TOTAL COST($)

      --------------------------------------------------------------


      LEVEL  NO.  1                                              11529.
           TEST  NO.  2   CYT   71.00 -54.00   5.00  20.00      11529.
      LEVEL  NO.  2                                              13090.
           TEST  NO.  3   RVIB   6.00   5.00   0.0    0.0        13090.
      LEVEL  NO.  3                                              15341.
           TEST  NO.  1   CT    70.00  48.00   0.0    0.0        15341.

      -----------------------------------------------------------------

      TOTAL COST                                         $       39960.



                                              -------------
                                              -------------




                INSTANTANEOUS MTBF FOR REMAINING
                     FLAWS AT END OF SCREENING


                            WORKMANSHIP
      PARTS :    5.     6.     7.     8.     9.     10.     11.

      -----------------------------------------------------------------
        0. :   1397.  1397.  1397.  1397.  1397.  1396.   1396.
        0. :   1397.  1397.  1397.  1397.  1397.  1396.   1396.
        0. :   1317.  1317.  1317.  1317.  1317.  1317.   1316.
        1. :   1043.  1043.  1043.  1042.  1042.  1042.   1042.
        2. :    863.   863.   863.   863.   863.   863.    862.
        3. :    736.   736.   736.   736.   736.   736.    736.
        4. :    642.   642.   641.   641.   641.   641.    641.
```

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:
?
1

ENTER PROBABILITY DESIRED:
?
.8

IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
7000	3	7.	40000.00	0.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	14.
2	7.
3	4.

REWORK COST

LEVEL 1	45.
LEVEL 2	500.
LEVEL 3	1000.

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INTERVAL MTBF

```
--------------------
TIME  :  MTBF
--------------------
 2000. :  1049.
 4000. :  1056.
 6000. :  1062.
 8000. :  1069.
10000. :  1075.
12000. :  1081.
14000. :  1087.
16000. :  1093.
18000. :  1098.
20000. :  1104.
```

IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
0
IF YOU WISH TO ANALYZE EQUIVALENT SCREENS ENTER ONE
 IF NOT ENTER ZERO:
?
0

   IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
    IF NOT, EXTER ZERO:
?
0
READY

STRESS SCREENING FLOW DIAGRAM

```
---------------    ---------------    ---------------    ---------------    ---------------
: INCOMING :    : LEVEL 1 :    : LEVEL 2 :    : LEVEL 3 :    : OUTGOING :
---------------    ---------------    ---------------    ---------------    ---------------
:#PARTS:  :    :ADEF=   :    :ADEF=   :    :ADEF=   :    :DEF P REM::
:     7000:    :     14.:    :     7.:    :     4.:    :      1.:
:         :-->:         :-->:         :-->:         :-->:         :
:#DEFECTS: :    :TS=     :    :TS=     :    :TS=     :    :DEF U REM::
:      7.:    :    0.615:    :    0.409:    :    0.237:    :      8.:
:         :    :         :    :         :    :         :    :         :
:         :    :DEF PASSED:    :DEF PASSED:    :DEF PASSED:    :MTBF:    :
:         :    :      8.:    :      9.:    :      9.:    :    1042.:
:         :    :         :    :         :    :         :    :         :
---------------    ---------------    ---------------    ---------------    ---------------
                    :                  :                  :
                    :                  :                  :
                    :                  :                  :
                    V                  V                  V
          ---------------    ---------------    ---------------
          :             : :             : :             :
          : EXPECTED    : : EXPECTED    : : EXPECTED    :
          : FALLOUT:    : : FALLOUT:    : : FALLOUT:    :
          :             : :             : :             :
          : PRT UKN TOT: : PRT UKN TOT: : PRT UKN TOT:
          : 4.  9. 13.: : 1.  5.  6.: : 0.  3.  3.:
          :             : :             : :             :
          :UPPR BND FOR: :UPPR BND FOR: :UPPR BND FOR:
          :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
          :             : :             : :             :
          : 8. 14. 18.: : 3.  9. 10.: : 0.  6.  6.:
          :             : :             : :             :
          :LOWR BND FOR: :LOWR BND FOR: :LOWR BND FOR:
          :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
          :             : :             : :             :
          : 1.  4.  7.: : 0.  1.  2.: : 0.  0.  0.:
          :             : :             : :             :
          ---------------    ---------------    ---------------
```

********TEST AND PARAMETER SELECTION********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

ENTER YOUR SCREEN SEQUENCE AS PROMPTED USING NUMBERS FROM ABOVE LISTING:
IF YOU DO NOT WISH TO SCREEN AT A PARTICULAR LEVEL, ENTER ZERO:
FOR LEVEL 1 THE SCREEN NUMBER DESIRED IS:
?
1
FOR LEVEL 2 THE SCREEN NUMBER DESIRED IS:
?
2
FOR LEVEL 3 THE SCREEN NUMBER DESIRED IS:
?
4

4.3.3   Tradeoff Option Examples

4.3.3.1   Evaluating an Existing Screen. The user has an existing
             screen and wishes to have the SSM determine the cost and
             test strength of that screen. After having evaluated an
             existing screen, the MTBF Option should be exercised to
             allow the SSM to determine an optimum screen to achieve
             the same MTBF. Alternatively, the Cost Option may be
             exercised to determine what MTBF is achievable for the
             same cost as the existing screen.

         ******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

     IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

     OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
     RELIABILITY REQUIREMENT

     OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

     OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS

     DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
     ENTER ZERO)
?
0

     COST BUDGET(OPTION B ONLY,FOR OPTION A OR C ENTER ZERO)
?
0

     TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
5000

     FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
     PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0

118

*********LEVEL 2*********

TEMPERATURE CYCLING, LEVEL 2
ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
UPPER TEMP.,LOWER TEMP.,TEMP. RATE OF CHANGE, NO. OF CYCLES:
(TEMPERATURE RANGE MUST BE WITHIN -55 TO +75 DEG C
AND RATE OF CHANGE BETWEEN 1 AND 20 DEG C/MIN)
?
70 -40 10 12

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0

VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

********LEVEL 1********

    CONSTANT TEMPERATURE, LEVEL 1
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    TEMP IN DEG C, TIME IN HRS:
    (TEMP MUST BE LESS THAN +75 DEG C)
?
70 96

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
0

    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CRESD	NTBF
5000	3	5.	NA	NA

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	10.
2	5.
3	3.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

T E S T   D E S C R I P T I O N

TEST SEQUENCE	TYPE	PARAMETER VALUE NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						3092.
TEST NO. 1	CT	70.00	96.00	0.0	0.0	3092.
LEVEL NO. 2						3380.
TEST NO. 2	CYT	70.00	-40.00	10.00	12.00	3380.
LEVEL NO. 3						2751.
TEST NO. 4	SSVB	6.00	20.00	0.0	0.0	2751.

TOTAL COST	$	9223.

********LEVEL 3*********

SINE SWEEP VIBRATION, LEVEL 3
ENTER IN ORDER, SEPARATED BY COMMAS OR SPACES:
G-LEVEL, TIME IN MIN:
(G LEVEL BETWEEN 0 AND 10)
?
6 20

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0

VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1

STRESS SCREENING FLOW DIAGRAM

```
-------------    -------------    -------------    -------------    -------------
! INCOMING  !    ! LEVEL 1   !    ! LEVEL 2   !    ! LEVEL 3   !    ! OUTGOING  !
-------------    -------------    -------------    -------------    -------------
!#PARTS:    !    !ADEF=      !    !ADEF=      !    !ADEF=      !    !DEF P REM: !
!      5000!    !        10.!    !         5.!    !         3.!    !         1.!
!           !-->!           !-->!           !-->!           !-->!           !
!#DEFECTS:  !    !TS=        !    !TS=        !    !TS=        !    !DEF U REM: !
!        5. !    !      0.314!    !      0.689!    !      0.311!    !         4.!
!           !    !           !    !           !    !           !    !           !
!           !    !DEF PASSED !    !DEF PASSED !    !DEF PASSED !    !MTBF:      !
!           !    !        10.!    !         5.!    !         4.!    !      1555.!
!           !    !           !    !           !    !           !    !           !
-------------    -------------    -------------    -------------    -------------
                       !               !               !
                       !               !               !
                       V               V               V
                 -------------    -------------    -------------
                 !           !!  !           !!  !           !
                 ! EXPECTED  !!  ! EXPECTED  !!  ! EXPECTED  !
                 ! FALLOUT:  !!  ! FALLOUT:  !!  ! FALLOUT:  !
                 !           !!  !           !!  !           !
                 ! PRT UKM TOT! ! PRT UKM TOT! ! PRT UKM TOT!
                 ! 1.  4.  5.!!! 2.  9. 11.!!! 0.  3.  3.!
                 !           !!  !           !!  !           !
                 !UPPR BND FOR! !UPPR BND FOR! !UPPR BND FOR!
                 !OBS FALLOUT:! !OBS FALLOUT:! !OBS FALLOUT:!
                 !           !!  !           !!  !           !
                 ! 5. 10. 12.!!! 7. 18. 21.!!! 0.  9.  9.!
                 !           !!  !           !!  !           !
                 !LOWR BND FOR! !LOWR BND FOR! !LOWR BND FOR!
                 !OBS FALLOUT:! !OBS FALLOUT:! !OBS FALLOUT:!
                 !           !!  !           !!  !           !
                 ! 0.  0.  0.!!! 0.  1.  2.!!! 0.  0.  0.!
                 !           !!  !           !!  !           !
                 -------------    -------------    -------------
```

INTERVAL MTBF

TIME	MTBF
2000.	1564.
4000.	1573.
6000.	1582.
8000.	1591.
10000.	1599.
12000.	1607.
14000.	1615.
16000.	1623.
18000.	1630.
20000.	1637.

125

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

			WORKMANSHIP				
PARTS :	1.	2.	3.	4.	5.	6.	7.
0. :	1957.	1957.	1957.	1956.	1956.	1955.	1955.
0. :	1957.	1957.	1957.	1956.	1956.	1955.	1955.
0. :	1957.	1957.	1957.	1956.	1956.	1955.	1955.
1. :	1556.	1555.	1555.	1555.	1555.	1554.	1554.
2. :	1187.	1186.	1186.	1186.	1186.	1186.	1186.
3. :	959.	959.	959.	959.	959.	959.	959.
4. :	805.	805.	805.	805.	805.	804.	804.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:
?
0

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IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1. CONSTANT TEMPERATURE
2. TEMPERATURE CYCLING
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
2
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
2

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
110 10 12

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
100 5 0

TEST STRENGTH FOR GIVEN SCREEN= 0.6887

PARAMETER IN DESIRED TEMP CYCLING SCREEN=   43.0

```
        IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
0
IF YOU WISH TO ANALYZE EQUIVALENT SCREENS  ENTER ONE
 IF NOT ENTER ZERO:
?
1


FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1.  CONSTANT TEMPERATURE
2.  TEMPERATURE CYCLING
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION



ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
1
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
2

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER ABSOLUTE VALUE OF DIFFERENCE BETWEEN TEMP IN DEG C AND 25 DEG C
 AND TIME IN HOURS
?
45 96

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
100 5 0

TEST STRENGTH FOR GIVEN SCREEN= 0.3143


PARAMETER IN DESIRED TEMP CYCLING SCREEN=      3.4
```

IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1. CONSTANT TEMPERATURE
2. TEMPERATURE CYCLING
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
4
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
3

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER G LEVEL AND TIME IN MINUTES
?
6 20

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER G LEVEL AND TIME IN MINUTES
?
5 0

TEST STRENGTH FOR GIVEN SCREEN= 0.3814

PARAMETER FOR DESIRED VIBRATION SCREEN=   6.3

IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
0

 IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
   IF NOT, ENTER ZERO:
?
0
READY

IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1. CONSTANT TEMPERATURE
2. TEMPERATURE CYCLING
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
4
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
3

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER G LEVEL AND TIME IN MINUTES
?
6 20

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER G LEVEL AND TIME IN MINUTES
?
0 15

 TEST STRENGTH FOR GIVEN SCREEN= 0.3814
 SOLUTION CANNOT BE FOUND BY INTERNAL METHOD.
  TRY A GRID OF POSSIBLE SOLUTIONS.

*********TEST AND PARAMETER SELECTION*********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

ENTER YOUR SCREEN SEQUENCE AS PROMPTED USING NUMBERS FROM ABOVE LISTING:
IF YOU DO NOT WISH TO SCREEN AT A PARTICULAR LEVEL, ENTER ZERO:
FOR LEVEL 1 THE SCREEN NUMBER DESIRED IS:
?
2
FOR LEVEL 2 THE SCREEN NUMBER DESIRED IS:
?
4
FOR LEVEL 3 THE SCREEN NUMBER DESIRED IS:
?
1

4.3.3.2   Adapting Screens Based on Observed Results. In this
           example, the user has actual screen data which falls outside
           the bounds of the selected probability interval. Note on
           the Stress Screening Flow Diagram at level 2 that the ex-
           pected number of workmanship defects is 8, with an 80 percent
           probability interval of 3 to 12. The actual number of work-
           manship defects observed is 2 which is entered into the SSM.
           A new screening strength is computed (0.158) based on observed
           results and an increase in vibration time from 20 minutes to
           60 minutes is recommended to achieve the desired screening
           strength.

                    ******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

           IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

           OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
           RELIABILITY REQUIREMENT

           OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

           OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS

           DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
           ENTER ZERO)
    ?
    0

           COST BUDGET(OPTION B ONLY,FOR OPTION A OR C ENTER ZERO)
    ?
    0

           TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
    ?
    9000

           FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
    ?
    0 0
            PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
    ?
    0

130

```
    SINE SWEEP VIBRATION, LEVEL 2
    ENTER IN ORDER, SEPARATED BY COMMAS OR SPACES:
    G-LEVEL, TIME IN MIN:
    (G LEVEL BETWEEN 0 AND 10)
?
6 20

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
20000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
50
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?

500
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

```
    TEMPERATURE CYCLING, LEVEL 1
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    UPPER TEMP.,LOWER TEMP.,TEMP. RATE OF CHANGE, NO. OF CYCLES:
    (TEMPERATURE RANGE MUST BE WITHIN -55 TO +75 DEG C
    AND RATE OF CHANGE BETWEEN 1 AND 20 DEG C/MIN)
?
70 -40 4 8

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
10000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
40
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
50
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
9000	3	9.	NA	NA

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	18.
2	9.
3	5.

REWORK COST

LEVEL 1	50.
LEVEL 2	500.
LEVEL 3	1000.

TEST DESCRIPTION

		PARAMETER VALUE				
TEST SEQUENCE	TYPE	NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						10962.
TEST NO. 2	CYT	70.00	-40.00	4.00	8.00	10962.
LEVEL NO. 2						24856.
TEST NO. 4	SSVB	6.00	20.00	0.0	0.0	24856.
LEVEL NO. 3						37922.
TEST NO. 1	CT	75.00	40.00	0.0	0.0	37922.

TOTAL COST 135 $ 73740.

CONSTANT TEMPERATURE, LEVEL 3
ENTER, IN ORDER, SEPARATED BY COMMAC OR SPACES:
TEMP IN DEG C, TIME IN HRS:
(TEMP MUST BE LESS THAN +75 DEG C)
?
75 48

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
30000
VARIABLE TEST COST IN DOLLARS PER HOUR=
?
60
AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
1000
ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1

STRESS SCREENING FLOW DIAGRAM

```
------------   -------------   -------------   -------------   -------------
: INCOMING :   : LEVEL 1  :   : LEVEL 2  :   : LEVEL 3  :   : OUTGOING :
------------   -------------   -------------   -------------   -------------
:#PARTS:   :   :ADEF=     :   :ADEF=     :   :ADEF=     :   :DEF P REM:!
:     9000:   :       18.!   :        9.!   :        5.!   :        3.!
:          :-->!          :-->!          :-->!          :-->:          :
:#DEFECTS: :   :TS=       :   :TS=       :   :TS=       :   :DEF W REM:!
:        9.!   :     0.394!   :     0.381!   :    0.250!   :       13.!
:          :   :          :   :          :   :          :   :          :
:          :   :DEF PASSED:   :DEF PASSED:   :DEF PASSED:   :MTBF:     :
:          :   :       16.!   :       16.!   :       15.!   :      701.!
:          :   :          :   :          :   :          :   :          :
------------   -------------   -------------   -------------   -------------
                     :              :              :
                     :              :              :
                     V              V              V
              -------------   -------------   -------------
              :           : : :           : : :           :
              :  EXPECTED : : :  EXPECTED : : :  EXPECTED :
              :  FALLOUT: : : :  FALLOUT: : : :  FALLOUT: :
              :           : : :           : : :           :
              : PRT WKM TOT! : PRT WKM TOT! : PRT WKM TOT!
              : 3.  8. 11.! : 2.  8. 10.! : 0.  5.  5.!
              :           : : :           : : :           :
              :UPPR BND FOR! :UPPR BND FOR! :UPPR BND FOR!
              :OBS FALLOUT:! :OBS FALLOUT:! :OBS FALLOUT:!
              :           : : :           : : :           :
              : 6. 12. 16.! : 5. 12. 15.! : 0.  9.  9.!
              :           : : :           : : :           :
              :LOWR BND FOR! :LOWR BND FOR! :LOWR BND FOR!
              :OBS FALLOUT:! :OBS FALLOUT:! :OBS FALLOUT:!
              :           : : :           : : :           :
              : 0.  3.  6.! : 0.  3.  5.! : 0.  1.  1.!
              :           : : :           : : :           :
              -------------   -------------   -------------
```

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

| | | | WORKMANSHIP | | | | |
PARTS :	10.	11.	12.	13.	14.	15.	16.
0. :	1086.	1086.	1086.	1086.	1086.	1086.	1086.
1. :	974.	974.	974.	973.	973.	973.	973.
2. :	815.	815.	815.	815.	815.	815.	815.
3. :	701.	701.	701.	701.	701.	701.	701.
4. :	615.	615.	615.	615.	615.	615.	615.
5. :	547.	547.	547.	547.	547.	547.	547.
6. :	493.	493.	493.	493.	493.	493.	493.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:
?
1

ENTER PROBABILITY DESIRED:
?
.8

STRESS SCREENING RESULTS:

```
-----------     -------------     -------------     -------------     -------------
: INCOMING :     : LEVEL 1 :       : LEVEL 2 :       : LEVEL 3 :       : OUTGOING :
-----------     -------------     -------------     -------------     -------------
:#PARTS:  :     :ADEF=    :       :ADEF=    :       :ADEF=    :       :DEF P REM:!
:    9000!       :     18.!         :     9.!         :     5.!         :      5.!
:        !-->!            !-->!           !-->!           !-->!            !
:#DEFECTS: :     :TS=     :        :TS=     :        :TS=     :        :DEF U REM:!
:      9.!       :    0.394!        :   0.158!        :   0.250!        :     14.!
:        !       :        !        :        !        :        !        :        !
:        !       :DEF PASSED!       :DEF PASSED!      :DEF PASSED!       :MTBF:   !
:        !       :     16.!         :    21.!         :    19.!         :    521.!
:        !       :        !        :        !        :        !        :        !
-----------     -------------     -------------     -------------     -------------
```

```
                  :                 :                 :
                  :                 :                 :
                  V                 V                 V
             ---------------   ---------------   ---------------
             :           !:   !           !:   !             !
             : EXPECTED  !:   ! EXPECTED  !:   ! EXPECTED    !
             : FALLOUT:  !:   ! FALLOUT:  !:   ! FALLOUT:    !
             :           !:   !           !:   !             !
             : PRT UKM TOT!  ! PRT UKM TOT! ! PRT UKM TOT!
             : 3.  8. 11.!  ! 0.  4.  4.!  ! 1.  6.  7.!
             :           !:   !           !:   !             !
             :UPPR BND FOR! :UPPR BND FOR! :UPPR BND FOR!
             :OBS FALLOUT:! :OBS FALLOUT:! :OBS FALLOUT:!
             :           !:   !           !:   !             !
             : 6. 12. 16.!  ! 0.  8.  8.!  ! 3.  9. 11.!
             :           !:   !           !:   !             !
             :LOWR BND FOR! :LOWR BND FOR! :LOWR BND FOR!
             :OBS FALLOUT:! :OBS FALLOUT:! :OBS FALLOUT:!
             :           !:   !           !:   !             !
             : 0.  3.  6.!  ! 0.  1.  1.!  ! 0.  2.  2.!
             :           !:   !           !:   !             !
             ---------------   ---------------   ---------------
```

INCREASE TIME ON LEVEL 2 TO   60.00 MINUTES

IF YOU WISH TO ANALYZE EQUIVALENT SCREENS ENTER ONE
  IF NOT ENTER ZERO:
  ?
  0

IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
  IF NOT, ENTER ZERO:
?
0
READY

INTERVAL MTBF

TIME	MTBF
2000.	709.
4000.	717.
6000.	725.
8000.	733.
10000.	740.
12000.	748.
14000.	755.
16000.	762.
18000.	769.
20000.	776.

IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
1

IF YOU HAVE SEPARATE FALLOUT FOR PARTS AND WORKMANSHIP ENTER ONE
IF YOU HAVE TOTAL FALLOUT ONLY AT EACH LEVEL, ENTER ZERO:
?
1

ENTER, IN ORDER, ACTUAL FALLOUT:
DUE TO   (A) PARTS   (B) WORKMANSHIP, AS PROMPTED:
FOR LEVEL 1:
?
3 7

FOR LEVEL 2:
?
2 2

FOR LEVEL 3:
?
0 6

********TEST AND PARAMETER SELECTION********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

DEFAULTS ARE:
        LEVEL 1   LEVEL 2   LEVEL 3
    TEMP. CYCLING   RAN.VIB   CONST. TEMP.
        (2)   (3)   (1)

IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:
?
0

4.3.4   Example Using the CDE Model to Evaluate Screening Results.

In this example, three levels of screens are used, based on model defaults. The stress screening flow diagram shows an expected fallout of 13 defects at Level 3. The user actually experienced 16 defects and also had times-to-failure for each defect. In this example, the times-to-failure are entered into the SSM and the CDE model is fit to the failure distribution, resulting in estimates for the number of defects entering the Level 3 screen and the screening strength at that level. In this example, the estimated number of defects is unchanged, (33), but the screening strength estimate is revised upward to 0.521 from 0.382.

EX SSM


```
         ******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

    IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

    OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
    RELIABILITY REQUIREMENT

    OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

    OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS



    DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
    ENTER ZERO)
?
600

    TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
20000

    FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
    PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

```
********LEVEL 2********


        RANDOM VIBRATION, LEVEL 2
        THE DEFAULT VALUES ARE:
        G-LEVEL=6 G
        RANGE OF TIME TO BE INVESTIGATED=0 TO 10 MIN.
        IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
  ?
  0


        ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

        IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

        FIXED TEST COST IN DOLLARS=
  ?
  30000
        VARIABLE TEST COST IN DOLLARS PER HOUR=
  ?
  0
        AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
  ?
  0
        ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
  ?
  0
```

```
      TEMPERATURE CYCLING, LEVEL 1
      THE DEFAULT VALUES ARE:
      LOWER TEMP=-54 DEG C
      UPPER TEMP=71 DEG C
      TEMP. RATE OF CHANGE=5 DEG C/MIN
      RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
      IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0


      ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

      IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

      FIXED TEST COST IN DOLLARS=
?
20000
      VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
      AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
      ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREBD	MTBF
20000	3	20.	0.0	600.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	40.
2	20.
3	10.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

REQUIREMENT CANNOT BE MET
MTBF POSSIBLE=   462.9
MTBF REQUIRED=   600.0

CONSTANT TEMPERATURE, LEVEL 3
THE DEFAULT VALUES ARE:
TEMPERATURE=70 DEG C
TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS
IF YOU WISH THE DEFAULT VALUES, ENTER ZERO, IF NOT, ENTER 1:
?
1

ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
TEMP IN DEG C, TIME IN HRS:
(TEMP MUST BE LESS THAN +75 DEG C)
?
70 160

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0

VARIABLE TEST COST IN DOLLARS PER HOUR=
0

AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0

ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?

?
0

IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1

INSTANTANEOUS NTBF FOR REMAINING
FLAWS AT END OF SCREENING

			WORKMANSHIP				
PARTS :	15.	16.	17.	18.	19.	20.	21.
0. :	489.	489.	489.	489.	489.	489.	489.
0. :	489.	489.	489.	489.	489.	489.	489.
1. :	446.	445.	445.	445.	445.	445.	445.
2. :	409.	409.	409.	409.	409.	409.	409.
3. :	378.	378.	378.	378.	378.	378.	378.
4. :	352.	352.	352.	352.	352.	352.	352.
5. :	328.	328.	328.	328.	328.	328.	328.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:
?
0

147

```
                    T E S T   D E S C R I P T I O N
                         PARAMETER VALUE
        TEST SEQUENCE      TYPE  NO. 1  NO. 2  NO. 3  NO. 4  TOTAL COST($)
-------------------------------------------------------------------------

        LEVEL  NO.  1                                          22371.
           TEST  NO.  2   CYT    71.00 -54.00   5.00  20.00    22371.
        LEVEL  NO.  2                                          36031.
           TEST  NO.  3   RVIB    6.00   7.50   0.0    0.0     36031.
        LEVEL  NO.  3                                          17283.
           TEST  NO.  1   CT     70.00 160.00   0.0    0.0     17283.

-------------------------------------------------------------------------

        TOTAL COST                                     $     75684.


                                                      ------------
                                                      ------------
```

INTERVAL MTBF

TIME	MTBF
2000.	393.
4000.	395.
6000.	397.
8000.	399.
10000.	401.
12000.	403.
14000.	404.
16000.	406.
18000.	407.
20000.	409.

STRESS SCREENING FLOW DIAGRAM

```
------------    -------------    -------------    -------------    -------------
: INCOMING :    : LEVEL 1  :    : LEVEL 2  :    : LEVEL 3  :    : OUTGOING :
------------    -------------    -------------    -------------    -------------
:NPARTS:   :    :ADEF=     :    :ADEF=     :    :ADEF=     :    :DEF P REM::
:    20000:     :      40.:     :      20.:     :      10.:     :       3.:
          :-->:           :-->:           :-->:           :-->:           :
:NDEFECTS: :    :TS=       :    :TS=       :    :TS=       :    :DEF U REM::
:      20.:     :    0.615:     :    0.466:     :    0.382:     :      18.:
:         :     :          :    :          :    :          :    :          :
:         :     :DEF PASSED:    :DEF PASSED:    :DEF PASSED:    :MTBF:     :
:         :     :      23.:     :      23.:     :      20.:     :     392.:
:         :     :          :    :          :    :          :    :          :
------------    -------------    -------------    -------------    -------------
                      :               :               :
                      :               :               :
                      V               V               V
              -------------    -------------    -------------
              :           : :  :          : :  :          :
              : EXPECTED  : :  : EXPECTED : :  : EXPECTED  :
              : FALLOUT:  : :  : FALLOUT: : :  : FALLOUT:  :
              :           : :  :          : :  :          :
              : PRT UKN TOT: : PRT UKN TOT: : PRT UKN TOT:
              : 12. 25. 37.: : 3. 17. 20.: : 1. 12. 13.:
              :           : :  :          : :  :          :
              :UPPR BND FOR: :UPPR BND FOR: :UPPR BND FOR:
              :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
              :           : :  :          : :  :          :
              : 23. 40. 55.: : 9. 30. 33.: : 5. 22. 24.:
              :           : :  :          : :  :          :
              :LOWR BND FOR: :LOWR BND FOR: :LOWR BND FOR:
              :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
              :           : :  :          : :  :          :
              : 3. 12. 21.: : 0. 6. 9.: : 0. 3. 4.:
              :           : :  :          : :  :          :
              -------------    -------------    -------------
```

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IF YOU HAVE FALLOUT NUMBERS ENTER 1, IF NOT, ENTER ZERO:
?
0

IF YOU WISH TO ANALYZE EQUIVALENT SCREENS ENTER ONE
IF NOT, ENTER ZERO:
?
0

IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
IF NOT, ENTER ZERO:
?
1

ENTER NUMBER OF FAILURES DURING FINAL SCREEN:
?
16

ENTER FAILURE TIMES (HOURS), IN ORDER, AS PROMPTED:
?
8
?
14
?
20
?
27
?
34
?
41
?
54
?
61
?
68
?
77
?
86
?
96
?
107
?
118
?
129
?
141
THE FAILURE TIMES INDICATE THAT THE ESTIMATED NUMBER
OF DEFECTIVES ENTERING THE SCREEN IS   33.
AND THE ESTIMATED SCREENING STRENGTH IS 0.521.
READY

20.   W. Silver, "Proposed Recommended Practices in Applying Broadband Vibration Screening to Electronic Hardware", Westinghouse Electric Corporation, Baltimore, Md., The Journal of Environmental Sciences, pp. 9-11, Jan.-Feb. 1981.

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15. P. L. Shove, "The Effect of Screening and Burn-in on Electronic Reliability", Admiralty Surface Weapons Establishment (UK), Report No. TR-72-46, (AD915959), November 1972.

16. C. S. Murphy, "A Guide-line Document for Early Life Failure Screening Procedures on GW Equipment", Sperry Gyroscope (UK), Report No. TR 591, September 1977.

17. C. M. Ryerson, "Principles of Manufacturing Data Management", Hughes Aircraft Company, Report No. FR 81-01-812, May 1981.

18. C. M. Ryerson, "Card Level Acceptance Testing", Hughes Aircraft Co., Paper presented at 6th Aerospace Testing Seminar, Los Angeles, March 1981.

19. K. L. Wong, "Unified Field (Failure) Theory-Demise of the Bathtub Curve", Hughes Aircraft Company, Proceedings of the 1981 Annual Reliability and Maintainability Symposium, pp. 402-406.

The values shown in Table A.2 were obtained.

Table A.2   Screening Strength Constants for Data Taken from
Raw Data.

	Constant		
G Level	B	C	D
1	6.006	.500	.201
2	4.004	.500	.401
3	3.003	.770	.401
4	2.279	.268	.720
5	4.004	.500	.801
6	2.697	.551	.751

A.1.3   Single Model Based on Averaged Table Data.   Since C = .500
occurred frequently, SAS NLIN programs were run with C fixed at
.500.   The resulting B and D values were nearly linear as
functions of g.   The lines

$$B = - .375 \ g + 5.047$$
$$D = .0863 \ g + .273$$

were fitted by use of SAS.

A.1.4   First Model Based on Weighted Averages of Table Data.   In
the Grumman tests there were 19 detectable type I faults and 12
detectable type II faults.   It was therefore decided to weight
the averages of the individual percents of detected faults by
using factors of 19/31 and 12/31, respectively.

Since the graph of time versus screening strength for 5 g
vibration level was somewhat different in shape than the graphs
for other g levels and since 1g and 2g are relatively low, the
values were found for 3, 4, and 6 g.

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APPENDIX A

DEVELOPMENT OF SCREENING STRENGTH EQUATIONS

A.1 **Screening Strength Model for Random Vibration.** Below are the steps used to obtain a single model for the screening strength of random vibration tests. Report ADR 14-04-73.2 by the Grumman Aerospace Corporation (Grumman Report, Ref. 8) supplied the raw data for the model.

A.1.1 Models Fitted to Data Taken from Graphs in Grumman Report. First, approximately fifteen ordered pairs (t, SS) were read for each of the 4 and 6 g vibration levels from the graphs. Type I and type II faults were averaged within each g level. The two resultant curves were analyzed and a model of the form

$$SS = D (1 - \exp (-t^C/B)).$$

B, C, D constants

was chosen for further analysis. The SAS NLIN program was used to find the best values of B, C, and D. The following constants were obtained and very good fit was exhibited.

Table A.1. Screening Strength Constants for Data Taken from Graphs.

	G-Level	
Constant	4g	6g
B	6.557	5.302
C	.935	.806
D	.496	.728

A.1.2 Models Fitted to Data Taken from Tables and Averaged. Since the Grumman report did not indicate how the screening strength curves were obtained from the raw data it was decided to fit a model to the data from Tables 6 and 7. Due to randomness, some of this data was not increasing with g. Wherever this occurred, an average failure value was used for both g levels. Also, the average values 2.5, 7.5, 17.5, and 42.5 were taken for t, time.

Again, SAS NLIN was used for fitting

Preceding page blank 155

was monotone increasing with g.

A.1.5 Final Model Based on Weighted Averages of Table Data. Due
to experience with the nonweighted averages, C was fixed at .500
and SAS NLIN was used to find the best corresponding values of B
and D for 3, 4, and 6 g. As before, these values were nearly
linear as functions of g. The lines

$$B = .266 \ g + 1.402$$

$$D = .144 \ g - .0862$$

were fitted using SAS.

Table A.5   Comparison of Single Model with Weighted Average
             Table Data.

g level			Time, In Minutes		
		2.5	7.5	17.5	42.5
3	#1.	.177	.246	.294	.328
	#2.	.210	.226	.278	.355
4	#1.	.232	.328	.400	.455
	#2.	.258	.307	.387	.452
6	#1.	.319	.466	.585	.689
	#2.	.307	.452	.613	.677

#1. Model value.
#2. Weighted average of table data.

A.2 Screening Strength Model for Swept Sine Vibration. Data was
obtained from tables 3 and 4 of the Grumman Report. Since there
were 19 detectable type I faults and 20 detectable type II faults,
a weighted average was used for screening strength at each value
of g and t. Average times were also taken. This averaged table
data follows in Table A.7 where it is compared to screening
strength values from the models for individual g levels and the
single model which has parameters time (t) and g levels.

     The values for constants for B, C, and D were computed
with SAS NLIN when SS was fitted to the table data for swept
sine. They were used for computation of the individual model
data in Table A.7 Constant values are shown in Table A.8.

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Following are comparisons of this model with the averaged table data.

Table A.3. Comparison of Single Model with Table Data.

g level		Time, in minutes			
		2.5	7.5	17.5	42.5
1	#1:	.103	.159	.213	.270
	#2:	.042	.042	.084	.167
2	#1:	.137	.210	.277	.348
	#2:	.167	.250	.250	.292
3	#1:	.177	.267	.349	.431
	#2:	.271	.292	.355	.428
4	#1:	.222	.333	.428	.520
	#2:	.311	.375	.445	.501
5	#1:	.277	.407	.516	.614
	#2:	.311	.375	.465	.627
6	#1:	.342	.494	.614	.714
	#2:	.350	.493	.638	.706

#1: SS = D $(1 - \exp(-t^c/B))$
#2: averaged table data.

Table A.4. Screening Strength Constants for Data from Tables Using Weighted Average.

	Constant		
g level	B	C	D
3	3.003	.500	.401
4	2.536	.240	.711
6	3.244	.621	.712

SS = D $(1 - \exp(-t^c/B))$

Parabolas were fitted through the B and C values as functions of g level. A half parabola was estimated through the D values. This approach did not yield an SS model which

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Table A.7   Comparison of Table Data with Single and
            Individual Models.

g level		Time, in minutes			
		2.5	7.5	17.5	42.5
1.5	Table	.0	.077	.180	.231
	Single Model	.051	.102	.151	.190
	Individual Model	.057	.113	.167	.208
3.0	Table	.077	.128	.205	.256
	Single Model	.075	.150	.222	.280
	Individual Model	.068	.136	.203	.256
5.0	Table	.103	.205	.359	.538
	Single Model	.107	.213	.317	.398
	Individual Model	.178	.356	.530	.668
10.0	Table	.154	.385	.564	.692
	Single Model	.185	.370	.551	.695
	Individual Model	.186	.372	.554	.698

Single Model:

$$SS = D (1 - \exp (-t^C/B)$$

$$C = .800$$

$$B(g) = .0176 \ g + 7.097$$

$$D(g) = .0635 \ g + .1065$$

"Compute.fort" was run to compare the resulting single
model to individual model and table data. See Table A.7.

Table A.6   Comparisons of Single Model with Models Fitted for
            Individual g Levels.

g level	Time, In Minutes					
	10	15	20	30	40	50
3	#1: .261	.291	.311	.336	.352	.363
	#2: .264	.286	.301	.317	.322	.332
4	#1: .353	.377	.395	.420	.438	.452
	#2: .354	.3\8	.410	.437	.445	.462
6	#1: .516	.576	.614	.656	.678	.691
	#2: .507	.564	.603	.652	.670	.704

#1:   Models fitted for each g level.
#2:   Single model:

Note that the values on the charts correspond closely and
that the single model exhibits other desired properties. SS is
monotone increasing in t and 0<D<1, t>o, C>0, B>0.

But $0 < D < 1$ for $.6 \leqslant g \leqslant 7.5$.   ($.5986.. < g < 7.543...$) and
$B > 0$ for $g > 0$.

The final screening strength model is,

$$SS = D (1 - \exp (t^{.5}/B)), \quad t > 0$$
$$B = .266 g + 1.402, \quad 0.6 < g < 7.5$$
$$D = .144 g - .0862$$

Due to experience with other SS functions, C was fixed at
.8 and SAS NLIN was run again. See Table A.9

It appeared that the 5 g constants were aberrant so lines
were fitted to the remaining values of B and D as functions of g.
These were

$$B(g) = .0176 g + 7.097$$

$$D(g) = .0635 g + .1065$$

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A.3 __Screening Strength Model for Sine Fixed Frequency__ __Vibration.__ Raw data was obtained from Table 5 and Figure 9 of the Grumman Report. In the case where table data exhibited non-monotonicity (reversals) in g, the average was taken and used for both values. There were 19 detectable type I faults and 20 detectable type II faults so a weighted average was used. Average times were also taken. This averaged table data follows in Table A.10 where it is compared to screening strength values from the single model for various g levels and the models for individual g levels.

Table A.10   Comparison of Table Data, Single Model, and Individual Models for Sine Fixed Frequency.

		Time, Minutes			
g level		2.5	7.5	17.5	42.5
1.5	Table	.0	.0	.0	.0
	Single Model	.054	.066	.077	.090
3.0	Table	.0	.051	.103	.103
	Single Model	.068	.084	.097	.113
	Individual Model	.051	.063	.073	.086
5.0	Table	.128	.154	.154	.154
	Single Model	.091	.111	.129	.150
	Individual Model	.109	.133	.154	.179
5.6	Table	.154	.205	.231	.231
	Single Model	.112	.136	.157	.183
	Individual Model	.156	.187	.215	.247
10.0	Table	.154	.179	.256	.282
	Single Model	.180	.217	.250	.288
	Individual Model	.171	.207	.240	.276
12.0	Table	.230	.230	.286	.336
	Single Model	.240	.288	.329	.376
	Individual Model	.208	.250	.287	.329

Single Model:

$$SS = D \ (1 - \exp \ (-t^C/B)$$
$$B = - .4187g + 8.620$$
$$D = .04354g + .3235 \qquad C = .200$$

Table A.8   Values for Constants for Individual Models
at Four g-Levels.

g Level	B	C	D
1.5	7.007	.800	.221
3.0	8.809	.600	.401
5.0	14.242	.789	.727
10.0	9.064	.954	.703

Table A.9   Constants for B and D with Fixed at .800:

g	B	D
1.5	7.007	.221
3.0	7.2917	.2734
5.0	14.253	.7127
10.0	7.248	.745

The single model

$$SS = D \ (1 - \exp(-t^C/B)$$

$$C = .800$$

$$B = .0176 \ g + 7.097$$

$$D = .0635 \ g + .1065$$

was selected for $0 < t < 60.0$ and $0 < g < 12.0$.

SS is monotone increasing in t for positive B, C, and D.
C is always positive. B and D are positive for positive g.
Also, $0 < D < 1$ for $g < 12.0$.

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Lines were fitted through B and D as functions of g. They are:

$$B = .4187g \_ 8.620$$

$$D - .04354g + .3235$$

The single model for sine fixed frequency,

$$SS - D (1 - \exp (-t^C/B)$$

$$C = .200$$

$$B = .419g + 8.620$$

$$D = .0435g + .324$$

t > 0 and 0 < g < 15.5 was selected. SS is monotone increasing in t for positive B, C, and D. C is always positive. D is positive for positive g. B is positive for 0 g 15.5. B is monotone decreasing in g so 1 - exp $(-t^C/B)$ is monotone increasing in g. Thus, with D also increasing in g, SS is increasing in g. Also, 0 < D < 1 for 0 < g < 15.5.

A.4   Screening Strength Models for Temperature Screens. Following is a description of the method used to obtain the screening strength equations for temperature screens. The temperature equation is an adaptation of it.
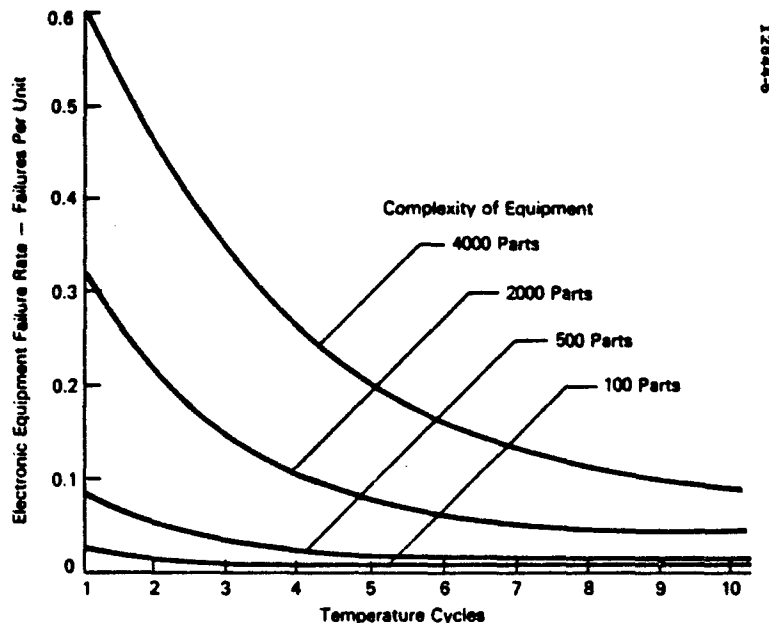
Figure A-1.   Cycles as a Function of Equipment Complexity (Ref NAVMAT P-9492)

The values for constants for B, C, and D were computed by SAS NLIN when SS was fitted to the table data. The values are shown in Table A.11. They were used for the computation of the individual model data on Table A.10.

Table A.11.   Values for Constants for Individual Models at Five g-Levels.

g level	B	C	D
3.0	7.007	.440	.201
5.0	6.006	.200	.601
6.5	4.004	.200	.601
10.0	5.005	.200	.801
12.0	4.004	.200	.801

Since C = .200 occurred frequently, C was fixed at .200 and the program run again on the 3g data. Fixing C at .200 yielded the constants

B = 8.800 and D = .401

for the 3g individual model. Thus for C = .200 the constants are:

Table A.12.   Values for B and D with C Fixed at 0.200.

g	B	D
3.0	8.800	.401
5.0	6.006	.601
6.5	4.004	.601
10.0	5.005	.801
12.0	4.004	.801

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C/minute or less and temperature extremes within -55 deg. C to
+ 75 deg. C.

Only slight modifications are necessary to adapt the SS
equation for temperature cycling to constant temperature. For
constant temperature DT becomes 1.0 and Ncy = 0.0. Replacing
Ncy is T = (time in hours) also to the 0.5 power. The range
is computed from 25 deg. C.

The revised model gives reasonable solutions for its
wide range of valid input parameters, exhibits consistency
for constant temperature and temperature cycling, and is of
the same general form as previously accepted test strength
equations without exhibiting their inconsistencies. Figures 1.5
and 1.6 show the screening strengths for the temperature
equations.

For the initial analysis, data was obtained from the temperature cycling curves of NAVMAT P-9492, shown above as Figure A.1. Comparisons of areas under the curves, reductions of failure rates, and other forms of analysis were used to obtain data points. The widely used 5 deg. C/minute rate of temperature change and 100 deg. C temperature range were assumed.

An exponential function was fit to the data. However, examination of a grid of screening strength values computed using this equation for typical ranges of the input parameters indicated that the computed screening strengths were higher than generally accepted test strengths.

Following extensive analysis, a set of subjective, but widely acceptable, screening strength values was fixed for 10 deg. C to 110 deg. C, range from 2 to 18 deg. C/minute temperature rate of change, and 5, 10, and 20 cycles. Curves were sketched through the set of points and additional data points were read from the graph. An equation which closely fit these data points and exhibits other desired properties follows:

$$SS = D \left(1.0 - \exp(-0.0023 \times (Ln(e + DT))^{2.7} x Ncy^{.5} x R^{.6}) \right) \quad (A-1)$$

$D = 0.85$

DT = temperature rate of change (deg. C/min)

$1 < DT < 20$ (see below)

Ncy = number of repeated cycles

R = temperature range (deg. C)= high temperature - low temperature

high temperature $<$ 75 deg. C; low temperature $>$ -55 deg. C

SS = screening strength

Examination of a grid of screening test strength points computed using the above equation revealed reasonable values for reasonable values of the input parameters.

Since extremely low rates of change do not yield real temperature cycling stress, the equation is not to be used for DT less than 1 deg. C/min. If low rates of change for screening strength should be computed use the modifications for constant temperature given below.

Also, the data considered did not include extremely high rates of change or extremely large ranges. Therefore, the equation is only proposed for rates of change of 20 deg.

If it is desired to make inferences on one or the other of SS or p this can be done as shown in the following example:

Example   Suppose that the planned values of p, SS are respectively, 0.005, 0.70 and that N = 10,000 "parts". After an assembly level temperature cycling screen X = 17 dropouts are observed.

The planned mean number of drop-outs = μ_p = 10,000 (0.005) (0.70) = 35 and the lower and upper bounds from the adaptive routines are (20, 51) and since 17 does not lie between 20 and 51 (inclusive) the screen has not behaved as planned. Assuming the planned p = 0.005 is about correct = μ_p obs. drop-outs = 17 = NpSS. This means SS = 17/50 = 0.34.

This estimated screening strength is considerably different than 0.70 and an adjustment in the screening parameters is indicated. If a confidence interval on the true SS (assuming p = 0.005 is correct) is desired it can be obtained from a confidence interval for μp. Based on X=17 a 0.99 confidence interval is (see page 190, Handbook of Probability and Statistics, Chemical Rubber Co., 1966 Cleveland, Ohio 44114 for ready to use tables)

$$P(8.2 < \mu < 30.7/X=17, p=0.005) = 0.99$$

Dividing each endpoint by Np = 50

$$P(0.164 < SS < 0.614/X=17, p=0.005) = 0.99$$

and (0.164, 0.614) is and 0.99 confidence interval for SS.

The SDO model has, in addition to the expected total dropouts (and the accompanying 0.99 bounds) the similar numbers for part/component dropouts and workmanship/manufacturing defects separately. Thus, if the user can classify failures into two categories: parts/components versus workmanship/manufacturing separate checks can be made of the expected dropouts as described in the above example.

B.1.2   Adaptive Screening for Unit/System Level Screens: In a unit/system level screen, failures that are precipitated will be repaired; an entire unit or system will not be discarded. Thus a model is needed to compute the expected number of failures in the selected test time T. In Ref. 22, a Chance Defective Exponential (CDE) time-to-failure distribution was introduced:

$$P \text{ (unit lifetime} \leq t) = \left[\exp - (a_0 t + a_1 (1-e^{-a_2 t})) \right] , t > 0, \; a_0, a_1, a_2 > 0$$

APPENDIX B

STATISTICAL ASPECTS OF ADAPTIVE SCREENING

B.1   Adaptive   Screening One of the cardinal "rules-of-thumb" of stress screening is that a screen should never be selected or applied without an idea of its screening strength (SS = probability of detecting a latent defect given that a latent defect is present).

In order to monitor and control a stress screening program, even one consisting only of a single screen, it is necessary to compare the actual results of the screen to the planned results.   The results of a screen are commonly of two forms:

    i)   number of dropouts/failures

    ii)   times to failure

The first is usually called "attribute" data and the latter is called "variables" data.

B.1.1 Adaptive   Screening   for   Dropout/Failure   Data:

Suppose that prior to the running of a given screen the planned (from, say, the screening strength equations) SS has been determined; suppose also the same is true of the incoming latent defect rate p. Further, let N denote the known or estimated total number of opportunities for latent defects to occur (usually parts, connections, solder joints, etc.). The probability distribution of X, the number of drop-outs, is

$$P(X=x) = \binom{N}{x} = (pSS)^x (1-pSS)^{N-x}, \text{ that is}$$

X has a binomial distribution. Since pSS is usually quite small (e.g. < 0.01) and N quite large (e.g. > 1000) the Poisson distribution is used (in the adaptive routine of the SDO model):

$$P(X=x)=(e^{-\mu} \mu^x)/x! \quad \mu=NpSS.$$

The SDO adaptive routine uses the planned values (from the main program) for p and SS to compute NpSS $\equiv \mu_p$ and using a computer routine prints out the upper and lower bounds on the total OBSERVED number of drop-outs based on a 0.99 probability interval. That is, if the observed number of drop-outs (symbolized by X above) is outside the bounds, the screening is not behaving as planned.

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APPENDIX C

THE CHANCE DEFECTIVE EXPONENTIAL (CDE) MODEL

The CDE Model:

$$\bar{F}_s(t) = P(\text{unit life} > t) = \exp\left[-(a_0 t + a_1 (1-e^{-a_2 t}))\right] \qquad (C-1)$$

is extremely attractive. It arises from reasonable physical considerations and it can furnish a direct (unconfounded with p) estimate of screening strength (SS).

Actually the CDE of C-1 involves two assumptions that need not be made and that do not seem to improve it's tractability. The assumption that the probability distribution of n (the random number of latent defects) is Poisson (with mean a_1 $=Np$) may be replaced by the exact binomial distribution:

$$P(n) = \binom{N}{n} p^n (1-p)^{N-n} \qquad (p = \text{the probility of a latent defect})$$

Also it was assumed that the total failure for all of the good parts (of which there are actually $N-n$) is a constant a_0. If we write a_0' for the failure rate of a <u>single</u> good part and remove both of these assumptions.

$$\bar{F}_s(t) = \left[(1-p) e^{-a_0' t} + p e^{-a_2 t}\right]^N.$$

The form (C-1) of the CDE has three unknown parameters $a = (a_0, a_1, a_2)$ while the "exact" CDE above has four parameters - or does it? The parameter N is known so that the only unknown parameters are a_0', a_2, p.

A quantity of interest is the probability that a defective unit (symbolized by D) will live through the test i.e. (if $t=$ unit life), $P(t > T/D)$, it can and has been shown that:

$$P(t>T|D) = \frac{e^{-\left[a_0 T + a_1 (1-e^{-a_2 T})\right]} - e^{-\left[a_1 + a_0 T\right]}}{(1-e^{-a_1})} \qquad (C-2)$$

The screening strength (SS) per latent defect is

It will be assumed, as in Ref. 22, that the unit/system failure process is a Nonhomogeneous Poisson Process (NHPP) with the mean value function (say $M(t)$) of the CDE:

$$M(t) = \text{Expected } \# \text{ of occurrences in } (0,t) = a_0 t + a_1 (1 - e^{-a_2 t})$$

The CDE arises naturally: assuming that a group of N parts contains $n \ll N$ latent defect parts with constant failure rate a_2; a large number $(N-n)$ of good parts with constant failure rate (<u>for the totality of good parts</u>) a_0; and expected number of latent defect parts $\bar{a}_1 = Np$ (p = the incoming latent defect rate) then the probability of survival of a system comprised a total of N parts (given n latent defective parts) is P (system live $> t/n$ bad parts)

$$= (e^{-a_0 t}) \left[e^{-a_2 nt} \right]$$

Multiplying by probability of n latent defective parts, namely

$$(e^{-a_1} a_1^n)/n!$$

and summing out n, the unconditional survival distribution is

$$P(\text{unit life time} > t) = \bar{F}_s(t) = \exp\left\{ - \left[a_0 t + a_1 (1 - e^{-a_2 t}) \right] \right\}$$

Since $a_1 = Np$, $a_0 = N \lambda g$ = failure rate of a good part, $a_2 = k \lambda g$ (latent defect failure rate),

PLANNED values of $a = (a_0, a_1, a_2)$, say $\underline{a}^* = (a_0^*, a_1^*, a_2^*)$

can be obtained. The planned expected number of occurrences in a screen of length T is

$$M(T) = a_0^* T + a_1^* (1 - e^{-a_2^* T})$$

and this is the value computed by the adaptive routine at the unit/system level screens.

When the actual failure times (during the unit/system level screen) are available, which is usually very costly, the parameter vector $\underline{a}$ might be estimated and more extensive data analysis performed. This topic is discussed in the Appendix C. At this point such data analysis is too costly and intractable for the adaptive routine.

maximizing vector $\hat{a}$ are said to be the maximum likelihood
estimates (MLE's). On the other hand one might differentiate
(C-4) or its logarithim with respect $a_0, a_1, a_2,$ and iter-
atively solve three equations in three unknowns.

There are non-trivial problems with either approach,
starting points are required and these are not easy to come by.
Also the orders of magnitude of $a_0, a_1, a_2,$ are quite different
which causes other problems. Usually good starting points are
obtained by using another method of estimation. For example the
moment estimates of $\underline{a}$ say $\bar{a}$ ($\bar{a}_0, \bar{a}_1, \bar{a}_2$) could be used as start-
ing points or in the worst case they could be used as estimates
directly. Unfortunately the moments of the CDE, even the first
(the mean) are intractable. All this discussion leaves aside
the important question: over the space of all possible observed
data $\{t_{ij}\}$ for which sets of t_{ij} will the maximum of (C-4) exist
and/or be unique?

However, assuming a user can obtain estimates of $\underline{a}$
which to him are satisfactory the direct estimate of SS can be
obtained, namely, $1-e^{-\hat{a}_2 T}$

In fact, there is another approach to estimating
$\underline{a}$. It is the non-linear squares approach using the
observed cumulative failures as the dependent variable and
fitting the observed cumulative failures to the mean value
function,

$$M(t) = a_0 t + a_1 (1-e^{-a_2 t})$$

From a purely statistical standpoint this method is not as
satisfying as the maximum likelihood method. Indeed the
method considered here would better be called "pseudo" least
squares. The UCLA BIOMED CAL non-linear least squares
program (BMD07R) seems to have problems of convergence and
starting points as well.

$$SS = 1 - \exp(-a_2 T) \qquad (C-3)$$

Thus, if a_2 can be estimated the component screening strength can be estimated directly (i.e. without being confounded with the incoming latent defect rate p.)

In fact the only method of estimating SS directly (other than the above method) which is known is that of "seeding" latent defects so that the number initially present is known. This latter approach has serious shortcomings. For example some latent defects are impossible to seed or perhaps a better word would be impossible to "simulate".

Unfortunately, obtaining estimates of the vector $\underline{a}$ in the CDE model is difficult even though Fertig (Ref. 22) presented some successful cases.

The likelihood function (i.e. the joint probability density of the failure times) is

$$\prod_{j=1}^{N} (1 - F(T_j; \underline{a})) \prod_{i=1}^{r_j} (a_0 + a_1 a_2 e^{-a_2 t_{ij}}) \qquad (C-4)$$

where: N = number of systems under test (screen)

T_j = length of test for jth system

r_j = number of failures observed on the jth system

t_{ij} = the ith the failure time ($i=1,\ldots,r_j$) on the jth system

$$t_{ij} \leqslant t_{i+1,j}, \quad i = 1,\ldots, r_j-1$$

$$1-F(T_j;\underline{a}) = \bar{F}_s(T) \text{ given in (C-1)}$$

Usually the N systems are all on the same screen and hence $T_j \equiv T$ for all j. It is also not uncommon that $N = 1$.

In any case, based on the failure times the function (in C-4)) can theoretically be evaluated by optimization techniques to find the vector $\hat{a} = (\hat{a}_0, \hat{a}_1, \hat{a}_2)$ which makes (C-4) the largest, i.e., maximizes (C-4). The components of the

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APPENDIX E

LONG TERM FIELD RELIABILITY IMPROVEMENT THROUGH NATURAL LATENT DEFECT REDUCTION

If N represents the total number of opportunities (parts, solder joints, connections et. al.) for a latent defect and if p is the probability of occurrence of a latent defect, then when an assembly, unit or equipment has been constructed the probability that exactly n of the N opportunities represent latent defects is given by the binomial distribution:

$$P(n) = \binom{N}{n} p^n (1-p)^{N-n}$$

which, because N is usually large and p usually small, is well-approximated by the Poisson distribution.

However, the major point of consideration is the behavior of n (the number of latent defects) and p (the latent defect rate or probability of occurrence) as the unit is operated for a long time in the field. Indeed suppose each time the unit fails, with constant rate $(N-n)\lambda g$ for the good "parts" and constant rate $nk\lambda g$ for the bad "parts", that it is repaired with a good "part" with probability $1-p$ and repaired with a bad (latent defect) "part" with probability p. That is, it is assumed that the repairs are made at the same (latent) defect rate as that which previously existed (when the unit was built). The factor $k > 1$ is the ratio of the latent defect failure rate to the good part failure rate.

It can be shown that as t (operating time) $\to \infty$

$$P(n) = \binom{N}{n} (p^*)^n (1-p^*)^{N-n} \qquad \text{(E-1)}$$

where $p^* = \dfrac{p}{k(1-p) + p} \approx \dfrac{p}{k}$

This does <u>not</u> mean that the random number of latent defects, n, will approach a constant and stay there; it means that n will vary, with mean Np^*. It also means that the long-run latent defect probability is p^*.

Note also that since $k > 1$, $p^* < p$ always.

APPENDIX D

APPROXIMATION OF SCREENING STRENGTH USING OBSERVED MTBF

Here it is assumed that, at the equipment or system level, estimates of the MTBF with and without a particular "screening sequence" (perhaps consisting of only one screen) are available.

Let N be the number of opportunities (parts connections) for the occurrence of a latent defect in an equipment or system. Then, in terms of expected values, the system failure rate at time $t = 0$ and prior to a screen is

$$\lambda_{u.s.} = N (1-p)\lambda_g + Npk\lambda_g \qquad (D-1)$$

where: $k > 1$ is the factor which when multiplied by the non-defective <u>part</u> failure rate yields the latent defect <u>part</u> failure rate; p is the latent defect occurrence probability (rate) and u.s. represents unscreened.

After the screen, in terms of expected values the equipment/system failure rate is

$$\lambda_s = N \left[(1-p)(1-SS)\right] \lambda_g + Npk\lambda_g (1-SS) \qquad (D-2)$$

where: SS is the screening strength of the screen. Using (D-1) and (D-2)

$$SS = (\lambda_{u.s.} - \lambda_s)/(\lambda_{u.s.} - N\lambda) \qquad \lambda_s > N\lambda$$

The largest SS can be is when $N\lambda = \lambda_s$; then SS is one. The smallest SS can be is when $N\lambda \to 0$ and then it is $1 - (\lambda_s/\lambda_{u.s.})$

$$= 1 - \frac{MTBF_{u.s.}}{MTBF_s} .$$

Example: Suppose that two pieces of electrical equipment have MTBF's (field observed) of 100 and 250, respectively, and that the first (100 hr. MTBF) has been unscreened while the latter (250 hr. MTBF) was subjected to a 15 min. 6g (RMS) random vibration screen. Then the strength of that screen, namely SS, is at least $1-100/250 = 0.6$.
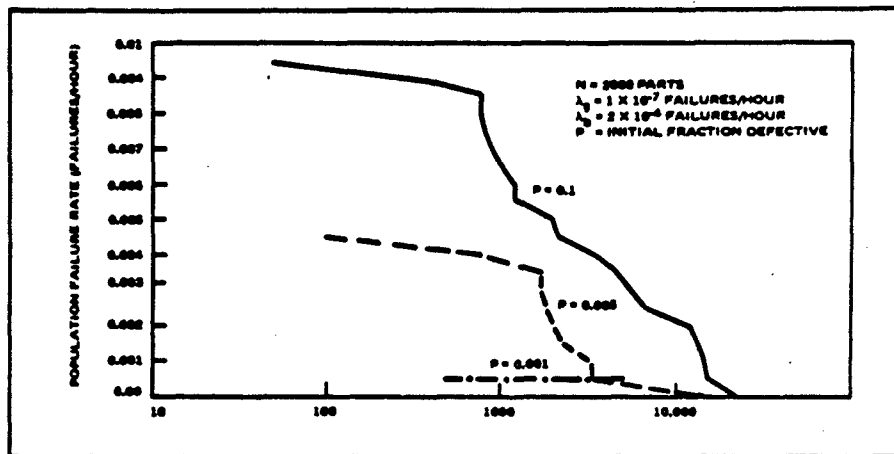
Figure E.1. Decreasing Failure Rate with Time, 2,000 Parts
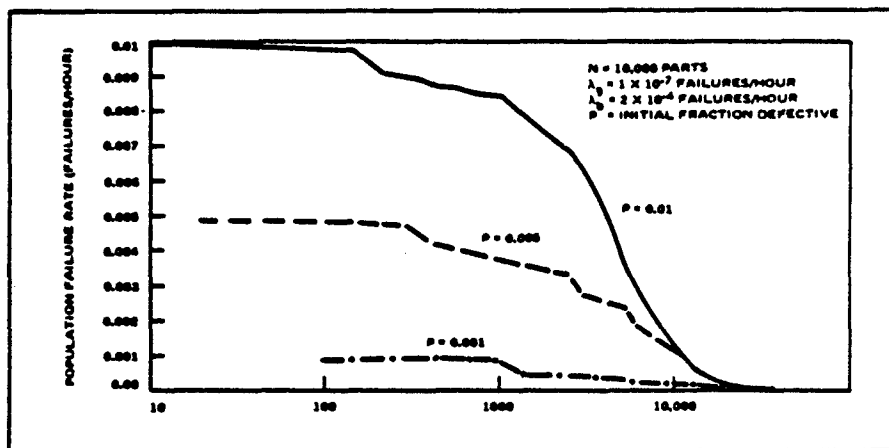
Figure E.2. Decreasing Failure Rate with Time, 10,000 Parts
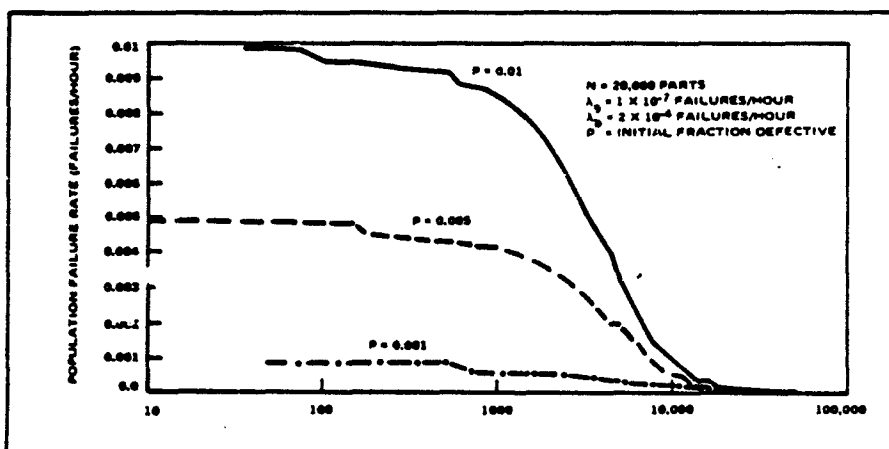
Figure E.3. Decreasing Failure Rate with Time, 20,000 Parts

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Example: Suppose $N = 2000$, $p = 0.005$, $\lambda g = 10^{-7}$ and $k = 2\times10^{3}$.

Then

$$p^* = \frac{0.005}{1990 + .005} = 2.5 \times 10^{-6}$$

An important question is: how long does it take to approach (E-1). The mathematical result requires $t \to \infty$. The accompanying three figures give an idea of the rate of decrease for nine typical cases: $p = .001$, .005 and .01,

$p = 0.001$, 0.005, and 0.01

$N = 2000$, 10,000, and 20,000

$\lambda_g = 10^{-7}$

$k\lambda g = 2 \times 10^{-4}$

The data in the three figures were derived from a simulation program which simulated failures of both good and bad parts and replacement of the failed part from populations containing p fraction defective.

TABLE F.1   SSM Internal Constants.

Description	Internal Value	Lines in Program Where Appears
If two (MTBF, cost) pairs differ by less than this amount during the optimization one of them is eliminated from consideration	0.00001	Program PREFIX.SDO.FORT, line: MAIN 200
Number of divisions in the range of the parameter to be optimized upon.	5	Program PREFIX.SDO.FORT, line: MAIN 190 (Note: Arrays will need to be made extremely large if this is increased).
Multipliers which yield failure rates of latent defective parts and workmanship (multiplied times failure rate of good parts or workmanship).	(parts) 2×10^3 (wkm) 1×10^3	Program PREFIX.SDO.FORT, lines: MAIN 2220 MAIN 2230
Repair costs: Assembly Unit System	$45 $300 $990	Program SDO.FORT, lines: DATA 890 DATA 910 DATA 930
Percent of test time considered labor time. Assembly Unit System	15% 15% 100%	Program SD01.FORT, lines: SSPR200 through SSPR1100 (each test can be handled separately).

APPENDIX F

MODEL COMPUTER PROGRAM LISTINGS

The three computer programs comprising the SSM are,

    1)   PREFIX

    2)   SDO1

    3)   ADAPT

Listings of those programs are contained in this appendix. Below is a table of internal constants, identifying the values assigned to the constants and the line number in the program where that constant can be found. This enables the user to modify the program by altering the constants to more closely fit the users own hardware characteristics, production processes and screening conditions.

PROGRAM LISTING FOR PREFIX. SDO. FORT

TABLE F.1 SSM Internal Constants (Continued)

Description	Internal Value	Lines in Program Where Appears
Detection Probability (probability of detection is inherent in screening strength equations)	1	Program SDO1.FORT, line: DATA 390
Maximum duration of suggested improved screen in "Adapt" Constant Temperature Cycled Temp. Vibration	240 hours 40 cycles 60 min.	Program ADAPT.FORT, lines: SOLV220 SOLV250 SOLV280
No. of levels	3	Program PREFIX.SDO.FORT, lines: MAIN 210
Number of Rework Cycles	1	(Requires fairly extensive rewriting)
Starting points for ZXSSQ	Computed from model data is expected values for a_1, a_2	Program ADAPT.FORT, lines: OPT180-190
Convergence Criterion and Options for ZXSSQ	See documentation for ZXSSQ.	Program ADAPT.FORT, lines: OPT100-170

```
      READ (5,*) BMIN11(KZ),BMAX12(KZ)                                    MAIN 560
      BMIN12(KZ)=0.                                                       MAIN 570
      IF (OPTC.EQ.1.0) BMIN12(KZ)=BMAX12(KZ)                             MAIN 580
      BMAX11(KZ)=BMIN11(KZ)                                              MAIN 590
      GO TO 180                                                          MAIN 600
 60   IF (ISCR(KZ).NE.2) GO TO 80                                        MAIN 610
      WRITE (6,410) KZ                                                   MAIN 620
      IF (OPTC.EQ.1.) GO TO 70                                           MAIN 630
      WRITE (6,420)                                                      MAIN 640
      READ (5,*) IDCYT                                                   MAIN 650
      IF (IDCYT.NE.0) GO TO 70                                           MAIN 660
      CMAX21(KZ)=71.0                                                    MAIN 670
      BMIN21(KZ)=71.0                                                    MAIN 680
      BMAX22(KZ)=-54.0                                                   MAIN 690
      BMIN22(KZ)=-54.0                                                   MAIN 700
      BMAX23(KZ)=5.0                                                     MAIN 710
      DMIN23(KZ)=5.0                                                     MAIN 720
      BMAX24(KZ)=20.0                                                    MAIN 730
      BMIN24(KZ)=0.0                                                     MAIN 740
      IF (OPTC.EQ.1.0) BMIN24(KZ)=BMAX24(KZ)                            MAIN 750
      GO TO 180                                                          MAIN 760
 70   WRITE (6,430)                                                      MAIN 770
      READ (5,*) BMAX21(KZ),BMAX22(KZ),BMAX23(KZ),BMAX24(KZ)            MAIN 780
      BMIN24(KZ)=0.                                                      MAIN 790
      IF (OPTC.EQ.1.0) BMIN24(KZ)=BMAX24(KZ)                            MAIN 800
      CMIN21(KZ)=BMAX21(KZ)                                              MAIN 810
      BMIN22(KZ)=BMAX22(KZ)                                              MAIN 820
      CMIN23(KZ)=BMAX23(KZ)                                              MAIN 830
      GO TO 180                                                          MAIN 840
 80   IF (ISCR(KZ).NE.3) GO TO 120                                       MAIN 850
      WRITE (6,440) KZ                                                   MAIN 860
      IF (OPTC.EQ.1.0) GO TO 90                                          MAIN 870
      WRITE (6,450)                                                      MAIN 880
      READ (5,*) IDRV                                                    MAIN 890
      IF (IDRV.NE.0) GO TO 90                                            MAIN 900
      CMAX31(KZ)=6.0                                                     MAIN 910
      BMIN31(KZ)=6.0                                                     MAIN 920
      BMAX32(KZ)=10.0                                                    MAIN 930
      BMIN32(KZ)=0.0                                                     MAIN 940
      IF (OPTC.EQ.1.0) BMIN32(KZ)=BMAX32(KZ)                            MAIN 950
      GO TO 180                                                          MAIN 960
 90   WRITE (6,460)                                                      MAIN 970
      READ (5,*) BMAX31(KZ),BMAX32(KZ)                                  MAIN 980
      IF (BMAX31(KZ).LE.7.5) GO TO 100                                   MAIN 990
      CMAX31(KZ)=7.5                                                     MAIN1000
      WRITE (6,470)                                                      MAIN1010
      GO TO 110                                                          MAIN1020
 100  IF (BMAX31(KZ).GE.0.6) GO TO 110                                   MAIN1030
      BMAX31(KZ)=0.6                                                     MAIN1040
      WRITE (6,480)                                                      MAIN1050
 110  BMIN32(KZ)=0.0                                                     MAIN1060
      CMIN31(KZ)=BMAX31(KZ)                                              MAIN1070
      IF (OPTC.EQ.1.0) BMIN32(KZ)=BMAX32(KZ)                            MAIN1080
      GO TO 180                                                          MAIN1090
 120  IF (ISCR(KZ).NE.4) GO TO 150                                       MAIN1100
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      WRITE (6,490) KZ                                            MAIN1110
      IF (OPTC.EQ.1.) GO TO 130                                   MAIN1120
      WRITE (6,500)                                               MAIN1130
      READ (5,*) IDSSV                                            MAIN1140
      IF (IDSSV.NE.0) GO TO 130                                   MAIN1150
      BMAX41(KZ)=6.0                                              MAIN1160
      BMIN41(KZ)=6.0                                              MAIN1170
      BMAX42(KZ)=10.0                                             MAIN1180
      BMIN42(KZ)=0.0                                              MAIN1190
      IF (OPTC.EQ.1.0) BMIN42(KZ)=BMAX42(KZ)                      MAIN1200
      GO TO 180                                                   MAIN1210
  130 WRITE (6,510)                                               MAIN1220
      READ (5,*) BMAX41(KZ),BMAX42(KZ)                            MAIN1230
      IF (BMAX41(KZ).LE.14.0) GO TO 140                           MAIN1240
      BMAX41(KZ)=14.0                                             MAIN1250
      WRITE (6,520)                                               MAIN1260
  140 BMIN42(KZ)=0.0                                              MAIN1270
      IF (OPTC.EQ.1.0) BMIN42(KZ)=BMAX42(KZ)                      MAIN1280
      BMIN41(KZ)=BMAX41(KZ)                                       MAIN1290
      GO TO 180                                                   MAIN1300
  150 IF (ISCR(KZ).NE.5) GO TO 190                                MAIN1310
      WRITE (6,530) KZ                                            MAIN1320
      IF (OPTC.EQ.1.) GO TO 160                                   MAIN1330
      WRITE (6,540)                                               MAIN1340
      READ (5,*) IDSFV                                            MAIN1350
      IF (IDSFV.NE.0) GO TO 160                                   MAIN1360
      BMAX51(KZ)=6.0                                              MAIN1370
      BMIN51(KZ)=6.0                                              MAIN1380
      BMAX52(KZ)=10.0                                             MAIN1390
      BMIN52(KZ)=0.0                                              MAIN1400
      IF (OPTC.EQ.1.0) BMIN52(KZ)=BMAX52(KZ)                      MAIN1410
      GO TO 180                                                   MAIN1420
  160 WRITE (6,550)                                               MAIN1430
      READ (5,*) BMAX51(KZ),BMAX52(KZ)                            MAIN1440
      IF (BMAX51(KZ).LE.15.5) GO TO 170                           MAIN1450
      BMAX51(KZ)=15.5                                             MAIN1460
      WRITE (6,560)                                               MAIN1470
  170 BMIN52(KZ)=0.0                                              MAIN1480
      IF (OPTC.EQ.1.0) BMIN52(KZ)=BMAX52(KZ)                      MAIN1490
      BMIN51(KZ)=BMAX51(KZ)                                       MAIN1500
  180 WRITE (6,570) KZ                                            MAIN1510
      READ (5,*) A1A(KZ)                                          MAIN1520
      WRITE (6,580)                                               MAIN1530
      READ (5,*) B1A(KZ)                                          MAIN1540
      IF (B1A(KZ).EQ.0.0) B1A(KZ)=CPHR                            MAIN1550
      B2(KZ)=0.                                                   MAIN1560
      WRITE (6,590)                                               MAIN1570
      READ (5,*) B3(KZ)                                           MAIN1580
      WRITE (6,600)                                               MAIN1590
      READ (5,*) ADEF(KZ)                                         MAIN1600
      IF (ADEF(1).EQ.0.0) ADEF(1)=.002                            MAIN1610
      IF (ADEF(2).EQ.0.0) ADEF(2)=.001                            MAIN1620
      IF (ADEF(3).EQ.0.0) ADEF(3)=.0005                           MAIN1630
  190 CONTINUE                                                    MAIN1640
      DO 200 IIS=1,3                                              MAIN1650
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200    IF (ISCR(IIS).LE.0) ISCR(IIS)=1 ...........................  MAIN1660
       WRITE (2,*) ISCR ...........................................  MAIN1670
       WRITE (8,*) F ..............................................  MAIN1680
       DO 220 INDEX=1,M ...........................................  MAIN1690
       DO 220 INDEX2=1,5 ..........................................  MAIN1700
       DUMB1=1000. ................................................  MAIN1710
       DUMB2=1000. ................................................  MAIN1720
       IF (ISCR(INDEX).EQ.INDEX2) GO TO 210 .......................  MAIN1730
       WRITE (10,*) DUMB1,DUMB2 ...................................  MAIN1740
       GO TO 220 ..................................................  MAIN1750
210    WRITE (10,*) A1A(INDEX),B1A(INDEX) .........................  MAIN1760
220    CONTINUE ...................................................  MAIN1770
       WRITE (11,610) P ...........................................  MAIN1780
       WRITE (9,620) R1,R2 ........................................  MAIN1790
       DO 230 I=1,3 ...............................................  MAIN1800
       WRITE (12,*) BMAX11(I),BMIN11(I) ...........................  MAIN1810
       WRITE (12,*) BMAX12(I),BMIN12(I) ...........................  MAIN1820
       WRITE (12,*) BMAX21(I),BMIN21(I) ...........................  MAIN1830
       WRITE (12,*) BMAX22(I),BMIN22(I) ...........................  MAIN1840
       WRITE (12,*) BMAX23(I),BMIN23(I) ...........................  MAIN1850
       WRITE (12,*) BMAX24(I),BMIN24(I) ...........................  MAIN1860
       WRITE (12,*) BMAX31(I),BMIN31(I) ...........................  MAIN1870
       WRITE (12,*) BMAX32(I),BMIN32(I) ...........................  MAIN1880
       WRITE (12,*) BMAX41(I),BMIN41(I) ...........................  MAIN1890
       WRITE (12,*) BMAX42(I),BMIN42(I) ...........................  MAIN1900
       WRITE (12,*) BMAX51(I),BMIN51(I) ...........................  MAIN1910
       WRITE (12,*) BMAX52(I),BMIN52(I) ...........................  MAIN1920
230    CONTINUE ...................................................  MAIN1930
       WRITE (4,*) NCYC,M,NPARTS,CREQO,E,ITV,XMTBF,CPHR ...........  MAIN1940
       WRITE (4,630) .............................................  MAIN1950
       WRITE (4,*) POEF ..........................................  MAIN1960
       DO 240 IX=1,M .............................................  MAIN1970
240    WRITE (4,*) ADEF(IX) ......................................  MAIN1980
       WRITE (4,630) .............................................  MAIN1990
       DO 260 IX=1,M .............................................  MAIN2000
       DO 250 IU=1,5 .............................................  MAIN2010
250    WRITE (4,*) B2(IX),B3(IX) .................................  MAIN2020
260    CONTINUE ..................................................  MAIN2030
       GO TO 300 .................................................  MAIN2040
270    WRITE (6,640) .............................................  MAIN2050
       WRITE (6,650) .............................................  MAIN2060
       READ (5,*) XMTBF ..........................................  MAIN2070
       IF (XMTBF.EQ.0.) GO TO 280 ................................  MAIN2080
       CREQO=0. ..................................................  MAIN2090
       GO TO 290 .................................................  MAIN2100
280    WRITE (6,660) .............................................  MAIN2110
       READ (5,*) CREQO ..........................................  MAIN2120
       IF (CREQO.NE.0.0) GO TO 290 ...............................  MAIN2130
       CREQO=1.E10 ...............................................  MAIN2140
       OPTC=1.0 ..................................................  MAIN2150
290    WRITE (6,670) .............................................  MAIN2160
       READ (5,*) NPARTS .........................................  MAIN2170
       WRITE (6,680) .............................................  MAIN2180
       READ (5,*) XLAMP1,XLAMC1 ..................................  MAIN2190
       IF (XLAMP1.EQ.0.0) XLAMP1=1.E-7 ...........................  MAIN2200
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      IF (XLAMC1.EQ.0.0) XLAMC1=1.E-10                              MAIN2210
      XLAMP2=2.E3*XLAMP1                                            MAIN2220
      XLAMC2=1.E3*XLAMC1                                            MAIN2230
      NOP=21.6*NPARTS                                               MAIN2240
      WRITE (13,*) NOP,XLAMP1,XLAMP2,XLAMC1,XLAMC2                  MAIN2250
      WRITE (6,690)                                                 MAIN2260
      READ (5,*) PDEF                                               MAIN2270
C     WRITE(6,586)                                                  MAIN2280
C     READ(5,*)CPHR                                                 MAIN2290
      CFHR=30.                                                      MAIN2300
      GO TO 10                                                      MAIN2310
300   STOP                                                          MAIN2320
C                                                                   MAIN2330
310   FORMAT (1X////14X,8('*'),'TEST AND PARAMETER SELECTION',8('*')////)MAIN2340
320   FORMAT (1X//5X,'FOLLOWING ',' ARE THE AVAILABLE SCREENS :'//5X,'1.MAIN2350
     1 CONSTANT',' TEMPERATURE'/5X,'2.  CYCLED TEMPERATURE'/5X,'3.  RANMAIN2360
     2DOM VIBRATION'/5X,'4.  SINE SWEEP',' VIBRATION'/5X,'5.  SINE FIXEDMAIN2370
     3 VIBRATION'//)                                                MAIN2380
330   FORMAT (5X/5X,'DEFAULTS ARE:'/10X,'LEVEL 1',10X,'LEVEL 2',10X,'LEVMAIN2390
     1EL 3'/6X,'TEMP. CYCLING',7X,'RAN.VIB',7X,'CONST. TEMP.'/11X,'(2)',MAIN2400
     214X,'(3)',14X,'(1)'////)                                     MAIN2410
340   FORMAT (5X,'IF YOU WISH DEFAULT SCREENS ENTER ZERO. IF NOT,',' ENTMAIN2420
     1ER 1:')                                                      MAIN2430
350   FORMAT (1X//5X,'ENTER YOUR SCREEN SEQUENCE AS PROMPTED USING ','NUMAIN2440
     1MBERS FROM ABOVE LISTING:'/5X,'IF YOU DO NOT WISH TO SCREEN ','AT MAIN2450
     2A PARTICULAR LEVEL, ENTER ZERO:')                            MAIN2460
360   FORMAT (1X,'FOR LEVEL',I2,' THE SCREEN NUMBER DESIRED IS:')   MAIN2470
370   FORMAT (1X//24X,8('*'),'LEVEL',I2,8('*')///)                 MAIN2480
380   FORMAT (5X,'CONSTANT TEMPERATURE, LEVEL',I2)                 MAIN2490
390   FORMAT (5X,'THE DEFAULT VALUES ARE:'/5X,'TEMPERATURE=70 DEG C'/5X,MAIN2500
     1'TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS'/5X,'IF YOU WISH THE MAIN2510
     2DEFAULT VALUES, ENTER ZERO. IF NOT,','ENTER 1:')             MAIN2520
400   FORMAT (5X,'ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'TMAIN2530
     1EMP IN DEG C. ',' TIME IN HRS:'/5X,'(TEMP MUST BE LESS THAN +75 DEGMAIN2540
     2 C)')                                                        MAIN2550
410   FORMAT (5X,'TEMPERATURE CYCLING, LEVEL',I2)                  MAIN2560
420   FORMAT (5X,'THE DEFAULT ',' VALUES ARE:'/5X,'LOWER TEMP=-54 DEG C'/MAIN2570
     15X,'UPPER TEMP=71 DEG C'/5X,'TEMP. RATE OF CHANGE=5 DEG C/MIN'/5X, MAIN2580
     2'RANGE OF CYCLES TO BE',' INVESTIGATED=0 TO 20'/5X,'IF YOU WISH THMAIN2590
     3E DEFAULT VALUES ','ENTER ZERO. IF NOT, ENTER 1:')           MAIN2600
430   FORMAT (5X,'ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'UMAIN2610
     1PPER TEMP.,LOWER TEMP.,TEMP. RATE OF CHANGE, NO.',' OF CYCLES:'/5XMAIN2620
     2,'(TEMPERATURE RANGE MUST BE WITHIN -55 TO +75',' DEG C'/5X,'AND RMAIN2630
     3ATE OF CHANGE BETWEEN 1 AND 20 DEG C/MIN)')                  MAIN2640
440   FORMAT (5X,'RANDOM VIBRATION, LEVEL',I2)                     MAIN2650
450   FORMAT (5X,'THE DEFAULT VALUES',' ARE:'/5X,'G-LEVEL=6 G'/5X,'RANGEMAIN2660
     1 OF TIME TO BE INVESTIGATED=0 TO 10 MIN.'/5X,'IF YOU WISH THE DEFAMAIN2670
     2ULT VALUES ENTER ZERO. IF NOT, ENTER 1:')                   MAIN2680
460   FORMAT (5X,'ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'GMAIN2690
     1 LEVEL,',' TIME IN MIN:'/5X,'(G LEVEL MUST BE BETWEEN .6 AND 7.5)'MAIN2700
     2)                                                            MAIN2710
470   FORMAT (5X,'G-LEVEL OUT OF ALLOWABLE RANGE--PARAMETER SET AT 7.5',MAIN2720
     1' G.')                                                       MAIN2730
480   FORMAT (5X,'G-LEVEL OUT OF ALLOWABLE RANGE--PARAMETER ','SET AT 0.MAIN2740
     16 G.')                                                       MAIN2750
```

```
490    FORMAT (5X,'SINE SWEEP VIBRATION, LEVEL',I2)              MAIN2760
500    FORMAT (5X,'THE DEFAULT VALUES ARE:'/5X,'G-LEVEL=6 G'/5X,'RANGE ',MAIN2770
1'OF TIME TO BE INVESTIGATED=0 TO 10 MIN.'/5X,'IF YOU',' WISH THE DMAIN2780
2EFAULT VALUES, ENTER ZERO, IF NOT, ENTER 1:')              MAIN2790
510    FORMAT (5X,'ENTER IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'G-MAIN2800
1LEVEL, TIME IN MIN:'/5X,'(G LEVEL BETWEEN 0 AND 10)')       MAIN2810
520    FORMAT (5X,'G-LEVEL OUT OF ALLOWABLE RANGE--','PARAMETER SET AT 14MAIN2820
1.0 G')                                                     MAIN2830
530    FORMAT (5X,'SINE-FIXED FREQ. VIBRATION, LEVEL',I2)         MAIN2840
540    FORMAT (5X,'THE DEFAULT VALUES ARE:'/5X,'G-LEVEL=6 G'/5X,'RANGE OFMAIN2850
1',' TIME TO BE INVESTIGATED=0 TO 10 MIN'/5X,'IF YOU WISH THE ','DEMAIN2860
2FAULT VALUES ENTER ZERO, IF NOT, ENTER 1:')              MAIN2870
550    FORMAT (5X,'ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'GMAIN2880
1-LEVEL, TIME IN MIN:'/5X,'(G-LEVEL BETWEEN 1 AND 10)')      MAIN2890
560    FORMAT (5X,'G-LEVEL OUT OF ALLOWABLE RANGE--','PARAMETER SET AT 15MAIN2900
1.5 G')                                                     MAIN2910
570    FORMAT (1X/5X,'ENTER THE FOLLOWING MANUFACTURING PROCESS DATA',', MAIN2920
1LEVEL',I2//5X,'IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZMAIN2930
2ERO:'//5X,'FIXED TEST COST IN DOLLARS=')                 MAIN2940
580    FORMAT (5X,'VARIABLE TEST COST IN DOLLARS PER HOUR=')       MAIN2950
590    FORMAT (5X,'AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT',' DETECTMAIN2960
1ED AT THIS LEVEL=')                                        MAIN2970
600    FORMAT (5X,'ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION ','OF TOTMAIN2980
1AL PARTS=')                                                MAIN2990
610    FORMAT (1X,F4.1)                                           MAIN3000
620    FORMAT (2(1X,F10.6))                                       MAIN3010
630    FORMAT (1X)                                                MAIN3020
640    FORMAT (5X////14X,8('*'),' SELECTION OF PROGRAM INPUTS AND ','OPTIMAIN3030
1ONS ',8('*')//5X,'IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:'//5MAIN3040
2X,'OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A',' GIVEN PRODMAIN3050
3UCT'/5X,' RELIABILITY REQUIREMENT'//5X,'OPTION B ','OPTIMIZES PRODMAIN3060
4UCT RELIABILITY GIVEN A FIXED COST'//5X,'OPTION C COMPUTES TEST STMAIN3070
5RENGTHS OF EXISTING SCREENS'//)                          MAIN3080
650    FORMAT (1X/5X,'DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ','ONLYMAIN3090
1,FOR OPTIONS B OR C '/5X,'ENTER ZERO)')                  MAIN3100
660    FORMAT (1X/5X,'COST BUDGET(OPTION B ONLY,','FOR OPTION A OR C ENTEMAIN3110
1R ZERO)')                                                MAIN3120
670    FORMAT (1X/5X,'TOTAL PART POPULATION(NO DEFAULT AVAILABLE)')  MAIN3130
680    FORMAT (1X/5X,'FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=')  MAIN3140
690    FORMAT (1X,5X,'PART QUALITY DEFECTS AS A FRACTION OF TOTAL',' PARTMAIN3150
1S=')                                                     MAIN3160
       END                                                       MAIN3170
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PROGRAM LISTING FOR SD01. FORT

```
      INTEGER T                                                    MAIN  10
      INTEGER*2 TV(20,300),SEQ(20,300),TV1(17000),SEQ1(17000)      MAIN  20
      DIMENSION N(5), ADEF(5), F(11,4,5), R1(11,4,5), R2(11,4,5),  MAIN  30
     +CT(5,5),                                                     MAIN  35
     1CR1(5,5), CR2(5,5), TS(20,1500), TC(20,1500), N1(20), NF(20), ISCRMAIN 40
     2(3), P(11,4,5), TS1(17000), TC1(17000), SCOST(5,5), IARRAY(20), MAIN 50
     +TIME(3,5),                                                   MAIN  55
     3 TSS(20,1500), PARRAY(11,4,5), AMAX11(3), AMIN11(3), AMAX12(3), MAIN 60
     4 AMIN12(3), AMAX21(3), AMIN21(3), AMAX22(3), AMIN22(3), AMAX23( MAIN 70
     53), AMIN23(3), AMAX24(3), AMIN24(3), AMAX31(3), AMIN31(3), AMAX32(MAIN 80
     63), AMIN32(3), AMAX41(3), AMIN41(3), AMAX42(3), AMIN42(3), AMAX51(MAIN 90
     73), AMIN51(3), AMAX52(3), AMIN52(3), X(11,4,5),TSS1(17000)   MAIN 100
      DATA NF,TS,TC,TSS,TSS1,TS1,TC1/20*0,141000*0./              MAIN 110
      DATA PARRAY/220*1.0/                                        MAIN 120
      DATA P,F,R1,R2/880*1.0/                                     MAIN 130
      DATA N/5*5/                                                 MAIN 140
      COMMON ISCR                                                 MAIN 150
      CALL DATA (NCYC,M,PDEF,CREGO,E,ITV,N,ADEF,CPHR,P,F,R1,R2,CR1,CR2,XMAIN 160
     1MTBF,LEVEL,ITYP,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMAX22,AMAIN 170
     2MIN22,AMAX23,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN32,AMAXMAIN 180
     341,AMIN41,AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52,NPARTS)   MAIN 190
      READ (2,*) ISCR                                             MAIN 200
      WRITE (2,*) M,NPARTS,PDEF,ADEF                              MAIN 210
      READ (13,*) XNOP,XLAMP1,XLAMP2,XLAMC1,XLAMC2                MAIN 220
      LL=0                                                        MAIN 230
      ADIN=0.0                                                    MAIN 240
      DO 10 I=1,M                                                 MAIN 250
10    ADIN=ADIN+ADEF(I)                                           MAIN 260
      DIN=ADIN+PDEF                                               MAIN 270
      IF (XMTBF.EQ.0.0) GO TO 20                                  MAIN 280
      FRF=1./XMTBF                                                MAIN 290
      FRM=0.0                                                     MAIN 300
      OPTS=0.0                                                    MAIN 310
      OPTS2=0.0                                                   MAIN 320
      HOURS2=0.0                                                  MAIN 330
      SREGO=XMTBF                                                 MAIN 340
20    DO 180 I1=1,M                                               MAIN 350
      NI1=N(I1)                                                   MAIN 360
      DO 170 I2=1,NI1                                             MAIN 370
      LL=LL+1                                                     MAIN 380
      MV=0                                                        MAIN 390
      READ (10,*,END=30) A1,B1                                    MAIN 400
      GO TO 40                                                    MAIN 410
30    A1=0.0                                                      MAIN 420
      B1=0.0                                                      MAIN 430
40    DO 90 KK4=1,ITV                                             MAIN 440
      DO 90 KK3=1,ITV                                             MAIN 450
      DO 70 KK2=1,ITV                                             MAIN 460
      DO 60 KK1=1,ITV                                             MAIN 470
      MV=MV+1                                                     MAIN 480
      DO 50 I=1,NCYC                                              MAIN 490
50    PARRAY(I,I1,I2)=P(I,I1,I2)                                  MAIN 500
      CALL SSPROB (KK1,KK2,KK3,KK4,I1,I2,PARRAY,NCYC,CT,A1,B1,ITV,HOURS,MAIN 510
     1CPHR,TIME,AMAX11(I1),AMIN11(I1),AMAX12(I1),AMIN12(I1),AMAX21(I1),AMAIN 520
     2MIN21(I1),AMAX22(I1),AMIN22(I1),AMAX23(I1),AMIN23(I1),AMAX24(I1),AMAIN 530
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          3MIN24(I1),AMAX31(I1),AMIN31(I1),AMAX32(I1),AMIN32(I1),AMAX41(I1),AMAIN 540
          4MIN41(I1),AMAX42(I1),AMIN42(I1),AMAX51(I1),AMIN51(I1),AMAX52(I1),AMAIN 550
          5MIN52(I1))                                                        MAIN 560
           CALL SCREEN (NCYC,M,N,POEF,DIN,AOEF,PARRAY,F,R1,R2,CT,CR1,CR2,SS,SMAIN 570
          1M,TCOST,I1,I2,SCOST,TCMIN,0.0,TIME,NPARTS,XNOP,XLAMP1,XLAMP2,XLAMCMAIN 580
          21,XLAMC2,X)                                                       MAIN 590
           TSS(LL,MV)=SS                                                     MAIN 600
           TS(LL,MV)=SM                                                      MAIN 610
           TC(LL,MV)=TCOST                                                   MAIN 620
   60      CONTINUE                                                          MAIN 630
   70      CONTINUE                                                          MAIN 640
           IF (((I2-1)*(I2-3)*(I2-4)*(I2-5)) 80,100,80                       MAIN 650
   80      CONTINUE                                                          MAIN 660
   90      CONTINUE                                                          MAIN 670
  100      CONTINUE                                                          MAIN 680
           DO 110 I=1,NCYC                                                   MAIN 690
  110      PARRAY(I,I1,I2)=1.0                                               MAIN 700
           N1(LL)=MV                                                         MAIN 710
           IF (LL-2) 170,120,130                                            MAIN 720
  120      K1=N1(LL-1)                                                       MAIN 730
           GO TO 140                                                         MAIN 740
  130      K1=K                                                              MAIN 750
  140      K2=N1(LL)                                                         MAIN 760
           NSEQ=K1*K2                                                        MAIN 770
           DO 150 J1=1,K1                                                    MAIN 780
           DO 150 J2=1,K2                                                    MAIN 790
           W=TSS(LL,J2)*(1.0-TSS(LL-1,J1))+TSS(LL-1,J1)                      MAIN 795
           U=TS(LL-1,J1)+(1.-TSS(LL-1,J1))*TSS(LL,J2)*TS(LL,J2)             MAIN 800
           V=TC(LL-1,J1)+(1.-TSS(LL-1,J1))*TSS(LL,J2)*TC(LL,J2)             MAIN 810
           MF(LL)=MF(LL)+1                                                   MAIN 820
           JJ=MF(LL)                                                         MAIN 830
           SEQ1(JJ)=J1                                                       MAIN 840
           TV1(JJ)=J2                                                        MAIN 850
           TS1(JJ)=U                                                         MAIN 860
           TC1(JJ)=V                                                         MAIN 870
           TSS1(JJ)=W                                                        MAIN 865
  150      CONTINUE                                                          MAIN 880
           CALL RANK (TS1,TC1,TSS1,NSEQ,SEQ1,TV1)                            MAIN 890
           QC=0.0                                                            MAIN 900
           QS=0.0                                                            MAIN 910
           K=0                                                               MAIN 920
           DO 160 I=1,NSEQ                                                   MAIN 930
           IF ((TS1(I).EQ.0.0).OR.(TC1(I).EQ.0.0)) GO TO 160                MAIN 940
           IF ((TS1(I)-QS)/TS1(I).LT.E) GO TO 160                           MAIN 950
           IF ((TC1(I)-QC)/TC1(I).LT.E) GO TO 160                           MAIN 960
           QC=TC1(I)                                                         MAIN 970
           QS=TS1(I)                                                         MAIN 980
           K=K+1                                                             MAIN 990
           TC(LL,K)=TC1(I)                                                   MAIN1000
           TS(LL,K)=TS1(I)                                                   MAIN1010
           TSS(LL,K)=TSS1(I)                                                 MAIN1015
           SEQ(LL,K)=SEQ1(I)                                                 MAIN1020
           TV(LL,K)=TV1(I)                                                   MAIN1030
           TC1(I)=0.                                                         MAIN1040
           TS1(I)=0.                                                         MAIN1050
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          TSS1(I)=0.                                                      MAIN1055
          SEQ1(I)=0                                                       MAIN1060
          TV1(I)=0                                                        MAIN1070
  160     CONTINUE                                                        MAIN1080
  170     CONTINUE                                                        MAIN1090
  180     CONTINUE                                                        MAIN1100
          CALL SEARCH (LL,K,CREQO,SREQO,SEQ,TV,TC,TSS,TS,IARRAY,TCMIN,TSMAX,MAIN1110
         1DIN,X)                                                          MAIN1120
          CALL REPORT (M,NCYC,N,ISCR,PDEF,DIN,ADEF,CPHR,P,F,R1,R2,CT,CR1,CR2MAIN1130
         1,IARRAY,A1,B1,ITV,TCMIN,TSMAX,NPARTS,XNOP,XLAMP1,XLAMP2,XLAMC1,XLAMAIN1140
         2MC2,X,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMAX22,AMIN22,AMAXMAIN1150
         323,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN32,AMAX41,AMIN41,MAIN1160
         4AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52)                      MAIN1170
          DEBUG SUBCHK                                                    MAIN1175
          END                                                            MAIN1180
          SUBROUTINE SCREEN (NCYC,M,N,PDEF,DIN,ADEF,P,F,R1,R2,CT,CR1,CR2,SS,SCRE   10
         1SM,TCOST,I1,I2,SCOST,TCMIN,FLAG,TIME,NPARTS,XNOP,XLAMP1,XLAMP2,XLASCRE   20
         2MC1,XLAMC2,X)                                                   SCRE   30
          DIMENSION X(11,4,5), P(11,4,5), F(11,4,5), R1(11,4,5), Q(20),   SCRE   40
         1ISCR(3), TIME(3,5), TCOSTL(5,5), COSTL(5), N(5), CT(5,5), CR1(5,5)SCRE   50
         2, ADEF(5), CR2(5,5), SCOST(5,5),R2(11,4,5)                      SCRE   60
          COMMON ISCR                                                     SCRE   70
          PLEFT=PDEF                                                      SCRE   80
          IF (FLAG.GT.0.) WRITE (13,*) TIME(1,ISCR(1)),TIME(2,ISCR(2)),TIME(SCRE   90
         13,ISCR(3))                                                      SCRE  100
          IF (FLAG.GT.0.) WRITE (2,*) P(1,1,ISCR(1)),P(1,2,ISCR(2)),P(1,3,ISSCRE  110
         *CR(3))                                                          SCRE  120
          NCYC1=NCYC+1                                                    SCRE  130
          DO 10 I=1,NCYC1                                                 SCRE  140
          DO 10 J=1,M                                                     SCRE  150
          NJ=N(J)                                                         SCRE  160
          DO 10 K=1,NJ                                                    SCRE  170
   10     X(I,J,K)=0.0                                                    SCRE  180
          X(1,1,1)=ADEF(1)+PDEF                                           SCRE  190
          DO 50 J=1,M                                                     SCRE  200
          NJ=N(J)                                                         SCRE  210
          DO 50 K=1,NJ                                                    SCRE  220
          IF (K-1) 20,20,40                                               SCRE  230
   20     IF (J-1) 50,50,30                                               SCRE  240
   30     CALL MEAN (XNOP,XLAMC1,X(1,J-1,N(J-1)),TIME(J-1,N(J-1)),P(1,J-1,N(SCRE  250
         1J-1)),FALL)                                                     SCRE  260
          PLEFT=PLEFT*P(1,J-1,N(J-1))                                     SCRE  270
          X(1,J,K)=X(1,J-1,N(J-1))-FALL+ADEF(J)                           SCRE  280
          GO TO 50                                                        SCRE  290
   99     X(1,J,K)=P(1,J,K-1)*X(1,J,K-1)                                  SCRE  300
          PLEFT=PLEFT*P(1,J,K-1)                                          SCRE  310
          GO TO 50                                                        SCRE  320
   40     CALL MEAN (XNOP,XLAMC1,X(1,J,K-1),TIME(J,K-1),P(1,J,K-1),FALL)   SCRE  330
          PLEFT=PLEFT*P(1,J,K-1)                                          SCRE  340
          X(1,J,K)=X(1,J,K-1)-FALL                                        SCRE  350
   50     CONTINUE                                                        SCRE  360
          IF (FLAG.GT.0.) WRITE (2,*) X(1,1,1),X(1,2,1),X(1,3,1)          SCRE  370
   C      IF (FLAG.GT.0.) WRITE(6,4000)((X(1,J,K),J=1,M),K=1,5)           SCRE  380
          IF (FLAG.GT.0.) WRITE (2,*) X(1,1,5),X(1,2,5),X(1,3,5),PLEFT    SCRE  390
          CLEFT=X(1,3,5)-PLEFT                                            SCRE  400
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         SUMX=0.                                                        SCRE 410
         DO 100 I=1,NCYC                                                SCRE 420
         X(I+1,1,1)=0.0                                                 SCRE 430
         DO 60 J=1,M                                                    SCRE 440
         NJ=N(J)                                                        SCRE 450
         DO 6C K=1,NJ                                                   SCRE 460
60       X(I+1,1,1)=X(I+1,1,1)+(1-P(I,J,K))*F(I,J,K)*(1-R1(I,J,K))*X(I,J,K)SCRE 470
         DO 90 J=1,M                                                    SCRE 480
         NJ=N(J)                                                        SCRE 490
         DO 90 K=1,NJ                                                   SCRE 500
         IF (X(I,J,K).LT.1.0) GO TO 90                                  SCRE 510
         IF (J.EQ.1.AND.K.EQ.1) GO TO 90                                SCRE 520
         IF (J.GT.1.AND.K.EQ.1) GO TO 70                                SCRE 530
         IF (J.GE.1.AND.K.GT.1) GO TO 80                                SCRE 540
         GO TO 90                                                       SCRE 550
70       X(I+1,J,1)=P(I+1,J-1,N(J-1))*X(I+1,J-1,N(J-1))+(1-P(I,J,1))*(1-F(ISCRE 560
        1,J,1))*(1-R2(I,J,1))*X(I,J,1)                                  SCRE 570
         GO TO 90                                                       SCRE 580
80       X(I+1,J,K)=P(I+1,J,K-1)*X(I+1,J,K-1)+(1-P(I,J,K))*(1-F(I,J,K))*(1-SCRE 590
        1R2(I,J,K))*X(I,J,K)                                            SCRE 600
90       CONTINUE                                                       SCRE 610
100      CONTINUE                                                       SCRE 620
C        IF (FLAG.GT.0.) WRITE(6,4001)((X(2,J,K),J=1,M),K=1,5)          SCRE 630
         SUM=0.0                                                        SCRE 640
         DO 110 I=1,NCYC                                                SCRE 650
         NM=N(M)                                                        SCRE 660
         SUM=SUM+X(I,M,NM)                                              SCRE 670
110      CONTINUE                                                       SCRE 680
         DOUT=SUM                                                       SCRE 690
         SM=1./((XNOP-CLEFT)*XLAMC1+(FLOAT(NPARTS)-PLEFT)*XLAMP1+CLEFT*XLAMSCRE 700
        1C2+PLEFT*XLAMP2)                                               SCRE 710
         SS=1.0-DOUT/DIN                                                SCRE 720
         DELTA=DIN-DOUT                                                 SCRE 730
         ACOST=0.0                                                      SCRE 740
         TCOST=0.0                                                      SCRE 750
         DO 120 J=1,M                                                   SCRE 760
         DO 120 K=1,5                                                   SCRE 770
120      SCOST(J,K)=0.0                                                 SCRE 780
         IF(FLAG.NE.0.0) GO TO 140                                      SCRE 790
         DO 130 I=1,NCYC                                                SCRE 800
         CR=CR1(I1,I2)*F(I,I1,I2)+CR2(I1,I2)*(1.0-F(I,I1,I2))           SCRE 810
         COST=CT(I1,I2)+CR*(X(I,I1,1)-X(I,I1,5))                        SCRE 820
130      ACOST=ACOST+COST                                              SCRE 840
         GO TO 170                                                      SCRE 850
140      DO 160 J=1,M                                                   SCRE 860
         DO 160 K=1,5                                                   SCRE 870
         SUMTS1=0.0                                                     SCRE 880
         SUMTS2=0.0                                                     SCRE 890
         DO 150 I=1,NCYC                                                SCRE 900
         SUMTS1=SUMTS1+(1.-P(I,J,K))*X(I,J,K)                           SCRE 910
         SUMTS2=SUMTS2+X(I,J,K)                                         SCRE 920
150      CONTINUE                                                       SCRE 930
         IF (ISCP(J).NE.K) GO TO 160                                    SCRE 940
         IF (P(1,J,ISCR(J)).GT.0.999) GO TO 160                         SCRE 950
         SCOST(J,K)=SUMTS1*CR2(J,K)+CT(J,K)                             SCRE 960
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160     TCOST=TCOST+SCOST(J,K)                                    SCRE 970
        SUMTC=TCOST                                               SCRE 980
        GO TO 190                                                 SCRE 990
170     IF ((DIN-DOUT).GE.1.0) GO TO 180                          SCRE1000
        DELTA=1.0                                                 SCRE1010
180     TCOST=ACOST/DELTA                                         SCRE1020
190     RETURN                                                    SCRE1030
        DEBUG SUBCHK                                              SCRE1035
        END                                                       SCRE1050
        SUBROUTINE RANK (TS1,TC1,TSS1,NSEQ,SEQ1,TV1)             RANK  10
        INTEGER*2 TV1(17000),SEQ1(17000)                         RANK  20
        DIMENSION TS1(17000), TC1(17000),TSS1(17000)             RANK  30
        N2=NSEQ                                                   RANK  40
        M1=N2                                                     RANK  50
10      M1=INT(M1/2.)                                            RANK  60
        IF (M1.EQ.0) GO TO 50                                    RANK  70
        M1=N2-M1                                                 RANK  80
        J=1                                                      RANK  90
20      I=J                                                      RANK 100
30      L1=I+M1                                                  RANK 110
        IF (TC1(I).LE.TC1(L1)) GO TO 40                         RANK 120
        A1=TC1(I)                                                RANK 130
        B1=TS1(I)                                                RANK 140
        C1=TSS1(I)                                               RANK 145
        A2=SEQ1(I)                                               RANK 150
        B2=TV1(I)                                                RANK 160
        TC1(I)=TC1(L1)                                           RANK 170
        TS1(I)=TS1(L1)                                           RANK 180
        TSS1(I)=TSS1(L1)                                         RANK 185
        SEQ1(I)=SEQ1(L1)                                         RANK 190
        TV1(I)=TV1(L1)                                           RANK 200
        TC1(L1)=A1                                               RANK 210
        TS1(L1)=B1                                               RANK 220
        TSS1(L1)=C1                                              RANK 225
        SEQ1(L1)=A2                                              RANK 230
        TV1(L1)=B2                                               RANK 240
        I=I-M1                                                   RANK 250
        IF (I.GE.1) GO TO 30                                    RANK 260
40      J=J+1                                                   RANK 270
        IF (J.LE.M1) GO TO 20                                   RANK 280
        GO TO 10                                                RANK 290
50      RETURN                                                  RANK 300
        END                                                     RANK 310
        SUBROUTINE SEARCH (LL,NO,CREQO,SREQO,SEQ,TV,TC,TSS,TS,IARRAY,TCMINSEAR  10
     1,TSMAX,DIN,X)                                             SEAR  20
        INTEGER T,S,S1,S2                                        SEAR  30
        INTEGER*2 TV(20,300),SEQ(20,300)                        SEAR  40
        DIMENSION TC(20,1500), TS(20,1500), IARRAY(20), X(11,4,5) SEAR  50
     +,TSS(20,1500)                                             SEAR  55
        PLACE=SREQO                                              SEAR  60
        DO 10 I=1,NO                                             SEAR  70
        TCTOT=TC(LL,I)+DIN+TSS(LL,I)                            SEAR  72
        TC(LL,I)=TCTOT                                           SEAR  74
10      CONTINUE                                                 SEAR  90
        DTCMIN=TC(LL,NO)                                         SEAR 100
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      DTSMAX=TS(LL,NO)                                                   SEAR 110
 20   IF (CREQD) 30,30,40                                                SEAR 120
 30   IF (SREQD) 160,160,60                                              SEAR 130
 40   K=NO                                                               SEAR 140
 50   IF (TC(LL,K)-CREQD) 80,80,90                                       SEAR 150
 60   K=1                                                                SEAR 160
 70   IF (TS(LL,K)-SREQD) 100,80,80                                      SEAR 170
 80   S1=SEQ(LL,K)                                                       SEAR 180
      T=TV(LL,K)                                                         SEAR 190
      IARRAY(LL)=T                                                       SEAR 200
      TCMIN=TC(LL,K)                                                     SEAR 210
      TSMAX=TS(LL,K)                                                     SEAR 220
      K=1                                                                SEAR 230
      GO TO 110                                                          SEAR 240
 90   K=K-1                                                              SEAR 250
      IF (K) 140,140,50                                                  SEAR 260
100   K=K+1                                                              SEAR 270
      IF (K-NO) 70,70,140                                                SEAR 280
110   I=LL-1                                                             SEAR 290
120   IF (I-1) 150,150,130                                              SEAR 300
130   S=SEQ(I,S1)                                                        SEAR 310
      T=TV(I,S1)                                                         SEAR 320
      S2=S1                                                              SEAR 330
      S1=S                                                               SEAR 340
      IARRAY(I)=T                                                        SEAR 350
      I=I-1                                                              SEAR 360
      GO TO 120                                                          SEAR 370
140   WRITE (6,180)                                                      SEAR 380
      SREQD=TS(LL,NO)                                                    SEAR 400
      GO TO 20                                                           SEAR 410
150   IARRAY(1)=S                                                        SEAR 420
      GO TO 170                                                          SEAR 430
160   WRITE (6,200)                                                      SEAR 440
      STOP                                                               SEAR 450
      DEBUG SUBCHK                                                       SEAR 455
170   CONTINUE                                                           SEAR 460
      SREQD=PLACE                                                        SEAR 470
      RETURN                                                             SEAR 480
C                                                                        SEAR 490
180   FORMAT (/1X,'REQUIREMENT CANNOT BE MET'/1X)                        SEAR 500
200   FORMAT (/1X,'REQUIREMENT CAN BE MET WITHOUT TEST SCREENS')         SEAR 520
      END                                                               SEAR 530
      SUBROUTINE SSPROB (K1,K2,K3,K4,I1,I2,P,NCYC,CT,A1,B1,ITV,HOURS,PHRSSPR  10
     1,TIME,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMAX22,AMIN22,AMAXSSPR  20
     223,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN32,AMAX41,AMIN41,SSPR  30
     3AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52)                         SSPR  40
      DIMENSION P(11,4,5), CT(5,5), TIME(3,5)                            SSPR  50
      GO TO (10,70,160,220,280), I2                                      SSPR  60
 10   CONTINUE                                                           SSPR  70
C  TEST ONE:  CONSTANT TEMPERATURE(CT)                                   SSPR  80
      RR=((AMAX11-AMIN11)*K1+AMIN11*ITV-AMAX11)/(ITV-1.)                 SSPR  90
      RR=ABS(RR-25.)                                                     SSPR 100
      TT=((AMAX12-AMIN12)*K2+AMIN12*ITV-AMAX12)/(ITV-1.)                 SSPR 110
      HOURS=TT                                                           SSPR 120
      DT=ALOG(EXP(1.)+1.)                                                SSPR 130
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      RNCY=1.0                                                           SSPR 140
      PFT=.05*(1.0-EXP(-0.0023*RR**.6*TT**.5*RNCY*DT**2.7))             SSPR 150
      SS=1.0-PFT                                                         SSPR 160
      TIME(I1,I2)=HOURS                                                  SSPR 170
      IF (B1) 20,20,340                                                  SSPR 180
20    GO TO (30,40,50,60), I1                                           SSPR 190
30    CT(1,I2)=(0.15)*HOURS*CPHR                                        SSPR 200
      GO TO 350                                                          SSPR 210
40    CT(2,I2)=(0.15)*HOURS*CPHR                                        SSPR 220
      GO TO 350                                                          SSPR 230
50    CT(3,I2)=HOURS*CPHR                                               SSPR 240
      GO TO 350                                                          SSPR 250
60    CT(4,I2)=HOURS*CPHR                                               SSPR 260
      GO TO 350                                                          SSPR 270
70    CONTINUE                                                           SSPR 280
C  TEST TWO:  CYCLED TEMPERATURE(CYT)                                    SSPR 290
      RR=ABS(AMAX21-AMAX22)                                             SSPR 300
      DT1=((AMAX23-AMIN23)*K3+AMIN23*ITV-AMAX23)/(ITV-1.)              SSPR 310
      DT=ALOG(EXP(1.)+DT1)**2.7                                         SSPR 320
      RNCY=((AMAX24-AMIN24)*K4+AMIN24*ITV-AMAX24)/(ITV-1.)            SSPR 330
      TT=1.                                                              SSPR 340
      PFDT=.05*(1.-EXP(-.0023*RR**.6*TT*RNCY**.5*DT))                  SSPR 350
      SS=1.0-PFDT                                                        SSPR 360
      IF ((AMAX23-AMIN23)*K3+AMIN23*ITV-AMAX23) 90,90,80              SSPR 370
80    HOURS=RNCY*(4./DT+(2.*RR)/(DT*60.))                             SSPR 380
      TIME(I1,I2)=HOURS                                                  SSPR 390
      GO TO 100                                                          SSPR 400
90    HOURS=0                                                            SSPR 410
      TIME(I1,I2)=HOURS                                                  SSPR 420
100   IF (B1) 110,110,340                                              SSPR 430
110   GO TO (120,130,140,150), I1                                      SSPR 440
120   CT(1,I2)=(0.15)*HOURS*CPHR                                       SSPR 450
      GO TO 350                                                          SSPR 460
130   CT(2,I2)=(0.15)*HOURS*CPHR                                       SSPR 470
      GO TO 350                                                          SSPR 460
140   CT(3,I2)=HOURS*CPHR                                              SSPR 490
      GO TO 350                                                          SSPR 500
150   CT(4,I2)=HOURS*CPHR                                              SSPR 510
      GO TO 350                                                          SSPR 520
160   CONTINUE                                                           SSPR 530
C  TEST THREE:  RANDOM VIBRATION(RVIB)                                   SSPR 540
      GG=((AMAX31-AMIN31)*K1+AMIN31*ITV-AMAX31)/(ITV-1.)              SSPR 550
      TT=((AMAX32-AMIN32)*K2+AMIN32*ITV-AMAX32)/(ITV-1.)             SSPR 560
      HOURS=TT/60.                                                       SSPR 570
      BB=.266*GG+1.402                                                  SSPR 580
      DD=.144*GG-.0862                                                  SSPR 590
      PFV=DD*(1.-EXP(-TT**.5/BB))                                      SSPR 600
      SS=1.0-PFV                                                         SSPR 610
      TIME(I1,I2)=HOURS                                                  SSPR 620
      IF (B1) 170,170,340                                              SSPR 630
170   GO TO (180,190,200,210), I1                                      SSPR 640
180   CT(1,I2)=(0.15)*HOURS                                            SSPR 650
      GO TO 350                                                          SSPR 660
190   CT(2,I2)=(0.15)*HOURS                                            SSPR 670
      GO TO 350                                                          SSPR 680
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200    CT(3,I2)=HOURS                                               SSPR 690
       GO TO 350                                                    SSPR 700
210    CT(4,I2)=HOURS                                               SSPR 710
       GO TO 350                                                    SSPR 720
220    CONTINUE                                                     SSPR 730
C   TEST FOUR: SINE-SWEEP VIBRATION(SSVIB)                          SSPR 740
       TT=((AMAX42-AMIN42)*K2+AMIN42*ITV-AMAX42)/(ITV-1.)           SSPR 750
       HOURS=TT/60.                                                 SSPR 760
       GG=((AMAX41-AMIN41)*K1+AMIN41*ITV-AMAX41)/(ITV-1.)           SSPR 770
       BB=.0176*GG+7.897                                            SSPR 780
       DD=.0435*GG+.1065                                            SSPR 790
       PHR=DD*(1.-EXP(-TT**.8/BB))                                  SSPR 800
       SS=1.-PHR                                                    SSPR 810
       TIME(I1,I2)=HOURS                                            SSPR 820
C   CARD/MODULE LEVELS                                              SSPR 830
       IF (B1) 230,230,340                                          SSPR 840
230    GO TO (240,250,260,270), I1                                  SSPR 850
240    CT(1,I2)=(0.15)*HOURS*CPHR                                   SSPR 860
       GO TO 350                                                    SSPR 870
250    CT(2,I2)=(0.15)*HOURS*CPHR                                   SSPR 880
       GO TO 350                                                    SSPR 890
C   EQUIPMENT/SYSTEM LEVELS                                         SSPR 900
260    CT(3,I2)=HOURS*CPHR                                          SSPR 910
       GO TO 350                                                    SSPR 920
270    CT(4,I2)=HOURS*CPHR                                          SSPR 930
       GO TO 350                                                    SSPR 940
280    CONTINUE                                                     SSPR 950
C   TEST FIVE:  SINE-FIXED VIBRATION (SFVIB)                        SSPR 960
       TT=((AMAX52-AMIN52)*K2+AMIN52*ITV-AMAX52)/(ITV-1.)           SSPR 970
       GG=((AMAX51-AMIN51)*K1+AMIN51*ITV-AMAX51)/(ITV-1.)           SSPR 980
       HOURS=TT/60.                                                 SSPR 990
       BB=-.419*G+6.620                                             SSPR1000
       DD=.0435*G+.324                                              SSPR1010
       PHRR=DD*(1.-EXP(-TT**.2/BB))                                 SSPR1020
       SS=1.-PHRR                                                   SSPR1030
       TIME(I1,I2)=HOURS                                           SSPR1040
C   CARD/MODULE LEVELS                                              SSPR1050
       IF (B1) 290,290,340                                          SSPR1060
290    GO TO (300,310,320,330), I1                                  SSPP1070
300    CT(1,I2)=(0.15)*HOURS*CPHR                                   SSPR1080
       GO TO 350                                                    SSPR1090
310    CT(2,I2)=(0.15)*HOURS*CPHR                                   SSPR1100
       GO TO 350                                                    SSPR1110
C   EQUIPMENT/SYSTEM LEVELS                                         SSPR1120
320    CT(3,I2)=HOURS*CPHR                                          SSPR1130
       GO TO 350                                                    SSPR1140
330    CT(4,I2)=HOURS*CPHR                                          SSPR1150
       GO TO 350                                                    SSPP1160
340    CT(I1,I2)=B1*HOURS+A1                                        SSPR1170
350    CONTINUE                                                     SSPR1180
       DO 360 I=1,NCYC                                              SSPR1190
       P(I,I1,I2)=SS                                                SSPR1200
360    IF (HOURS.EQ.0.0) P(I,I1,I2)=1.0                            SSPR1210
       RETURN                                                       SSPR1220
       END                                                          SSPR1230
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      SUBROUTINE REPORT (M,NCYC,N,ISCR,PDEF,OIN,ADEF,CPHR,P,F,R1,R2,CT,CREPO   10
     1R1,CR2,IARRAY,A1,B1,ITV,TCMIN,TSMAX,NPARTS,XNOP,XLAMP1,XLAMP2,XLAMREPO   20
     2C1,XLAMC2,X,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMAX22,AMIN2REPO   30
     32,AMAXZ3,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN32,AMAX41,AREPO   40
     4MIN41,AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52)                 REPO    50
      REAL LCOST(5)                                                    REPO    60
      DIMENSION AMAX11(3), AMIN11(3), AMAX12(3), AMIN12(3), AMAX21(3), AREPO   70
     1MIN21(3), AMAX22(3), AMIN22(3), AMAX23(3), AMIN23(3), AMAX24(3), AREPO   80
     2MIN24(3), AMAX31(3), AMIN31(3), AMAX32(3), AMIN32(3), AMAX41(3), AREPO   90
     3MIN41(3), AMAX42(3), AMIN42(3), AMAX51(3), AMIN51(3), AMAX52(3), AREPO  100
     4MINS2(3)                                                         REPO   110
      DIMENSION NP(5,5,5), N(5), P(11,4,5), F(11,4,5), ISCR(3),        REPO   120
     1R1(11,4,5), R2(11,4,5), CR1(5,5), CR2(5,5), CT(5,5), SCOST(5,5), REPO   130
     2TEST(5), IR(5), IARRAY(20), ANP(5,5,5), ADEF(5), TIME(3,5),      REPO   140
     +X(11,4,5)                                                        REPO   145
      REWIND 10                                                        REPO   150
      DATA NP/125*1/                                                   REPO   160
      DATA LCOST/5*0./                                                 REPO   170
      DATA TEST/'CT  ','CYT ','RVIB','SSVB','SFVB'/                    REPO   180
      DATA ANP/125*0./                                                 REPO   190
      I=0                                                              REPO   200
      DO 130 I1=1,M                                                    REPO   220
      DO 130 I2=1,5                                                    REPO   230
      READ (10,*) A1,B1                                                REPO   240
      I=I+1                                                            REPO   250
      IR(1)=IARRAY(I)                                                  REPO   260
      GO TO (10,80,10,10,10) I2                                        REPO   270
      NP(I1,I2,1)=IARRAY(I)                                            REPO   280
      GO TO 120                                                        REPO   290
 10   DO 40 K=2,3                                                      REPO   300
      IR(K)=MOD(IR(K-1),ITV**(3-K))                                    REPO   310
      IF (IR(K-1)) 30,30,20                                            REPO   320
 20   NP(I1,I2,4-K)=INT(FLOAT(IR(K-1))/(FLOAT(ITV))**(3-K)+.999999)    REPO   330
      GO TO 40                                                         REPO   340
 30   NP(I1,I2,4-K)=ITV                                                REPO   350
 40   CONTINUE                                                         REPO   360
      GO TO 120                                                        REPO   370
 80   DO 70 K=2,4                                                      REPO   380
      IR(K)=MOD(IR(K-1),ITV**(4-K))                                    REPO   390
      IF (IR(K-1)) 60,60,50                                            REPO   400
 50   NP(I1,I2,5-K)=INT(FLOAT(IR(K-1))/(FLOAT(ITV))**(4-K)+.999999)    REPO   410
      GO TO 70                                                         REPO   420
 60   NP(I1,I2,5-K)=ITV                                                REPO   430
 70   CONTINUE                                                         REPO   440
      GO TO 120                                                        REPO   450
 80   DO 110 K=2,5                                                     REPO   460
      IR(K)=MOD(IR(K-1),ITV**(5-K))                                    REPO   470
      IF (IR(K-1)) 100,100,90                                          REPO   480
 90   NP(I1,I2,6-K)=INT(FLOAT(IR(K-1))/(FLOAT(ITV))**(5-K)+.999999)    REPO   490
      GO TO 110                                                        REPO   500
 100  NP(I1,I2,6-K)=ITV                                                REPO   510
 110  CONTINUE                                                         REPO   520
      GO TO 120                                                        REPO   530
 120  CALL SSPROB (NP(I1,I2,1),NP(I1,I2,2),NP(I1,I2,3),NP(I1,I2,4),I1,I2REPO  540
     1,P,NCYC,CT,A1,B1,ITV,HOURS,CPHR,TIME,AMAX11(I1),AMIN11(I1),AMAX12(REPO  550
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        2I1),AMIN12(I1),AMAX21(I1),AMIN21(I1),AMAX22(I1),AMIN22(I1),AMAX23(REPO 560
        3I1),AMIN23(I1),AMAX24(I1),AMIN24(I1),AMAX31(I1),AMIN31(I1),AMAX32(REPO 570
        4I1),AMIN32(I1),AMAX41(I1),AMIN41(I1),AMAX42(I1),AMIN42(I1),AMAX51(REPO 580
        5I1),AMIN51(I1),AMAX52(I1),AMIN52(I1))                               REPO 590
130     CONTINUE                                                            REPO 600
        CALL SCREEN (NCYC,M,N,PDEF,DIN,ADEF,P,F,R1,R2,CT,CR1,CR2,S,SM,FCOSREPO 610
       1T,I1,I2,SCOST,TCMIN,1.0,TIME,NPARTS,XNOP,XLAMP1,XLAMP2,XLAMC1,XLAMREPO 620
       2C2,X)                                                               REPO 630
        DO 140 I1=1,M                                                       REPO 640
        DO 140 I2=1,5                                                       REPO 650
140     LCOST(I1)=LCOST(I1)+SCOST(I1,I2)                                    REPO 660
        IQ=0                                                                REPO 670
        WRITE (6,260)                                                       REPO 680
        DO 250 I1=1,M                                                       REPO 690
        ANP(I1,4,1)=((AMAX41(I1)-AMIN41(I1))*NP(I1,4,1)+AMIN41(I1)*ITV-AMAREPO 700
       1X41(I1))/(ITV-1.)                                                   REPO 710
        ANP(I1,1,1)=((AMAX11(I1)-AMIN11(I1))*NP(I1,1,1)+AMIN11(I1)*ITV-AMAREPO 720
       1X11(I1))/(ITV-1.)                                                   REPO 730
        ANP(I1,1,2)=((AMAX12(I1)-AMIN12(I1))*NP(I1,1,2)+AMIN12(I1)*ITV-AMAREPO 740
       1X12(I1))/(ITV-1.)                                                   REPO 750
        ANP(I1,5,1)=((AMAX51(I1)-AMIN51(I1))*NP(I1,5,1)+AMIN51(I1)*ITV-AMAREPO 760
       1X51(I1))/(ITV-1.)                                                   REPO 770
        ANP(I1,5,2)=((AMAX52(I1)-AMIN52(I1))*NP(I1,5,2)+AMIN52(I1)*ITV-AMAREPO 780
       1X52(I1))/(ITV-1.)                                                   REPO 790
        ANP(I1,2,1)=((AMAX21(I1)-AMIN21(I1))*NP(I1,2,1)+AMIN21(I1)*ITV-AMAREPO 800
       1X21(I1))/(ITV-1.)                                                   REPO 810
        ANP(I1,2,2)=((AMAX22(I1,-AMIN22(I1))*NP(I1,2,2)+AMIN22(I1)*ITV-AMAREPO 820
       1X22(I1))/(ITV-1.)                                                   REPO 830
        ANP(I1,2,3)=((AMAX23(I1)-AMIN23(I1))*NP(I1,2,3)+AMIN23(I1)*ITV-AMAREPO 840
       1X23(I1))/(ITV-1.)                                                   REPO 850
        ANP(I1,2,4)=((AMAX24(I1)-AMIN24(I1))*NP(I1,2,4)+AMIN24(I1)*ITV-AMAREPO 860
       1X24(I1))/(ITV-1.)                                                   REPO 870
        ANP(I1,3,1)=((AMAX31(I1)-AMIN31(I1))*NP(I1,3,1)+AMIN31(I1)*ITV-AMAREPO 880
       1X31(I1))/(ITV-1.)                                                   REPO 890
        ANP(I1,3,2)=((AMAX32(I1)-AMIN32(I1))*NP(I1,3,2)+AMIN32(I1)*ITV-AMAREPO 900
       1X32(I1))/(ITV-1.)                                                   REPO 910
        ANP(I1,4,2)=((AMAX42(I1)-AMIN42(I1))*NP(I1,4,2)+AMIN42(I1)*ITV-AMAREPO 920
       1X42(I1))/(ITV-1.)                                                   REPO 930
        KTT=2                                                               REPO 940
        IF (ISCR(I1).EQ.2) KTT=4                                           REPO 950
        WRITE (13,*) ANP(I1,ISCR(I1),KTT)                                   REPO 960
        DO 250 I2=1,5                                                       REPO 970
        GO TO (150,160,170,180,190), I2                                     REPO 980
150     IF (ANP(I1,1,2).EQ.0) GO TO 200                                     REPO 990
        GO TO 220                                                          REPO1000
160     IF (ANP(I1,2,3).EQ.0) GO TO 200                                    REPO1010
        GO TO 220                                                          REPO1020
170     IF (ANP(I1,3,2).EQ.0) GO TO 200                                    REPO1030
        GO TO 220                                                          REPO1040
180     IF (ANP(I1,4,1).EQ.0) GO TO 200                                    REPO1050
        GO TO 220                                                          REPO1060
190     IF (ANP(I1,5,1).EQ.0) GO TO 200                                    REPO1070
        GO TO 220                                                          REPO1080
200     DO 210 K=1,4                                                       REPO1090
210     ANP(I1,I2,K)=0.                                                    REPO1100
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228   IF (I1-IQ) 240,240,230                                              REPO1110
230   WRITE (6,270) I1,LCOST(I1)                                          REPO1120
240   IF (ISCR(I1).NE.I2) GO TO 250                                       REPO1130
      WRITE (6,280) I2,TEST(I2),(ANP(I1,I2,K),K=1,4),SCOST(I1,I2)         REPO1140
250   IQ=I1                                                               REPO1150
      WRITE (6,290) FCOST                                                 REPO1160
      DEBUG SUBCHK                                                        REPO1170
      RETURN                                                             REPO1180
C                                                                         REPO1190
260   FORMAT (1X/////////29X,'T E S T   D E S C R I P T I O N'/39X,'PARREPO1200
     1AMETER VALUE'/10X,'TEST SEQUENCE',5X,'TYPE',2X,'NO. 1',2X,'NO. 2',REPO1210
     22X,'NO. 3',2X,'NO. 4',2X,'TOTAL COST','($)'/7X,66('_')//)          REPO1220
270   FORMAT (' ',8X,'LEVEL',2X,'NO. ',I2,39X,F12.0)                     REPO1230
280   FORMAT (' ',12X,'TEST  NO. ',I2,3X,A4,1X,4F7.2,F12.0)              REPO1240
290   FORMAT (' ',7X,67('_')//' ',8X,'TOTAL',' COST',41X,'$',F12.0//' ',REPO1250
     161X,12('_')/' ',61X,12('_'))                                       REPO1260
      END                                                                REPO1270
      SUBROUTINE DATA (NCYC,M,PDEF,CREQO,E,ITV,N,ADEF,CPHR,P,F,R1,R2,CR1DATA   10
     1CR2,XMTBF,LEVEL,ITYP,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMDATA   20
     2AX22,AMIN22,AMAX23,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN3DATA   30
     32,AMAX41,AMIN41,AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52,NPARTS) DATA   40
      DIMENSION N(5), ADEF(5), P(11,4,5), F(11,4,5), R1(11,4,5),        DATA   50
     1 CR1(5,5), CR2(5,5), AMAX11(3), AMIN11(3), AMAX12(3), AMIN12(3), ADATA   60
     2MAX21(3), AMIN21(3), AMAX22(3), AMIN22(3), AMAX23(3), AMIN23(3), ADATA   70
     3MAX24(3), AMIN24(3), AMAX31(3), AMIN31(3), AMAX32(3), AMIN32(3), ADATA   80
     4MAX41(3), AMIN41(3), AMAX42(3), AMIN42(3), AMAX51(3), AMIN51(3), ADATA   90
     5MAX52(3), AMIN52(3) ...(11,4,.                                      DATA  100
      READ (4,*) NCYC,M,NPARTS,CREQO,E,ITV,XMTBF,CPHR                    DATA  110
      READ (4,*,END=10) PDEF                                             DATA  120
      IF (PDEF) 10,10,20                                                 DATA  130
10    PDEF=0.001*NPARTS                                                  DATA  140
      GO TO 30                                                           DATA  150
20    PDEF=PDEF*NPARTS                                                   DATA  160
30    DO 60 I=1,M                                                        DATA  170
      READ (4,*,END=40) ADEF(I)                                         DATA  180
      IF (ADEF(I)) 40,40,50                                              DATA  190
40    ADEF(I)=.005*NPARTS                                                DATA  200
      GO TO 60                                                           DATA  210
50    ADEF(I)=ADEF(I)*NPARTS                                            DATA  220
60    CONTINUE                                                           DATA  230
      WRITE (6,470)                                                      DATA  240
      READ (5,*) ITABLE                                                  DATA  250
      IF (ITABLE.LT.1) GO TO 90                                          DATA  260
      WRITE (6,500)                                                      DATA  270
      IF (CREQO.GE.9.E9) GO TO 70                                        DATA  280
      WRITE (6,520) NPARTS,M,PDEF,CREQO,XMTBF                            DATA  290
      GO TO 80                                                           DATA  300
70    WRITE (6,480) NPARTS,M,PDEF                                        DATA  310
80    WRITE (6,510)                                                      DATA  320
      WRITE (6,530) (I,ADEF(I),I=1,M)                                    DATA  330
90    DO 140 I1=1,M                                                      DATA  340
      DO 140 I2=1,5                                                      DATA  350
      READ (11,*,END=100) P(1,I1,I2)                                     DATA  360
      IF (P(1,I1,I2)) 100,100,120                                        DATA  370
100   DO 110 I=1,NCYC                                                    DATA  380
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110    P(I,I1,I2)=1.0 ............................................  DATA 390
       GO TO 140 ...............................................  DATA 400
120    DO 130 I=1,NCYC .........................................  DATA 410
130    P(I,I1,I2)=P(1,I1,I2) ...................................  DATA 420
140    CONTINUE ................................................  DATA 430
       DO 190 I1=1,M ...........................................  DATA 440
       DO 190 I2=1,5 ...........................................  DATA 450
       READ (8,*,END=150) F(1,I1,I2) ...........................  DATA 460
       IF (F(1,I1,I2)) 150,150,170 .............................  DATA 470
150    DO 160 I=1,NCYC .........................................  DATA 480
       F(I,1,I2)=0.0 ...........................................  DATA 490
       F(I,2,I2)=0.0 ...........................................  DATA 500
       F(I,3,I2)=0.0 ...........................................  DATA 510
160    F(I,4,I2)=0.0 ...........................................  DATA 520
       GO TO 190 ...............................................  DATA 530
170    DO 180 I=1,NCYC .........................................  DATA 540
180    F(I,I1,I2)=F(1,I1,I2) ...................................  DATA 550
190    CONTINUE ................................................  DATA 560
       DO 290 I1=1,M ...........................................  DATA 570
       DO 290 I2=1,5 ...........................................  DATA 580
       READ (9,*,END=200) R1(1,I1,I2),R2(1,I1,I2) ..............  DATA 590
       IF (R1(1,I1,I2)) 200,200,220 ............................  DATA 600
200    DO 210 I=1,NCYC .........................................  DATA 610
210    R1(I,I1,I2)=0.5 .........................................  DATA 620
       GO TO 240 ...............................................  DATA 630
220    DO 230 I=1,NCYC .........................................  DATA 640
230    R1(I,I1,I2)=R1(1,I1,I2) .................................  DATA 650
240    IF (R2(1,I1,I2)) 250,250,270 ............................  DATA 660
250    DO 260 I=1,NCYC .........................................  DATA 670
260    R2(I,I1,K2)=0.5 .........................................  DATA 680
       GO TO 290 ...............................................  DATA 690
270    DO 280 I=1,NCYC .........................................  DATA 700
280    R2(I,I1,I2)=R2(1,I1,I2) .................................  DATA 710
290    CONTINUE ................................................  DATA 720
       DO 430 I1=1,M ...........................................  DATA 730
       DO 430 I2=1,5 ...........................................  DATA 740
       READ (4,*,END=300) B2,B3 ................................  DATA 750
       IF (B2) 300,300,350 .....................................  DATA 760
300    GO TO (310,320,330,340), I1 .............................  DATA 770
310    CR1(1,I2)=0.0 ...........................................  DATA 780
       GO TO 360 ...............................................  DATA 790
320    CR1(2,I2)=0.0 ...........................................  DATA 800
       GO TO 360 ...............................................  DATA 810
330    CR1(3,I2)=0.0 ...........................................  DATA 820
       GO TO 360 ...............................................  DATA 830
340    CR1(4,I2)=0.0 ...........................................  DATA 840
       GO TO 360 ...............................................  DATA 850
350    CR1(I1,I2)=B2 ...........................................  DATA 860
360    IF (B3) 370,370,420 .....................................  DATA 870
370    GO TO (380,390,400,410), I1 .............................  DATA 880
380    CR2(1,I2)=45. ...........................................  DATA 890
       GO TO 430 ...............................................  DATA 900
390    CR2(2,I2)=300. ..........................................  DATA 910
       GO TO 430 ...............................................  DATA 920
400    CR2(3,I2)=990. ..........................................  DATA 930
```

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        GO TO 430                                                       DATA 940
410     CR2(4,I2)=0.0                                                   DATA 950
        GO TO 430                                                       DATA 960
420     CR2(I1,I2)=83                                                   DATA 970
430     CONTINUE                                                        DATA 980
        IF (ITABLE.LT.1) GO TO 440                                      DATA 990
        WRITE (6,540)                                                   DATA1000
        WRITE (6,490) (J,CR2(J,1),J=1,M)                                DATA1010
440     DO 450 I=1,NCYC                                                 DATA1020
        DO 450 J=1,M                                                    DATA1030
        NJ=N(J)                                                         DATA1040
        DO 450 K=1,NJ                                                   DATA1050
        F(I,J,K)=F(1,J,K)                                               DATA1060
        R1(I,J,K)=R1(1,J,K)                                             DATA1070
450     R2(I,J,K)=R2(1,J,K)                                             DATA1080
        DO 460 IZ=1,M                                                   DATA1090
C   TEST ONE:  CONSTANT TEMPERATURE                                     DATA1100
        READ (12,*) AMAX11(IZ),AMIN11(IZ)                              DATA1110
        READ (12,*) AMAX12(IZ),AMIN12(IZ)                              DATA1120
C   TEST TWO:  CYCLED TEMPERATURE                                       DATA1130
        READ (12,*) AMAX21(IZ),AMIN21(IZ)                              DATA1140
        READ (12,*) AMAX22(IZ),AMIN22(IZ)                              DATA1150
        READ (12,*) AMAX23(IZ),AMIN23(IZ)                              DATA1160
        READ (12,*) AMAX24(IZ),AMIN24(IZ)                              DATA1170
C   TEST THREE: RANDOM  VIBRATION                                       DATA1180
        READ (12,*) AMAX31(IZ),AMIN31(IZ)                              DATA1190
        READ (12,*) AMAX32(IZ),AMIN32(IZ)                              DATA1200
C   TEST FOUR:  SINE-SWEEP VIBRATION                                    DATA1210
        READ (12,*) AMAX41(IZ),AMIN41(IZ)                              DATA1220
        READ (12,*) AMAX42(IZ),AMIN42(IZ)                              DATA1230
C   TEST FIVE:  SINE-FIXED VIBRATION                                    DATA1240
        READ (12,*) AMAX51(IZ),AMIN51(IZ)                              DATA1250
        READ (12,*) AMAX52(IZ),AMIN52(IZ)                              DATA1260
460     CONTINUE                                                        DATA1270
        RETURN                                                          DATA1280
C                                                                       DATA1290
470     FORMAT (5X//5X,'IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT,',' DATA1300
       1ENTER ZERO:')                                                   DATA1310
480     FORMAT (' ',5X,I7,5X,I1,4X,F13.0,12X,'NA',13X,'NA')            DATA1320
490     FORMAT (17X,'LEVEL',I3,30X,F10.0)                              DATA1330
500     FORMAT (1X///////34X,' PROGRAM DATA'/' ',80('_')/' ',7X,'NPARTS',30ATA1340
       1X,'LEVELS',3X,'(PDEF X NPARTS)',6X,'CREQD',10X,'MTBF'/' ',80('-')/DATA1350
       2/)                                                             DATA1360
510     FORMAT (1X////33X,'  ASSEMBLY DATA'/' ',80('_')/' ',8X,'ASSEMBLY LDATA1370
       1EVEL',2X,' ',2X,'EXPECTED NUMBER OF ASSEMBLY DEFECTS'/' ',8X,14('_DATA1380
       2'),5X,35('_')//)                                               DATA1390
520     FORMAT (' ',5X,I7,5X,I1,4X,F13.0,2X,F13.2,5X,2X,F13.0)         DATA1400
530     FORMAT (' ',11X,I2,27X,F9.0)                                    DATA1410
540     FORMAT (1X////35X,' REWORK ','COST '/' ',80('_')//)            DATA1420
        END                                                            DATA1430
        SUBROUTINE MEAN (XN,XLAMB,XNP,T,OMSS,FALL)                      MEAN  10
        IF (OMSS.GT.0.999) GO TO 10                                     MEAN  20
        IF (T.LE.1.E-9) GO TO 10                                        MEAN  30
        A0=XN*XLAMB                                                     MEAN  40
        A1=XNP                                                          MEAN  50
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        RK=-ALOG(OMSS)/(XLAMB*T)                                              MEAN  60
        A2=RK*XLAMB                                                           MEAN  70
        FALL=A0*T+A1*(1.-EXP(-A2*T))                                          MEAN  80
        GO TO 20                                                              MEAN  90
10      FALL=0.0                                                              MEAN 100
20      RETURN                                                                MEAN 110
        END                                                                   MEAN 120
```

PROGRAM LISTING FOR ADAPT. FORT

```
      DIMENSION ADEF(5), ISCR(3), TIME(3), TS(3), COME(3), ON(3), PFALL(MAIN  1.
     1*), NFALL(3), AFALL(3), APFALL(3), AMFALL(3), F(3), MARK(3), MARKPMAIN  20
     2N(3), PL(3), PBL(3), WBL(3), BU(3), PBU(3), WBU(3), TS1(3), AT(3),MAIN   30
     3 AMTBF(7,7), PREM(7), WREM(7)                                    MAIN   40
      FLAG=0.0                                                         MAIN   50
      READ (2,*) ISCR,M,NPARTS,PDEF,ADEF                              MAIN   60
      READ (13,*) XNOP,XLAMP1,XLAMP2,XLAMC1,XLAMC2                    MAIN   70
      READ (13,*) TIME,AT                                            MAIN   80
      READ (2,*) TS(1),TS(2),TS(3)                                  MAIN   90
      DO 10 I=1,3                                                    MAIN  100
      TS(I)=1.-TS(I)                                                 MAIN  110
      TS1(I)=TS(I)                                                   MAIN  120
   10 CONTINUE                                                       MAIN  130
      READ (2,*) COME(1),COME(2),COME(3)                            MAIN  140
      READ (2,*) ON(1),ON(2),ON(3),PLEFT                            MAIN  150
      WRITE (6,260)                                                  MAIN  160
      ON3=(ON(3)-PLEFT)                                              MAIN  170
      DO 20 KK=1,7                                                   MAIN  180
      PREM(KK)=(AMAX1(0.,PLEFT-4.+FLOAT(KK)))                       MAIN  190
      DO 20 KL=1,7                                                   MAIN  200
      WREM(KL)=AMAX1(0.,ON3-4.+FLOAT(KL))                           MAIN  210
      AMTBF(KK,KL)=(XNOP-WREM(KL))*XLAMC1+(FLOAT(NPARTS)-PREM(KK))*XLAMPMAIN  220
     11+WREM(KL)*XLAMC2+PREM(KK)*XLAMP2                              MAIN  230
      AMTBF(KK,KL)=1./AMTBF(KK,KL)                                   MAIN  240
   20 CONTINUE                                                       MAIN  250
      WRITE (6,270) WREM                                            MAIN  260
      DO 30 KK=1,7                                                   MAIN  270
   30 WRITE (6,280) PREM(KK),(AMTBF(KK,KL),KL=1,7)                  MAIN  280
      WRITE (6,290)                                                  MAIN  290
      READ (5,*) INTER                                              MAIN  300
      IF (INTER.GT.0) GO TO 40                                      MAIN  310
      PER=.99                                                        MAIN  320
      GO TO 50                                                       MAIN  330
   40 WRITE (6,300)                                                  MAIN  340
      READ (5,*) PER                                                MAIN  350
   50 WRITE (6,310)                                                  MAIN  360
      DO 60 K=1,3                                                    MAIN  370
      F(K)=COME(K)-ON(K)                                            MAIN  380
   60 CONTINUE                                                       MAIN  390
   70 PFALL(1)=IFIX((PDEF*(COME(1)-ON(1)))/COME(1))                MAIN  400
      NFALL(1)=COME(1)-ON(1)-PFALL(1)                              MAIN  410
      PFALL(2)=IFIX((PDEF-PFALL(1))*(COME(2)-ON(2))/COME(2))       MAIN  420
      NFALL(2)=COME(2)-ON(2)-PFALL(2)                              MAIN  430
      FFALL(3)=IFIX((PDEF-PFALL(1)-PFALL(2))*(COME(3)-ON(3))/COME(3))MAIN  440
      NFALL(3)=COME(3)-ON(3)-PFALL(3)                              MAIN  450
      IF (FLAG.GT.0.0) PLEFT=PDEF-PFALL(1)-PFALL(2)-PFALL(3)       MAIN  460
      WLEFT=ON(3)-PLEFT                                            MAIN  470
      WRITE (6,320)                                                 MAIN  480
      WRITE (6,330)                                                 MAIN  490
      WRITE (6,320)                                                 MAIN  500
      WRITE (6,350)                                                 MAIN  510
      WRITE (6,360) NPARTS,ADEF(1),ADEF(2),ADEF(3),PLEFT           MAIN  520
      WRITE (6,370)                                                 MAIN  530
      WRITE (6,380)                                                 MAIN  540
      RMTBF=(XNOP-WLEFT)*XLAMC1+(FLOAT(NPARTS)-PLEFT)*XLAMP1+WLEFT*XLAMCMAIN  550
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12+PLEFT*XLAMP2                                                              MAIN 560
      RMTBF=1./RMTBF                                                         MAIN 570
      WRITE (6,390) PDEF,TS(1),TS(2),TS(3),WLEFT                             MAIN 580
      WRITE (6,340)                                                          MAIN 590
      WRITE (6,400)                                                          MAIN 600
      WRITE (6,410) ON(1),ON(2),ON(3),RMTBF                                  MAIN 610
      WRITE (6,340)                                                          MAIN 620
      WRITE (6,320)                                                          MAIN 630
      WRITE (6,420)                                                          MAIN 640
      WRITE (6,420)                                                          MAIN 650
      WRITE (6,430)                                                          MAIN 660
      WRITE (6,440)                                                          MAIN 670
      WRITE (6,460)                                                          MAIN 680
      WRITE (6,450)                                                          MAIN 690
      WRITE (6,470)                                                          MAIN 700
      WRITE (6,460)                                                          MAIN 710
      WRITE (6,480)                                                          MAIN 720
      DO 80 IJ=1,3                                                           MAIN 730
      CALL BOUND (F(IJ),BL(IJ),BU (IJ),PER)                                  MAIN 740
      CALL BOUND (PFALL(IJ),PBL(IJ),PBU(IJ),PER)                             MAIN 750
      CALL BOUND (WFALL(IJ),WBL(IJ),WBU(IJ),PER)                             MAIN 760
   80 CONTINUE                                                               MAIN 770
      WRITE (6,490) PFALL(1),WFALL(1),F(1),PFALL(2),WFALL(2),F(2),PFALL(MAIN 780
     13),WFALL(3),F(3)                                                       MAIN 790
      WRITE (6,460)                                                          MAIN 800
      WRITE (6,520)                                                          MAIN 810
      WRITE (6,510)                                                          MAIN 820
      WRITE (6,460)                                                          MAIN 830
      WRITE (6,490) PBU(1),WBU(1),BU(1),PBU(2),WBU(2),BU(2),PBU(3),WBU(3MAIN 840
     1),BU(3)                                                                MAIN 850
      WRITE (6,460)                                                          MAIN 860
      WRITE (6,500)                                                          MAIN 870
      WRITE (6,510)                                                          MAIN 880
      WRITE (6,460)                                                          MAIN 890
      WRITE (6,490) PBL(1),WBL(1),BL(1),PBL(2),WBL(2),BL(2),PBL(3),WBL(3MAIN 900
     1),BL(3)                                                                MAIN 910
      WRITE (6,460)                                                          MAIN 920
      WRITE (6,440)                                                          MAIN 930
      IF (FLAG.GT.0.0) GO TO 180                                             MAIN 940
      GO TO 90                                                               MAIN 950
   90 CALL INT (XNOP,NPARTS,PLEFT,ON(3),XLAMP1,XLAMP2,XLAMC1,XLAMC2)         MAIN 960
      WRITE (6,530)                                                          MAIN 970
      READ (5,*) IADAPT                                                      MAIN 980
      IF (IADAPT.LT.1) GO TO 220                                             MAIN 990
      WRITE (6,540)                                                          MAIN1000
      READ (5,*) IFALL                                                       MAIN1010
      IF (IFALL.GT.0) GO TO 120                                              MAIN1020
      WRITE (6,550)                                                          MAIN1030
      READ (5,*) AFALL(1),AFALL(2),AFALL(3)                                  MAIN1040
      ICUE=0                                                                 MAIN1050
  100 DO 110 I=1,3                                                           MAIN1060
      MARK(I)=0                                                              MAIN1070
      IF (AFALL(I).LT.BL(I)) MARK(I)=1                                       MAIN1080
  110 CONTINUE                                                               MAIN1090
      MARKT=MARK(1)+MARK(2)+MARK(3)                                          MAIN1100
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      IF ((MARKT.EQ.0).AND.(ICUE.GT.0)) GO TO 140              MAIN1110
      IF (MARKT.LE.0) GO TO 240                                MAIN1120
      CALL MJFLOW (MARK,COME,ON,TS,AFALL,F,TIME,XLAMP1,NPARTS)  MAIN1130
      FLAG=1.0                                                 MAIN1140
      WRITE (6,560)                                            MAIN1150
      GO TO 70                                                 MAIN1160
120   WRITE (6,570)                                            MAIN1170
      IFW=0                                                    MAIN1180
      DO 130 I=1,3                                             MAIN1190
      WRITE (6,580) I                                          MAIN1200
      READ (5,*) APFALL(I),AMFALL(I)                           MAIN1210
      AFALL(I)=APFALL(I)+AMFALL(I)                             MAIN1220
130   CONTINUE                                                 MAIN1230
      ICUE=1                                                   MAIN1240
      GO TO 100                                                MAIN1250
140   DO 170 I=1,3                                             MAIN1260
      IF (APFALL(I).GE.PBL(I)) GO TO 150                       MAIN1270
      PFALL(I)=APFALL(I)                                       MAIN1280
      WFALL(I)=AMFALL(I)                                       MAIN1290
      MARKPW(I)=1                                              MAIN1300
150   IF (AMFALL(I).GE.WBL(I)) GO TO 160                       MAIN1310
      WFALL(I)=AMFALL(I)                                       MAIN1320
      PFALL(I)=APFALL(I)                                       MAIN1330
      MARKPW(I)=1                                              MAIN1340
160   AFALL(I)=PFALL(I)+WFALL(I)                               MAIN1350
170   CONTINUE                                                 MAIN1360
      IPW=MARKPW(1)+MARKPW(2)+MARKPW(3)                        MAIN1370
      IF (IPW.EQ.0) GO TO 240                                  MAIN1380
      CALL MJFLOW (MARKPW,COME,ON,TS,AFALL,F,TIME,XLAMP1,NPARTS, MAIN1390
      FLAG=1.0                                                 MAIN1400
      WRITE (6,560)                                            MAIN1410
      GO TO 70                                                 MAIN1420
180   IF (IPW.LT.1) GO TO 200                                  MAIN1430
      DO 190 J=1,3                                             MAIN1440
190   MARK(J)=MARKPW(J)                                        MAIN1450
200   CONTINUE                                                 MAIN1460
      DO 210 J=1,3                                             MAIN1470
      IF (MARK(J).LT.1) GO TO 210                              MAIN1480
      CALL SOLVE (J,ISCR,TS,TS1,AT)                            MAIN1490
210   CONTINUE                                                 MAIN1500
220   WRITE (6,590)                                            MAIN1510
      READ (5,*) IEQ                                           MAIN1520
      IF (IEQ.LT.1) GO TO 230                                  MAIN1530
      CALL ECUIV (IEQ)                                         MAIN1540
230   WRITE (6,250)                                            MAIN1550
      READ (5,*) ICUMF                                         MAIN1560
      IF (ICUMF.LT.1) GO TO 240                                MAIN1570
      XNP=ON(2)+ADEF(3)                                        MAIN1580
      CALL FTIME (NPARTS,XLAMP1,XNP,TS(3),TIME(3))             MAIN1590
240   STOP                                                     MAIN1600
C                                                              MAIN1610
C                                                              MAIN1620
250   FORMAT (1X/5X,'IF YOU HAVE TIMES TO FAILURE FOR LEVEL III',' ENTERMAIN1630
     1 1.'/6/,'IF NOT, ENTER ZERO:')                          MAIN1640
260   FORMAT (1X///.'///20X,'INSTANTANEOUS MTBF FOR REMAINING'/23X,' FLAGMAIN1650
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      )S AT END OF SCREENING'///28X,' WORKMANSHIP')              MAIN1660
270   FORMAT (1X,'   PARTS  |',7(4X,F5.0)/1X,72('-'))            MAIN1670
280   FORMAT (1X,F7.0,1X,'|',7(4X,F5.0))                         MAIN1680
290   FORMAT (1X//////5X,'IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER'MAIN1690
      1,' ZERO'/5X,'IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR',' A MAIN1700
      2NARROWER INTERVAL)'/5X,'ENTER ONE:')                      MAIN1710
300   FORMAT (5X,'ENTER PROBABILITY DESIRED:')                   MAIN1720
310   FORMAT (/////////25X,'STRESS SCREENING FLOW DIAGRAM'//)    MAIN1730
320   FORMAT (1X,5(12('-'),3X))                                  MAIN1740
330   FORMAT (1X,'| INCOMING |',3X,'| LEVEL 1  |',3X,'| LEVEL 2  |',3X,'MAIN1750
      1| LEVEL 3  |',3X,'| OUTGOING |')                          MAIN1760
340   FORMAT (1X,5('|',10X,'|',3X))                              MAIN1770
350   FORMAT (1X,'|#PARTS:   |',3X,3('|ADEF= ',4X,'|',3X),'|DEF P REM:|'MAIN1780
      1)                                                         MAIN1790
360   FORMAT (1X,'|',I10,'|',3X,3('|',F10.0,'|',3X),'|',F10.0,'|')  MAIN1800
370   FORMAT (1X,4('|',10X,'|-->'),'|',10X,'|')                  MAIN1810
380   FORMAT (1X,'|#DEFECTS: |',3X,3('|TS=    ',4X,'|',3X),'|','DEF W REM:|MAIN1820
      1')                                                        MAIN1830
390   FORMAT (1X,'|',F10.0,'|',3X,3('|',F10.3,'|',3X),'|',F10.0,'|')  MAIN1840
400   FORMAT (1X,'|',10X,'|',3X,3('|DEF PASSED|',3X),'|MTBF:     |')  MAIN1850
410   FORMAT (1X,'|',10X,'|',3X,4('|',F10.0,'|',3X))             MAIN1860
420   FORMAT (21X,3('|',14X))                                    MAIN1870
430   FORMAT (21X,3('V',14X))                                    MAIN1880
440   FORMAT (15X,3(14('-'),1X))                                 MAIN1890
450   FORMAT (15X,3('|  EXPECTED  |',1X))                        MAIN1900
460   FORMAT (15X,3('|',12X,'|',1X))                             MAIN1910
470   FORMAT (15X,3('|      FALLOUT:  |',1X))                    MAIN1920
480   FORMAT (15X,3('| PRT WKM TOT|',1X))                        MAIN1930
490   FORMAT (15X,3('|',3(F4.0),'|',1X))                         MAIN1940
500   FORMAT (15X,3('|LOWR END FOR|',1X))                        MAIN1950
510   FORMAT (15X,3('|C3S FALLOUT:|',1X))                        MAIN1960
520   FORMAT (15X,3('|UPPR BND FOR|',1X))                        MAIN1970
530   FORMAT (1X////5X,'IF YOU HAVE FALLOUT NUMBERS ENTER 1, IF NOT',', MAIN1980
      1ENTER ZERO:')                                             MAIN1990
540   FORMAT (5X,'IF YOU HAVE SEPARATE FALLOUT FOR PARTS AND ','WORKMANSMAIN2000
      1HIP ENTER ONE'/5X,'IF YOU HAVE TOTAL FALLOUT ONLY AT',' EACH LEVELMAIN2010
      2, ENTER ZERO:')                                           MAIN2020
550   FORMAT (5X,' ENTER THE THREE ACTUAL FALLOUT NUMBERS, IN ORDER, ','MAIN2030
      1BY LEVEL:')                                               MAIN2040
560   FORMAT (1X/////24X,'STRESS SCREENING RESULTS:'///)         MAIN2050
570   FORMAT (5X,'ENTER, IN ORDER, ACTUAL FALLOUT:'/5X,'DUE TO    (A)','MAIN2060
      1 PARTS    (B) WORKMANSHIP, AS PROMPTED:')                 MAIN2070
580   FORMAT (5X,'FOR LEVEL',I2,':')                             MAIN2080
590   FORMAT (1X/5X,'IF YOU WISH TO ANALYZE EQUIVALENT SCREENS ','ENTER MAIN2090
      1 ONE'/6X,'IF NOT, ENTER ZERO:')                           MAIN2100
      END                                                        MAIN2110
      SUBROUTINE BOUND (X,BL,BU,PER)                             BOUN  10
      DIMENSION B(2), PR(2)                                      BOUN  20
      IF (X.LE.0.) GO TO 50                                      BOUN  30
      PR(2)=(1.-PER)/2.                                          BOUN  40
      PR(1)=PER+PR(2)                                            BOUN  50
      X1=2*X                                                     BOUN  60
C                                                                BOUN  70
      DO 40 I=1,2                                                BOUN  80
      B(I)=(((FLOAT(I-2)*2.58*SQRT(2.))+SQRT(2.*2.58**2+4*X1))/2)**2  BOUN  90
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10      IF (B(I).LT.0.5) GO TO 20                                        BOUN 100
        CALL HOCH (X1,B(I),P,IER)                                        BOUN 110
        P=P-FR(I)                                                        BOUN 120
        B1=B(I)+0.005                                                    BOUN 130
        CALL HOCH (X1,B1,P1,IER)                                         BOUN 140
        P1=P1-FR(I)                                                      BOUN 150
        BN=B(I)-(P*0.005)/(P1-P)                                         BOUN 160
        IF (ABS(BN-B(I)).LE.0.0005) GO TO 30                             BOUN 170
        B(I)=BN                                                          BOUN 180
        GO TO 10                                                         BOUN 190
20      B(I)=0.0                                                         BOUN 200
        GO TO 40                                                         BOUN 210
30      B(I)=BN                                                          BOUN 220
40      CONTINUE                                                         BOUN 230
        BL=FLOAT(IFIX((AMAX1(B(1),2.)-2.)/2.))                           BOUN 240
        IF (B(1).LE.2.4) BL=0.                                           BOUN 250
        BU=FLOAT(IFIX(B(2)/2.+0.9))                                      BOUN 260
        IF (BU.LE.0.) BU=0.                                              BOUN 270
        GO TO 60                                                         BOUN 280
50      BL=0.                                                            BOUN 290
        BU=0.                                                            BOUN 300
60      RETURN                                                           BOUN 310
        END                                                              BOUN 320
        SUBROUTINE MEAN (N,XLAMB,XNP,T,CMSS,FALL)                        MEAN  10
        IF (CMSS.GT.0.999) GO TO 10                                      MEAN  20
        A0=N*XLAMB                                                       MEAN  30
        A1=XNP                                                           MEAN  40
        RK=-ALOG(CMSS)/(XLAMB*T)                                         MEAN  50
        A2=RK*XLAMB                                                      MEAN  60
        FALL=A0*T+A1*(1.-EXP(-A2*T))                                     MEAN  70
        GO TO 20                                                         MEAN  80
10      FALL=0.0                                                         MEAN  90
20      RETURN                                                           MEAN 100
        END                                                             MEAN 110
        SUBROUTINE NUFLOW (MARK,COME,ON,TS,AFALL,F,TIME,XLAMB1,NPARTS)   NUFL  10
        DIMENSION MARK(3), COME(3), ON(3), TS(3), AFALL(3), F(3), TIME(3) NUFL  20
        DO 10 I=1,1                                                      NUFL  30
        IF (MARK(I).LT.1) GO TO 10                                       NUFL  40
        TS(I)=AFALL(I)/COME(I)                                           NUFL  50
10      CONTINUE                                                         NUFL  60
        IF (MARK(1).LE.0) GO TO 20                                       NUFL  70
        PLACE=COME(1)*(1.-TS(1))                                         NUFL  80
        COME(2)=COME(2)+(PLACE-ON(1))                                    NUFL  90
        ON(1)=PLACE                                                      NUFL 100
        F(1)=COME(1)-ON(1)                                               NUFL 110
20      IF (MARK(2).LT.1) GO TO 30                                       NUFL 120
        TS(2)=AFALL(2)/COME(2)                                           NUFL 130
30      CMSS=1.-TS(2)                                                    NUFL 140
        CALL MEAN (NPARTS,XLAMB1,COME(2),TIME(2),CMSS,F(2))             NUFL 150
        PLACE=COME(2)-F(2)                                               NUFL 160
        COME(3)=COME(3)+(PLACE-ON(2))                                    NUFL 170
        ON(2)=PLACE                                                      NUFL 180
        IF (MARK(3).LT.1) GO TO 40                                       NUFL 190
        TS(3)=AFALL(3)/COME(3)                                           NUFL 200
40      CMSS=1.-TS(3)                                                    NUFL 210
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      CALL MEAN (NPARTS,XLAMB1,COME(3),TIME(3),OMSS,F(3))              NUFL 220
      CN(3)=COME(3)-F(3)                                               NUFL 230
      RETURN                                                           NUFL 240
      END                                                             NUFL 250
      SUBROUTINE SOLVE (J,ISCR,TS,TS1,AT)                              SOLV  10
      DIMENSION ISCR(3), TS(3), TS1(3), AT(3), PARAM(3,5,4)            SOLV  20
      REWIND 12                                                        SOLV  30
      DO 10 IM=1,3                                                     SOLV  40
      DO 10 K=1,5                                                      SOLV  50
      DO 10 M=1,4                                                      SOLV  60
      IF ((K.NE.2).AND.(M.GT.2)) GO TO 10                             SOLV  70
      READ (12,*) PARAM(IM,K,M),PARAM(IM,K,M)                          SOLV  80
   10 CONTINUE                                                         SOLV  90
      DO 20 N=1,3                                                      SOLV 100
      MM=2                                                             SOLV 110
      IF (ISCR(N).EQ.2) MM=4                                           SOLV 120
      PARAM(J,ISCR(N),MM)=AT(N)                                        SOLV 130
   20 CONTINUE                                                         SOLV 140
      IT=0                                                             SOLV 150
      CALL F (J,C1,IT,PARAM,TS,TS1,ISCR,T1,TNEW)                       SOLV 160
      IT=1                                                             SOLV 170
      T1=AT(J)                                                         SOLV 180
      CALL F (J,C1,IT,PARAM,TS,TS1,ISCR,T1,TNEW)                       SOLV 190
      IG=ISCR(J)                                                       SOLV 200
      GO TO (30,40,50,50,50), IG                                       SOLV 210
   30 IF (TNEW.GT.240.) TNEW=240.                                      SOLV 220
      WRITE (6,70) J,TNEW                                              SOLV 230
      GO TO 60                                                         SOLV 240
   40 IF (TNEW.GT.40.) TNEW=40.                                        SOLV 250
      WRITE (6,80) J,TNEW                                              SOLV 260
      GO TO 60                                                         SOLV 270
   50 IF (TNEW.GT.60.) TNEW=60.                                        SOLV 280
      WRITE (6,90) J,TNEW                                              SOLV 290
   60 CONTINUE                                                         SOLV 300
      RETURN                                                           SOLV 310
C                                                                      SOLV 320
C                                                                      SOLV 330
   70 FORMAT (1X//5X,'INCREASE TIME ON LEVEL',I2,' TO ',F10.2,' HOURS.')SOLV 340
   80 FORMAT (1X//5X,'INCREASE NUMBER OF CYCLES ON LEVEL',I2,' TO ',F10.SOLV 350
     12//)                                                             SOLV 360
   90 FORMAT (1X//5X,'INCREASE TIME ON LEVEL',I2,' TO ',F10.2,' MINUTES'SOLV 370
     1//)                                                              SOLV 380
      END                                                             SOLV 390
      SUBROUTINE F (J,C1,IT,PARAM,TS,TS1,ISCR,T1,TNEW)                 F     10
      DIMENSION PARAM(3,5,4), ISCR(3), TS(3), TS1(3)                   F     20
      IG=ISCR(J)                                                       F     30
      GO TO (10,50,80,80,80), IG                                       F     40
   10 IF (IT.GT.0) GO TO 20                                            F     50
      TIME=PARAM(J,1,2)                                                F     60
      ST=TS(J)                                                         F     70
      GO TO 30                                                         F     80
   20 TNEW=((CUN(ISCR(J),PARAM(J,ISCR(J),1))*T1**.5)/C1)**2            F     90
      GO TO 40                                                         F    100
   30 R=ABS(25.-PARAM(J,1,1))                                          F    110
      DT=ALOG(EXP(1.)+1.)                                              F    120
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      C1=(-ALOG(1.-ST/.85)/(R**.6*OT**2.7*TIME**.5))           F  130
40    RETURN                                                    F  140
50    IF (IT.GT.0) GO TO 60                                     F  150
      NCY=PARAM(J,2,4)                                          F  160
      ST=TS(J)                                                  F  170
      GO TO 70                                                  F  180
60    THEN=((CON(ISCR(J),PARAM(J,ISCR(J),1)*T1**.5)/C1)**2      F  190
      RETURN                                                    F  200
70    R=PARAM(J,2,1)-PARAM(J,2,2)                               F  210
      OT=ALOG(EXP(1.)+PARAM(J,2,3))                             F  220
      C1=(-ALOG(1.-ST/.85)/(R**.6*OT**2.7*NCY**.5))             F  230
      RETURN                                                    F  240
80    T=PARAM(J,ISCR(J),2)                                      F  250
      ST=TS(J)                                                  F  260
      IG=ISCR(J)                                                F  270
      GO TO (90,90,90,100,110), IG                              F  280
90    D=.144*PARAM(J,3,1)-.0862                                 F  290
      E=0.5                                                     F  300
      GO TO 120                                                 F  310
100   D=.0635*PARAM(J,4,1)+.1065                                F  320
      E=0.6                                                     F  330
      GO TO 120                                                 F  340
110   D=.0435*PARAM(J,5,1)+.324                                 F  350
      E=0.2                                                     F  360
120   IF (IT.GT.0) GO TO 130                                    F  370
      C1=-ALOG(1.-ST/D)/T**E                                    F  380
      RETURN                                                    F  390
130   THEN=((T1**E*CON(ISCR(J),PARAM(J,ISCR(J),1)))/C1)**(1./E) F  400
      RETURN                                                    F  410
      END                                                       F  420
      FUNCTION CON (I,PARAM)                                    CON  10
      CON=0.0023                                                CON  20
      GO TO (40,40,10,20,30), I                                 CON  30
10    CON=(.266*PARAM+1.402)**(-1)                              CON  40
      GO TO 40                                                  CON  50
20    CON=(.0176*PARAM+7.097)**(-1)                             CON  60
      GO TO 40                                                  CON  70
30    CON=(-.419*PARAM+8.620)**(-1)                             CON  80
40    RETURN                                                    CON  90
      END                                                       CON 100
      SUBROUTINE EQUIV (MEQ)                                    EQUI  10
      DIMENSION P(5,3,2), ISCR(2)                               EQUI  20
10    WRITE (6,130)                                             EQUI  30
      FLAG=0.                                                   EQUI  40
C                                                               EQUI  50
      WRITE (6,140)                                             EQUI  60
      READ (5,*) ISCR(1)                                        EQUI  70
      WRITE (6,150)                                             EQUI  80
      READ (5,*) ISCR(2)                                        EQUI  90
C                                                               EQUI 100
      DO 70 I=1,2                                               EQUI 110
      GO TO (20,30), I                                          EQUI 120
20    WRITE (6,160)                                             EQUI 130
      M=ISCR(I)                                                 EQUI 140
      GO TO (40,50,60,60,60), M                                 EQUI 150
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30      WRITE (6,170)                                               EQUI 160
        M=ISCR(I)                                                   EQUI 170
        GO TO (40,50,60,60,60), M                                   EQUI 180
40      WRITE (6,180)                                               EQUI 190
        READ (5,*) P(1,1,I),P(1,2,I)                                EQUI 200
        GO TO 70                                                    EQUI 210
50      WRITE (6,190)                                               EQUI 220
        READ (5,*) P(2,1,I),P(2,2,I),P(2,3,I)                       EQUI 230
        GO TO 70                                                    EQUI 240
60      WRITE (6,200)                                               EQUI 250
        READ (5,*) P(ISCR(I),1,I),P(ISCR(I),2,I)                    EQUI 260
70      CONTINUE                                                    EQUI 270
C                                                                   EQUI 280
        K=1                                                         EQUI 290
        CALL SSF (ISCR(1),K,P,X,FLAG,GTS)                           EQUI 300
        WRITE (6,210) GTS                                           EQUI 310
        K=2                                                         EQUI 320
        X1=1.                                                       EQUI 330
        J=0                                                         EQUI 340
        CALL SSF (ISCR(K),K,P,X,FLAG,GTS)                           EQUI 350
        IF (FLAG.GT.0.) GO TO 110                                   EQUI 360
        MM=ISCR(2)                                                  EQUI 370
        GO TO (80,90,100,100,100), MM                               EQUI 380
80      WRITE (6,220) X                                             EQUI 390
        GO TO 120                                                   EQUI 400
90      WRITE (6,230) X                                             EQUI 410
        GO TO 120                                                   EQUI 420
100     WRITE (6,240) X                                             EQUI 430
110     FLAG=0.                                                     EQUI 440
120     WRITE (6,250)                                               EQUI 450
        READ (5,*) L                                                EQUI 460
        IF (L.GT.0) GO TO 10                                        EQUI 470
        RETURN                                                      EQUI 480
C                                                                   EQUI 490
C                                                                   EQUI 500
130     FORMAT (1X/1X,'FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:'/1X,'EQUI 510
       11.  CONSTANT TEMPERATURE'/1X,'2.  TEMPERATURE CYCLING'/1X,'3.  RANEQUI 520
       2DOM VIBRATION'/1X,'4.  SINE SWEEP VIBRATION'/1X,'5.',' SINE FIXEDEQUI 530
       3 VIBRATION'///)                                             EQUI 540
140     FORMAT (1X,'ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN ',EQUI 550
       1'SCREEN:')                                                  EQUI 560
150     FORMAT (1X,'ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO ','DESIREQUI 570
       1ED SCREEN:')                                                EQUI 580
160     FORMAT (1X/1X,'ENTER PARAMETERS FOR GIVEN SCREEN:')         EQUI 590
170     FORMAT (1X/1X,'ENTER PARAMETERS FOR DESIRED SCREEN;'/2X,'ENTER ZEREQUI 600
       10 FOR PARAMETER TO BE FOUND:')                              EQUI 610
180     FORMAT (1X/1X,'ENTER ABSOLUTE VALUE OF DIFFERENCE BETWEEN',' TEMP EQUI 620
       1IN DEG C AND 25 DEG C'/2X,'AND TIME IN HOURS')              EQUI 630
190     FORMAT (1X/1X,'ENTER RANGE IN DEG C'/2X,'TEMP RATE OF CHANGE IN DEEQUI 640
       1G C/MIN'/2X,'AND NUMBER OF CYCLES')                         EQUI 650
200     FORMAT (1X/1X,'ENTER G LEVEL AND TIME IN MINUTES')          EQUI 660
210     FORMAT (1X/1X,'TEST STRENGTH FOR GIVEN SCREEN=',F7.4)       EQUI 670
220     FORMAT (1X/1X,' PARAMETER IN DESIRED CONSTANT TEMP SCREEN=',F10.1)EQUI 680
230     FORMAT (1X//1X,'PARAMETER IN DESIRED TEMP CYCLING ','SCREEN=',F10.EQUI 690
       11)                                                          EQUI 700
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240   FORMAT (1X//1X,'PARAMETER FOR DESIRED VIBRATION ','SCREEN=',F10.1)EQUI  710
250   FORMAT (1X/////1X,'IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE,',' IEQUI  720
      IF NOT, ENTER ZERO:')                                          IEQUI  720
      END                                                            EQUI   730
      SUBROUTINE SSF (ICUE,K,P,X,FLAG,GTS)                           EQUI   740
      DIMENSION P(5,3,2)                                             SSF     10
      GO TO (10,50,90,90,90), ICUE                                   SSF     20
10    IF (K.EQ.1) GO TO 30                                           SSF     30
      IF (P(1,1,2).GT.0.0) GO TO 20                                  SSF     40
      X=((ALOG(1.-GTS/.85))/(-.0023*ALOG(EXP(1.)+1.)**2.7*P(1,2,2)**.5))SSF  60
      X=X**(5./3.)                                                   SSF     60
      GO TO 40                                                       SSF     70
20    X=((ALOG(1.-GTS/.85))/(-.0023*ALOG(EXP(1.)+1.)**2.7*P(1,1,2)**.6))SSF  80
      X=X**2.                                                        SSF     90
      RETURN                                                         SSF    100
30    R=P(1,1,K)                                                     SSF    110
      T=P(1,2,K)                                                     SSF    120
      GTS=.85*(1.-EXP(-.0023*R**.6*ALOG(EXP(1.)+1.)**2.7*T**.5))     SSF    130
40    RETURN                                                         SSF    140
50    IF (K.EQ.1) GO TO 80                                           SSF    150
      IF (P(2,1,K).GT.0.0) GO TO 60                                  SSF    160
      X=((ALOG(1.-GTS/.85))/(-.0023*ALOG(EXP(1.)+P(2,2,K))**2.7))    SSF    170
      X=(X/P(2,3,K)**.5)**(5./3.)                                    SSF    180
      RETURN                                                         SSF    190
60    IF (P(2,2,K).GT.0.0) GO TO 70                                  SSF    200
      X=(ALOG(1.-GTS/.85)/(-.0023*P(2,1,K)**.6*P(2,3,K)**.5))**(1./2.7)SSF  210
      X=EXP(X)-EXP(1.)                                               SSF    220
      RETURN                                                         SSF    230
70    X=((ALOG(1.-GTS/.85))/(-.0023*ALOG(EXP(1.)+P(2,2,K))**2.7))    SSF    240
      X=(X/P(2,1,K)**.6)**2.                                         SSF    250
      RETURN                                                         SSF    260
80    R=P(2,1,K)                                                     SSF    270
      RNCY=P(2,3,K)                                                  SSF    280
      DT=ALOG(EXP(1.)+P(2,2,K))                                      SSF    290
      GTS=.85*(1.-EXP(-.0023*R**.6*DT**2.7*RNCY**.5))                SSF    300
      RETURN                                                         SSF    310
90    IF (K.EQ.1) GO TO 100                                          SSF    320
      IF (P(ICUE,2,K).GT.0.0) GO TO 190                              SSF    330
100   T=P(ICUE,2,K)                                                  SSF    340
      GO TO (110,110,110,120,130), ICUE                             SSF    350
110   B=.266*P(ICUE,1,K)+1.402                                      SSF    360
      D=.144*P(ICUE,1,K)-.0362                                       SSF    370
      C=.5                                                           SSF    380
      GO TO 140                                                      SSF    390
120   B=.0174*P(ICUE,1,K)+7.097                                     SSF    400
      D=.0635*P(ICUE,1,K)+.1065                                      SSF    410
      C=.8                                                           SSF    420
      GO TO 140                                                      SSF    430
130   B=-.419*P(ICUE,1,K)+8.62                                      SSF    440
      D=.0433*P(ICUE,1,K)+.324                                      SSF    450
      C=.2                                                           SSF    460
140   GO TO (160,150), K                                            SSF    470
150   IF (GTS.GT.D) GO TO 160                                        SSF    480
      X=(-B*ALOG(1.-GTS/D))**(1./C)                                  SSF    490
      GO TO 170                                                      SSF    500
                                                                     SSF    510
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160    WRITE (6,230)                                                    SSF  520
       FLAG=1.                                                          SSF  530
170    RETURN                                                           SSF  540
180    GTS=O*(1.-EXP(-T**C/B))                                          SSF  550
       RETURN                                                           SSF  560
190    X1=1.                                                            SSF  570
       J=0                                                              SSF  580
200    XN=X1-(SSF1(ICUE,1,P,X1)-GTS)/SSF1(ICUE,2,P,X1)                  SSF  590
       J=J+1                                                            SSF  600
       IF (J.GT.50) GO TO 220                                           SSF  610
       IF (ABS(XN-X1).LE.0.005) GO TO 210                              SSF  620
       X1=XN                                                            SSF  630
       IF (X1.LE.0.) X1=J                                               SSF  640
       GO TO 200                                                        SSF  650
210    X=XN                                                             SSF  660
       RETURN                                                           SSF  670
220    WRITE (6,240)                                                    SSF  680
       FLAG=1.                                                          SSF  690
       RETURN                                                           SSF  700
C      DEBUG INIT                                                       SSF  710
C                                                                       SSF  720
C                                                                       SSF  730
230    FORMAT (1X,'SOLUTION NOT POSSIBLE FOR DESIRED G LEVEL.')         SSF  740
240    FORMAT (1X,'SOLUTION CANNOT BE FOUND BY INTERNAL METHOD.'/2X,'TRY SSF  750
      1A GRID OF POSSIBLE SOLUTIONS.')                                  SSF  760
       END                                                              SSF  770
       FUNCTION SSF1 (IDS,L,P,X1)                                       SSF1  10
       DIMENSION P(5,3,2)                                               SSF1  20
       GO TO (10,20,30,30,30), IDS                                      SSF1  30
10     T=X1                                                             SSF1  40
       RETURN                                                           SSF1  50
20     RNCY=X1                                                          SSF1  60
       RETURN                                                           SSF1  70
30     T=P(IDS,2,2)                                                     SSF1  80
       GO TO (40,40,40,50,60), IDS                                      SSF1  90
40     B=.266*X1+1.402                                                  SSF1 100
       BB=.266                                                          SSF1 110
       D=.144*X1-.0862                                                  SSF1 120
       DD=.144                                                          SSF1 130
       C=.5                                                             SSF1 140
       GO TO 70                                                         SSF1 150
50     B=.0176*X1+7.097                                                 SSF1 160
       BB=.0176                                                         SSF1 170
       D=.0635*X1+.1065                                                 SSF1 180
       DD=.0635                                                         SSF1 190
       C=.8                                                             SSF1 200
       GO TO 70                                                         SSF1 210
60     B=-.419*X1+8.628                                                 SSF1 220
       BB=-.419                                                         SSF1 230
       D=.0435*X1+.324                                                  SSF1 240
       DD=.0435                                                         SSF1 250
       C=.2                                                             SSF1 260
70     IF (L.LT.2) GO TO 80                                             SSF1 270
       SSF1=DD-DD*EXP(-T**C/B)-D*((T**C/B**2)**BB*EXP(-T**C/B))         SSF1 280
       RETURN                                                           SSF1 290
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80      SSF1=D*(1.-EXP(-T**C/B))                              SSF1 300
        RETURN                                                SSF1 310
        END                                                   SSF1 320
        SUBROUTINE INT (XNOP,NPARTS,PLEFT,TLEFT,XLAMP1,XLAMP2,XLAMC1,XLAMCINT  10
     12)                                                      INT   20
C                                                             INT   30
        WRITE (6,20)                                          INT   40
        A0=(XNOP-TLEFT+PLEFT)*XLAMC1+(FLOAT(NPARTS)-PLEFT)*XLAMP1  INT   50
        A1=TLEFT                                              INT   60
        A2=(PLEFT*XLAMP2+(TLEFT-PLEFT)*XLAMC2)/TLEFT          INT   70
        T=2000.                                               INT   80
        DO 10 I=1,10                                          INT   90
        E=A0*T+A1*(1.-EXP(-A2*T))                             INT  100
        XMTBF=T/E                                             INT  110
        WRITE (6,30) T,XMTBF                                  INT  120
        T=T+2000.                                             INT  130
10      CONTINUE                                              INT  140
        RETURN                                                INT  150
C                                                             INT  160
C                                                             INT  170
20      FORMAT (1X///////29X,'INTERVAL MTBF'//27X,17('-')/29X,'TIME   |',' INT  180
     1 MTBF'/27X,17('-'))                                     INT  190
30      FORMAT (28X,F6.0,' |',F7.0)                           INT  200
        END                                                   INT  210
        SUBROUTINE FTIME (NPARTS,XLAMB,XNP,SS,TIME)           FTIM  10
C       SUBPROGRAM TO FIT FAILURE DATA TO                     FTIM  20
C       M(T)=A0*T+A1(1-EXP(-A2*T))                            FTIM  30
C       USING IMSL ROUTINE ZXSSQ                              FTIM  40
C                                                             FTIM  50
        EXTERNAL AMEANV                                       FTIM  60
        REAL*4 PARM(4),X(2),F(200),XJAC(200,2),XJTJ(3),WORK(413)  FTIM  70
        REAL*4 T(200)                                         FTIM  80
        COMMON ZSQ,A0                                         FTIM  90
C                                                             FTIM 100
        XN=FLOAT(NPARTS)                                      FTIM 110
        RK=-ALOG(1.-SS)/(TIME*XLAMB)                          FTIM 120
        WRITE (6,10)                                          FTIM 130
        READ (5,*) M                                          FTIM 140
        K=2*M+13                                              FTIM 150
        CALL OPT (AMEANV,XN,XLAMB,XNP,RK,PARM,X,F,XJAC,XJTJ,WORK,T,M,K,TIMFTIM 160
     1E)                                                      FTIM 170
        RETURN                                                FTIM 180
C                                                             FTIM 190
10      FORMAT (5X,'ENTER NUMBER OF FAILURES DURING FINAL SCREEN:')  FTIM 200
        END                                                   FTIM 210
        SUBROUTINE OPT (AMEANV,XN,XLAMB,XNP,RK,PARM,X,F,XJAC,XJTJ,WORK,T,MOPT   10
     1,K,TIME)                                                OPT   20
        DIMENSION PARM(4), X(2), F(M), XJAC(M,2), XJTJ(3), WORK(K), T(M)  OPT   30
        COMMON ZSQ,A0                                         OPT   40
        WRITE (6,20)                                          OPT   50
        DO 10 IJ=1,M                                          OPT   60
        READ (5,*) T(IJ)                                      OPT   70
        WRITE (17,*) T(IJ)                                    OPT   80
10      CONTINUE                                              OPT   90
        N=2                                                   OPT  100
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          IXJAC=M                                                       OPT  110
          NSIG=4                                                        OPT  120
          EPS=0.0                                                       OPT  130
          DELTA=0.0                                                     OPT  140
          MAXFN=500                                                     OPT  150
          IOPT=1                                                        OPT  160
          A0=XN*XLAMB                                                   OPT  170
          X(1)=XNP                                                      OPT  180
          X(2)=RK*XLAMB*1.E3                                            OPT  190
          CALL ZXSSQ (AMEANV,M,N,NSIG,EPS,DELTA,MAXFN,IOPT,PARM,X,SSQ,F,XJACOPT  200
         1,IXJAC,XJTJ,WORK,INFER,IER)                                   OPT  210
          X(2)=X(2)*1.E-3                                               OPT  220
          CSS=(1.-EXP(-X(2)*TIME))                                      OPT  230
          WRITE (6,30) X(1),CSS                                         OPT  240
          RETURN                                                        OPT  250
C                                                                       OPT  260
20        FORMAT (5X,'ENTER FAILURE TIMES (HOURS), IN ORDER, AS PROMPTED:') OPT  270
30        FORMAT (5X,'THE FAILURE TIMES INDICATE THAT THE ESTIMATED NUMBER'/OPT  280
         15X,' OF DEFECTIVES ENTERING THE SCREEN IS  ',F10.0/5X,' AND THE ESOPT  290
         2TIMATED SCREENING STRENGTH IS ',F5.3,'.')                     OPT  300
          END                                                          OPT  310
          SUBROUTINE AMEANV (X,M,N,F)                                   AMEA  10
          REAL*8 XX(2),FF(200),TT(200)                                  AMEA  20
          REAL*4 X(N),F(M),T(200)                                       AMEA  30
          COMMON ZSQ,A0                                                 AMEA  40
          REWIND 17                                                     AMEA  50
          XX(1)=X(1)                                                    AMEA  60
          XX(2)=X(2)*1.E-3                                              AMEA  70
          DO 30 I=1,M                                                   AMEA  80
          READ (17,*) T(I)                                              AMEA  90
          TT(I)=T(I)                                                    AMEA  100
          IF (TT(I)*XX(2).GT.170.00) GO TO 10                           AMEA  110
          IF (XX(2).LT.0.D0) WRITE (6,40)                               AMEA  120
          FF(I)=A0*TT(I)+XX(1)*(1.00-DEXP(-XX(2)*TT(I)))-DFLOAT(I)      AMEA  130
          GO TO 20                                                      AMEA  140
10        FF(I)=A0*TT(I)+XX(1)-DFLOAT(I)                                AMEA  150
20        F(I)=FF(I)                                                    AMEA  160
30        CONTINUE                                                      AMEA  170
          RETURN                                                        AMEA  180
C                                                                       AMEA  190
40        FORMAT (1X,'NEGATIVE A2 ATTEMPTED--NEW EXPECTED VALUES MAY',' BE NAMEA  200
         1EEDED.')                                                      AMEA  210
          END                                                          AMEA  220
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