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BURN-IN: WHICH ENVIRONMENTAL STRESS SCREENS SHOULD BE USED

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is based on a literature survey of stress screening studies and concludes that thermal cycling and random vibration are the two most powerful screens. Reports dealing with thermal cycling and random vibration tests are discussed and some conclusions and areas that need further research are drawn from them. Recommendations are also given for a military standard on burn-in based on the findings in this report.

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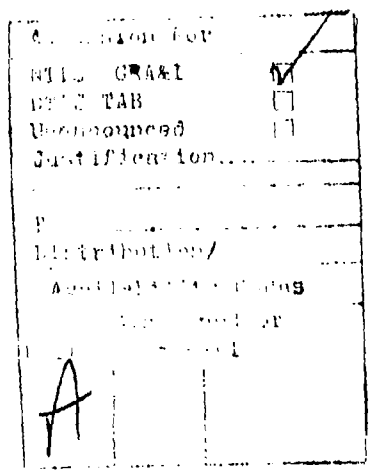

FIGURES

0.0 INTRODUCTION

Burn-in, also commonly called "Environmental Stress Screening," can have a significant impact on reliability when appropriately used during the development and production of electronic equipment. The objective of environmental stress screening is to detect any design, part or workmanship defects in an equipment before it is delivered to the field. Environmental stress screening can be used during the production and development stages. In the developmental stage, environmental stress screening can be instrumental in revealing errors in design, which can then be corrected and a new design tested before production begins. When design problems are discovered after the start of full production, the cost of making the proper corrections becomes immense. Stress screening is also important for production because electronic equipment will always have some infant mortality failures. Infant mortality failures tend to occur early in the life of equipment and are usually caused by either defective parts or workmanship. It is desirable to use stress screening at lower levels of assembly because the earlier a fault is found, the cheaper and easier it is to repair.

Stress screening has been found to be very effective in improving equipment reliability by reducing the occurrence of early life failures, but there are conflicting opinions about which screening approaches are most efficient. This report briefly discusses the most popular stress

screens and attempts to determine which screens are the most powerful. This was accomplished through a literature survey which revealed the results of various screening programs and experiments.

1.0 Hughes' Screening Models

In a study done on contract for the Rome Air Development Center (RADC) and published in RADC-TR-78-55 (14), Hughes Aircraft Company provides information on the possible effectiveness of some commonly used stress screens. The information was obtained by using equations, formulated by Hughes, dealing with constant temperature dwells, temperature cycling and sinusoidal vibration. The equations were formulated from data obtained from an industry survey performed by Hughes and from Hughes' own internal data. The value of each screen is assessed by its test strength. Test strength is defined as "the probability that a given screen, including the test set-up, will detect an incipient/latent defect." The use of the test strength concept facilitates comparison of the relative effectiveness of:

a. a particular screen with different combinations of test variables.

b. different types of screens.

c. different screening sequences (combinations).

The equations for the different screens and definitions of the variables are listed in Figure 1. Since the probability of detection, P_d, is highly dependent on individual test setups, its value is assumed to be 1

$$TS1 \text{ (constant temp)} = \left[0.6 \times P_d \left[1 - e^{-N \times t_T \times 2.63 \times 10^{-5} \times e^{0.0122(T_a + 273)}} \right] \right]$$

$$TS2 \text{ (cycled temp)} = \left[0.8 \times P_d \left[1 - e^{-N \times \frac{dT_i}{dt} \times 11.835 \times 10^{-5} \times e^{.0122(T_{dt}) + 273)}} \right] \right]$$

$$TS3 \text{ (vibration)} = \left[0.2 \times P_d \left[1 - e^{-N \times g \times t_v \times 7.89 \times 10^{-5} \times e^{.0122(T_v + 273)}} \right] \right]$$

where N = number of cycles

t_T = time of temperature exposure (hours)

T_a = actual temperature (^oC)

$\frac{dT_i}{dt}$ = rate of temperature change (^oC/min)

T_{dt} = $(|\text{hi temp} - 25| + |\text{lo temp} - 25| + 50)/2 (^oC)$ $\begin{cases} T_{high} \geq T_{low} \\ T_{low} \leq 250C \end{cases}$

where g = vibration (g's) (sinusoidal at nonresonant frequency)

t_v = length of vibration (minutes)

T_v = |temp at vibration -25| + 25 (^oC)

FIGURE 1. HUGHES TEST STRENGTH MODELS

for all subsequent work in this report, (i.e., once a defect is degraded to a detectable level by the screen it is assumed that it will be found during electrical test). Therefore, the absolute values obtained for test strength are not as important as the relative test strengths which can be used to compare different screens. The total test strength for k combined screens is defined as:

$$TS = 1 - \prod_{i=1}^{k} (1-TS_i)$$

where TS_i is the individual test strength of the $_i$th screen.

1.1 Constant Temperature Dwell Model

A graph of the constant temperature formula is plotted in Figure 2. The abscissa of this graph is the total exposure time which is the product of the number of cycles and the time of exposure for each cycle. The number of cycles for all the temperatures on this graph is assumed to be one because, when constant temperature dwells are considered without temperature cycling in between, the exposure is essentially only one constant cycle. This graph was plotted without considering any limit of time exposure due to production scheduling or any maximum temperature that a component or assembly could withstand without damaging it. Obviously it would not be feasible to subject thousands of black boxes to a temperature of 180°C. for 260 hours each.

In general, defects are not detected until a temperature of at least 50°C. is used and temperatures above 125°C. are believed to damage some good parts. For all temperatures the test strength increases rapidly until about 180 hours of exposure.

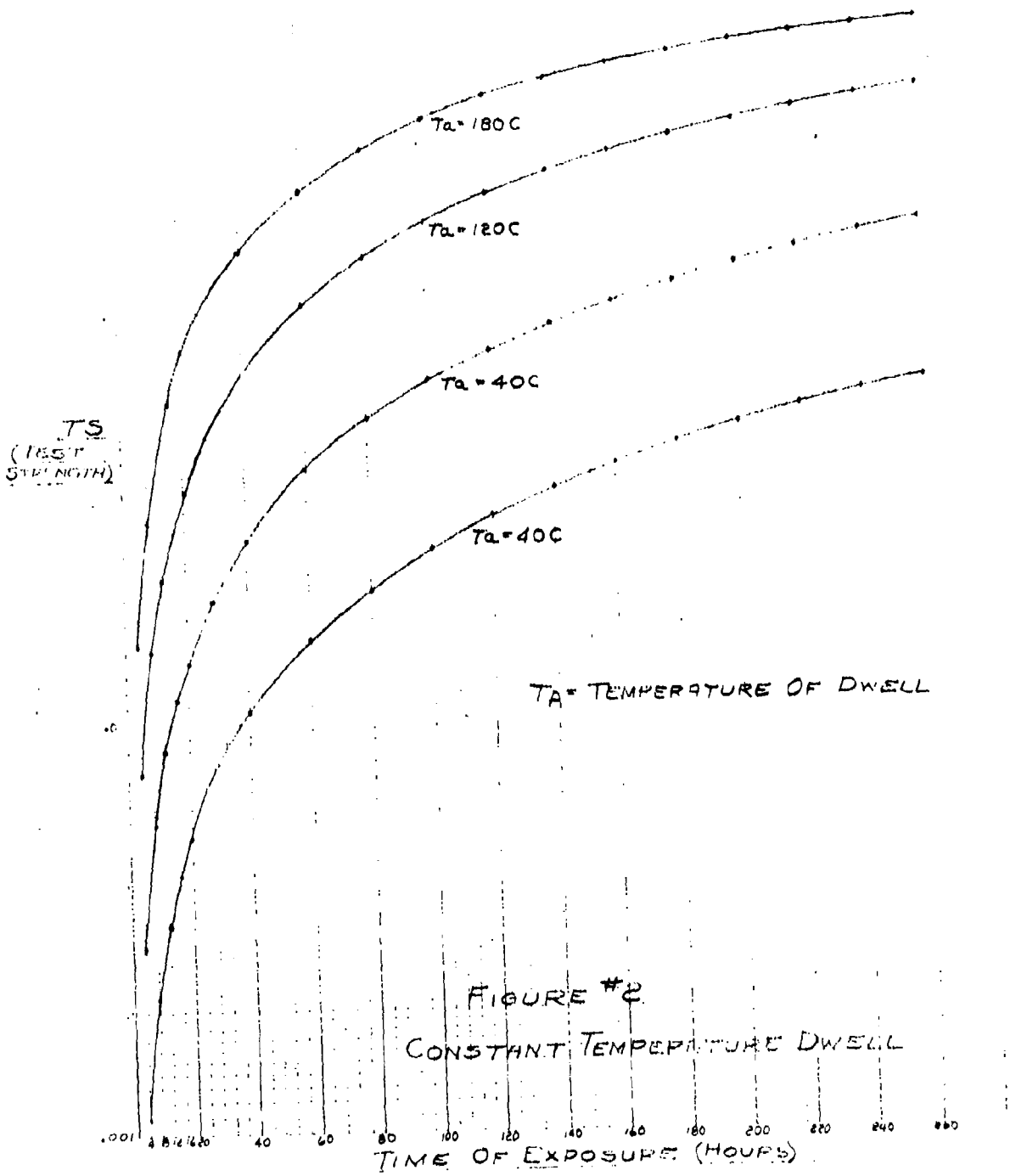

FIGURE #2

CONSTANT TEMPERATURE DWELL

1.2 Sinusoidal Vibration Model

Two graphs have been plotted from the sinusoidal vibration equation. The first graph, Figure 3, shows various g levels for different lengths of vibration to determine test strength with the vibration taking place at room temperature. The second graph, Figure 4, is similar to Figure 3 except that the temperature of vibration can be either 100°C. or -50°C. For both graphs the time of vibration is equal to the product of the number of cycles and the time of vibration for each cycle. The slopes of both graphs tend to level off at about 30 minutes of vibration, but the test strengths for the 100°C. vibrations are, on the average, almost twice the test strengths for the vibrations at room temperature. The test strength limit for the vibration equation is .2 and the graphs show that this limit is approached much more rapidly for higher temperatures.

One obvious conclusion can be made from the inspection of these graphs. Vibration at extreme temperature levels is much more effective than ambient vibration. Although the graphs include a 10 g vibration curve, it has been found that vibration at 8 to 10 g and above can introduce fatigue problems and are thus not recommended (Ref 6).

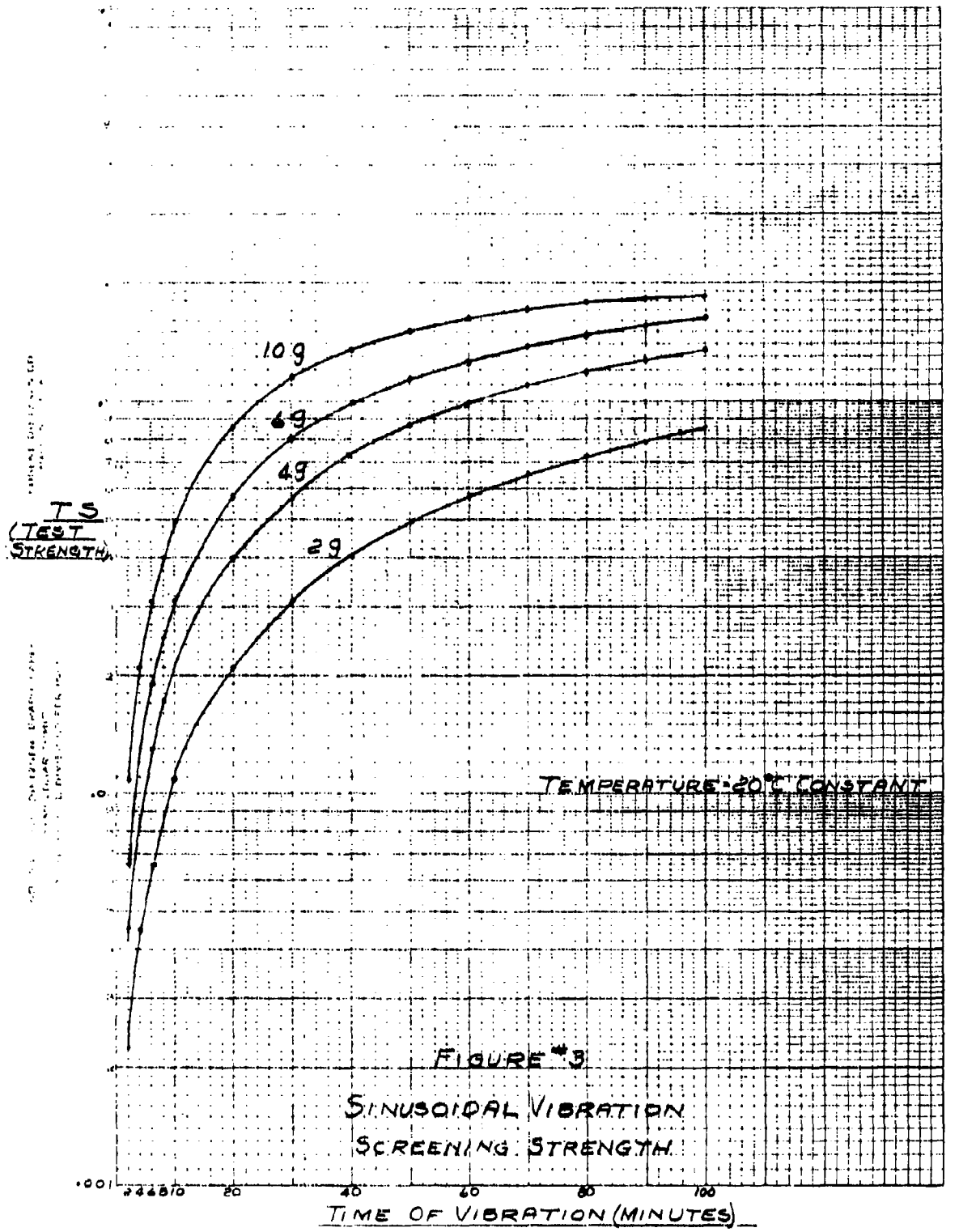

FIGURE #3

SINUSOIDAL VIBRATION

SCREENING STRENGTH

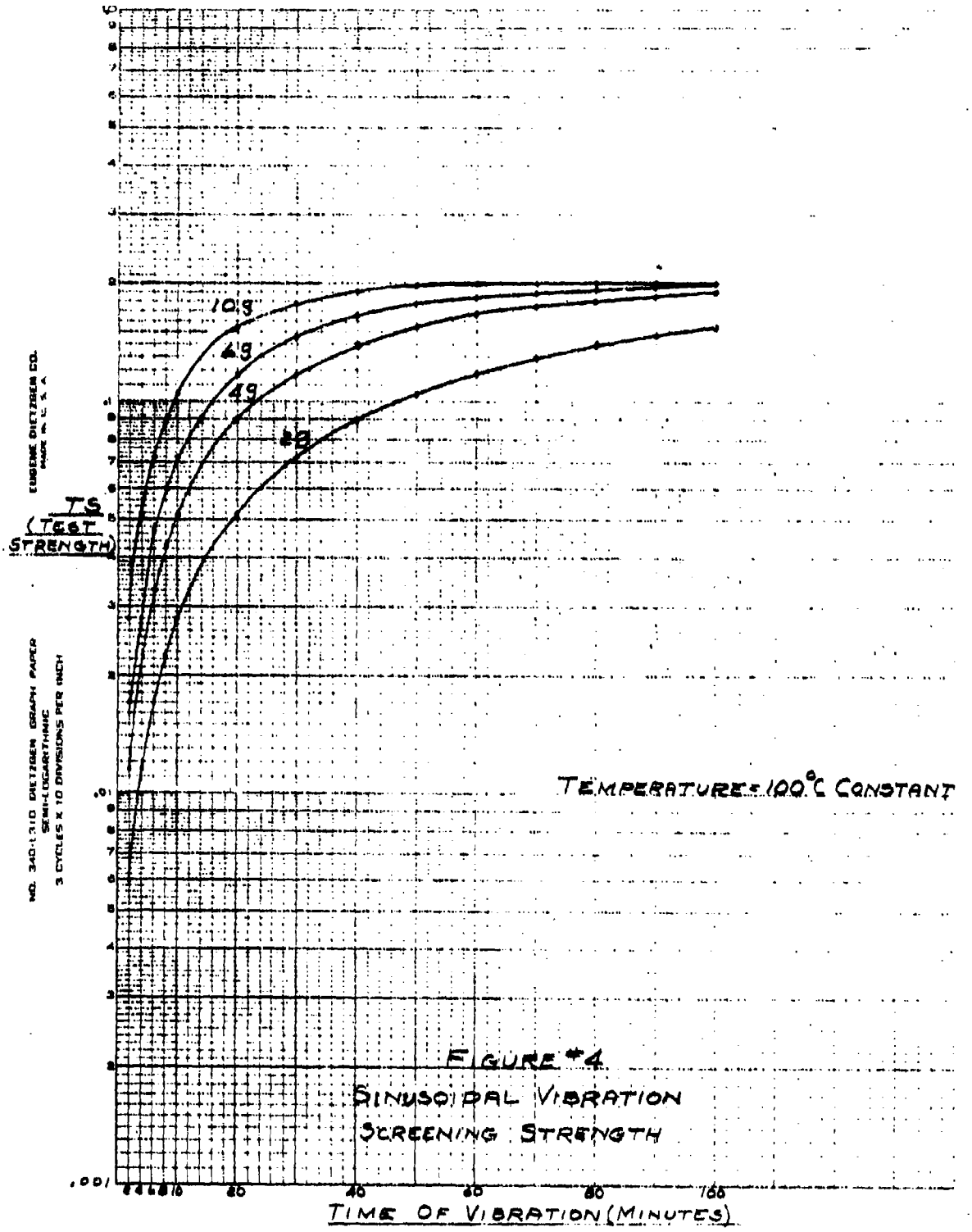

FIGURE #4

SINUSOIDAL VIBRATION

SCREENING STRENGTH

1.3 Temperature Cycling Model

Figure 5 is a graph of the temperature cycling equation. The graph shows the effect of the rate of temperature change with test strength for different numbers of cycles. The graph also shows that for an increasing rate of temperature change the test strength increases. Another advantage of a high rate of change is that the higher it is, the faster the cycles will be completed, thus saving production time and money. Another graph of the temperature cycling equation (Figure 6), shows how increasing the temperature range affects test strength.

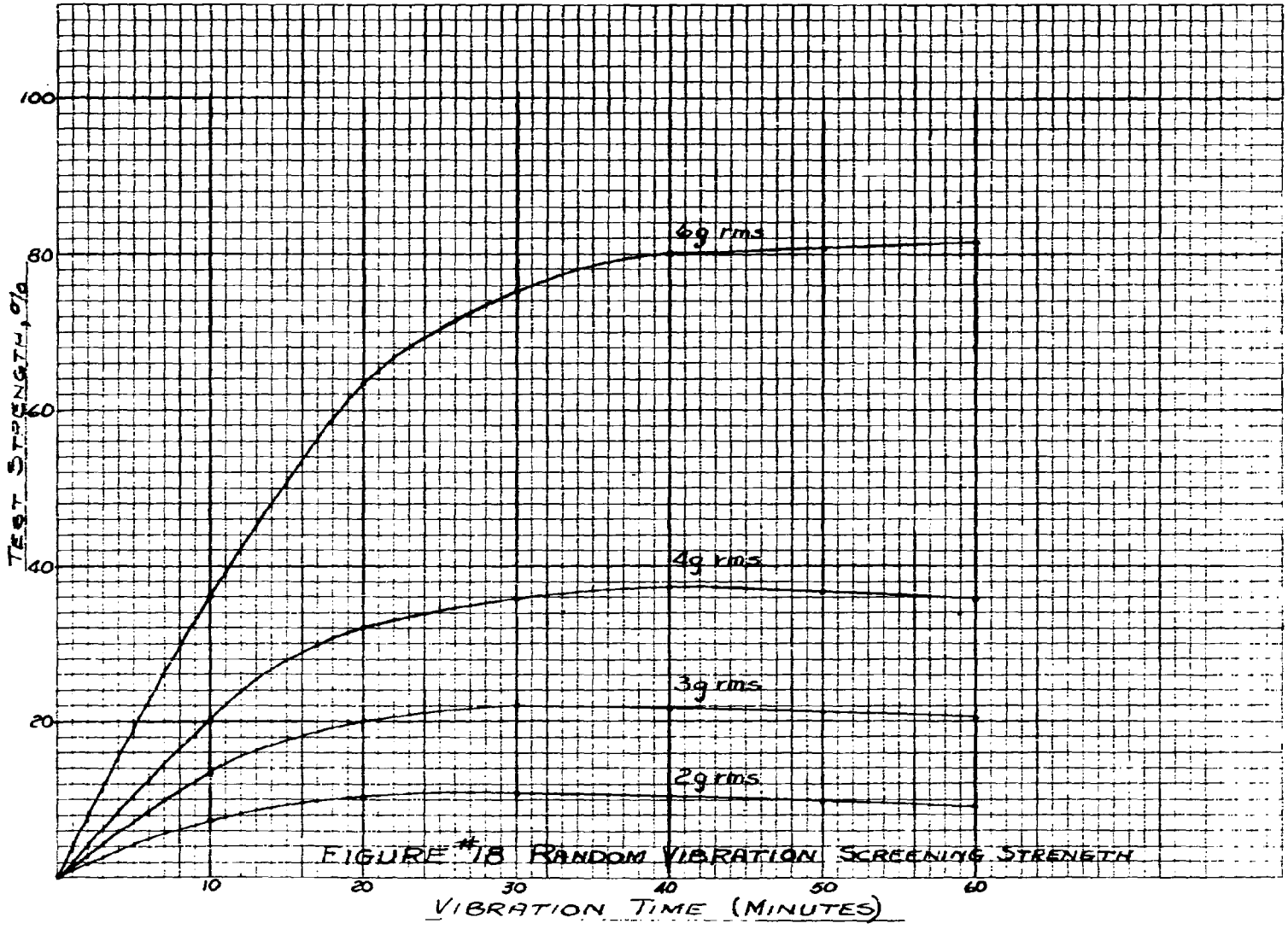

FIGURE #18 RANDOM VIBRATION SCREENING STRENGTH

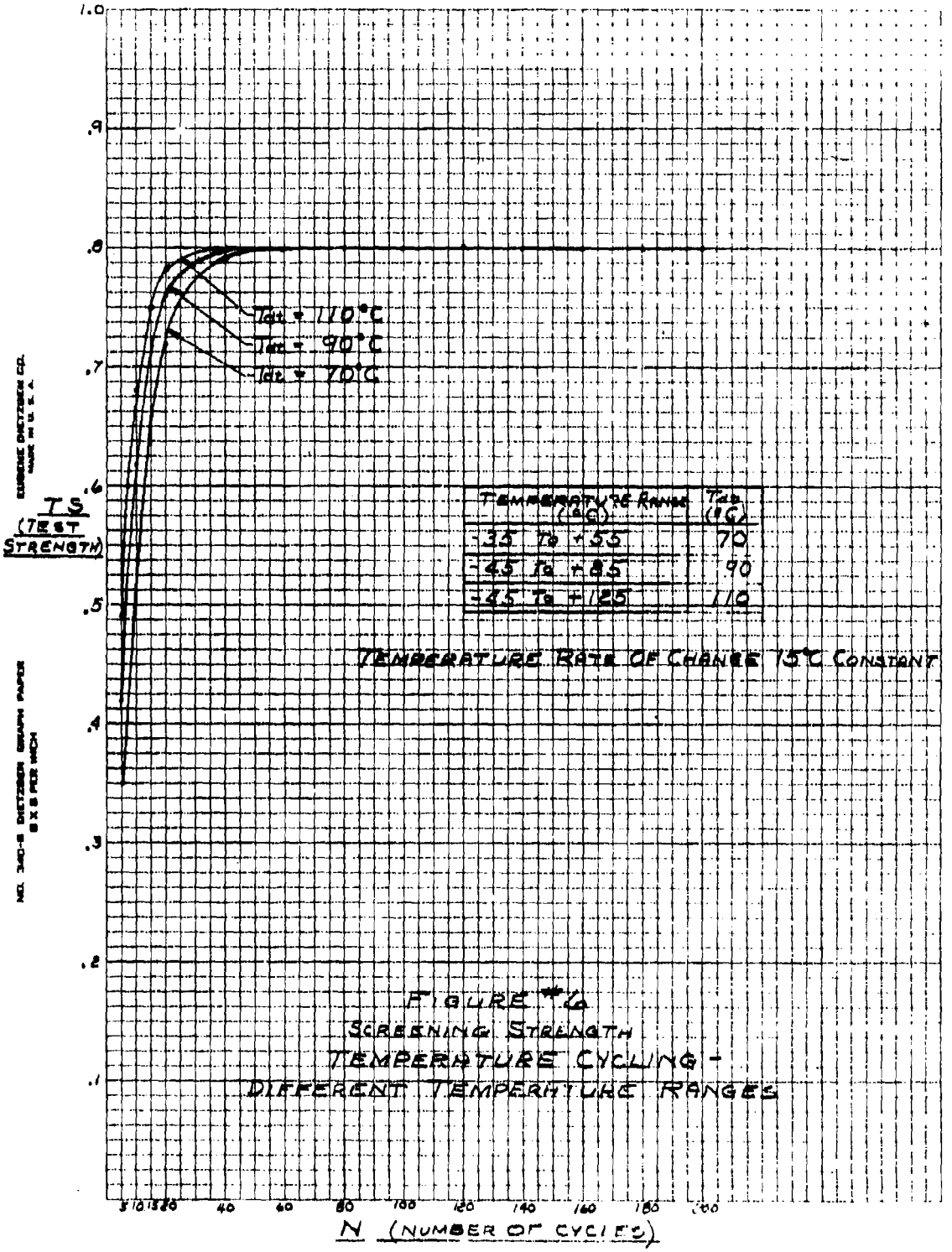

FIGURE #2a
SCREENING STRENGTH
TEMPERATURE CYCLING -
DIFFERENT TEMPERATURE RANGES

1.4 Temperature Cycling is Most Effective

A comparison of all the graphs made from the Hughes formulas (Figures 2, 3, 4, 5, and 6) show that, for the types of screens considered, temperature cycling is clearly the most powerful. In Figure 2, for a constant 120°C. temperature dwell, the TS is below .3 for up to 220 hours of exposure. For 6 g's sinusoidal vibration, in Figure 4, the test strength starts to level off at about 50 minutes with value of only .18. Figure 5, a temperature cycling graph, shows that for 40 cycles of 10°C. per minute rate of change between +55°C. and -55°C., the test strength is .78. The total test time for the 40 cycles is about 14.5 hours. Of course, these test strengths will change for different parameter values, but the point is clearly made that, according to these models, temperature cycling is more effective than constant temperature dwells or sinusoidal vibration.

Some may feel that comparing a thermal cycling screen with a constant temperature dwell screen is acceptable because they are both thermal screens, but may become uncomfortable when a thermal screen is compared to a vibration screen because they are two totally different environments. It must be understood that environmental qualification testing is not being considered here, rather, stress screening is, and this entails stressing electronic equipment for the purpose of uncovering and detecting faults

which could otherwise be responsible for causing field failures. So whether the stress is imposed mechanically, thermally, electrically, or by any combination of screens, the objective is to economically find as many faults as possible

A paper written by Mr. Anthony Coppola of the Rome Air Development Center (RADC), tells of an experiment performed on the AN/ARC-164 UHF Airborne Radio in 1976 which showed how inefficient the constant temperature dwell screen is (Ref 4). The AN/ARC-164 burn-in was originally specified as a 48 hour failure free period using test level E and the standard temperature cycling profile from MIL-STD-781B. Each cycle contained two hours of operation at a constant +55^{o}C. When the burn-in was completed the equipment was subjected to a production reliability verification test (PRVT) to prove that it had achieved the required 1000 hour MTBF. The PRVT showed that the MTBF was only 250 hours, so it was decided that more burn-in was necessary. Increasing the burn-in time would be very difficult since the production schedule was closely matched to the capacity of the test chambers. To avoid this problem the two hour high temperature dwell was omitted, which reduced the original 6-hour cycle to 4 hours. No discernable difference in the screening power was exhibited in a comparison between the 4-hour and 6-hour cycles. It was thus concluded that increasing thermal cycling, at the expense of the sustained high temperature dwell, provided a more powerful burn-in. This strongly supports the conclusions obtained from the Hughes models.

2.0 Thermal Cycling

Since thermal cycling is obviously one of the most powerful of the stress screens mentioned thus far, this section of the report concentrates exclusively on the thermal cycling screen.

2.1 The Martin Marietta Report

The Martin Marietta Report (2) contains a section devoted to temperature cycling at the black box level. The majority of the section is based on information obtained from an industry survey of 26 companies/agencies. It is recommended, in the report, that higher rates of temperature change (up to 22°C. per minute) be used for the best screening. The report also suggests that the temperature range be no less than 88°C., that the range of a typical screen might be from -54°C. to +55°C. and that the final cycle be failure free. The Martin results do not differ greatly from the results derived from the Hughes model (14), except that the Hughes models tend to favor larger temperature ranges.

There is a conflict between the Hughes report and the Martin Marietta report, however, over how many thermal cycles should be used during burn-in. Martin Marietta concludes that 10 cycles should be used for very complex equipment (4000 or more parts) and that fewer cycles are necessary as equipment complexity decreases (Figure 7). As Figure 5 shows, the Hughes models indicate that tests with higher rates of temperature change reach their peak strength between 20 and 30 cycles and between 30 and 40 cycles are needed for the lower rates of change.

It appears that the Hughes' authors feel that the rate of temperature change and the temperature range (Figure 6) are important factors in determining how many cycles should be performed during black-box burn-in. Although the Martin Marietta Report discusses other factors, it appears that the authors have concluded that equipment complexity is the primary factor. Of course, there are other considerations which could have an effect on the amount of cycling needed. Some of the more important ones are:

a. The quality of parts used

b. The stage of production

(1) development

(2) prototype

(3) preproduction

(4) early production

(5) mature production

c. the amount of screening performed in lower assembly levels

d. Whether the cost of the screening program will be justified by reducing field failures and maintenance.

The Martin Marietta study substantiates their recommendation, that no more than 10 temperature cycles are necessary, with experience data collected from many industry sources. Figure 8, extracted from their report, provides the curves derived from experience data of various manufacturers. The curves show the number of failures per unit decreasing until ten or less cycles are achieved and then they level off.

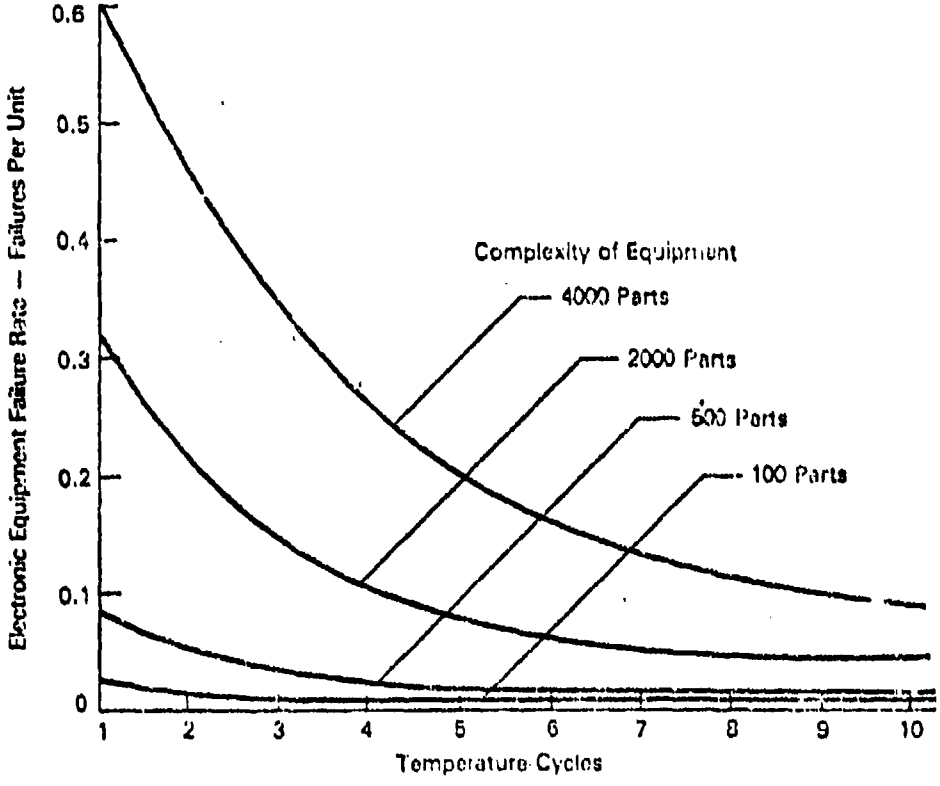

FIGURE 7. NUMBER OF TEMP CYCLES AS A FUNCTION OF EQUIPMENT COMPLEXITY

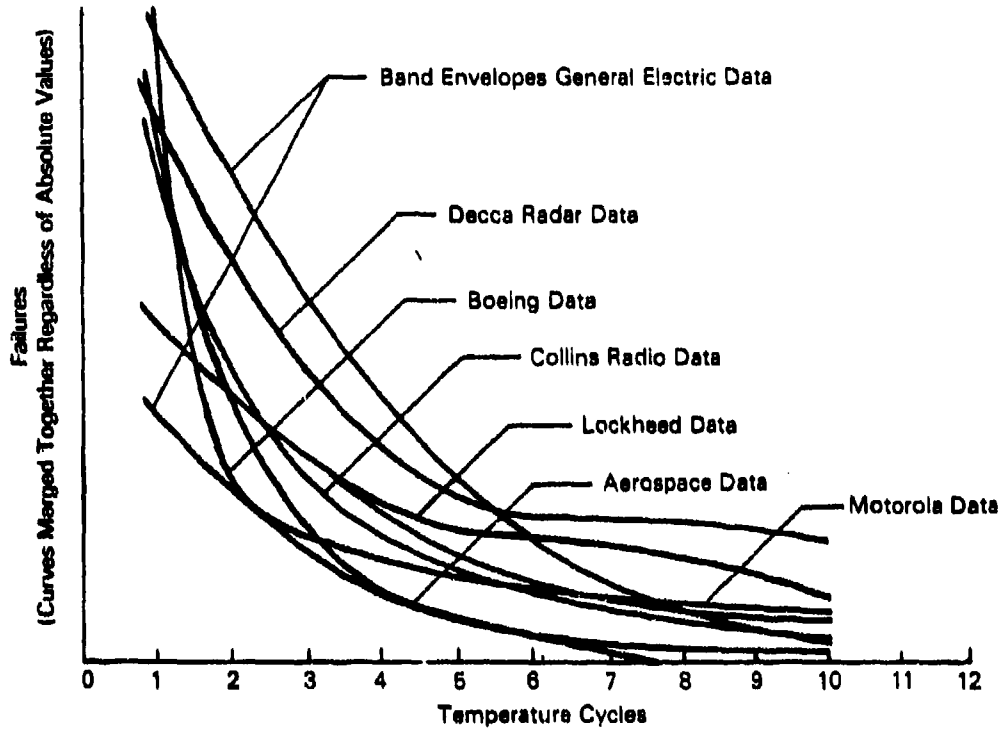

FIGURE 8. TEMPERATURE CYCLES FOR DEFECT ELIMINATION

Some interesting information from the Martin Marietta report was given by Radiation Incorporated concerning the AN/ASW-25 Digital Data Communication Set. The AN/ASW-25 equipment is the essential data link in the Navy All-Weather Carrier Landing System and had a minimum MTBF requirement of 1000 hours. Formal demonstration tests were required in the contract which consisted of 100 hours (16 cycles) in the Test Level E environment of MIL-STD-781. Prior to the formal demonstration tests a "Manufacturing Run-In Test" (MRIT) of up to 24 hours bench ambient conditions was performed. Early in the program, demonstration results indicated an MTBF of 259 hours.

After some parts were changed and the MRIT was increased to 75 hours, the MTBF increased to 327 hours. To increase the reliability, a preconditioning program of a minimum of 75 hours (12 cycles) of Test Level E was instituted which resulted in an MTBF of 1200 hours. The length of the preconditioning was increased to 100 hours (16 cycles) and then to 200 hours (32 cycles) with these increases accompanied by higher MTBF's. Initital tests under these conditions demonstrated MTBF's in excess of 1700 hours. The 200 hour preconditioning period was adopted for the AN/ASW-25 program because of the successful test results. Figure 9 shows how the average MTBF increased with the number of cycles of preconditioning prior to demonstration.

The AN/ASW-25 program is one example that does not follow the temperature cycling schedule recommended in the Martin Marietta report. Mr. T. M. Barlow of Radiation's Reliability Engineering Section believes that part quality is an important factor in determining the amount of temperature cycling necessary and recommends that:

> "Longer periods of cycling should be considered for equipment using standard military parts than for those using screened or "hi-rel" parts. Sixteen to 25 cycles are recommended for equipment containing unscreened MIL-SPEC parts and about 10 cycles are appropriate for equipment containing Hi-Rel parts."

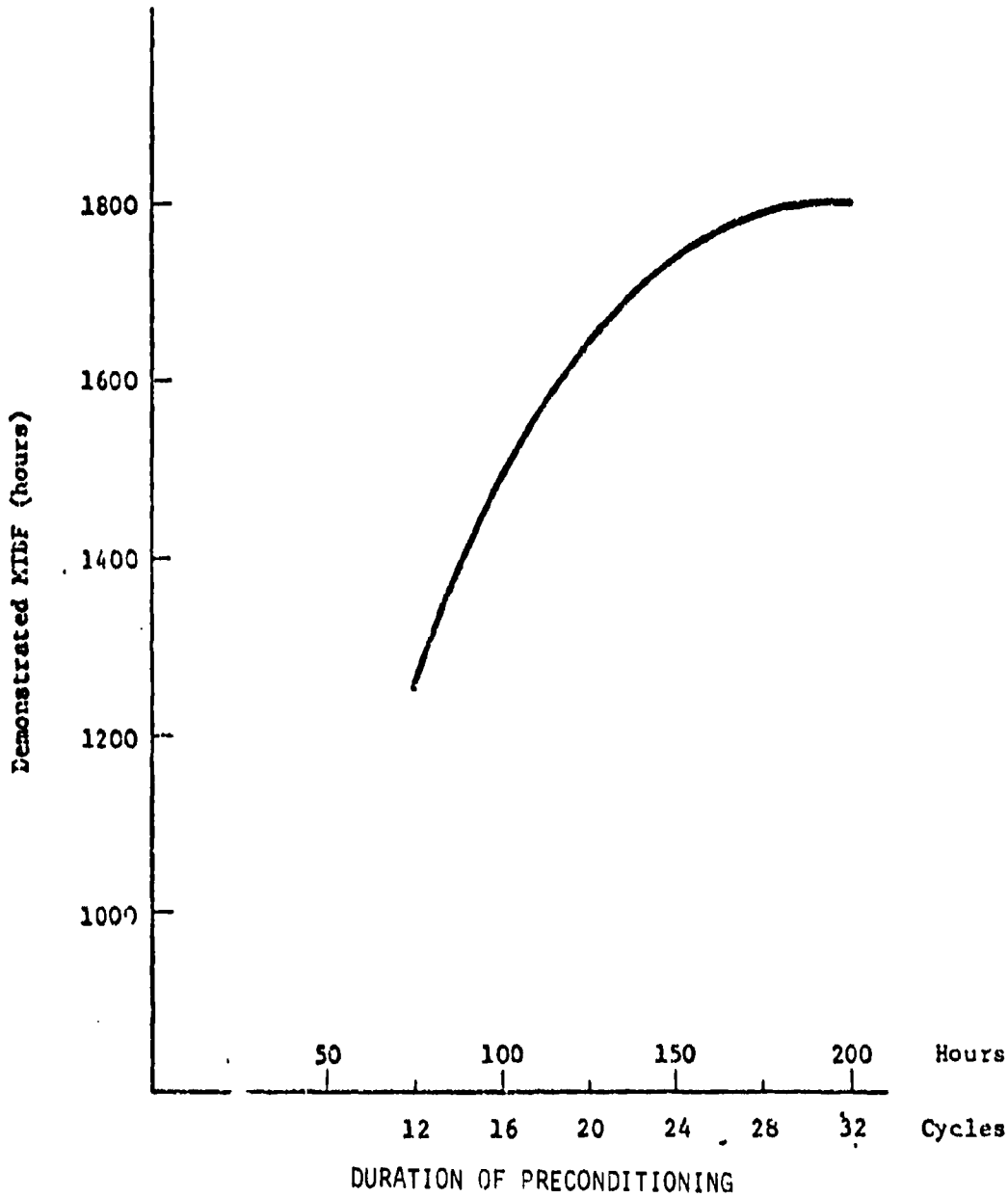

FIGURE 9. TEMPERATURE CYCLING vs. RELIABILITY IMPROVEMENT - AN/ASW-25 EQUIPMENT

2.2 Hughes Studies

The generalized temperature cycling curves (Figure 7) contained in the Martin Marietta report receive some support from tests performed by Hughes Aircraft Company on their AWG-9 program (Ref 11). The AWG-9 is a complete weapon control system developed for use in the Navy F-14 Tomcat aircraft. The screening program for the AWG-9 included environmental cycling tests at the part, module and unit levels. Initially, standard military "C" grade parts were used for the AWG-9 program. As a result of a reliablity upgrade program, part quality was improved to "B" level through the use of the appropriate environmental screens. The module level screening consisted of 36 non-operating cycles between -40°C. and +94°C. at a rate of 5°C. per minute. The next stage of production was the unit level. The dotted line in Figure 10 is the generalized curve for equipment of the complexity of the AWG-9 units. This curve predicted that a constant low failure rate would be achieved after approximately seven cycles. Figure 11 shows a curve that was plotted from test data obtained from unit burn-in. This curve looks very similar to that shown in Figure 10. Since each cycle was equivalent to seven hours on-time, forty-nine hours of operating burn-in represents seven cycles. The temperature range for these cycles was from -54°C. to +55°C. at a rate of 3 1/3°C. per minute (6°F. per minute).

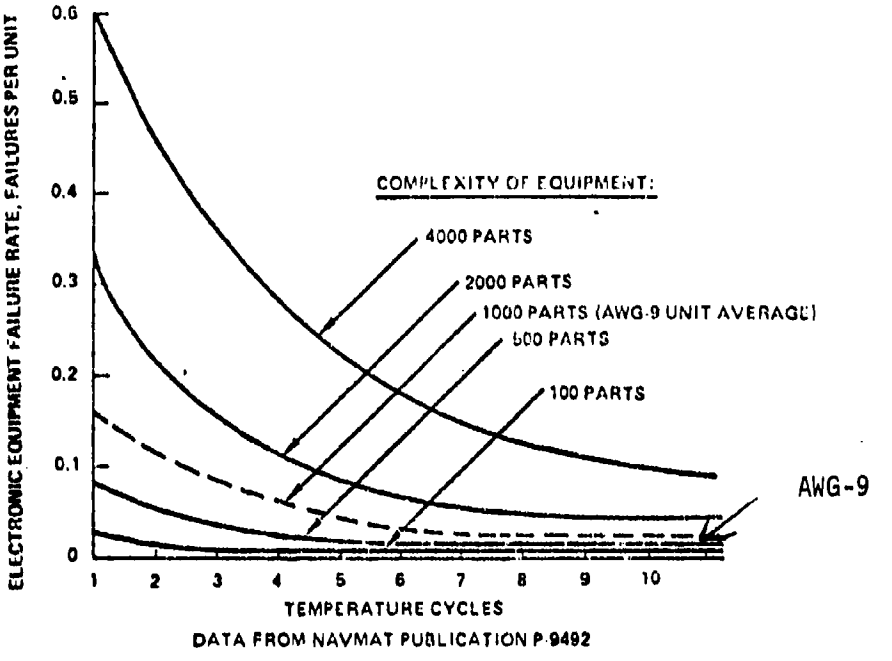

FIGURE 10. TEMPERATURE CYCLES AS A FUNCTION OF EQUIPMENT COMPLEXITY - NAVMAT

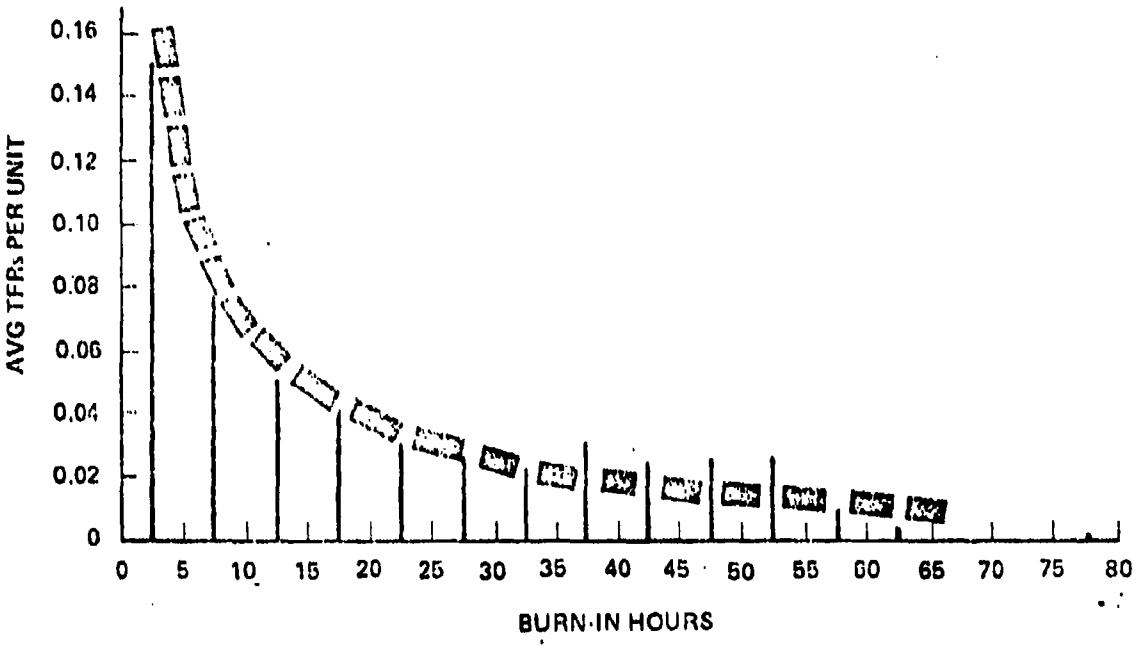

FIGURE 11. BURN-IN HOURS vs. FAILURES PER UNIT (AWG-9)

Even though the unit burn-in tests came out the way they were expected, the results could have been different if the amount of screening at lower assembly levels was changed. For instance, if the program stayed with its initial plans to use standard military "C" grade parts, then more module and unit screening would have been necessary. Sample data taken from systems before and after the part quality was improved indicated that an initial reduction of 9% in part replacements resulted from the use of hi-rel parts.

A more drastic difference was noted between modules that were screened and modules that were not screened. A sample of antenna/test control unit modules from the AWG-9 were selected to show how important module screening was. Figure 12 shows that 20.1% of the nonconditioned modules failed compared to only 5.8% of the conditioned modules. This significant difference, together with the benefit of using high reliability parts, proved that what went on in the lower assembly levels had a meaningful influence on the unit level tests. If the screening program had been devised differently to use more relaxed screens on parts and modules, the chances are good that Figure 11 would show that many more than seven cycles were needed and thus disprove the prediction of Figure 10.

	NUMBER OF MODULES	MODULE FAILURES IN SUBSEQUENT UNIT/SYSTEM TEST	% OF MODULES FAILED
• NON-CONDITIONED MODULES	219	43	20.1%
• CONDITIONED MODULES	208	12	5.8%

FIGURE 12. TEST RESULTS FOR CONDITIONED vs. NON-CONDITIONED MODULES

Another study done by the Hughes Aircraft Company revealed some interesting information about how much screening is necessary for module and assembly level equipment (Ref 12). Although tests were run at other assembly levels, the majority of the testing was performed on modules*. The modules, which were taken from three different types of equipment (FLIR, radar and missile), were broken up into groups and each group was subjected to a different set of test conditions. The average number of parts for each type of module ranged from 135 to 200. The radar system was the only one that used hi-rel, "B" level, parts; the parts used on the FLIR and missile systems were "C" level.

*the word "module" as used in this Hughes Study (Ref 11) can also be taken to mean the "card" assembly level.

The top chart of Figure 13 shows the distribution of failures for the FLIR, radar, and missile modules for different numbers of temperature cycles. Each data point represents a group of modules that were subjected to a certain number of cycles. As expected, the number of failures detected increased with the number of temperature cycles. This trend continues until the graph levels off at approximately 60 cycles. The previously mentioned Martin Marietta report recommends that only 10 cycles are necessary for complex equipment of 4000 parts or more, but this test shows that simple modules of less than 200 parts may require from 40 to 60 thermal cycles.

It may be thought that it is not appropriate to make such comparisons because the Martin-Marietta report was written for black boxes and not modules. The bottom chart, however, shows the progress of the radar and missile modules after being tested in a higher level of assembly. This chart shows that the maximum screening effectiveness for a higher assembly level is achieved using 20 to 40 thermal cycles.

In another part of this study, extensive tests were conducted at the module level to determine what effect, if any, different rates of temperature change had on test effectiveness. An optimum rate could not be determined from these tests. Some tests showed that higher rates were best, while others showed that lower rates were most effective. There was even a test which showed that both high and low rates of change had almost the same effect on test results. It was recommended in the study, however, that higher rates of temperature change be used since this would reduce chamber and screen time.

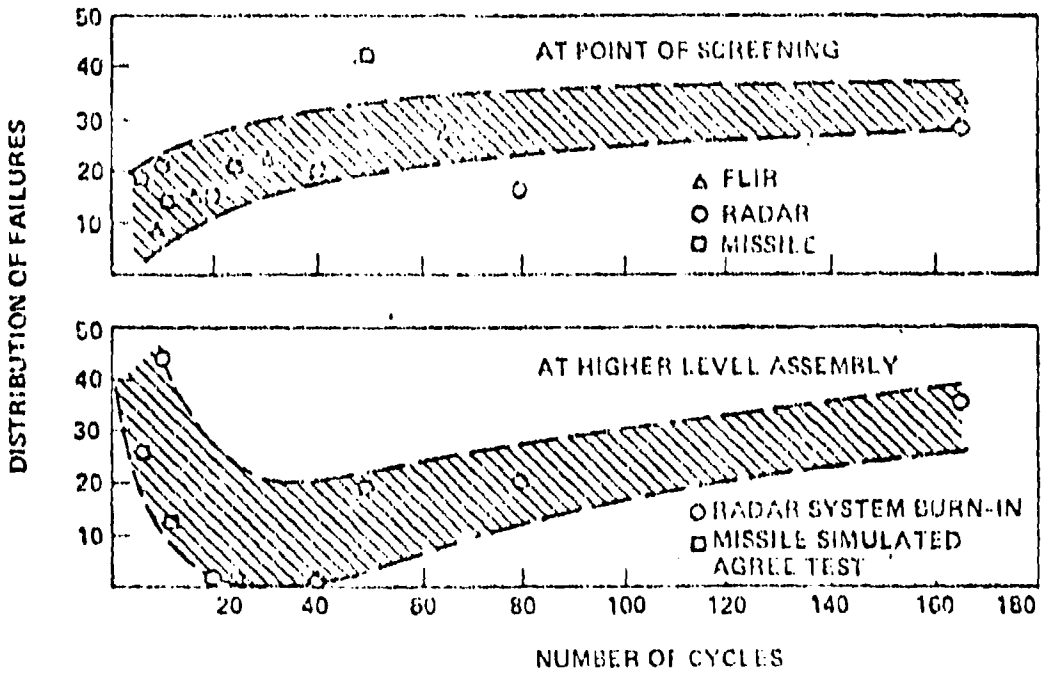

FIGURE 13. RESULTS OF HUGHES TEMPERATURE CYCLING EXPERIMENTS

2.3 IBM's Test Results

IBM has developed their own thermal cycling curves for environmental screening at the unit level (Ref 1). These curves, shown in Figure 14, are based on data from some major programs at IBM and recommend 10 to 30 thermal cycles depending on complexity. Typical IBM unit level programs utilize a $5^{o}C.$ per minute rate of temperature change and contain about six hours of power "on" per cycle. Figure 15 summarizes the burn-in being employed on the programs that are represented in Figure 14.

It should also be mentioned that, prior to unit level tests, IBM performs extensive testing at the part and subassembly levels of production. Subassemblies are subjected to a nonoperating thermal cycle screening consisting of 55 cycles at a range of $-55^{o}C.$ to $+80^{o}C.$ An average fallout rate of 6% has been observed from the approximately 40,000 subassemblies that are subjected to this screen each year. Yet, despite this lower level testing, the curves of Figure 14 show that 10 or more thermal cycles are needed before the failure rates become constant.

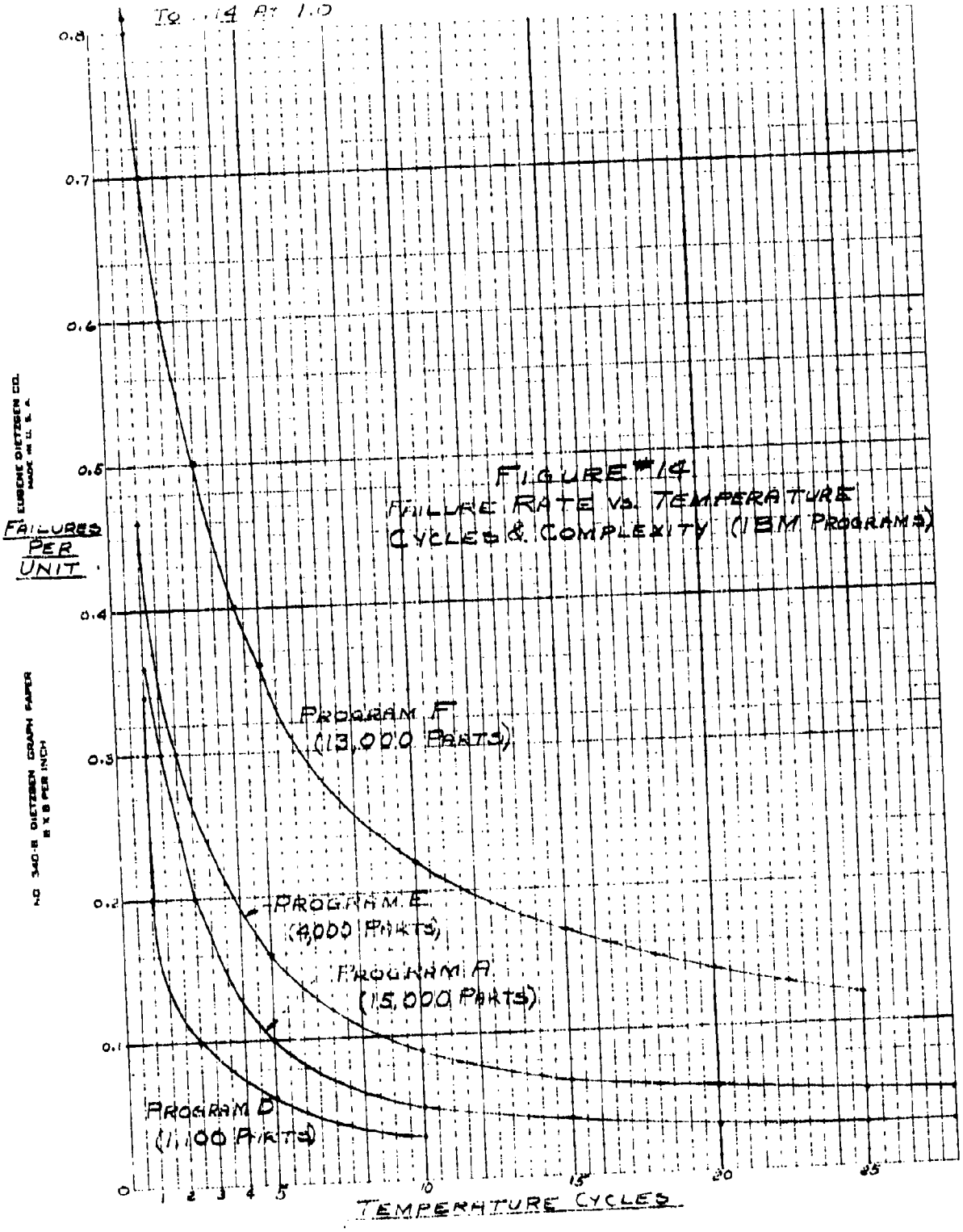

FIGURE #14.
FAILURE RATE Vs. TEMPERATURE CYCLES & COMPLEXITY (IBM PROGRAMS)

PROGRAM	TOTAL OPERATE HOURS	FAILURE FREE HOURS	TEMPERATURE (^{o}C)
A	200	100	-54 to +71
D	42	18	-45 to +55
E	200	50	-54 to +71
F	105	15	-54 to +55

FIGURE 15. THERMAL CYCLE SCREEN SUMMARY - IBM PROGRAMS

2.4 NAVMAT P-9492

In May 1979, the Naval Material Command published a document entitled "Navy Manufacturing Screening Program," Publication 9492 (Ref 9). This publication recommends a stress screening program utilizing thermal cycling and random vibration. The recommendations for the thermal cycling screen are based on the previously mentioned Martin Marietta report (Ref 2), which generally calls for 10 thermal cycles for complex equipment (> 4,000 parts) with fast rates of temperature change, and short dwell times. The Navy has adopted the Martin Marietta recommendations (Figure 7), as their guideline to determine the amount of cycling needed.

The random vibration screening recommendations are based on a study done by the Grumman Aerospace Corporation (Ref 6). This study, which will be discussed further in Section 3 of this report, concluded that 6 g rms broad spectrum random vibration was most effective in detecting latent defects.

The Navy has published NAVMAT P-9492 because they feel this screening program is more efficient than the conventional MIL-STD-781 approach (Ref 20). Earlier versions of MIL-STD-781 prescribed constant temperature soaks and low level sinusoidal vibration, both of which have been proven to be ineffective. So the Navy has left these costly and time consuming screens out of their program and are instead concentrating on the more effective thermal cycling and random vibration.

3.0 Random Vibration

Vibration was one of the environmental tests recommended by the Advisory Group on Reliability of Electronic Equipment (AGREE) in 1957. The vibration test was limited to a sinusoidal excitation of $\pm$ 2 g at a fixed nonresonant frequency between 20 and 60 Hertz. Continuing advances in technology have increased the complexity and the density of packaging of electronic equipment to the point where the 1957 AGREE vibration requirement has practically no power to improve equipment reliability. There are often latent manufacturing defects contained in modern electronic hardware and most often, simple bench qualification tests cannot detect these imperfections.

In general, there are three fundamental types of vibration tests: sine fixed frequency, sine swept frequency and random. Under sinusoidal fixed frequency vibration, the test item is vibrated to a prescribed amplitude at only one forcing frequency for an extended period of time. Under sinusoidal sweep vibration a sinusoidal excitation is applied to the test item with the frequency slowly varying over a given bandwidth, thus exciting every resonance for a certain time. In random vibration, all resonances are simultaneously excited. It has become obvious that random vibration is the most powerful vibration screening technique.

In 1977, MIL-STD-781, Revision C (Ref 8) was published and for the first time a requirement for random vibration on avionic equipment was included. The requirement for random vibration caused much concern among Government contractors because the mechanical shakers they owned could not

meet the random vibration requirements of MIL-STD-781C although they were fine for MIL-STD-781B specifications. In order to meet these new requirements, more expensive shakers would have to be purchased.

Electromagnetic and electrohydraulic shakers both have random vibration as well as sine vibration capabilities. Electromagnetic shakers have a frequency range up to 2000 Hz and are usually used for most tests on missiles and avionics packages (Ref 15). Electrohydraulic shakers are capable of frequencies up to about 200 Hz and are popular for simulating earthquakes and land and sea vehicle vibrations (ref 15). Mechanical shakers are used for sinusoidal vibration tests from 10 to 60 Hz(Ref 15).

Most missile and avionics vibration is conducted to 2000 Hz as specified in MIL-STD-781C. Some experts however, believe that not all vibration tests on missiles and avionics packages should be subjected to a standard 2000 Hz even though vibrations of 2000 Hz and even 20,000 Hz are sometimes measured in flight (Refs 3, 15).

Mr. Wayne Tustin, in one of his papers (Ref 15), gives his reasons why all electronic equipment need not be vibrated to the same limit:

"Shakers are appropriate to perhaps 500 Hz when testing missile and avionics packages of about the size of a basketball which weigh up to 50 pounds (mass 20 Kg). Vibratory inputs to such objects travel

through structures that support them, but only at quite low frequencies. At frequencies higher than 500 Hz, supporting structures are so nonrigid that test items are isolated from vibratory inputs. Higher frequency inputs should be applied, not by shakes, but acoustically."

Mr. Tustin goes on to say how laboratory specialists who vibrate all hardware items to 200 Hz despite their size and weight often run into problems constructing test fixtures. Building one of these fixtures to mount and control the motion of test items, which is free of resonances up to 2000 Hz, is not always easy. MIL-STD-810C, as mentioned in the paper, is unique since it provides maximum frequency levels based on the size and the weight of the test item.

Messrs. Henry Caruso and William Silver from Westinghouse contend that too much emphasis is put on overall g-rms levels and not enough on spectral content (Ref 3). Tests they have run on an airborne radar system (5000 parts) show that most of the vibration energy occurred below 500 Hz which supports Mr. Tustin's view. They say that similar results can be expected in higher levels of assembly "consisting of somewhat 'loose', nonlinear structural assembly with relatively large masses and many mechanical interfaces."

3.1 How Good is Random Vibration?

In 1971, the Grumman Aerospace Corporation began a study to compare the effectiveness of sinusoidal and random vibration (Ref 6). Typical manufacturing defects (e.g., poor solder connections, inadequately secured

parts) were purposely inserted into typical avionic black boxes. A series of controlled tests were then conducted to determine the kind of vibration excitation which most effectively revealed these flaws. Tests were conducted using sine fixed frequency, sine sweep and random vibration at different levels and for various periods of exposure.

Figure 16 shows the Grumman results, which compares the effectiveness of the three types of vibration for "typically" used acceptance test levels over the period of one hour. The dashed lines show the test effectiveness in screening out one type of defect (component mounting) and the solid lines show the effectiveness of screening out solder joint flaws. The graph shows that the 6 g rms test is better than both the fixed and swept frequency sinusoidal vibration tests. Interestingly, the 1.5 g fixed frequency test did not detect any failures. In Figure 17, a comparison is made using the typical random vibration level with sinusoidal testing levels that exceed these normally used for qualification. Notice that for one type of fault the 10 g sine sweep curve eventually attains equal strength to the 6 g rms random test, but it takes well over twice the time to do so. For the other type of fault the 10 g sine sweep curve is always less than the random curve. The Navy has noted (Ref 9) that running a sine sweep test at 10 g for nearly an hour would "certainly present a fatigue problem and would never be utilized in an acceptance test."

Though the abcissa's of these graphs show a maximum vibration time of sixty minutes, the tests were actually run for more than twice this time.

Since few additional failures were found in this extra time, Grumman concluded that only the first hour of vibration is significant for any type of excitation.

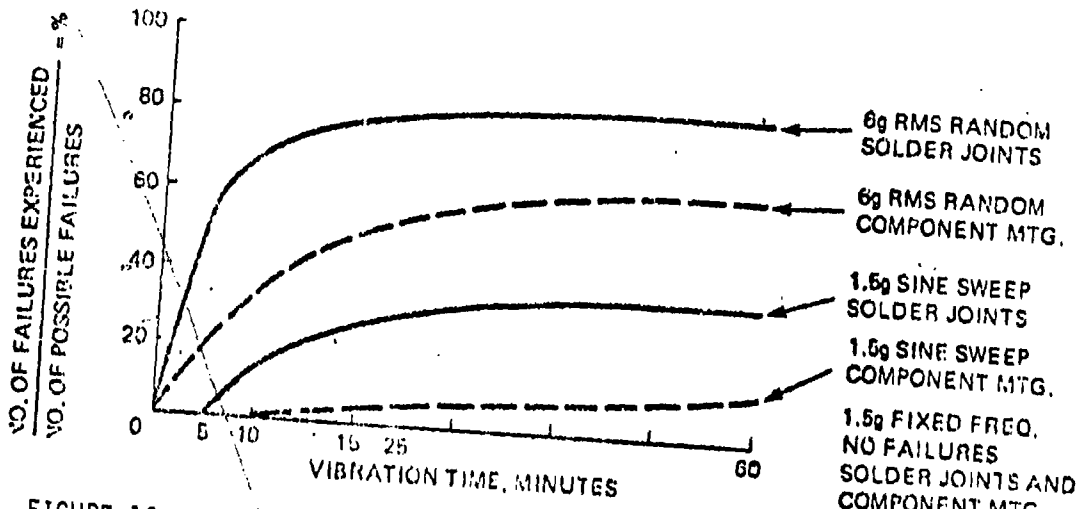

FIGURE 16. COMPARISON OF TYPICAL ACCEPTANCE TEST LEVELS - RANDOM vs. SINUSOIDAL VIBRATION

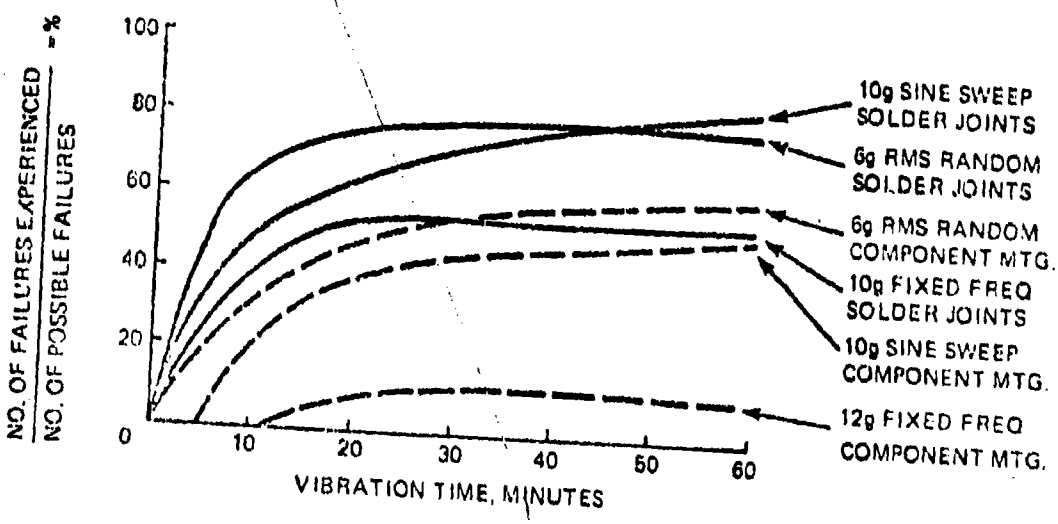

FIGURE 17. COMPARISON OF TYPICAL RANDOM AND INCREASED LEVELS (≥10g) OF SINUSOIDAL VIBRATION

Random excitation is becoming more widely used as more companies acquire the proper equipment. The Navy now requires 100% random vibration screening on every WRA off the production line for new avionics contracts (Ref 7). Following the recommendations of the Grumman Aerospace study, the Navy requires 6 g rms broadband random vibration in NAVMAT P-9492. To defend these requirements, NAVMAT P-9492 gives three examples of programs that had MTBF improvements from 50 to 200% when random vibration was added to the screening program. Even if these increases were not totally caused by the new screen, it is still obvious that random vibration was the primary reason for the big improvements.

An experiment by IBM on the F-15 4Π computer using a random vibration screen significantly increased the number of failures detected during screening (Ref 7). Prior to random vibration there were no defects found in over 2000 hours of 2 g fixed frequency vibration at 25 Hz. Random vibration not only caught more defects, it also degraded other latent defects enough so that the temperature cycles that followed resulted in more failures than were evident before random vibration was used. With random vibration at 4.1 g rms the fallout was three times that noted in a control group not subjected to vibration.

A mathematical random vibration model has been developed by Mr. Cliff Ryerson of Hughes Aircraft Company (Ref 13). Curves plotted from this model are shown in Figure 18. The graph shows minutes of vibration plotted against "test strength," which is as defined in the Hughes models (Ref 14). The ordinate of this graph facilitates a direct comparison with the random vibration test data plotted by Grumman, Figures 19 and 20. Ryerson's

model shows that below 4 g rms the random vibration screen is not very effective. Above this level, and particularly at 6 g rms, the screen becomes much better. The 6 g rms curve illustrates that 80% of the failures will be detected within 30 minutes of vibration. Grumman's test data shows, however, that only 10 to 15 minutes are necessary for the screen to reach its maximum effectiveness.

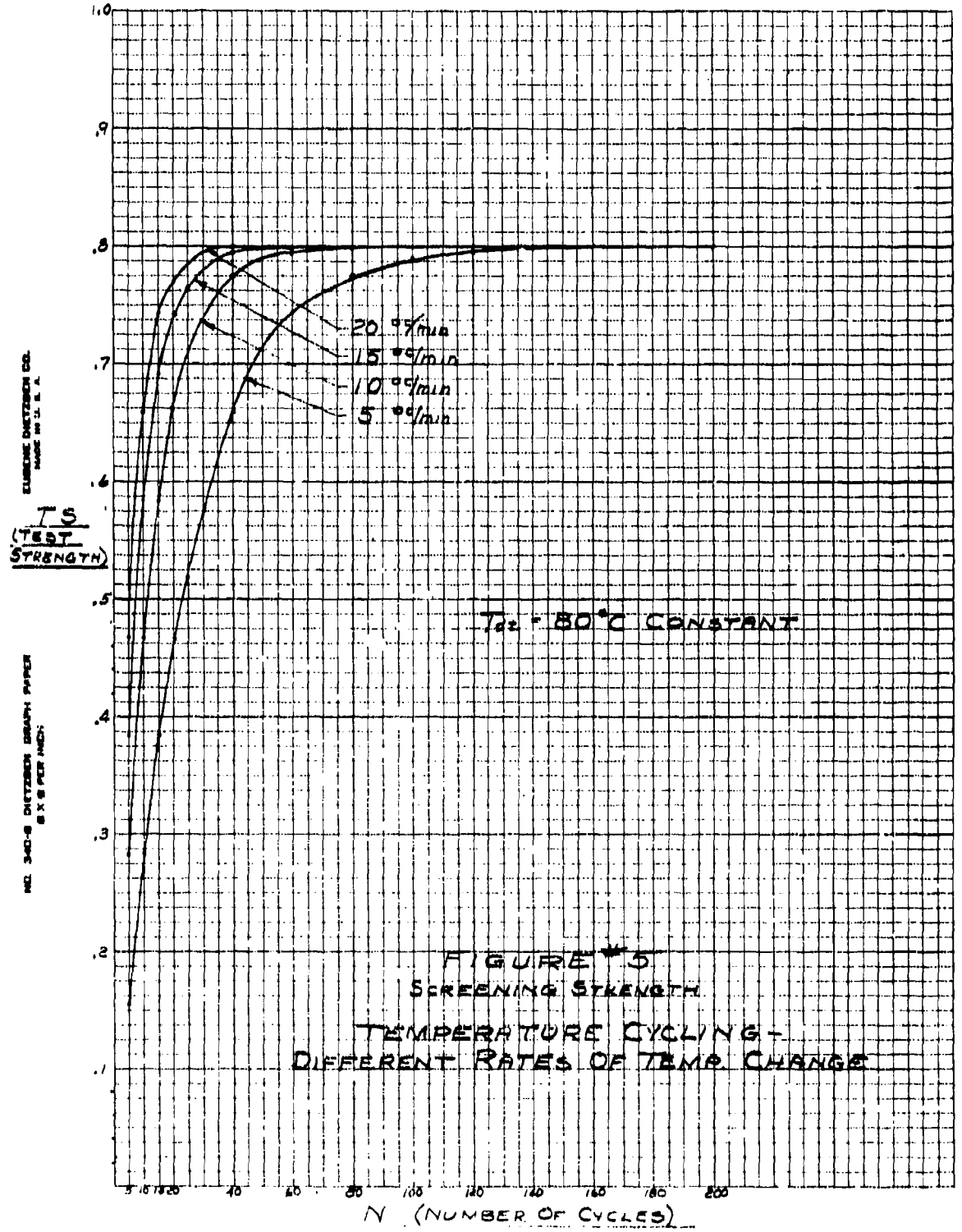

FIGURE #5

SCREENING STRENGTH

TEMPERATURE CYCLING -

DIFFERENT RATES OF TEMP. CHANGE

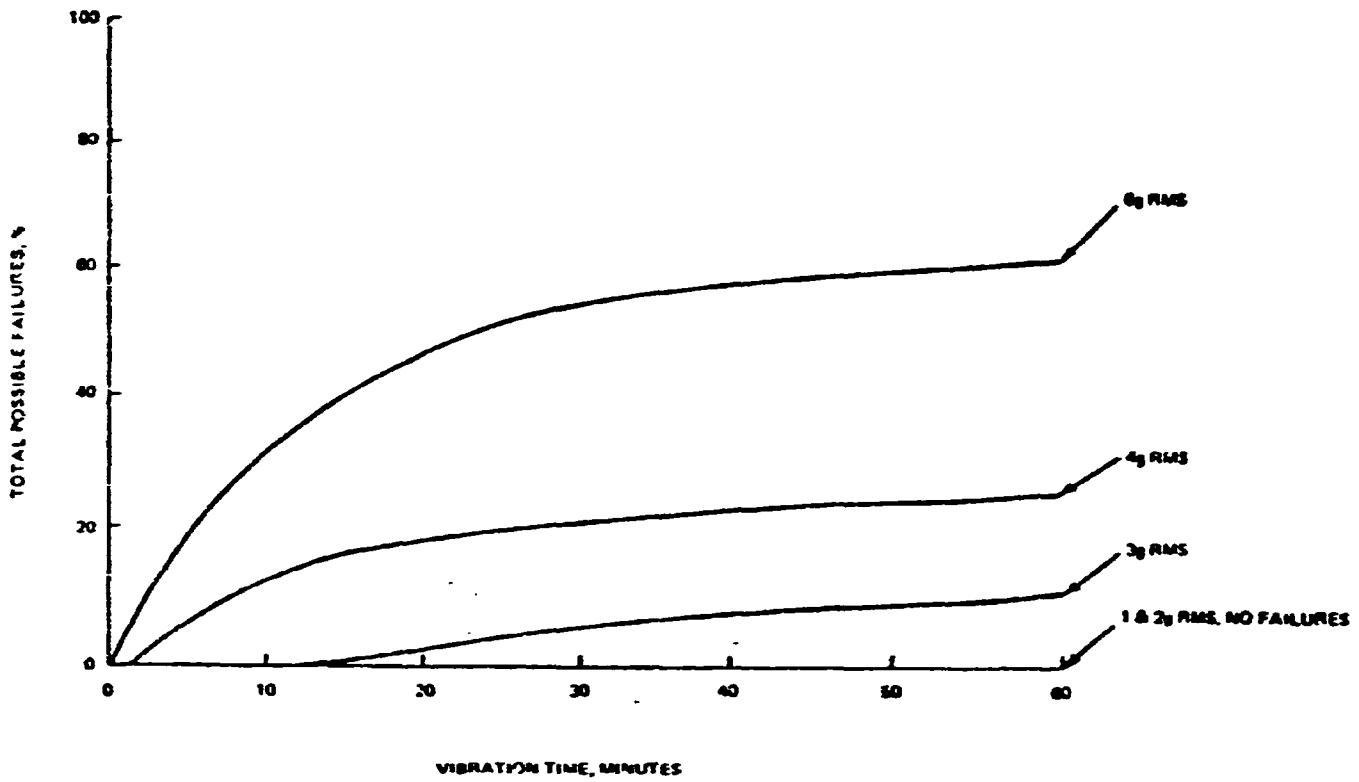

FIGURE 19. TYPE 1 FAULTS, RANDOM VIBRATION

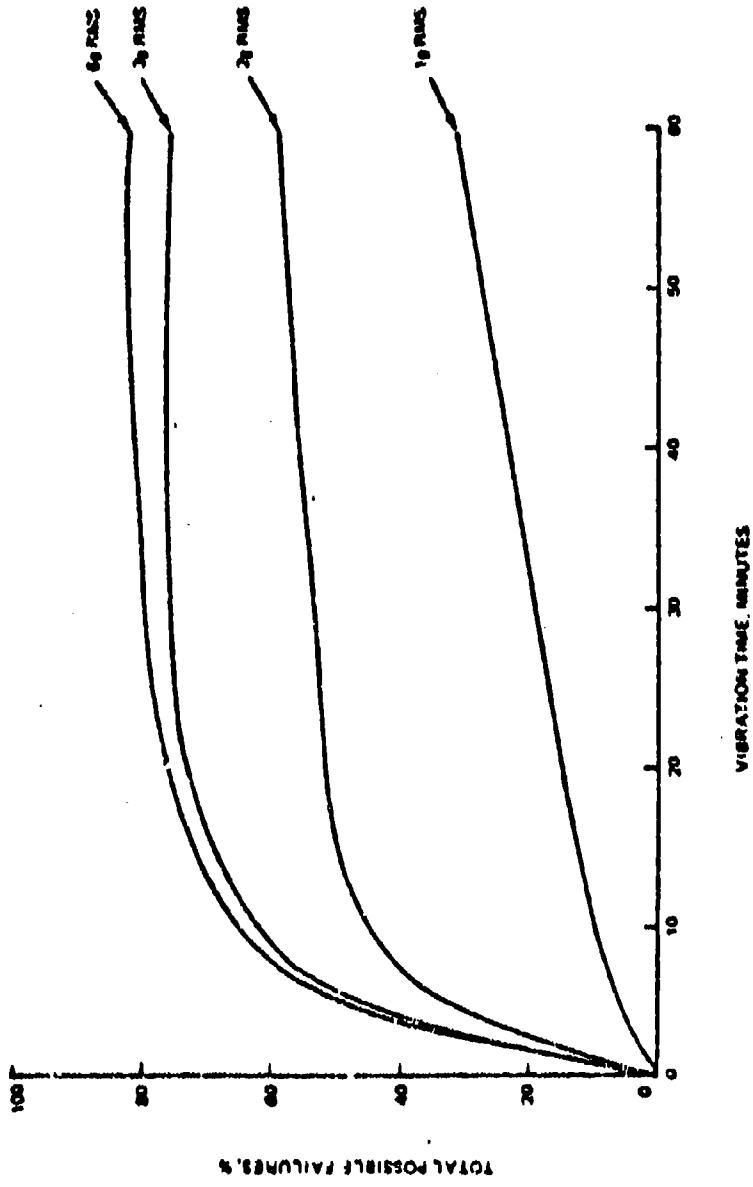

FIGURE 20. TYPE 2 FAULTS, RANDOM VIBRATION

Random vibration is one of the more effective screens because it excites every resonance during the entire test. Sine sweeps (which sequentially excite test item resonances) do not allow these resonances to get excited enough to peak out because of the short time spent in any one resonance bandwidth (Ref 9). Therefore, random excitation should be used for the majority of vibration and acoustic tests no matter what the range of frequencies is (Ref 15).

Despite the fact that random vibration is the most powerful type of vibration screen it has not yet become widely accepted. The reasons for this are that a random vibration test facility is much more expensive, complex, difficult to control and costly to maintain, than a sinusodial facility. In another one of Mr. Wayne Tustin's numerous papers on vibration, he explains why random vibration is difficult to control (Ref 16),

> "The relatively simple controls of Figure 8* are satisfactory for single-frequency-at-a-time sine testing because a test signal at any f_f needs only one correction to maintain the specified intensity of motion, to correct for varying shaker efficiency, also for test item resonances, across the frequency range.
>
> But random vibration, as we have seen, exists simultaneously at all frequencies and correction must be accomplished simultaneously at all f_f's. This is far more difficult to accomplish."

*This figure is not shown in this report.

It has been observed that random vibration tests are axis dependant. In the Caruso and Silver Study (Ref 3), it was found that an airborne radar equipment had failures that could be detected only from vibration in a particular axis. The authors arrived at this conclusion when they found that each different axis showed failures that went undetected in the previously vibrated axis. The equipment tested consisted of four LRU's which were mounted together on a single vibration fixture and vibrated in three axes to MIL-STD-810C levels (6 g rms to 2000 Hz). The two most common faults were: lead failures on unbounded components and loosening of hardware holding the LRU's to the racks. These results occurred in a preliminary safety-of-flight test on early hardware so the failures were credited to imperfect design.

Before in-depth testing was started for the Grumman vibration study, (Ref 6), a critical vibration axis was to be found, if one existed, to minimize test time. A vibration survey identified a critical axis and this axis was used for all subsequent testing. No further research was done to investigate the reason why there was a critical axis or to determine how critical this axis was.

The information given above has not been derived from rigorous testing to determine whether random vibration is axis dependent. It is based on what was observed during two different studies. It is evident, however, that the axis of vibration does influence the results. How great this influence is and whether it is necessary to vibrate electronic equipment in all three axes are areas that need further investigation.

3.2 The Search for Low Cost Random Vibration

The understanding of how effective random vibration screening is and the random vibration requirements in MIL-STD-781C has led to a search for a low cost alternative to the very expensive electrodynamic random shakers. One of the products of this search is a pneumatically-driven shaker. The pneumatic shaker motion is not exactly the same as random motion. It has instead been called complex vibration or quasi-random vibration. Mr. Wayne Tustin gives this description of complex vibration (Ref 15),

> "A great number of forcing frequencies are present at all times. Generally, they do not vary in frequency or intensity. They can be described in terms of a multiple-line spectrum (as opposed to the continuous spectrum of random vibration). However, complex vibration can produce almost the same effect as does random vibration, in terms of simultantously stimulating all resonance responses."

A comparison of the quasi-random (pneumatic) shaker and the electrodynamic random shaker is shown in Figure 21 which was extracted from reference 7. Advantages of the quasi-random shaker are that it provides triaxial broadband vibration, it is much cheaper than the electrodynamic random shaker and it is easy to operate. The only disadvantage is that it has limited spectrum control. This is significant because without this control the shaker will have trouble meeting the tolerances required in present military standards.

Another innovation, which was developed by Grummman Aerospace, enables a basic electrodynamic sinusoidal vibration test facility to economically be converted to random vibration. This is accomplished by using a cassette tape deck as a single source. The procedure for doing this is given in the appendix of NAVMAT P-9492 (Ref 9).

	QUASI-RANDOM SHAKER	ELECTRODYNAMIC RANDOM SHAKER
COST/FACILITY	35 – 50K	100 – 200K
INPUT	TRIAXIAL	SINGLE AXIS
CLOSED LOOP CONTROL?	YES	YES
SPECTRUM CONTROL?	LIMITED	YES (±3 dB)
EASY TO OPERATE?	YES	NO
EFFECTIVENESS (YIELD)	?	?

FIGURE 21. COMPARISON OF QUASI-RANDOM AND ELECTRODYNAMIC RANDOM SHAKER CHARACTERISTICS

4.0 Ideas for a Military Standard on Burn-In

A military standard on burn-in would be very difficult to develop because of the different complexities, packaging densities and failure modes of the many types of electronic equipment being produced today. Thermal cycling and random vibration should be required for the majority of the screens included in a MIL-STD since they have been proven to be the two most effective stress screens.

The standard should also include some guidelines for screening at all levels of assembly higher than the part level. Screening at lower production levels (e.g., modules and subassemblies) is important because it is easier and cheaper to detect and repair failures at these levels. Proper screening at lower levels should also reduce the amount of screening needed at the higher assembly levels.

The screening program for higher assembly levels may most probably be the most important part of the standard and also the most difficult to develop standards for. The reason for this is that the screening requirements cannot be too restrictive. The screening requirements must be flexible enough so that they can be effectively adapted to different types of equipment.

Thermal cycling should be characterized by fast rates of temperature change with short dwells and temperature limits that do not damage good parts. The amount of thermal cycling cannot be fixed, even on a complexity basis, as is recommended in NAVMAT P-9492, because different studies have

shown a wide variety of thermal cycling needs for different projects. Instead, possibly thermal cycling could be run until a specified failure rate is achieved or until completion of a specified number of failure free cycles. Random vibration tests should be run at the highest known nondegrading level for short periods of time (no longer than an hour). Another test that might be effective, but of which there is little known, is simultaneous random vibration and thermal cycling.

The preceding paragraphs have been a brief, simplified and general description of what a military standard on burn-in might consist of. The ideas presented were derived from the basic conclusions of this report. It is believed, however, that these conclusions can assist in the construction of a preliminary foundation for a military standard. Of course, any such standard would have to provide much more detailed requirements.

5.0 Summary

This report, by investigating different studies and test results, concludes that thermal cycling and random vibration are the two most effective environmental stress screens. Given below is a list of other conclusions derived from this report and some interesting areas that, if researched more, could provide some useful information to all stress screening practitioners.

5.1 Conclusions

5.1.1 Vibration at extreme temperatures is more effective than ambient vibration.

5.1.2 Fast rates of temperature change are recommended because they reduce chamber screen time.

5.1.3 The amount of thermal cycling performed on black boxes and higher assembly levels is greatly influenced by the quality of parts used and the amount of screening performed during lower levels of assembly. The number of cycles can vary from 1 to 60.

5.1.4 Random vibration is clearly a more effective screen than sine sweep and fixed frequency vibration.

5.1.5 6 g rms appears to be the most effective nondegrading level of random vibration.

5.2 Areas Where More Research Needs to Be Done

5.2.1 Thermal cycling with the temperature range extended to maximum temperatures that would not damage good parts.

5.2.2 Tests to determine the degree to which rates of temperature change affect screening strength.

5.2.3 Research to develop a method which will determine the amount of temperature cycling necessary for different levels of production based on the failure rate decreasing to a set limit with a certain number of failure free cycles at the end of the test.

5.2.4 More thorough investigation of the effect of different random vibration frequency spectrums on different sized test specimens.

5.2.5 Evaluation of higher levels of random vibration (8 g rms and above) to determine their screening effectiveness and also determine if these levels damage good parts and workmanship.

5.2.6 Determine the benefit of vibrating in three axes instead of one.

5.2.7 Experiment with different combinations of thermal cycling and random vibration to evaluate synergistic effects.

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