Cost Effectiveness of Environmental Stress Screening (ESS):
A Case History

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Summary and Conclusions

Although the government is interested in programs that improve the reliability of its avionics systems, the finances needed to support such programs must remain a vital concern. Environmental Stress Screening (ESS) seems like an expensive process, but it actually saves money in the long run. Performing a low budget ESS program on twenty newly manufactured circuit cards presented an ideal opportunity to prove to skeptics that ESS is an engineering tool that management should promote. The screen precipitated defects that could have occurred on the aircraft; thus, improving reliability of the system. When the economics of the project were examined, a greater Return on Investment (ROI) was realized than earlier anticipated. This successful ESS project initiated support for an intensive ESS program.

A favorable ESS program incorporates trained personnel, adequate time, cooperation, environmental chambers, fixtures, power supplies, interconnects, monitoring equipment, a reliable failure analysis program, etc... However, if limitations exist in any of the above items, an adequate ESS program can still be successfully performed yielding improvements in reliability.

Introduction

For several years, government managerial/technical personnel had questioned the feasibility of Environmental Stress Screening (ESS) despite the fact that private industry had presented documented proof of its benefits. These skeptics viewed ESS as a technical effort designed for the more advanced electronic systems, rather than the older systems of the Air Force. Negative criticism suggested that ESS was an expensive process that damaged perfectly functional electronic assemblies. Therefore, ESS, as well as its underlying concepts, required justification before gaining governmental acceptance.

Environmental Stress Screening is the process of applying environmental stimuli to an item in order to precipitate and detect latent defects which could cause failures to occur during field usage. Many benefits accompany a well-orchestrated ESS program. Significant benefits to the Air Force include:

- * Reductions in manufacturing and support costs
- * Reductions in schedule delays caused by excessive rework
- * Improvements in the reliability and mission readiness
- * Redesign suggestions

In April 1988, Air Force Logistics Command (AFLC) Regulation 74-25 established the requirement for incorporating ESS into AFLC operations. In section 3-1, it states that ESS is required for all organically manufactured electronic hardware unless a waiver is used. It was obvious, that Headquarters AFLC considered ESS as a beneficial technical effort; however, before ESS could gain local acceptance, the cost savings needed to be demonstrated inhouse. Unfortunately, funding for an initial ESS regimen was limited.

In May 1988, preparations were made to expose 20 newly manufactured circuit card assemblies to an ESS program; however, limiting factors accompanied this project. No prototype circuit card was provided for step-stress testing. Also, no equipment was available to supply power to the individual circuit cards, preventing us from monitoring the cards during the screen. Our organization had only one environmental chamber. Finally, production allocated a maximum time of eighteen days for ESS. With these constraints in mind, an ESS program was developed.

ESS Program and Equipment

A Screening Systems, Inc. QRS-400 portable triaxial quasirandom vibration and temperature system was used to perform the needed ESS program for the project. This environmental chamber is capable of temperature extremes of -60C and 125C, a maximum temperature rate of change of 30C/minute, and frequencies of 20Hz to 2000Hz. The environmental chamber has threaded holes in the vibration table used to attach the needed fixtures. The fixtures used for this particular project were capable of screening two circuit cards per session.

The items to be screened were dynamic focus generator circuit board assemblies (ALR-20 system) used on the B-52. These circuit card assemblies were being manufactured to replenish supply. There are twenty-nine components on the focus generator circuit card assembly (eighteen resistors, two capacitors, five transistors, and four diodes).

We modeled the screen using our knowledge of the components on the circuit card assembly and published Thermotron guidelines (1988) for temperature cycling (Ref. 2). Although most of the studies suggest 20 temperature cycles, our screening program exposed the circuit cards to five temperature cycles using -55C and 85C as the extremes. We would not have had time to screen all of the cards had we chosen more than five temperature cycles. A three minute dwell time was used to compensate for the difference in the temperature of the circuit card and the chamber. The program also included 10 minutes of random triaxial vibration (6 GRMS) previous to the temperature cycles (Ref. 1). Figure 1 displays the ESS program used to screen the focus generators.

Figure 1

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ESS Results

Faulty capacitors were found on five of the 20 boards (25%) totalling seven component failures. All of these documented failures were breaks at the base of the capacitors' leads (close to the body of the component), and all occurred at the same general location on the board. It is important to mention that two of the seven broken capacitor leads were still making a connection, possibly causing intermittent failures to occur in the field.

After discovering this trend, all of the installed capacitor leads were analyzed. At first, the assumption was made that the leads had broken due to the large size and bulkiness of the components; however, corrosive matter was found on the leads. Many of the leads had begun to neck. Necks are a reduction in diameter due to mechanical stressing. They are weak points in the leads and sometimes lead to brittle failure.

All capacitors with this particular stock number were removed from storage to check the condition of the unused capacitors. A corrosive film was found on these capacitor leads also. On two of the unused samples, cracks were found on the base of the lead, in exactly the same location that the breaks occurred on the screened capacitors.

Wavelength Dispersive Spectroscopy (WDS) was performed on the surface of the leads and revealed an average oxygen count of 450 counts/sec. This value is significantly high and confirms that an oxide product was present. Infrared Spectroscopy and chemical analysis indicated that the oxide product on the lead surface was lead carbonate. From these results, it was confirmed that corrosion weakened the base metal, making it susceptible to fatiguing.

A Quality Deficiency Report (QDR) was processed recommending screening all of the capacitors under the cited contract number using component screening techniques. It also suggested that the vendor replace or reimburse at no cost to the government, all faulty capacitors found during the project.

It was recommended that capacitors over a certain diameter be tied-down to the board to prevent unnecessary stressing of the leads. The boards were repaired with new capacitors. A sample of the repaired boards was screened and returned with no failures.

Economic Analysis

As mentioned before, the Environmental Stress Screening program identified the faulty capacitors, proving that ESS does increase the reliability of systems in certain instances. The failures precipitated during ESS could have occurred on the aircraft. At this point, the economic benefits/disadvantages could be examined for this particular project.

ESS is a Poor Quality Cost (PQC) which is simply the extra cost associated with initially producing good quality products. It is the cost incurred to find and fix products which were not correct at the time of manufacture. ESS is a preventive measure to deter errors from occurring in the field while improving first-time yield; therefore, ESS is Preventive Poor Quality Cost (PPQC). Figure 2 displays the relationship between PPQC and the number of failures expected to occur early in end-use. By increasing preventive measures for a product, the number of errors decreases (Ref. 3).

NUMBER ERRORS vs PREVENTION COST

Figure 2

Resultant Poor-Quality Costs are the costs that the company incurs because all activities were not done correctly before the end-use of the product. ESS is a Controllable PQC because management can control the funding for ESS projects. Figure 3 displays the relationship between Controllable PQC and Resultant PQC. On the left side of the curve, Controllable PQC is very low, causing resultant PQC to be very high. As the controllable PQC increases, resultant PQC is decreased because more errors are detected before the end-product is used.

After combining the Resultant PQC Curve and the Controllable PQC Curve, another curve is formed. The lowest point of the new curve is the Best Interim Operating Point (BIOP). This is the point where maximum benefits are gained with minimal cost (Ref. 3).

COST vs POOR-QUALITY COST

RESULTANT PQC
CONTROLLABLE PQC

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Figure 3

We predicted that our ESS program was operating somewhere on the left side of the Best Interim Operating Point due to the negligible funding for the project and lack of screening strength; however, the extent of the cost savings was amazing in relation to the price of our modest ESS program. The following is the breakdown of the savings with details included in the appendix (Ref. 4):

Assembly Level	Cost Savings
Circuit Card (SRU)	\$ 3,563.00
Next Level Assembly (LRU)	\$13,183.00
Aircraft	\$28,023.00

In this particular case, the benefits realized from the ESS program surpassed the actual expense of ESS. It is hard to believe that screening twenty cards could have saved \$28,000.00 and improved mission readiness. The project proved to local management that ESS is a cost

effective tool in some situations. This project, in turn, brought increased support in the realm of ESS and other reliability tools. Limited resources and equipment should not prevent reliability engineers from pursuing increases in reliability and cost savings from ESS.

APPENDIX

Cost of Environmental Stress Screening

(Cost of ESS) = \$1978
(Program)

The cost of an entire ESS program encompasses the cost of the initial screen (\$1536) plus the cost of rework (\$462). The following chart shows the variables used to attain the total cost of ESS.

Manhours to Screen 20 Cards.....	40 Hours
RCC Rate* (Engineering).....	\$38.40/Hr
# of New Capacitors.....	40
Cost per Capacitor.....	\$2.27
RCC Rate* (Shop).....	\$37.10
Rework Time/Card.....	30 min

* Standard rate for labor plus overhead

Cost Without Environmental Stress Screening

The following is the cost of repair at the different assembly levels (SRU, LRU, Aircraft), assuming the problem went undetected.

Cost of Repair (SRU) = \$5560

The cost of repair was calculated by multiplying the cost of repair/card (\$278) and the number of cards (20). The cost of repair estimate was obtained from the a B-52 item manager.

Cost of Repair (LRU) = \$15,180

The cost of repair (LRU) was calculated by multiplying the cost of repair/LRU (\$759.00) and the number of LRUs (20). The cost of repair estimate was obtained from the item manager.

Cost of Repair (Aircraft) = \$30,020

The cost of repair (aircraft) was calculated by multiplying the costs associated with an LRU failure on an aircraft (\$1500) and the number of LRUs (20). A chart

with the applicable variables is below.

DATA (For the Particular LRU, 1989)

G Model	H Model
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165 Aircraft	95 Aircraft
67 Failed	64 Failed
MTBF = 995 Hrs	MTBF = 560 Hrs
1.6 Manhours	5.35 Manhours
100 Flight Hrs	100 Flight Hrs
1068 Manhours	1915 Manhours

Total # of Aircraft..... 260

Total # LRU Failures..... 131

Total # Manhours..... 2983

Cost Savings

Cost Savings (SRU) = \$3,563

Cost Savings (LRU) = \$13,183

Cost Savings (Aircraft) = \$28,023

These estimates were calculated by subtracting the cost of ESS from the cost of repair for each level of assembly.

References

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Biography

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