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Long-Term Reliability of Hand-Soldering M55365 Ta Capacitors

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ABSTRACT

This is a continuation of the report "Effects of Hand Soldering MIL-PRF-55365 Tantalum Capacitors," which discusses the parametric effects of convection reflow soldering, JPL standard hand soldering, and optimized hand soldering on solid tantalum capacitors. The current focus is determining the long-term reliability effects of the various soldering techniques.

Unfortunately, the 100-piece sample size chosen for the highly accelerated life tests was too small to reliably determine the effects of the different soldering techniques on the lifespan of the parts. In hindsight, this likely could have been predicted based on the large alphas and small betas of the Weibull failure distributions discovered during the scouting trials.

Now that the effects of inadequate sample size are better understood, an opportunity exists to not only discover whether there are real differences in the reliability associated with the various soldering techniques, but also the potential to discover the voltage acceleration model and the temperature acceleration effect for these capacitors. It is recommended that the testing be repeated with a more appropriate sample size to capture this useful information.

1.0 INTRODUCTION

Hand soldering of M55365 tantalum chip capacitors is common during assembly of hybrid circuits such as DC/DC converters and during rework of circuits to replace failed capacitors. Considerable debate exists regarding the relative safety of hand soldering versus conventional high-volume soldering techniques such as convection reflow soldering. The previous paper titled "Effects of Hand Soldering MIL-PRF-55365 Tantalum Capacitors" explored the effects of different soldering techniques on capacitance, dissipation factor (DF), equivalent series resistance (ESR), and DC leakage (DCL). The paper concludes that none of the soldering techniques was harmful to the capacitors, but does not investigate the long-term effects of soldering and whether any of the techniques affect reliability.

Military-grade parts were chosen to make the test results as authentic as possible with respect to the projects done at the Jet Propulsion Laboratory (JPL). The details of the parts chosen are displayed in Table 1. Four different case sizes were tested to see the varying results for each. Each different case size was subjected to three different soldering techniques: convection reflow soldering, JPL standard hand soldering, and optimized hand soldering.

After being soldered, the parts were subjected to a highly accelerated life test to see if one or more soldering technique was detrimental to the lifespan of the parts. Scouting data were collected before life testing to determine the best testing conditions for the highly accelerated life tests.

Table 1. Tantalum Capacitors Used in This Report

Part Number	Case Size	Capacitance (µF)	Voltage Rating (V)
CWR11KH474KB	A	0.47	25
CWR11JH225KB	B	2.2	20
CWR11KH475KB	C	4.7	25
CWR11KH106KB	D	10	25

Among the topics discussed here are the results of the preliminary scouting tests, important Weibull parameters, highly accelerated life test data, and sample size issues. The goal of this research effort was to determine if any of the soldering techniques cause degradation in the reliability of the parts.

2.0 PRELIMINARY SCOUTING TESTS

Scouting tests were conducted to determine the best testing conditions for each case size. The objective was to obtain a reasonable number of failures (10–15%) in a reasonable amount of time (approximately 10 hours), but not to obtain too many initial failures (less than approximately 5%). Note that all scouting tests were performed on capacitors mounted by optimized hand soldering.

Testing was performed at 125°C and twice-rated voltage, but did not result in an adequate percentage of failures in times less than 10 hours. As a result, a higher temperature, 145°C, was chosen to achieve a good distribution of failures in the short available time without having to resort to voltage stress levels, which might introduce new failure mechanisms.

Case size A was tested at four different voltages: 60 V, 50 V, 45 V and 40 V. Figure 1 shows the Weibull plots created for all voltages except for 40 V. 40 V is not included because the accelerated test ran for seven days without any failures. The final voltage condition chosen for case size A was 50 V since too many initial failures occurred at 60 V and not enough failures occurred at 45 V or 40 V. The case size A parts were subjected to a grading stress of 2. See Equation 1, where V_a = accelerated voltage and V_r = rated voltage.

Equation 1. Grading Stress = V_a/V_r [1]

Case size B was also tested at four different voltage levels: 40 V, 36 V, 32 V, and 28 V. Referring to Figure 2, 40 V created more initial failures than desired. 28 V was not harsh enough having only one failure in a 20-day period. 36 V and 32 V had comparable initial failures, but 32 V exhibited a shallower slope and was chosen for the life test. The resulting grading stress was 1.6. In hindsight, 36 V should have been chosen because the number of failures at 100 hours meets our criteria of at least 10% failures, while the number of failures at 100 hours and 28 V was only slightly above 5%.

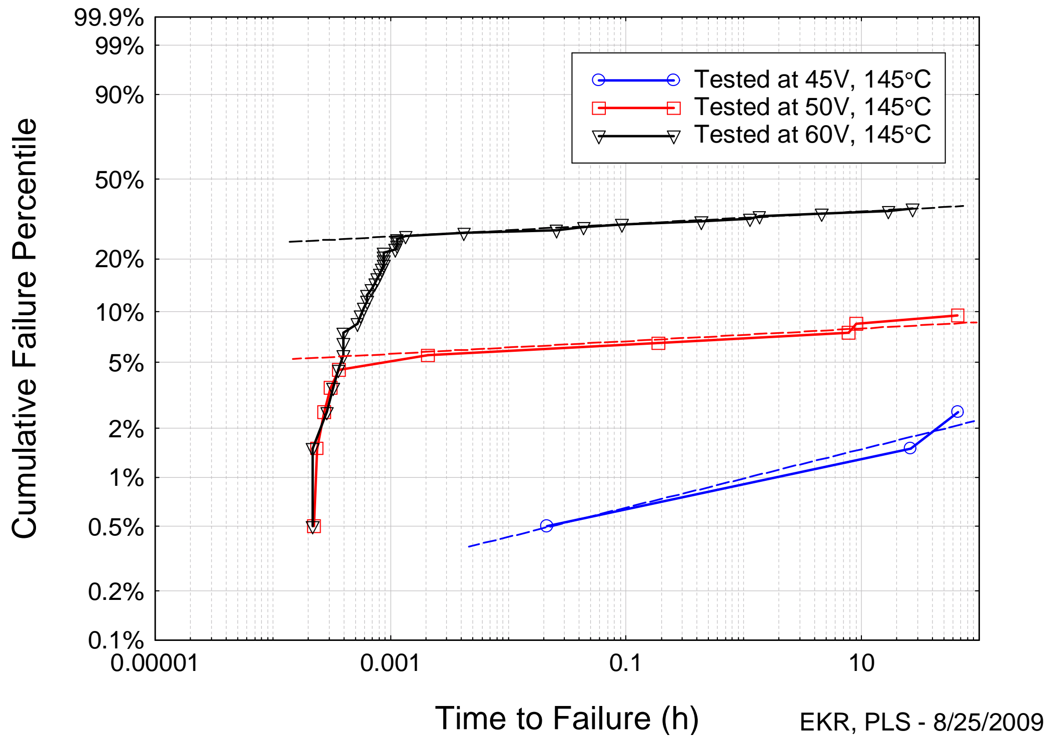

Figure 1. Case Size A

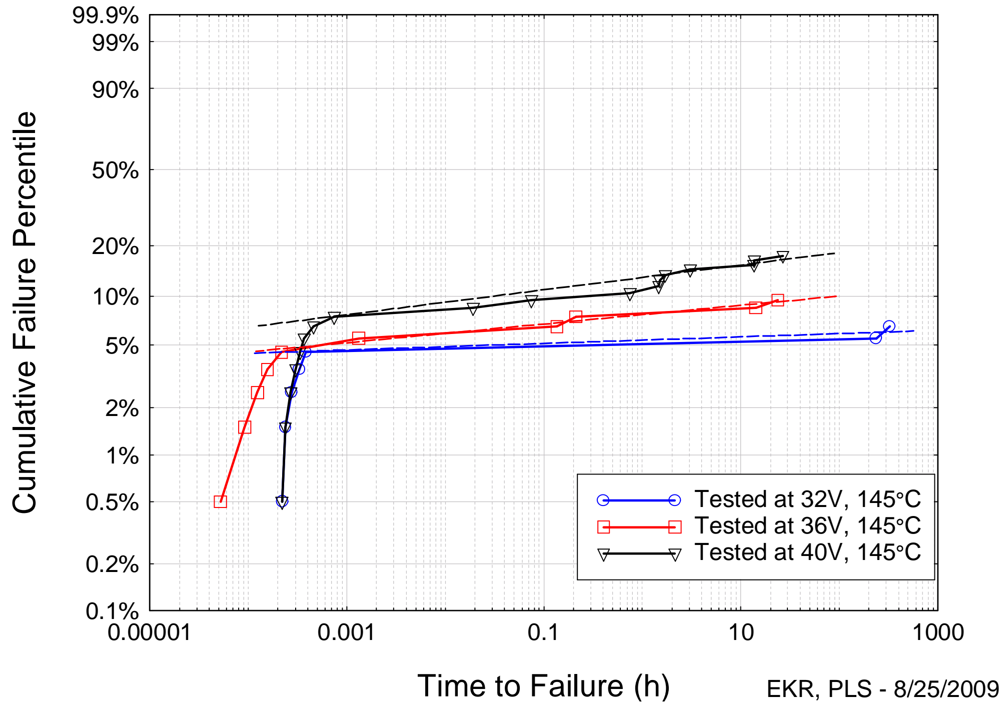

Figure 2. Case Size B

The results of the case size C scouting tests are shown in Figure 3. Only two voltages were tested: 35 V and 45 V. Too many failures resulted from using 45 V, so 35 V was chosen as the desired voltage with a grading stress of 1.4. In hindsight, perhaps a better test voltage would have been 40 V since not as many failures were generated at 35 V in times less than 10 hours as we would have liked to have seen.

The scouting tests for case size D, shown in Figure 4, were conducted at only two voltage levels: 30 V and 35 V. The 30 V condition was not harsh enough so 35 V was chosen as the accelerated testing condition with a grading stress of 1.4. Since scouting tests had already been done on the three other case sizes, the tests run for case size D were more of a verification of what was already expected than a blind search for acceptable test conditions.

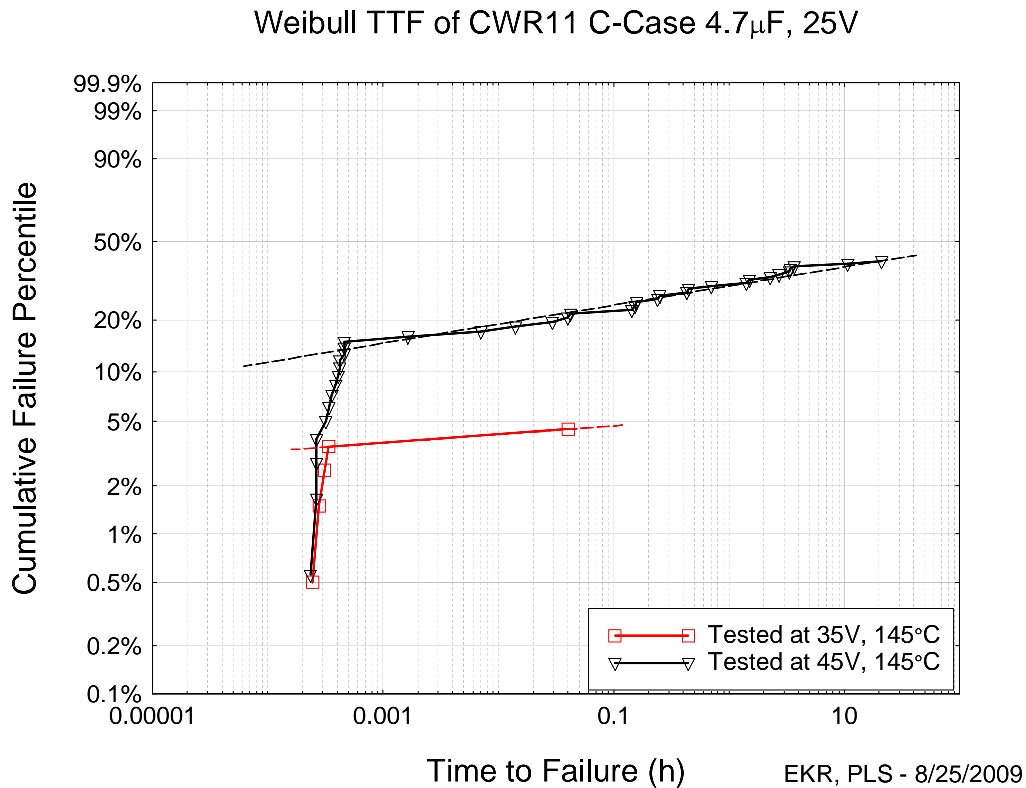

Figure 3. Case Size C

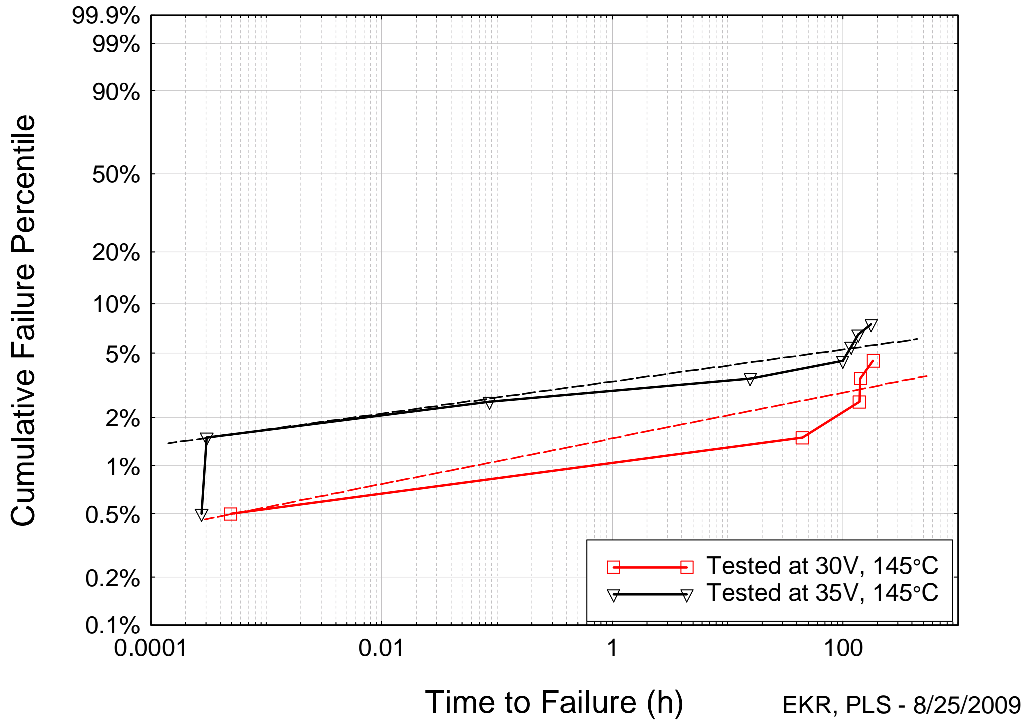

Figure 4. Case Size D

Table 2. Testing Conditions

Case Size	Accelerated Temperature (°C)	Accelerated Voltage (V)	Voltage Rating (V)	Grading Stress (Va/Vr)
A	145	50	25	2
B	145	32	20	1.6
C	145	35	25	1.4
D	145	35	25	1.4

Table 2 summarizes the accelerated testing conditions based on the scouting test results.

In the scouting data, there are a number of early failures followed by later failures that are more spread out in time and better fit the Weibull statistical distribution. Several factors contribute to early failures. There is a strong possibility that some of the initial failures seen in Figures 1–4 are caused by the stress of the various soldering techniques. However, since the accelerated test conditions are harsher than anything the parts have seen prior to the life test, this second factor could also generate some early failures.

Finally, the early portion of the Weibull graph becomes somewhat distorted by the removal of early failures from the population during the required MIL-PRF-55365 screening. This gives the appearance of early failures in the graph because of the statistical ranking process employed to plot the data in the graph. The ranking process requires that the first reported failure appear at a fixed percentage even if this percentage is smaller than the percentage of parts removed during the screening process.

However, because the statistical sampling error is large, sorting out the relative contributions of each of these effects is difficult. These issues will be discussed in more detail later in the report.

3.0 IMPORTANT WEIBULL PARAMETERS

Two important parameters of the Weibull distribution are the scale and shape parameters. The scale parameter, α, indicates the y-intercept at time 1 hour. To be exact, the following equation is used to calculate α:

Equation 2. $y = -\ln(\alpha)$ [2]

A large value of α implies fewer early failures, and fewer early failures are consistent with a generally lower cumulative failure percentile. Referring to Figure 3 as an example, the plot for 35 V will have a larger α than the plot for 45 V, because there are fewer cumulative failures at 1 hour.

The shape parameter, β, is the slope of the curve after the initial failures and specifies the failure rate behavior. A β value of 1 means the failure rate stays constant with time. A β value greater than 1 means the failure rate increases with time. The most desirable case is when β is less than 1. This means the failure rate decreases with time. The lower the value of β, the more rapidly the failure rate decreases. This means that flatter curves reflect more desirable reliability performance.

Another common Weibull parameter is the location parameter, γ, which reflects offsets in time from the start of the test to the early failures. This parameter is assumed to be zero for all the Weibull calculations in this report as is done in MIL-PRF-55365.

4.0 HIGHLY ACCELERATED LIFE TEST

The parts were subjected to a highly accelerated life test, the details of which are summarized in Table 2. A sample of 100 capacitors was tested for each soldering technique and each case size.

Using the method of Agresti and Coull from NIST, confidence intervals (CI) were derived from the convection reflow distributions [3]. The convection reflow distributions were chosen since convection reflow is the most standardized process of the three different soldering techniques. The resulting case size A Weibull plot for the three soldering techniques with confidence interval is shown in Figure 5. The shallow slopes for all three curves indicate a decreasing failure rate in time (small value of β). Not many failures occurred in the time allotted, signifying a large value of α. Overall, the reliability performance of all of these parts was excellent.

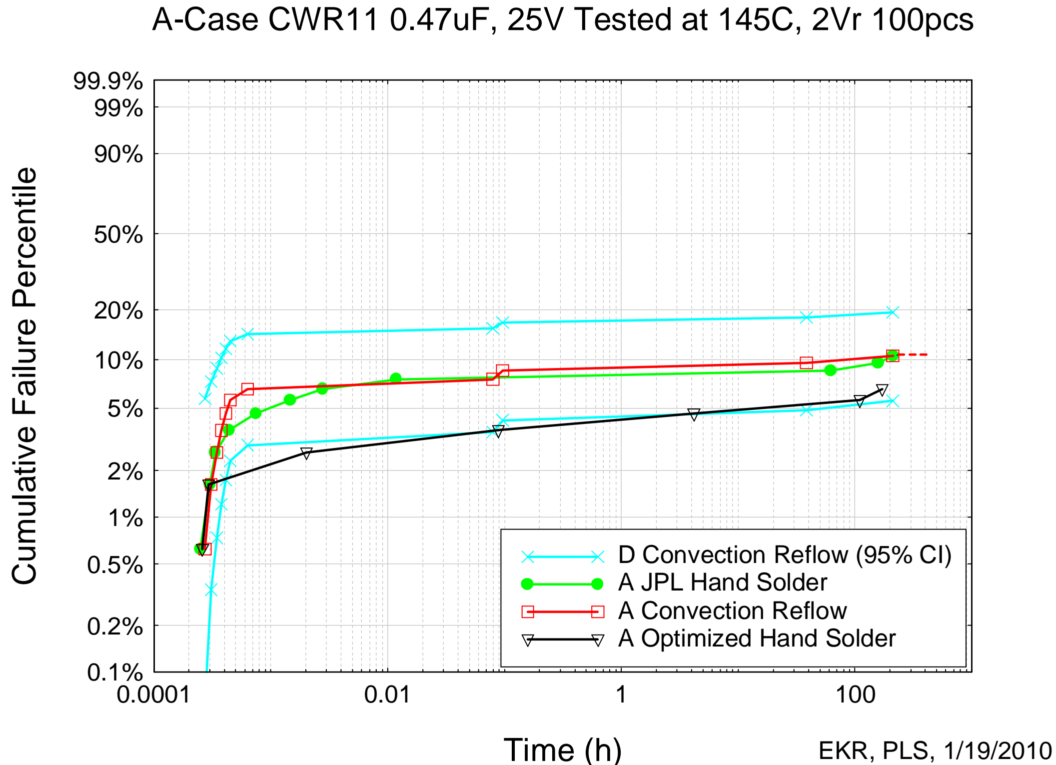

Figure 5. Case Size A Weibull Plot

The Weibull parameters are recorded in Table 3. It appears at first glance the optimized hand solder data are better than the other techniques, but because of the limited number of failures, it is questionable whether this apparently superior performance is real or an artifact of inadequate sampling as will be more fully discussed later.

Table 3. Weibull Parameters for Case Size A

	Optimized Hand Solder	JPL Hand Solder	Convection Reflow
β	0.07749	0.05259	0.03635
α	23.21	12.59	10.99

Since both the convection reflow and JPL hand soldering distributions are within the 95% confidence interval, they statistically cannot be distinguished from each other. The optimized hand solder data almost follow the lower limit of the confidence interval in Figure 5, which makes them too close to statistically differentiate from the other two distributions.

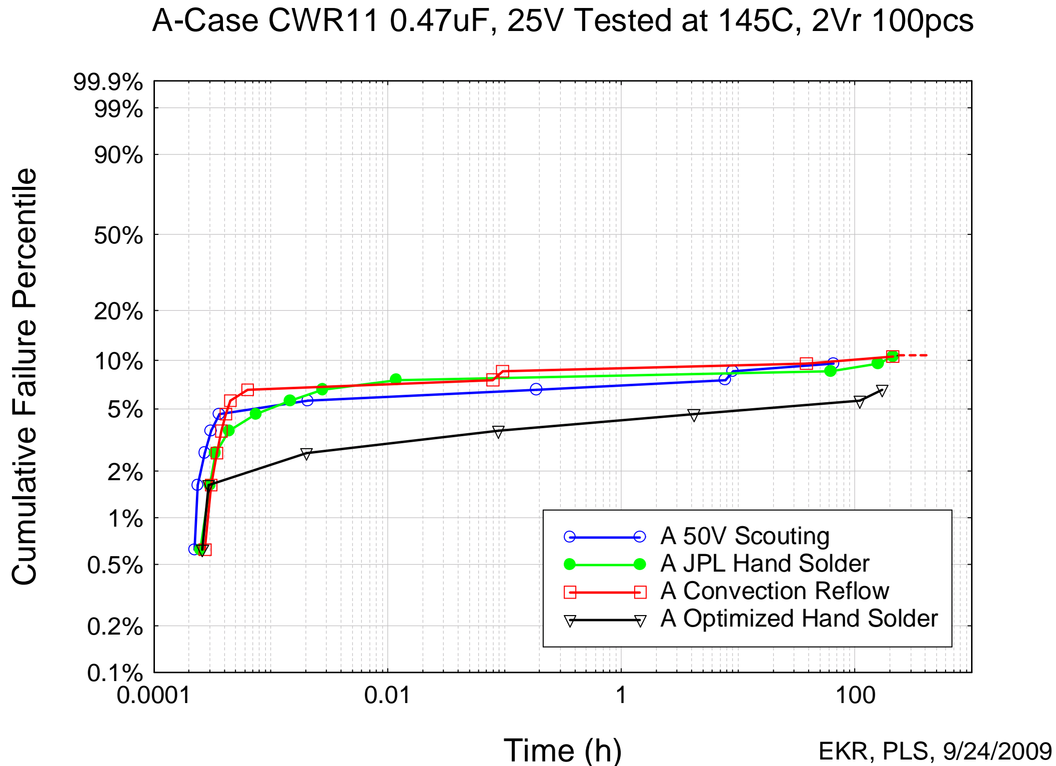

Figure 6. Case Size A Time to Failure Data vs. Scouting Data

The scouting data for the case size A parts are plotted with the accelerated life test data in Figure 6. While the scouting data predicted appropriate test conditions fairly well, there is a considerable discrepancy between the scouting data and the data for optimized hand soldering, even though the scouting capacitors were soldered with the same technique. This gives the first hint that there is considerable variability in the results for separate 100-piece samples of the same devices mounted by the same technique.

The case size B Weibull plot for the three soldering techniques is shown in Figure 7. Very little data was obtained on the case size B parts since they refused to fail. No conclusions can be determined from the Weibull plot due to the lack of data.

The lack of failure data was initially surprising since the scouting tests indicate 32 V would produce a reasonable number of failures in a short period of time. The 32 V scouting data is included with the final case size B soldering data in Figure 8. In hindsight, the intensity of conditions was not high enough for the case size B parts.

Referring to the scouting data in Figure 8, there were many initial failures, but not enough later failures. Harsher test conditions should have been chosen, but not enough attention was paid to the shallow slope at later times and the number of early failures let the study astray.

The shallow slope strongly hints that the test conditions were inadequate to produce a meaningful number of failures in the allocated test time. The case size B parts should have been tested at 36 V (grading stress = 1.8) to produce a more meaningful number of failures.

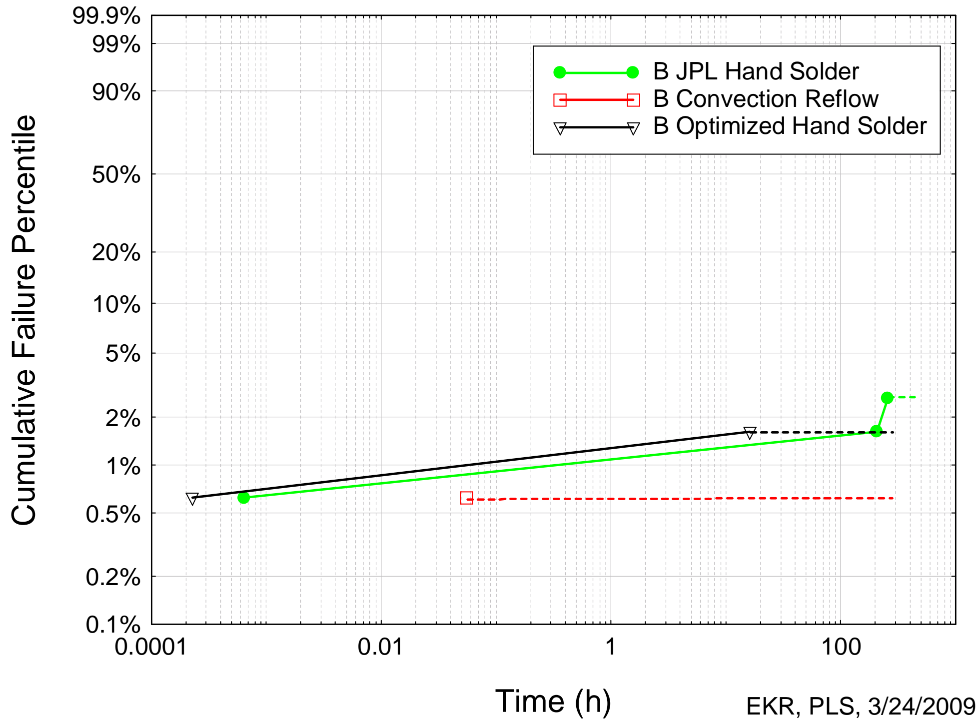

Figure 7. Case Size B Weibull Plot

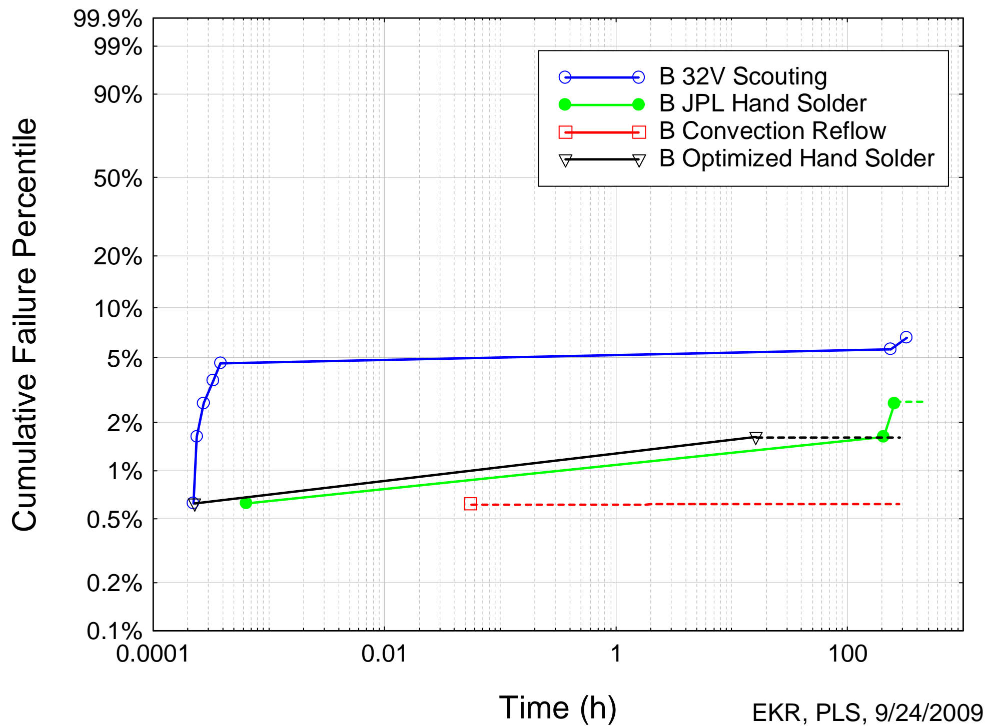

Figure 8. Case Size B Time to Failure Data vs. Scouting Data

The case size C Weibull plots for the three soldering techniques and 95% confidence interval are shown in Figure 9. The Weibull parameters can be found in Table 4. The β values for all soldering techniques are very low, corresponding to decreasing failures in time. The α values are appropriately high, indicating there were not many failures. The results for the JPL hand solder technique appear superior and fall well below the 95% confidence interval.

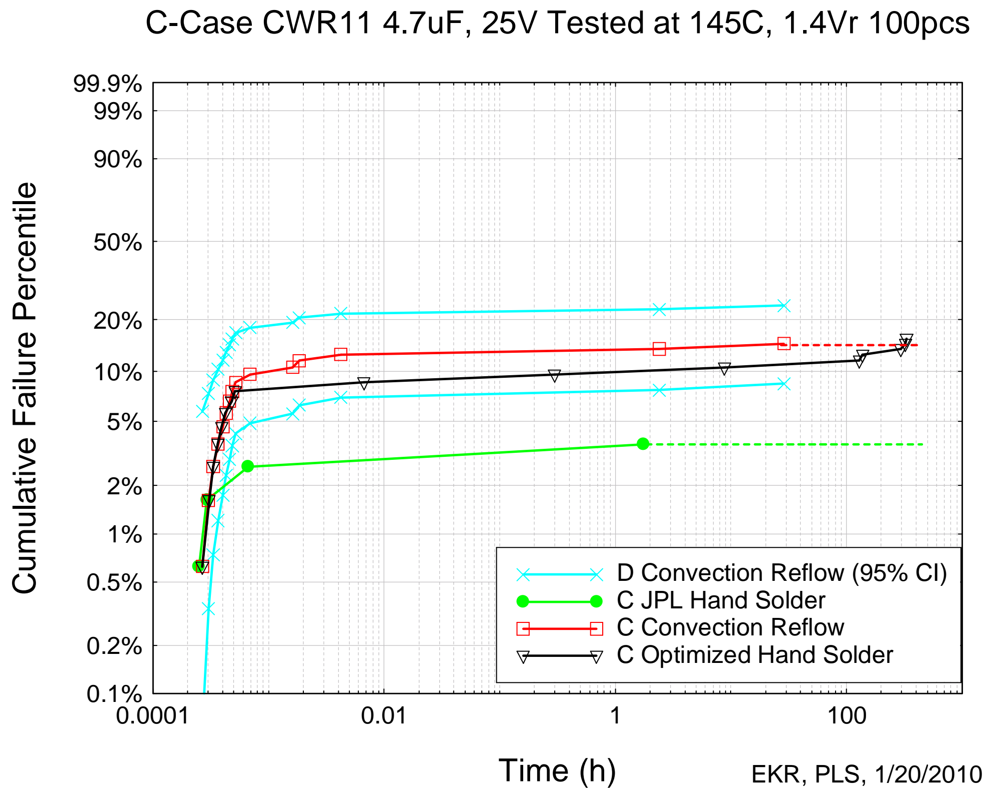

Figure 9. Case Size C Weibull Plot

Table 4. Weibull Parameters for Case Size C

	Optimized Hand Solder	JPL Hand Solder	Convection Reflow
β	0.05506	0.04164	0.03152
α	9.255	27.8	6.989

Figure 10 compares the three soldering techniques to the original scouting data.

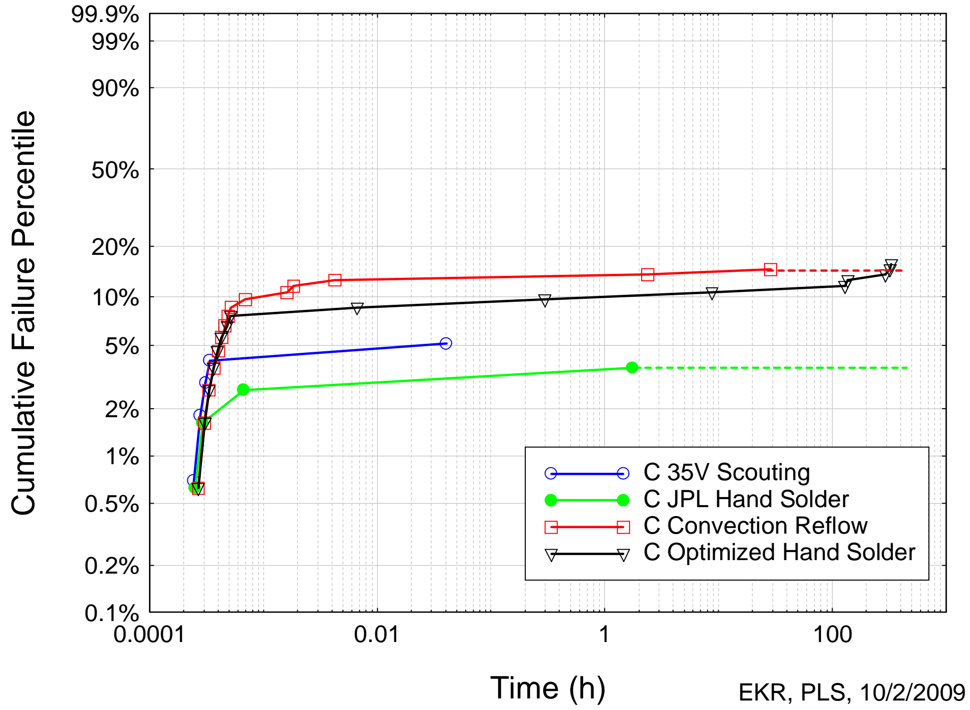

Figure 10. Case Size C Time to Failure Data vs. Scouting Data

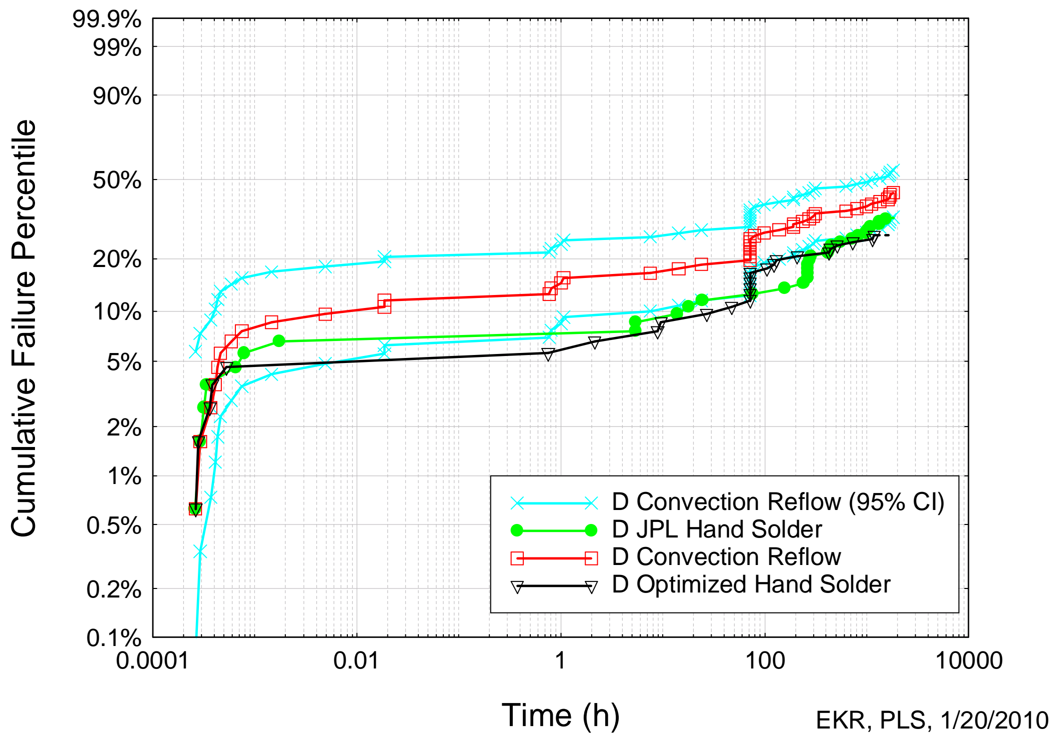

Figure 11. Case Size D Weibull Plot

The Weibull plot for the three soldering techniques for the case size D parts is shown in Figure 11. Due to time constraints, the case size D life test was the only test performed with testing time extended beyond a few hundred hours. This test was performed to just short of 2000 hours.

The higher failure percentage of the convection reflow parts persists beyond 20% failures and is probably valid. Indeed much of the data for the two hand soldering techniques falls outside the 95% confidence interval surrounding the convection reflow data. This indicates that convection reflow likely impacts reliability more than hand soldering.

Table 5. Weibull Parameters for Case Size D

	Optimized Hand Solder	JPL Hand Solder	Convection Reflow
β	0.2543	0.3143	0.1712
α	18.88	26.97	6.955

Values for α and β are shown in Table 5. A comparison between the time to failure data and the appropriate scouting data for the case size D parts are shown in Figure 12.

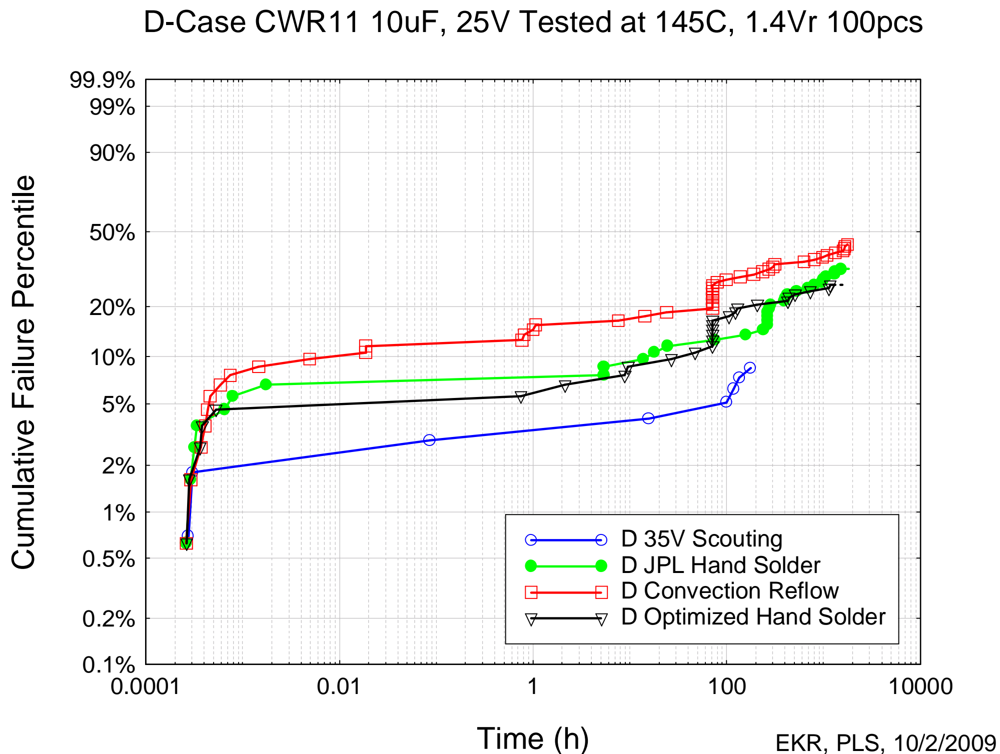

Figure 12. Case Size D Time to Failure Data vs. Scouting Data

5.0 SAMPLE SIZE CONCERN

Because the data were not as ideal as hoped, an investigation into the effects of sample size on the Weibull graph was conducted. The goal was to determine how much of the observed difference in the curves was due to actual differences in stresses and how much resulted from inadequate sampling. To investigate this issue, a theoretical random Weibull distribution was created using β and α values similar to those of the measured data of Figures 5–12.

This numerically created failure distribution was randomly sampled to determine the impact of sample size on the final Weibull graphs. Figures 13 and 14 are distributions with β of 0.25 and α of 27. Figure 13 shows distributions with 100-piece samples compared to a 1000-piece control sample, while Figure 14 shows distributions with 300-piece samples compared to the same 1000-piece control sample.

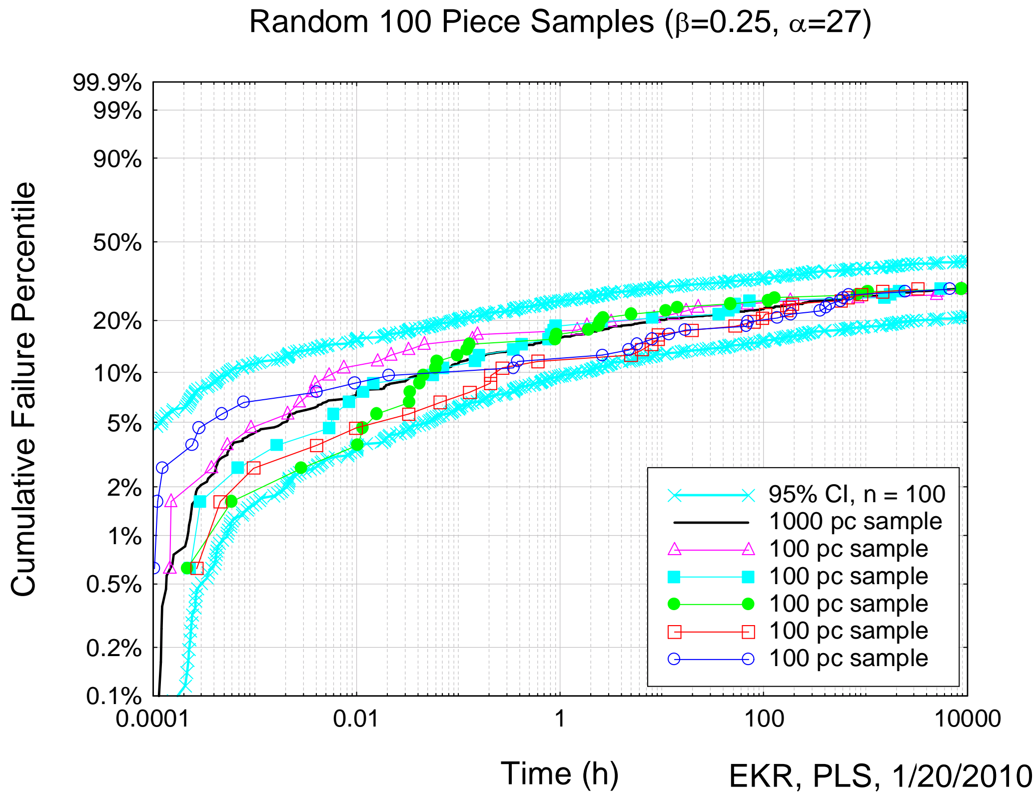

Figure 13. Variability of Data with Sample Size of 100

Figure 13 shows the plot created using a sample size of 100. The 95% confidence interval was calculated with 100 as the number of pieces tested (n) and center around the data for the 1000 piece sample. Each sample of 100 pieces contains 30 random failures (30% of sample) that occur before 10,000 hours. It is clear at times less than 100 hours that there is considerable variation in the results among the 100-piece samples with respect to the 1000-piece sample. This reflects the relatively poor statistical representation of the early time failures in the 100-piece samples, which is mirrored in the confidence interval. There is less variation at the later times (greater than 100 hours) when the total number of failures is high and the statistical representation of this part of the failure distribution is good.

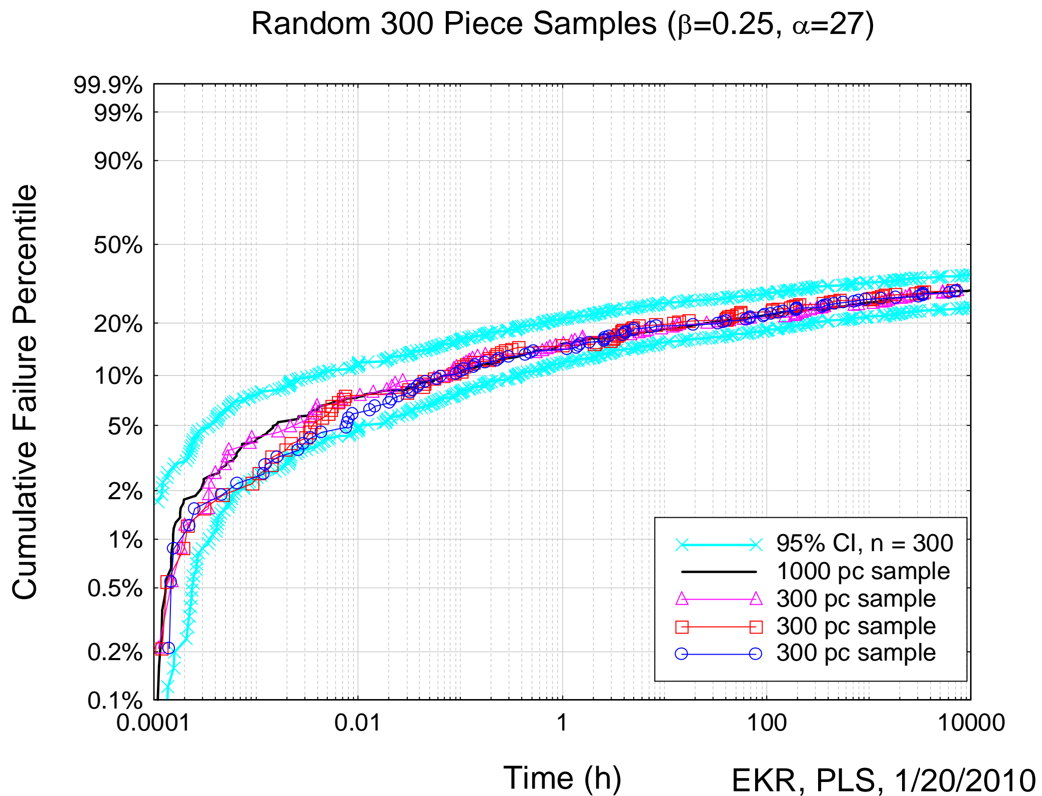

Figure 14. Variability of Data with Sample Size of 300

The experiment was repeated with 300-piece samples that contained 90 failures (30%) occurring by 10,000 hours, and the results were compared with the 1000-piece sample in Figure 14. The 95% confidence interval was calculated with the number of pieces tested equaling 300. It is clear that the 300-piece samples are much closer to the 1000-piece sample, which is also mirrored in the tighter confidence interval. While the repeatability is not perfect, it is probably sufficient for a Weibull distribution with these parameters, since the repeatability is very good at all times greater than 0.1 hour and much improved at earlier times.

The 100-piece sample size used for the accelerated life tests in this study was inadequate to reliably distinguish differences among the soldering techniques. This observation is supported by the statistical data and confidence interval of Figure 13. Much better resolution can be achieved using 300 piece samples as is demonstrated in Figure 14.

6.0 SUMMARY AND CONCLUSIONS

Accelerated life tests were performed in an effort to determine if the stresses of various soldering techniques influence the long-term life of MIL-PRF-55365 capacitors, and if so, by how much. Scouting life tests were performed to discover appropriate accelerated test conditions that would create between roughly 10% and 20% failures in approximately 100 hours. The scouting trials led to a choice of accelerated testing at 145°C and grading stress ratios between 2.0 and 1.4.

Due to limited funding and the desire to use MIL-PRF-55365 parts, the sample size for each life test was limited to 100 pieces. It was subsequently determined that this sample size is inadequate to discriminate among the soldering techniques, except perhaps for the case size D parts where the testing time exceeds 100 hours and the statistical representation is better.

Differences did appear in the time to failure plots from the life tests, but unfortunately there was no consistent pattern regarding the relative harshness of the various soldering techniques. In some cases there were large differences in the number of early failures and in other cases there were differences in the slope of the curves at later times, which implies differences in failure rates.

It is hard to say there is any consistent statistical difference between the three soldering techniques. The hand soldering techniques are not any worse than convection reflow and seem to be a little better. No evidence exists in the data indicating that hand soldering is harmful, while some evidence implies it is less harmful. But what is most important, none of the soldering techniques stands out as clearly preferred indicating that current soldering techniques being used are acceptable and have only limited reliability impact.

It is recommended that this experiment be repeated using a larger sample size, but that commercial tantalum capacitors be used instead of MIL-PRF-55365 parts to reduce cost. Sample sizes between 300 and 500 pieces should provide sufficient resolution to detect any meaningful differences among the soldering techniques.

During the scouting exercise, data at multiple voltages were generated. It is possible to make an estimate of acceleration due to voltage from these data. It would be good to repeat these scouting experiments with a larger sample size to allow an accurate estimation of a voltage acceleration formula. Test data should also be created at 125°C with a larger sample size so that a meaningful estimate of acceleration due to temperature can be attempted.

7.0 REFERENCES

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