

From HALT Results to an Accurate Field MTBF Estimate

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PART 1: ABSTRACT

HALT is a process that is essential for producing high reliability products¹. HALT, Highly Accelerated Life Test, is great for quickly finding failure mechanisms in a hardware design and product.

HALT takes only a few days to run and to implement its corrective action(s). Even if it takes a bit longer, this time would be far less than running an RDT (Reliability Demonstration Test) and then implementing its corrective action(s). This paper discusses a new and innovative mathematical model which can be a huge time and cost saver. By not performing RDT and simply doing an effective HALT, time and money can be saved. This is not to say that RDT isn't important. Long term RDT's should be reserved for new technologies, for part or design changes of different or new applications. RDT's may not be the best process to accurately estimate AFR (defined herein as Actual field Failure Rate).

This new math model is a tool that can accurately estimate the field MTBF or AFR from HALT results. It is important to have this estimate before launching a new product. Typical HALT stress levels are shown by Table 1 and reflect guard bands for typical customer product environments. These levels can assure the producer that the product should exceed customer expectations and allow the producer to accurately forecast warranty expenditures. One basic assumption of HALT is that there should be at least 75% test coverage and product fault detection in place for the HALT to be effective.

The *AFR Estimator* is a model that has been validated on almost thirty products from diverse manufacturers and design environments. With seven to ten simple data entry points and most of them coming from the HALT effort, the *AFR Estimator* can provide an accurate field AFR estimate with its associated 90% statistical confidence limits. Additionally, there are simple inputs for HASS and HASA¹.

The math model can accommodate HALT samples sizes from one to six with the optimum size being four. Sample sizes of greater than four will have a small impact on the estimate. The 90% upper and lower confidence limits are calculated based on the HALT AFR and the HALT Sample Size. Conversely, HALT sample sizes of less than four will adversely impact the AFR and MTBF estimates as well as the confidence limits.

PART 2: DETAILS

Introduction

The author began thinking about an approach of converting HALT results into MTBF numbers in the late 1990's. From this thinking, a model was started and development began shortly thereafter. In 2005, this effort was restarted using a different approach and was worked on sporadically until a functioning and partially validated model was demonstrated to three

engineers in 2008. As more validation data became available, the author decided that the time had arrived to get feedback from a wider audience. This was done at the IEEE/ASTR symposium in Portland, Oregon in 2008.

Background

Many of us have wanted to use the HALT data to estimate the field AFR but were...

- Told that it couldn't be done...
- Frustrated by the lack of sufficient data...
- Lacked the bandwidth to develop a model...
- Stopped by other impediments?

Many of us have performed HALT and have had a need to provide an MTBF estimate. When this is the situation, most have turned to RDT. A question arises and that is, "*Is there a better way?*". The answer is yes! The author has developed a mathematical model that, when provided with the appropriate HALT and product information, will accurately estimate the products' field AFR as well as its MTBF. Three acceleration models are used, linear, exponential, and quadratic forms. Additionally, this math model also provides HASS or HASA time to detect a shift in the desired outgoing failure rate.

HALT AFR:

The HALT AFR estimate is a function of the following factors: MTBF, Thermal Range, Vibration, and Sample Size.

Confidence Limits are based upon the χ^2 estimates derived from Semi E10.

Days for Detectable Shift in AFR (HASS):

$$N = \frac{(Z_{\alpha} + Z_{\beta})^2 p(1-p)}{d^2}$$

and Days = N/ Daily Test Sample Size

Where:

N is the sample size to be tested in HALT

Z_{α} is the producer's risk and it measures the probability of rejecting a good lot based upon a sample.

Z_{β} is the consumer's risk and it measures the probability of accepting a bad lot based upon a sample.

p is the baseline historical failure rate.

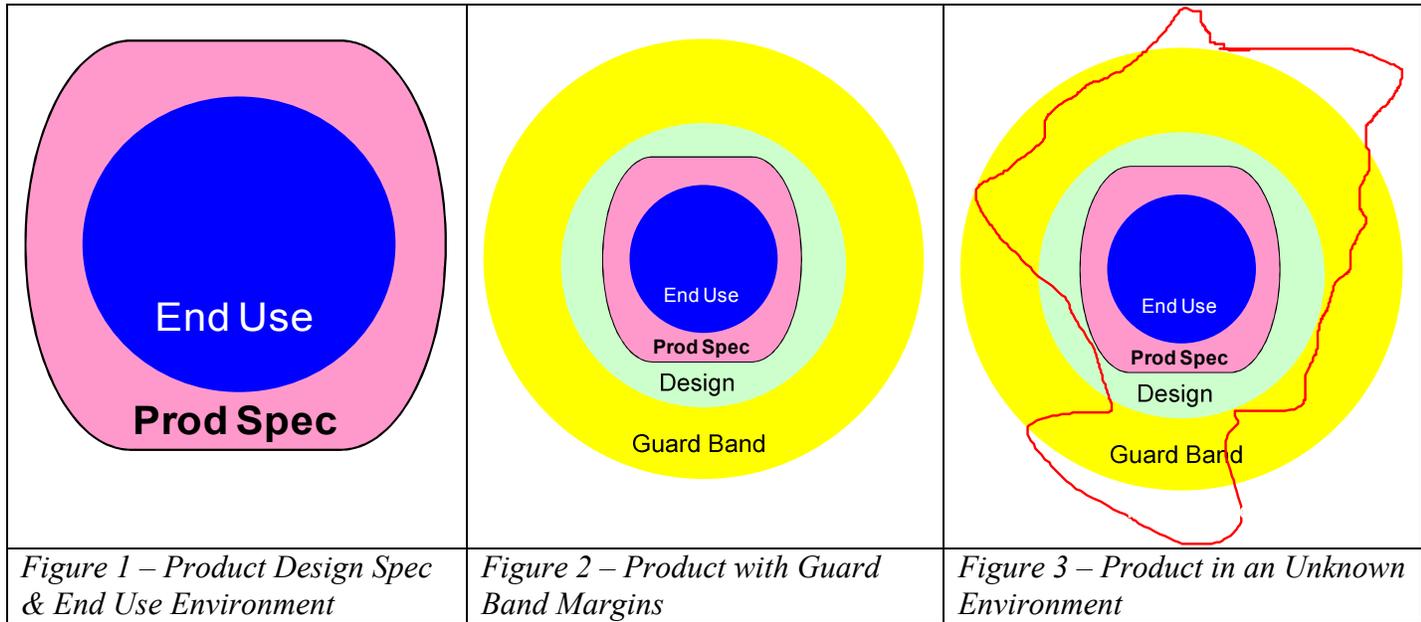
d measures the shift from p that is to be detected.

Preparation to Use the AFR Estimator

HALT needs to be performed correctly for accurate results from the estimator. The author highly recommends that the user complete at least one HALT before using the estimator. In this HALT (and others) the author recommends the following:

- Use a sample size of at least three, preferably four units. HALT sample sizes of three or less will dramatically affect the ability to detect product defects and the statistical confidence is likewise adversely impacted.
- Perform HALT at each phase of the Product Development Process.
- Dwells for the thermal and vibration steps of HALT are to be at least 10 minutes in duration.
- Properly execute rapid thermal transitions and combined environment steps. Even though they are not inputs to the calculator, they have been proven to be effective stresses for HALT and will help improve product margins.
- The products must be operated throughout the HALT. Include power cycling at temperature extremes and use a robust test protocol with at least 75% coverage.
- All issues that are uncovered are to be corrected at least up to Guard Band Limits.
- Timely corrective actions should be verified by a re-HALT.
- The HALT units are the same configuration and the same software as the ones that will be field deployed.
- All interfaces, even if HALT tested on a prior design, will be retested by the HALT of the new product.
- Ensure that the end-use environment for the product is included when developing HALT limits. Look at loads, thermal excursions, product duty cycle, AC power and other stresses. All stresses should be reviewed when using a HALT qualified unit in a new or different application. This is shown in Figures 1 through 3.
- Any cutoffs that have been designed into the product should be defeated once their functionality has been verified at the appropriate stress level. These can be thermal cutoffs to protect against thermal runaway, vibration cutoffs (often seen with hard drives where an accelerometer is used to park the drive heads if excessive vibration is detected), or any cutoff. If these are not defeated, then it is very likely the test will stop at these limits and not discover the true operational limit of the product. This problem will cause the AFR estimate to be erroneously high. Note that the cutoffs need not be physical but may be imbedded in firmware.
- You may need to build extender cables or mitigation for assemblies that fail at low stress levels. If this is not done, then the testing will be limited by early failures and additional failure mechanisms will be missed. The operating limits that are used for the calculation are the limits achieved AFTER corrective action has been incorporated. Therefore, operating limits will be the limits related to the any new failures found after the first round has been corrected. But if you cannot get past the early failures, then using extender cables or some other mitigation means, will allow the true operating limit to be found.

The Unknown Environment contingency shown by the red line of Figure 3 represents the true limit of product failure. This customer use environment limits are different from the one for which it was originally intended (See Figure 2 for a proper set of Guard Bands).



In order to successfully use the *AFR Estimator*, the following input information is required:

- **The Product Type.** From the product’s published specifications, match these with one that most closely matches the “**Published Spec °C**” shown in the first column of Table 1. The numerical value in the column marked “**Level**” will be needed. Note: if the limits don’t exactly match the product use then select the one that most closely matches. Be conservative and choose the next higher stress level. The product should achieve at least the levels shown under the Guard Band Limits in Table 1 for best results. These are very achievable based on experience. Most of the time, extended temperature range components (more costly) are not needed.

Published Spec, °C	Level	Application	Guard Band, °C
0 to +40	1	Consumer	-30 to +80
0 to +50	2	Hi-end Consumer	-30 to +100
-10 to +50	3	Hi Performance	-40 to +110
-20 to +50	4	Critical Application	-50 to +110
-25 to +65	5	Sheltered	-50 to +110
-40 to +85	6	All Outdoor	-65 to +110

Table 1 – Product Type & Guard Band

- **HALT Sample Size.** This is the number of units used in the most recent HALT.
- **Chamber Manufacturer and Model.** The chamber information used in the HALT is needed.
- **HALT Results.** From the HALT report (all product responses) identify:
 - The Hot temperature OL (Operational Limit) in °C
 - The Cold temperature OL in °C
 - The Vibration OL in Grms

Each of the failures encountered during the HALT need to be understood through root cause analysis. Corrective action should be implemented and then verified by a re-HALT under the same stress conditions. Exceptions to this would be limitations that occur beyond the Guard Band Limits. Issues encountered beyond these levels shall have root cause analysis performed but corrective action implementation may be a business decision based on timeliness, cost, and program delays.

- Estimated AFR or MTBF. The MTBF estimate is expressed in thousands of hours and can be derived from Telcordia, Relex™, or a similar prediction tool. If a text book estimate is not available, use 40,000 hours as a default value for the estimator. This parameter has very little effect on the final field AFR estimate.
- If HASS or HASA Will be Performed. If either will be performed then the following inputs will be needed:
 - The chamber capacity expressed as daily sample size. The daily sample size is the number of units that will be subjected to the HASS or HASA process in a twenty-four hour shift. If the HASS or HASA process control chart varies dramatically from shift to shift, then use an eight hour shift sample size until the chart indicates statistical control is present.
 - The Detectable Shift in AFR is the difference between the actual outgoing AFR and the detectable shift in outgoing AFR from the HASS or HASA results. For example, if the product baseline AFR is 4% and the worst case AFR that your business can tolerate is 10%, the Detectable Shift value is to be 6%.
 - If HASS or HASA are being considered, the chamber vibration tables need to be normalized. You will need to make the HASS vibration level be equated to some fraction of the HALT level. If HALT was performed on a rigid table and HASS will be performed on a non-rigid table one cannot assume that 15Grms on the rigid table is equal to the same level on the non-rigid table. For this case, the HASS or HASA level will actually be set at about 8Grms.

With all of these input values, the calculator may be used to estimate the product's AFR, MTBF, and Confidence Limits. If HASS or HASA are used, the days to detect a shift in the AFR may also be estimated.

Examples of the AFR Estimator Output

Figures 4 through 6 show typical calculator outputs with the green boxes representing the data inputs described in Section 3. The red boxes contain the outputs while the yellow boxes are for data input verification. The lower blue boxes represent Table 1 definitions.

The example shown in Figure 4 is for a vehicle inverter/charger product. Notice that its stressed parts count MTBF estimate of 56,800 is not close to the projected field MTBF of 275,972 hours. This MTBF input has very little effect on the output. The HALT based inputs are the predominate factors of the model. Make sure that the product response levels are used as the inputs to the estimator and not chamber set point values.

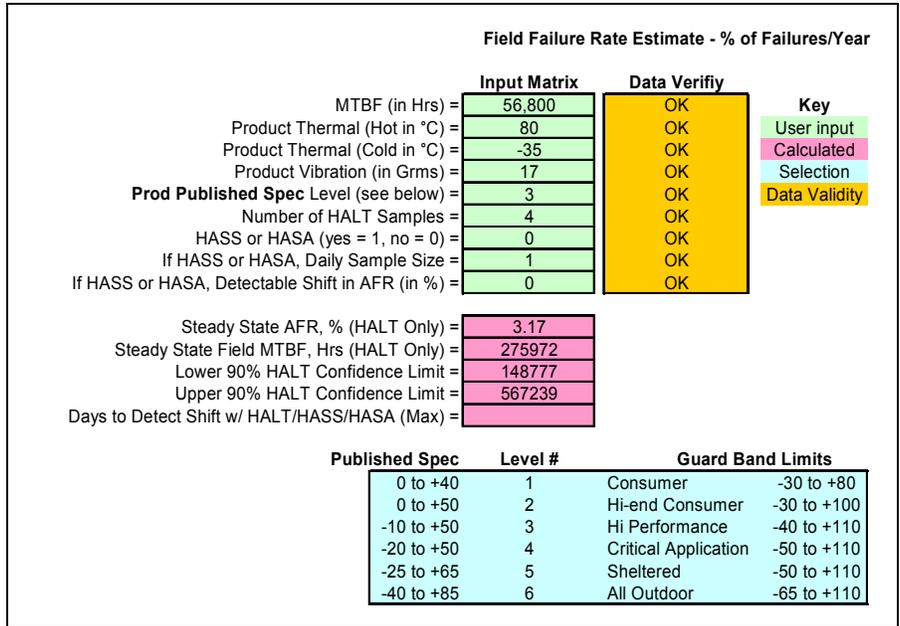


Figure 4 – Example of a Vehicle Inverter/Charger Product

Figure 5 shows the result of an office product being run through HALT. The actual field failure data and the calculation performed by the *AFR Estimator* have a difference of around 0.5%. See Table 2.

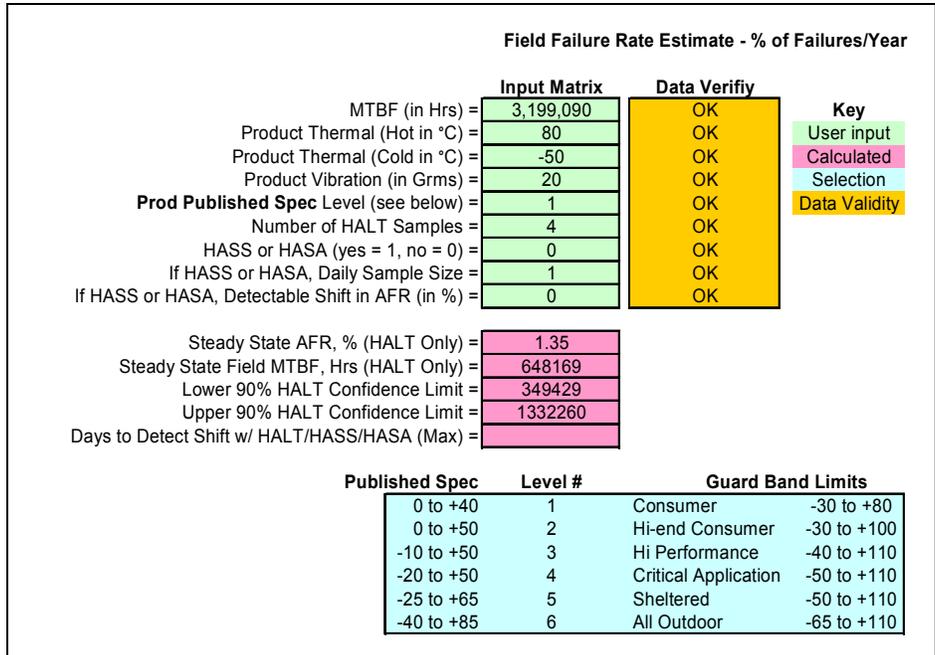


Figure 5 – Example of an Office Product

The example shown in Figure 6 is for a vehicle power inverter and the math model indicates a projected field AFR of 1.07%. Its field AFR was actually 0.70% and so the delta is 0.37%.

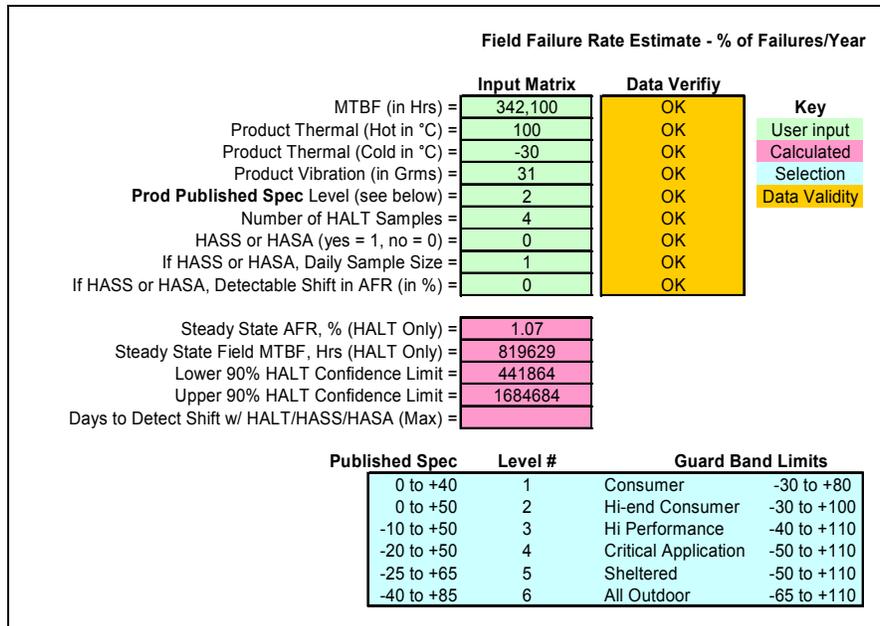


Figure 6 – Example of a Vehicle Product

Limitations of the Model

Table 2 shows that the model does a great job in providing a field AFR estimate that is close to reality, but it does have a few limitations. The limitations include:

- The model has not been validated on mechanical designs.
- The output of the *AFR Estimator* is only as good as the test protocol used in HALT. HALT does not capture every possible design defect, for example humidity related issues, field operation beyond Guard Band limits, and some wear-out mechanisms are not included. The HALT protocol needs to sufficiently test the product in each stress environment. A recommended starting point is 75% test coverage, but the higher the better.
- The HALT usually cannot find failure mechanisms related to wear-out because the acceleration factors are too high to allow the wear to occur. Therefore, the calculator will also not be able to estimate the life of the mechanism. Use Accelerated Life Testing instead in this instance.
- The HALT may not duplicate all RDT scenarios. For example, power cycle testing for FETs or capacitors may not be well covered. Look at the Physics of Failure and the HALT data before making a decision whether or not to perform a separate life test.

Products:	Calculated		HALT Results			Level	Table Tech	AFR, %		Return Rate, %
	MTBF	AFR, %	Hot	Cold	Vib			HALT Calc	Field Act	
Display	415,000	2.1	130	-80	28	4	2	0.27	0.21	
Outdoor	175,800	5.0	100	-60	28	6	3	1.26	0.75	8.30
Vehicle	143,600	6.1	102	-67	20	6	2	1.35	1.05	2.80
Vehicle	342,100	2.6	100	-30	31	2	2	1.07	0.70	5.60
Outdoor	275,000	3.2	110	-60	17	6	3	1.40	0.30	3.70
Vehicle	157,100	5.6	90	-60	21	2	2	1.17	0.90	10.10
Vehicle	192,500	4.6	90	-60	21	5	2	1.15	1.00	9.80
Vehicle	106,800	8.2	100	-50	13	2	2	2.27	2.20	14.06
Hi Perf	616,200	1.4	110	-42	19	3	3	1.28	1.00	
Vehicle	56,800	15.4	80	-35	17	3	2	3.40	3.75	
Vehicle	109,800	8.0	105	-35	14	6	2	3.25	4.40	8.40
Office	3,199,090	0.3	80	-50	20	1	2	1.35	0.8	1.4
Telecom (Out)	200,000	4.4	100	-80	28	6	1	0.83	0.5	
Telecom	200,000	4.4	83	-82	31	4	1	0.88	0.5	
Telecom	200,000	4.4	85	-60	50	4	1	1.21	0.5	
Telecom	200,000	4.4	121	-54	21	4	1	1.06	0.5	
Telecom	200,000	4.4	102	-72	25	4	1	0.82	0.5	
Consumer	70,000	12.5	100	-30	10	1	2	5.31	3.00	
Consumer	70,000	12.5	100	-30	16	1	2	3.13	3.00	
Consumer	70,000	12.5	90	-30	19	1	2	2.82	2.92	
Internet	67,200	13.0	90	-50	40	1	2	0.93		
Hi Perf	40,000	21.9	90	-100	50	3	3	0.73		
Avionics	17,000	51.6	120	-70	48	4	3	1.18	1.36	1.89
Avionics	32,000	27.4	125	-100	48	4	3	0.39	0.78	1.61
Avionics	14,000	62.6	120	-60	50	4	3	1.87	1.55	2.12
Avionics	18,900	46.4	120	-80	62	4	3	0.89	1.78	2.49
Avionics	20,600	42.6	120	-90	65	4	3	0.57	1.16	2.43
Avionics	14,600	60.0	120	-90	55	4	3	0.81	0.16	0.61
Avionics	71,000	12.3	120	-65	40	4	3	0.86	0.51	1.08
Avionics	11,000	79.7	125	-70	25	4	3	1.34	0.36	2.08

Table 2 – Products Used in Validation

Model Validation

Twenty-eight different products have both HALT estimates and actual field data. These examples validate that the average margin of error between the field AFR and the output varies less than 1.0% with only three being larger than one percent. Clearly indicates that the model is sound!

Table 2 shows a list of the products used in this validation. The columns of interest are the two AFR% columns, second and third from the right edge. When these two columns are depicted graphically, the data variation becomes very clear as is shown in Figure 7.

When the author first created the chart in Figure 7, it was quite obvious that something was wrong with the data at unit 18 (along the x-axis). When the person who supplied the data was asked a few questions about the HALT, it became clear that there were issues. The first was in the sample size of the HALT which was three and not four units. Second, the HALT data provided were chamber set points and not product responses. Once the proper data was supplied, the AFR delta became 0.13% (plotted as Unit 19) and the data from a subsequent re-HALT (as Unit 20) with slightly different HALT limits, showed a delta of -0.1%.

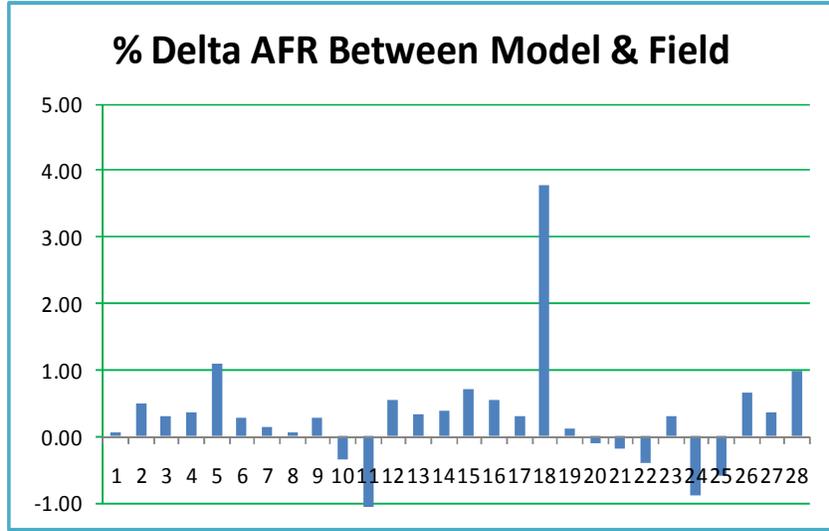


Figure 7 – % Delta Between Model & Field

The bottom line is that the *AFR Estimator* can identify the level of field AFR before the product is launched. The data for unit 18 remains in the table as an example of erroneous data input.

Parameter	Possible HALT	AFR	HALT Result	AFR
Thermal	-30°C to +100°C	----	-30°C to +100°C	---
Vibration	19 Grms		10 Grms	
Sample Size	4	1.81	3	5.31
Delta				3.50

Table 3 – Data Summary for A Correct HALT and for Unit 18

Table 3 would have shown 1.81% for this AFR had a correct HALT been performed. (**Possible HALT** column). With a sample size of three rather than four and the vibration input of 10 Grms rather than 19Grms, the AFR becomes 5.31% (**HALT Result** column). In this latter case the delta would have be 3.5%.

Conclusion / Looking Ahead

Table 2 and Figure 7 show that the HALT results correlate very well with the actual field failure percentage. The maximum delta is less than 1.0% as shown in Figure 7 and this is much closer than the field failure estimate generated from a reliability prediction. Thus, for these electronic circuit board-based products, the method appears to be validated. The author would like to extend a free trial of the model to those who have performed a HALT based upon three or more units and that have significant field data. Please contact the author using the contact information below. Your contribution to this effort will be recognized without divulging your company’s name or product details. Today, the use of the model is available through Ops A La

Carte. The author has received a Provisional US Patent on the mathematical model behind the AFR Estimator.

Reference

- 1- Harry McLean, "HALT, HASS, and HASA Explained", *ASQ Quality Press*, (2000, 2009)

Biographies

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Harry was with Hewlett-Packard for 25 years where he held various positions in production, R&D, quality and reliability engineering. He has extensive knowledge in medical electronics and personal printers. His main responsibility was for the manufacturing reliability of dot matrix impact and thermal inkjet printers. During this time he uncovered a way that customer field failures could be duplicated in-house through HALT and HASS. He designed and implemented a HASA process and wrote papers regarding this topic and others to better manage production facility departments. Next, he joined Qualmark and has consulted with many companies in the successful applications of the HALT and HASS process. At Qualmark he was the project research and development manager in addition to teaching many HALT and HASS seminars during these four years. Later, he joined AT&T Wireless and was the reliability engineering manager for five years. Here he received four US Patents, one for a fixture and three others for mathematical models relating to HALT. The patents are 6,491,528, 7,120,566, 7,149,673, and 7,260,509. He has also published a book titled, "HALT, HASS, and HASA Explained", published by the American Society for Quality and is currently in its second edition. His independent consulting lasted over two years before he joined Xantrex Technology in British Columbia, where he managed the reliability team. In 2007, he joined Advanced Energy where he is the Corporate Reliability Engineering Lab Manager with a reliability team that is focused on HALT and HASS development. He received his engineering degree from Northeastern University in Boston, MA and is fluent in Portuguese. Harry has taught HALT, HASS, and HASA techniques in Portuguese. He is a Senior Member of the ASQ.

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Mike Silverman is Managing Partner of Ops A La Carte, a Reliability Consulting firm. He has over 25 years experience in reliability engineering, reliability management and reliability

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