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THE EDUCATION OF TWO YOUNG TEST ENGINEERS BY AN EXPERT VETERAN IN LIFE TESTING TECHNIQUES

INTRODUCTION

Two young test engineers were having a discussion about life testing with an old time veteran, who had over thirty years of experience in designing laboratory life tests on components and assemblies, and correlating the lab results with actual field experiences in the hands of customers. Let us call the two young test engineers Mr. A and Mr. B, respectively. Furthermore, we'll call the old time veteran Mr. V. The conversation which took place between these three individuals is written up in the subsequent pages of this bulletin. Each section of the discussion deals with a special problem encountered in the design or analysis of life testing experiments, which are supposed to evaluate the ability of a manufactured component or assembly to have sufficient reliability to survive a desired service period or goal (miles, cycles, hours, etc.) in the field.

PROBLEM # 1:
ESTABLISHING A FIELD GOAL FOR LIFE

Mr. A: "Tell me, Mr. V, how can we decide how much life we should demand for an item operating in the field?"

Mr. V: "You must realize that the life of an item (component or assembly) in the field can experience a variety of conditions affecting its life. Among these are :

I. Different Types of Customers
   1. Conscientious users, who are careful not to abuse their product.
   2. Careful users, who abuse an item.
   3. Users with intermediate ratings on carefulness to obey the instructions in the user's manual.

II. Different Environments, such as,
   1. Different climates, if used outdoors
   2. Different conditions of cleanliness, corrosive exposure, temperature, speeds, loads, etc."

"After examining all the conditions which could be imposed on an item (component or assembly), we select an estimated most severe condition (such as the 95th percentile) for all factors involved in field operations, and then we establish a desirable life as far as the customer is concerned, say, one full year of trouble -free operation as a warranty promise on a machine used daily, or, perhaps, 100,000 miles on an engine or transmission without any major breakdown which would render the item useless without a major repair or replacement. Then when we know that a severely operated item (at the 95th percentile) will survive to the life which would satisfy a reasonable customer when he looks at the successful operating periods of competitive designs, and finds they have no advantage over the one we are selling, we can conclude that we have arrived at a reasonable goal for all customers (except for the upper 5% which would subject our item to still higher damage and, consequently, realize a lower field life)."

PROBLEM # 2:
THE AMOUNT OF CONFIDENCE NEEDED FOR COMPLYING TO A FIELD GOAL

Mr. B: "Mr. V., could you tell us how we can establish the level of confidence required that a product will operate successfully to an established field life goal?"

Mr. V: "This all depends on how severe a loss is experienced in case of failure to keep our promise about the length of the life of an item, as well as the profits we get from selling such items. We must keep failure rates low enough to prevent the consequent losses from exceeding our profits from sales. In fact, we want our profits to end up being greater than our losses due to failures by some comfortable factor, such as having twice as much gained as lost. The actual amount of profit in excess of losses due to failures should be made as large as possible within the range of economic feasibility toward the perfection of a design, by considering price competition with other manufacturers of a similar items. In simple mathematical terms, the ***Odds*** in favor of lasting to the desired field life is given by the formula

ODDS REQUIRED =
(PROFITABILITY RATIO)(FAILURE LOSS/SALES GAINS)

For example, if failures to meet the life goal produce a loss of 2 million dollars , and sales profits are half a million dollars, and we want to gain 3 times as much from sales as we lose from failures to last to the field life goal, then

Odds Required = 3(2,000,000/500,000) = 12/1

Thus, 12 to 1 odds would be required in this case, which is a ***confidence*** given by

Confidence = Odds/(1 + Odds) = 12/13 = .923 .

PROBLEM # 3:
RELATING ACCELERATED LABORATORY TEST LIFE TO FIELD LIFE

Mr. A: "Mr. V, I'd like to know what conclusion I can reach about field life on a new and better design, if the only information I have is a data set on the new design in the accelerated lab test, without any field experience, as yet, on the new design."

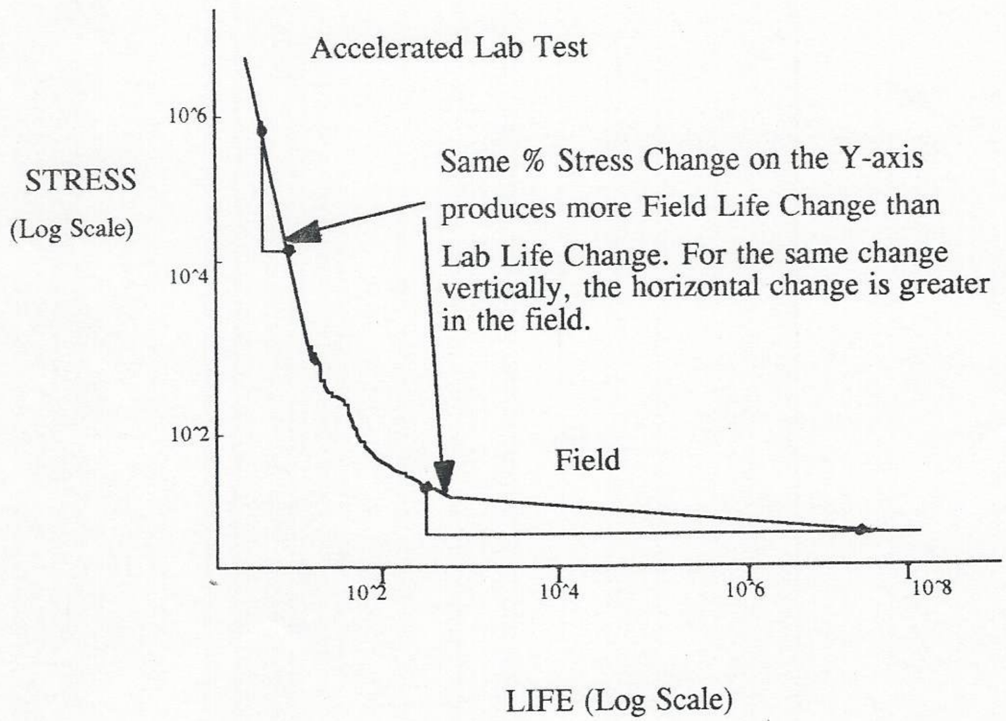
Mr. V: "You bring up a very important question. The only way to answer your question is to compare lab results on the new design with the lab results on the old design. In this way, you determine how many times better the new design in the accelerated lab test is life-wise than the old design was when subjected to the same accelerated lab test. But, one more thing you need is field information about the life of the old design in the field."

"Then, you can predict that the field life of the new design (in the same environment where the old design was in the field) will show at least the same life improvement factor with respect to the old design as that which was found in the lab test comparison of the two designs, namely,

(New Design Lab Test/Old Design Lab Life) .

We can say this because the S - N Diagram shows more life improvement for a given percent reduction in stress under field conditions than does an accelerated lab test for the same percent reduction in stress. This is show graphically in the following diagram:"

(**Remember:** A more durable design experiences a lower stress under a given load)



PROBLEM # 4:
WHAT DETERMINES THE SAMPLE SIZE OF A TEST?

Mr. B: "I am puzzled about the problem of selecting a sample size for any lab life test which I might run on a newly designed component or assembly. How is this sample size puzzle handled?"

Mr. V: "A sample size in a life test is considered to be sufficiently large only when statistical analysis shows that the sample plot on Weibull paper shows a high enough confidence that the sample plot's life exceeds the desirable field life at the quantile level under study. An example of this would be the life at which we want less than one in a thousand to fail prior to the desirable field life, in case we are going to sell 1000 items. The odds that this observed test life exceeds the desirable field life must be large enough to beat **Required Odds = (Profitability Ratio)(Fail. Dollar losses/Sales Dollar Gains)** ."

"The odds required for acceptance of a tested product might not be realized in the first test of a small sample (such as a lab test on 6 items). What this means is that the product does not have a high enough life safety factor with respect to the desirable field life, or its equivalent under test conditions. In other words, favorable odds are generated by two factors working together.

These are:

1. The new design's safety factor with respect to the required (desirable) field life.
2. The size of the test sample and its confidence band width.

In case the first small test sample (say 6 items) does not yield the required confidence (say, 92.3% as in Problem # 2), but only, say 90%, we test a second (independent) sample, and obtain, for example, 80% confidence of beating the desirable life. We can then combine the 90% confidence from the first test with 80% confidence from the second test, and come up with a resultant confidence calculated to be (.90)(.80)/[(.90)(.80) + (.10)(.20)] = 97.3%. Since this exceeds the required 92.3%, we would accept the design after these two tests."

"In other cases, we might have to run even more than two tests for confidence of beating the desirable life goal. This is known as ***Sequential Testing,*** where we test one small sample after another until we reach the point of acceptance by the superposition of all the confidence indices obtained from the separate tests. This can be shown to actually reduce the total number of test items needed, when compared to the one single sample size which would be required to yield the required confidence dictated by gains and losses. It is not considered wise to pick a tremendously large sample size right off the bat, for this could be a big waste of test specimens just to generate a high confidence of beating the life desired life goal, when we don't even know if we have a positive durability safety factor."

"For all we know, the desired field life might not even be realized for the design being tested, because the design might actually be inferior, with a confidence less than 50% of meeting the required life. Consequently, we might as well find this out with a small sample, and quit before we waste too many test specimens on a lousy designs."

Mr. V's Concluding Summary and Comments About the Topics Discussed in the Interview

Mr. V: "The four problems we have discussed cover the most important aspects of life test design and the associated statistical analysis. These can be summarized as follows, with simple acronyms:

Desirable Operating Goal (Service)	≡	DOGS
Odds Required	≡	OR
Correlated Accelerated Test Sample	≡	CATS

The desirable operating goal in service is the service life which is considered to be adequate to satisfy customers who buy the product. The odds required in favor of compliance to the desirable operating goal in service are determined by three factors:

(1) Profits (gains) from sales.

(2) Losses due to failure to comply with the promised life goal.

(3) The desired profitability from gains as a multiple of losses."

"The correlated accelerated test sample must be of sufficient size to yield the required odds of compliance to the desired operating goal for service life. As long as we have test samples showing odds which are more than 1:1 in favor of compliance, we can reach the required odds by multiplication of all the test odds from a sufficient number of test samples. This is the sequential approach, which minimizes the number of test specimens needed in totality.

In Problem # 1 we discussed the establishment of a desirable operating goal for service life.

In Problem # 2 we discussed the economic factors involved in calculating the odds required in favor of the desirable life in service.

In Problem # 3 we discussed how to relate lab test life to field life. This is known as the correlation between lab tests and field performance.

In Problem # 4 we showed how test sample sizes can be judged as to whether or not they are adequate with respect to the required odds of compliance with the service life goal."

Final Comments by Mr. V

"We found that even though the first small sample tested is inadequate, we need not quit our program of proving compliance, as long as that first sample showed odds above 1:1. Then we can test as many more small samples as needed (each with odds exceeding 1:1) in order to reach the required odds by multiplying all the individual test odds together until the resultant odds from such multiplication exceeds the odds required according to the principles explained in **Problem # 2**.

The basic principles of life testing for adequate field reliability of a proposed design which have been discussed in this interview are a necessary part of the education and training of all test engineers involved in durability testing of components and assemblies which need to be certified as acceptable before they are sold to the public."