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A Definitive Guide to Accelerated Testing

This article is derived from a recent 300-page state-of-the-art report on accelerated testing published by AMMTIAC. The report is titled "Accelerated Testing: Methodologies for Determining Life and Degradation of Materials." The article presented here is excerpted from the first chapter, which provides an introduction and overview of accelerated testing. For more information on this report or to request a copy, please contact AMMTIAC at ammtiac@alionscience.com or 315.339.7117.

INTRODUCTION

The proposition of specifying, designing, or constructing a new system or one or more of its sub-elements (e.g., production articles, assemblies, components, or constituent materials) is one that is common and familiar to most engineers. Admittedly, no one engineer is involved in all aspects of bringing a new system from product definition through deployment, but rather, each is more likely to confine his activity to his individual technical specialty. Regardless of their level of involvement in the evolutionary process of a product, most engineers have a vested interest in ensuring that a system or its subcomponents all meet their required form, fit, and function.

Designing systems and their components to meet specified form, fit, and function requirements is vital to successful product development. Ultimately, the degree to which a system complies with the initial stated objectives (usually in the form of a specification) is the single best measure of its performance. For too many engineers, however, their concept of performance is defined by how well the system operates the day it leaves the factory. Traditionally, little or no attention has been paid to how such a system would perform in the years or decades after deployment. Out of this relative ignorance to long-term system performance a new engineering paradigm has evolved that places greater importance on fully understanding a system's useful lifespan, and how and under what conditions a system can or will fail. In addition, the analysis of what effect a given type of failure may have on a system has unearthed a whole new level of material properties that are taken into account when developing a new system.

This new paradigm has fostered an evolution in the way new systems are designed and fielded systems are evaluated. Today, the emphasis is placed on the total life cycle of the system. System performance and incurred costs through each stage of the life cycle (definition, design, production, sustainment, and retirement/disposal) are all considered in evaluating the degree of system success. When assessing the efficiency of a new or fielded system, three questions need to be asked:

- How well does the system fulfill its mission requirements at a given point in time?
- What is the probability the system will carry out its function when called upon to do so?
- How long will the system be useful and cost-efficient?

The answers to these questions embody the qualities that are most indicative of a system's ability to fulfill its mission over the period of time that it is in active service. These three qualities, respectively, are performance, reliability, and life.

Performance

Performance is a measure of how well a material, component, assembly, product, or system meets the functional requirements established for it. Performance may be measured as a static or dynamic quantity, and thus can be assessed either as a constant or as a function of time. These requirements are either specified by the customer (typically via an engineering specification), or may be inferred through the requirements of higher order systems. For example, most military systems today are specified strictly in terms of the field performance of the finished product, thus leaving the details of manufacture, design, and material decisions in the hands of the contractors. Therefore, most performance specifications below the product level are dictated and self-imposed by the contractor, since they must be structured to support the objectives of the next level up in the product hierarchy. Figure 1 illustrates how these requirements are passed down from the product level through constituent materials.

Reliability

The term reliability has similar connotations in both lay and technical contexts. Simply put, reliability is a measure of how a system can be counted on to carry out its function when called upon to do so. These definitions are reasonably intuitive and straightforward. However, the concept of reliability within scientific circles is expressed more as a statistical quantity, and thus its formal

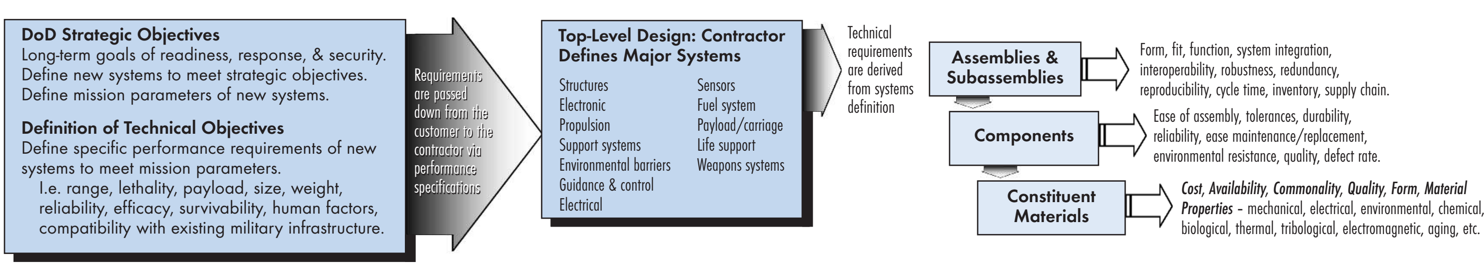

Figure 1. Established performance requirements are the results of a 'top-down' process.

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definition is more mathematical in nature. It is typically expressed as the probability of success and is an integral component of mathematical models which predict failure rates, time-to-failure, and total service life.

LIFE

Products are 'born' in the sense that they are manufactured. They enjoy some period of useful service and ultimately 'die' when their service comes to an end, typically by one of the following: product failure, retirement, replacement, or disposal. Also known as life cycle, service life, or useful life, life is defined as the quantity that most accurately represents how long a product or system lasts. Service life may be defined in terms of total calendar time since fielding, or may be defined exclusively in terms of use-hours (such as flight-hours for aircraft). In some cases, life may even be measured strictly in terms of usage (such as the total mileage on a car), and not on any time measurement. What varies by each case is what constitutes the end of life. At the material and component levels, many of these items are allowed to serve in their capacity until they fail to work, at which time they are usually replaced, either with an identical article or an upgrade. However, high-criticality* materials or components are not allowed to run until failure for reasons of safety. Assembly level constituents or higher are usually considered critical, and thus are not allowed to operate until failure either. Instead, they are operated for a fixed interval of time before they are serviced or replaced. Beyond reasons of safety, the service lives of non-critical elements are fixed because their service or replacement follows a set schedule for reasons of economics or convenience.

How Performance and Reliability Contribute to Overall Product Life

Until recently, the design and development of new systems was almost entirely driven by performance and unit cost. In the past few decades, the concept of affordable system operational effectiveness has gained prominence. Under this paradigm, program managers must consider the initial performance of the system, as well as system availability, process efficiency, and life cycle costs as shown in Figure 2. As such, performance and reliability should be evaluated over the projected life of the system. This accentuates the need for analytical methods which generate the data used to make such assessments. To accomplish this, engineers employ a methodology known as accelerated testing.

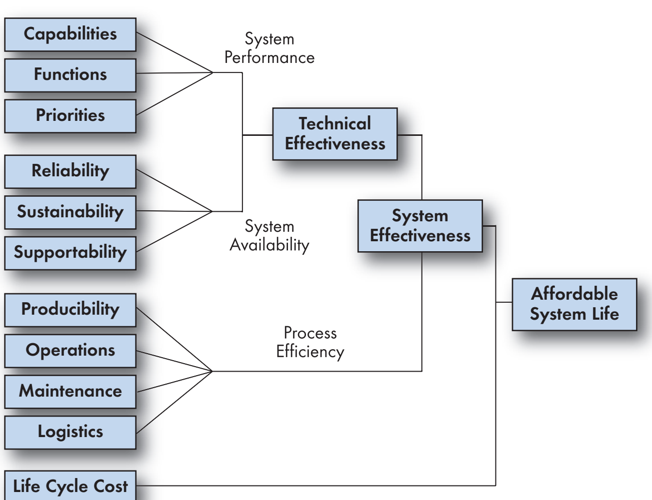

Figure 2. Affordable system operational effectiveness.

WHAT IS ACCELERATED TESTING?

Accelerated testing is a methodology comprised of a series of test methods, which can shorten the service life of products or significantly increase the rate at which their properties degrade.[1] Accelerated tests are performed on materials, components, or entire systems, under conditions of accelerated stresses† compared to normal operating parameters. Accelerated test data, when properly analyzed and modeled, can provide valuable information that could be used to project a product's long-term performance and service life under normal operating conditions. The information derived from this process may also be incorporated into one or more aspects of developing or fielding a product, thereby making some fundamental improvement in product quality, life, cost, or other desired characteristic.

Types of Accelerated Testing

Accelerated tests are designed with one of two objectives in mind, and thus can be differentiated into two separate categories: 1) qualitative accelerated testing and 2) quantitative accelerated testing. The differences between these two categories are significant in that each approach is based on the underlying assumptions and rules incorporated into their test protocols when examining degradation or life phenomena. Both types of tests employ the application of accelerated stresses to induce degradation and failure. Qualitative and quantitative testing, while not test methods themselves, represent the natural grouping of accelerated test methods into their two parallel but distinct objectives, as shown in Table 1.

Qualitative Testing

Sometimes referred to as elephant tests, torture tests, or shake-and-bake tests, qualitative tests have been developed in the last quarter-century to identify failure modes. To accomplish this task, qualitative tests are usually conducted on small sample sizes in controlled chambers where several samples are tested using increased stress levels and then compared against each other. In addition to small samples, qualitative tests can also be conducted on complete systems to either validate the material selection and design on a pass/fail basis, or identify systemic failure modes, which then will require re-design and/or selection of alternate materials. With the ultimate goal being to improve a system's reliability and per-

Table 1. Qualitative and quantitative testing.

Category	Objectives	Prerequisites
Qualitative Testing	• Establish failure modes for the materials, components, systems, and operational environment. • Identify best candidate material or component for the application.	• Requires a basic understanding, or at least a working knowledge, of basic failure mechanisms.
Quantitative Testing	• Provide reliability information about a component or system by quantifying the life characteristics of the system.	• Requires an understanding beforehand of the anticipated failure mechanism(s). • Requires a model to quantify the degree to which the test accelerated failure.

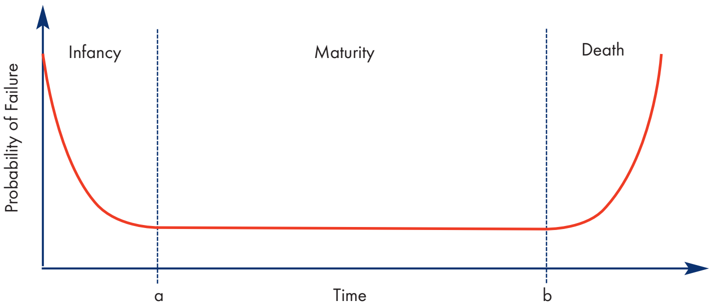

Figure 3. **Bath tub curve.**

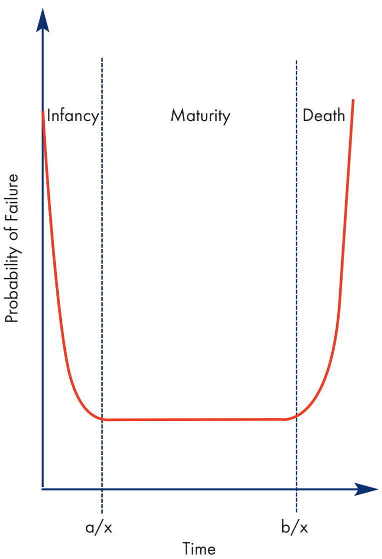

Figure 4. **Accelerated bath tub curve.**

formance, qualitative testing is extremely beneficial in providing valuable insight into the types (not amounts) of stresses and conditions that could be used in subsequent quantitative life tests. Qualitative tests provide very little insight as to the overall reliability and/or life of a system under normal working conditions. Calculation of a system's overall reliability and/or life expectancy is the purpose of quantitative tests.

Quantitative Testing

Quantitative testing (commonly referred to as quantitative accelerated life testing or QALT) is traditionally designed to quantify the life characteristics of a given system (see Figure 3). This can include quantifying the effects that a given failure mode may have on a system's performance, ensuring that a system meets performance and reliability specifications, assisting in risk assessments, and performing design comparisons. When testing a product's time-to-failure (TTF), the test is accelerated by either overstressing the component under load or increasing the usage rate of the product.

Usage rate acceleration is best used in tests where the system or component under test is not operated continuously (e.g., light switch). Because this system does not run continuously under normal conditions, its usage rate can be multiplied by '*x*' value. The resultant data then can be multiplied by the same '*x*' value and an accurate lifespan can be calculated, as shown in Figure 4. However, for systems that are expected to run at a very high or continuous rate (e.g., electrical transformer), usage rate acceleration will result in inaccurate TTF data.

For continuous or very-high rate components or systems, overstressing acceleration is the best way to obtain accurate life results. When using overstressing, one or more factors (e.g., environmental, physical, etc.) are applied that have shown the ability to facilitate failure in a component or system compared to normal conditions. As in qualitative testing, the types and levels of stress that are applied in this type of test must be carefully chosen so as not to introduce failure modes that will not occur under normal operation.

The Concept of Failure

The prerequisite of performing either qualitative or quantitative accelerated tests is an underlying knowledge of failure in materials and components. In simplest terms, a material, component, assembly, or system experiences failure when it no longer functions as intended. Premature failures in engineering systems are due to poor selection of materials, improper design, inappropriate manufacturing, and assembly processes, lack of adequate technology, improper handling by user, and poor quality control. Such failures can be classified as a *catastrophic* or *hard* failure when they stop working completely (e.g., a burned-out light bulb), or they are a *defined* or *soft* failure when performance falls outside of some acceptable level or range (e.g., when a tire tread wears below minimum thickness).

Catastrophic Failure

Catastrophic failure is considered to have occurred when a product stops working completely and is past any possibility of repair. There is a large market of products that are designed specifically with catastrophic failure as an acceptable result. These products have a relatively low overall cost and as a result are inexpensive to replace. Most of these products are relatively low-tech and have a long operational life. Some examples of these "throw away" products are shown in Table 2.

Defined Failure

Materials, components, assemblies, or systems that cannot be allowed to fail catastrophically, as mentioned above, instead have their life span preset. Similarly, there are other types of components whose performance will slowly diminish with cumulative usage; however, there is no definable end of life. Many of these products are assigned a defined failure, which specifies that a material, component, assembly, or system fails when its perform-

Table 2. **Examples of products expected to fail catastrophically.**

Product	Mode of Failure
Light Bulb	Performs at full output until it burns out.
Disposable Battery	Used until charge is gone and then discarded.
Pen/Marker	Works until the ink supply is exhausted. Disposable pens are discarded. Reusable pens have their ink cartridge replaced or refilled.
Electric Fuse	Common electrical fuses (such as in cars and in houses) are used until they burn out and then are replaced. Many such fuses last the entire useful service life of the product. Fuses in more critical applications (e.g., sensitive electronics) are replaced before catastrophic failure (see defined failures).
Hand Tools	Various handheld implements, such as tools, utensils, and others, can be used until they break.

Table 3. Roles of accelerated tests.

Process	Role of Accelerated Tests
Material Selection	Assist in the material qualification process given the design, lifetime, and operating environment of a system.
Identify Design Failures	By identifying faulty aspects of a design up front, their frequency of occurrence can be reduced or eliminated completely through better material selection, improving or changing manufacturing processes, and using more robust design approaches.
Identify Manufacturing Defects	The product wear and failures induced by accelerated testing will highlight manufacturing defects, which in turn may be corrected or obviated through the use of better raw materials, design modifications, improvements to the manufacturing processes, and the adoption of procedures to eliminate out-of-box failures. It also allows engineers to estimate improvements to product reliability via reducing or eliminating certain failure modes.
Quality Control	Accelerated testing is used in assessing raw material lots and in periodic testing of production runs. As a result, defects are identified before the product leaves the facility. In these instances, accelerated test data identifies a previously unknown failure mode or performance values degrade below established levels. These early warnings give engineering and manufacturing personnel the opportunity to isolate the cause of the problem and take corrective action before failures occur in the field.
Monitor Operational Performance	Accelerated test procedures can be used to develop and monitor the engineering relationship between operating conditions and reliability, degradation, or failure.
Evaluate Other Variables	Accelerated test data can assist in analysis of the effects of materials, design, production, sustainment efforts, and overall operating conditions on a system's overall performance. Consequently, this information can be beneficial in helping engineers to optimize a products' overall reliability by controlling critical parameters.
Verification/Qualification	Testing can be used to qualify design features, manufacturing steps, raw materials, components, and even vendors.
Demonstrate Reliability	Accelerated testing can be used to show that product reliability meets or exceeds customer specifications.
Test Validation	Sometimes accelerated testing is performed to validate the test method itself by comparison to previous tests, tests from other laboratories, and against field data.
Assess Model	Can be used to help develop, assess, and modify engineering and statistical models.
Service Policy	Data from accelerated tests can provide information beneficial for scheduling sustainment activities (i.e., inspection, maintenance, spare part acquisition, and part replacement). Accelerated tests are also used to set warranties and mitigate warranty issues.
Cost	Optimize the cost of a system to meet reliability and lifetime specifications.

ance drops below some threshold value. The threshold value could be anything ranging from a pressure value, a voltage, a measure of physical distance (feet, meters, miles), to a period of time. For example, it is strongly recommended for most vehicles to have the engine oil changed and filter replaced every 3,000 miles or three months, whichever comes first. In reality, most vehicles will perform without defect for longer than 3,000 miles between oil changes. The recommended three months/3,000 mile limit was instituted as a type of defined failure because a vehicle's performance can be negatively affected when that barrier has been crossed.

Why Use Accelerated Testing?

Accelerated tests are often performed for a number of purposes relating to materials selection, component design, quality, performance, and reliability. Table 3 presents the roles that accelerated tests play in regard to each topic.

PITFALLS AND LIMITATIONS OF ACCELERATED TESTING

One of the great pitfalls of accelerated testing is that test specimens may fail under an alternative failure mode not experienced under normal operating conditions. If such conditions manifest themselves, then the accelerated and normal results of that test may not be compared, as they are mutually exclusive and not representative of the other in any way.

Several factors can lead to a poorly performing accelerated test. One of the most common causes of inaccurate results is not properly identifying and recreating the operating conditions and/or environment. If the operating conditions are not properly recorded and qualitatively tested, the potential for unanticipated failure modes to occur is very high. This occurrence can be eliminated through proper background research and analysis of conditions. In addition to thorough research, comparison of test data against field data can qualify an experiment for full scale use.

Another factor leading to poor test planning is the error of not identifying all possible failure modes. Often these errors occur as a result of not taking into consideration all factors affecting the entire system. That is, non-critical systems may only rely on piece part accelerated testing in the system's design, only to have an unidentified failure mode occur due to the interaction of various parts in conjunction with the operating environment. A crude example may be galvanic corrosion. To eliminate such failures from occurring, critical systems undergo a full system accelerated test program (prototype testing) prior to full-scale production.

Accelerated tests can also render inaccurate results if the wrong analytical model is chosen. Several models only apply to certain acceleration variables (i.e., temperature, humidity, etc.) and can produce drastically different results if not used properly. Miner's Rule for calculating fatigue damage is a great example of a test equation that is commonly misused. The major pitfall in Miner's Rule is that it looks at each applied stress individually and does not take into account that certain stresses can work in a synergistic method.

Test Planning

A properly planned accelerated testing experiment can eliminate a large majority of the errors that may occur in a test. Poor planning can actually lead to situations where additional failure modes could be introduced, and as a result the test and its data will be invalid. After all, the best statistical analysis cannot overcome a poorly planned test, whereas the conclusions are quite obvious from good test planning. The following questions can help to properly plan and carry out accelerated tests:

1. **What are you testing?**
   Having a detailed knowledge of what type of component or system you are testing is a vital foundation for developing your experiment.
2. **How critical is the component or system you are testing?**
   Understanding the criticality of the component or system can have a significant impact on the level of detail required when performing a test.
3. **What failure modes are you testing for?**
   Knowing what you are testing for will influence what type of tests you perform, what models need to be followed, and how the results will be interpreted.
4. **What is your component made of?**
   The material composition of a component will help identify the types of tests that can be performed in order to obtain the desired testing.
5. **What type of test do you need to perform?**
   Selecting the proper test will help ensure that you get the desired results from your experiment.
6. **Are you performing this test for qualitative or quantitative results?**
   Not all components can be accurately tested using quantitative methods (i.e., corrosion testing). Knowing what the types of results are needed greatly impacts the experiment.
7. **What model do you need?**
   Choosing the correct model to compare the data against will greatly affect the accuracy of your analysis.
8. a. **What statistical analyses will you need to conduct?**
   Picking the appropriate method of analyzing the collected data is vital for obtaining accurate results. Clearly defining the problem statement and the purpose of the analysis is extremely beneficial in choosing the proper statistical test.

   b. **What confidence levels are you trying to obtain?**
   Higher confidence levels (92.5%, 95%, and 99%) are noticeably difficult to obtain due to the level of planning and attention to detail required when setting up those tests. Understanding what confidence level you really need to achieve the desired performance levels will have a significant impact on the level of detail when performing the test and subsequent analysis
9. **What kind of data (information) do you expect to get from this test?**
   Knowing what type of data you are expecting directly correlates to what you plan on doing with the data. For example, if you are performing qualitative testing, you are most likely not looking for numerical data, but failure modes that can be further tested using quantitative means.
10. **What do you plan to do with this data?**

    a. **What kind of decisions will you make from it?**
    The purpose of the collected data is directly related to the level of accuracy required and the necessity to reproduce the test and get similar results.

    b. **Does the test need to be repeatable? If so, how often?**
    The ability to reproduce the accelerated test helps to lend credibility to the test results.
11. **Do you need to perform any additional testing to verify/compliment/refute/disqualify earlier results?**
    Based on the criticality of the results, it is common for accelerated tests to be performed numerous times in order to ensure test reliability/repeatability and accuracy of results.

SUMMARY

Accelerated testing is an interdisciplinary field covering topics such as aging characteristics of materials, degradation mechanisms, testing, reliability, statistics, and life assessment. This article provided an introduction to the field of accelerated testing. Accelerated testing can prove to be a valuable tool for a variety of applications including reliability and life prediction, materials and manufacturing processes selection, and quality control. However, accelerated testing is extremely context-critical and thus easily misapplied. Such tests can produce erroneous results through improper test planning and in cases where the operating environment is difficult to predict. The report from which this article was derived provides an in-depth look into these applications issues, gives engineers and program managers valuable insight on how to conduct, use, and benefit from accelerated testing.[2]

ACKNOWLEDGMENT

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REFERENCES

*These are materials or components that, if they were to fail in operation, would result in a catastrophic event, such as the loss of the system or even loss of human life.

†The term stress as it is used here refers not necessarily to a physical or mechanical stress, but rather to any factor within the operating environment of a system that contributes to degrading that system, and thus depleting it of remaining service life. Most systems experience multiple stresses during the course of their use, but typically only one or two of them are accelerated in a test. In reliability terminology, an accelerated stress is also referred to as an overstress.

[1] Nelson, W., *Accelerated Testing: Statistical Models, Test Plans, and Data Analyses*, John Wiley and Sons, 1990.

[2] Lane, R.A., C. Lane, B. Battat, C. Grethlein, et al., “Accelerated Testing: Methodologies for Determining Life and Degradation of Materials,” Advanced Materials, Manufacturing, and Testing Information Analysis Center, AMMT-37, June 2009.

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