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Reliability Analysis of Avionics in the Commercial Aerospace Industry

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Abstract

The reliability of avionics using commercial-off-the-shelf (COTS) items and products is a concern for the aerospace industry. The results of collecting and analyzing field return records of avionics are documented in this article. Our analysis shows that the exponential distribution is still appropriate for describing the life of most avionics manufactured over the past 20 years. Results also show that failure rates decrease at the introduction of products. An increasing trend in failure rate can be noted, for systems made after 1994, suggesting the need for further investigation.

Introduction

Microelectronic systems built with COTS are now widely used in the aerospace industry and are becoming increasingly important. After the Department of Defense (DoD) changed the acquisition process (one formerly based on military standards and specifications) in 1994, military-specified avionics have become rare. The aerospace industry's use of microelectronics is shrinking as a percentage of the entire market, so it must face the reality of a commercially-driven market. Commercial integrated circuit (IC) products' life cycles are decreasing to 2-4 years [Reference 6]. In contrast, the aerospace industry assumes the life of a Line Replacement Unit (LRU) is more than 10 years. This discrepancy will worsen given the continuing advancement in functionality and speed in the microelectronic industry. To understand the impact of technology advancement on avionics, we needed to find out what had happened in field operation. Field records of return-for-service of avionics in the past 20 years were collected and analyzed, and the results are documented herein.

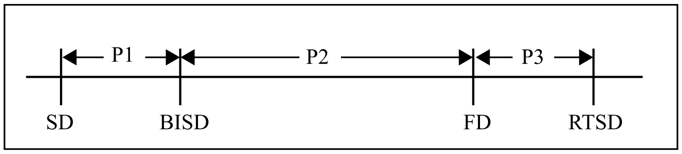
Data Collection

Return-for-service records were collected from two major suppliers of avionics. Several types of systems were included, such as a flight control system, autopilot, flight director system, and symbol generator. Records from company A include eight systems dating from 1982 to 2002. Company B's records are dated from 1997 to 2002 and include one system. Most of these records include the unit serial number, date sold, return for service date, replaced IC types, and quantities. Some of the original data were found to be insufficient for analysis. We compiled the original records to weed out and discard the useless ones; the remaining records had sufficient data to support statistically significant conclusions. We also made some assumptions to facilitate the statistical analysis. Our assumptions were as follows.

1. Systems were grouped by type and the year of "date sold" assuming they were manufactured and used in the same year.
2. For units with multiple returns, only the first return was calculated and analyzed.
3. It is assumed that all ICs replaced in service have experienced failure. This assumption may have caused us to overestimate the number of failures.
4. Censor time: the time to check the status of system. It is set to April 30, 2002.

Based on these assumptions, a C language program was used to select the useful records, check the end status of the systems, and calculate the service hours. The method used to calculate the service hours follows Figure 1, in which the different periods between sold date and return-to-service date are shown.

INSIDE



SD – Sold Date, BISD – Begin In Service Date,
FD – Failure Date, RTSD – Return To Supplier Date

Figure 1. Time Line of Field Records

The P_1 interval between *SD* and *BISD* includes delivery time and installation time. The unit service period (days), P_2, is:

$$P_2 = (RTSD - SD) - P_1 - P_3 \qquad (1)$$

P_3 is the return time from customers to suppliers. If the unit did not fail to the censor time, the service period is between *BISD* and the censor time. Generally, there are only *SD* and *RTSD* in the raw records. P_1 and P_3 are estimated based on the information given by the suppliers. Different suppliers have different P_1 and P_3. Once P_2 is found, the unit service hours are calculated from: $ServiceHours = H_{on} * P_2$. The H_{on} is the power-on hours per day of system. Different companies give different H_{on}.

Data Analysis

Analysis of System Records from Company A. There are records for about 21,535 systems sold between August 17, 1982 and December 30, 2001 from company A. Categorized by system type and year of "date sold," there are 87 groups of data, which include 9 groups with zero failures and 6 groups with one failure. The statistical analysis process and results follow.

Probability plotting. As the generally accepted lifetime distribution in microelectronic industry, Weibull distribution is used to analyze the service hours. To verify its usage, we plotted probability and calculated the correlation coefficient (CC) of Weibull distribution and lognormal distribution respectively (Groups with 0 or 1 failure are omitted). Results show that the CC for 42 groups of Weibull distribution was greater than the CC for the lognormal distribution. The CCs of Weibull distribution were also compared with the 90% critical CC [Reference 1] to determine if the distribution is appropriate or not. Results show that 62 of 72 groups CC was greater than the given critical CC.

Parameter estimation. The parameters of Weibull distribution are estimated by using the maximum likelihood estimation (MLE) method. The histogram of the estimated shape parameters is shown in Figure 2. It shows the values of most of the shape parameters are distributed between 0.6 and 1.1.

Exponential distribution verification. Although the wide use of exponential distribution has been questioned for a long time, it is unwise to blindly accept or reject it. The exponential distribution was theoretically shown to be the appropriate failure distribution for complex systems by R.F. Drenick [Reference 5]. He stated that "Under some reasonably general conditions, the distribution of the time between equipment failures tends to the exponential as the complexity and the time of operation increases; and somewhat less generally, so does the time up to the first failure of the equipment."

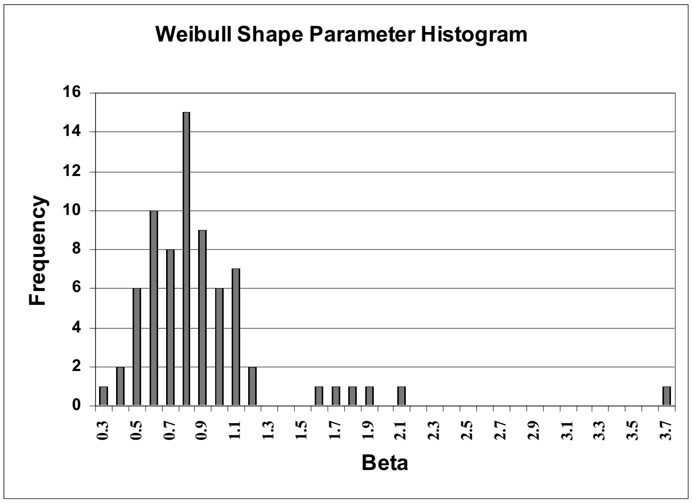


Figure 2. Weibull Shape Parameter Histogram

In the microelectronic industry, due to the advance of technology, chips are becoming more and more complex following Moore's law. Additionally, avionics have complex structures. A flight director system may consist of 460 digital ICs, 97 linear ICs, 34 memories, 25 ASICs, and 7 processors. The number of components in such a system is huge. For these components, external failure mechanisms caused by random factors such as electrical overstress, electrostatic discharge, and other environmental and human interaction, and intrinsic failure mechanisms, which include dielectric breakdown, electromigration, and hot carrier injection, can cause the components to fail. These failure modes combine together to form a constant failure rate process, as Abernethy [Reference 2] stated that as the number of failure modes mixed together increases to five or more, the Weibull shape parameter will tend toward one unless all the modes have the same shape parameter and similar scale parameter. Some recent research that focuses on intrinsic wearout failure mechanisms lends support to the exponential distribution. Degraeve [Reference 4], Stathis [Reference 7], and Alam [Reference 3] pointed out that the Weibull shape parameter of oxide breakdown is thickness dependent and goes to unity for ultra-thin oxides. As the Weibull shape parameter approaches 1, the intrinsic wearout becomes more random and the device times to failure become statistically indistinguishable from a random pattern of times to failure.

We use the likelihood ratio test to verify the hypothesis of the exponential distribution – the special case of Weibull distribution with the shape parameter equals to 1. Setting the significance level to 0.05, for systems grouped in different years, the likelihood ratio test is done using the following steps.

a. H_0: $\beta = 1$; H_1: $\beta \neq 1$

b. Calculate the statistics $T = 2(\hat{L} - \hat{L}_0)$
  $\hat{L}$: global maximum log likelihood
  $\hat{L}_0$: constrained maximum log likelihood at $\beta = 1$
c. If, $T \leq \chi^2(0.95, 1)$, accepts H_0, else rejects H_0.

The hypothesis test results show that exponential distribution is acceptable for 56 groups.

System failure rate results. Since the exponential distribution is appropriate for most of those systems, we use MLE to calculate the failure rate. The systems' failure rates vs. year are shown in Figure 3. The data shows that, with the exception of system 2 and 8, the systems' failure rates decrease at the beginning of use. For system 4, 5, 6, and 7, whose use spanned the 1980s and 1990s, the trend of system reliability increase around 1994 and after that, could be noted. System 1 shows the same trend around 1997.

Analysis of system records from company B. Records from company B are dated between January 14, 1988 and October 27, 2001. Since the population size and the failure number of each year are small, we statistically analyze the moving five-year's records using the exponential distribution to get better results. We also analyze all records of company A in the same way to compare the change in reliability. Figure 4 shows the overall failure rates of systems from company A and B (Year in the X-axis is the middle point of the moving five-year period). From this result, we determined that there is an increasing trend of failure rate after 1994 for systems from both companies.

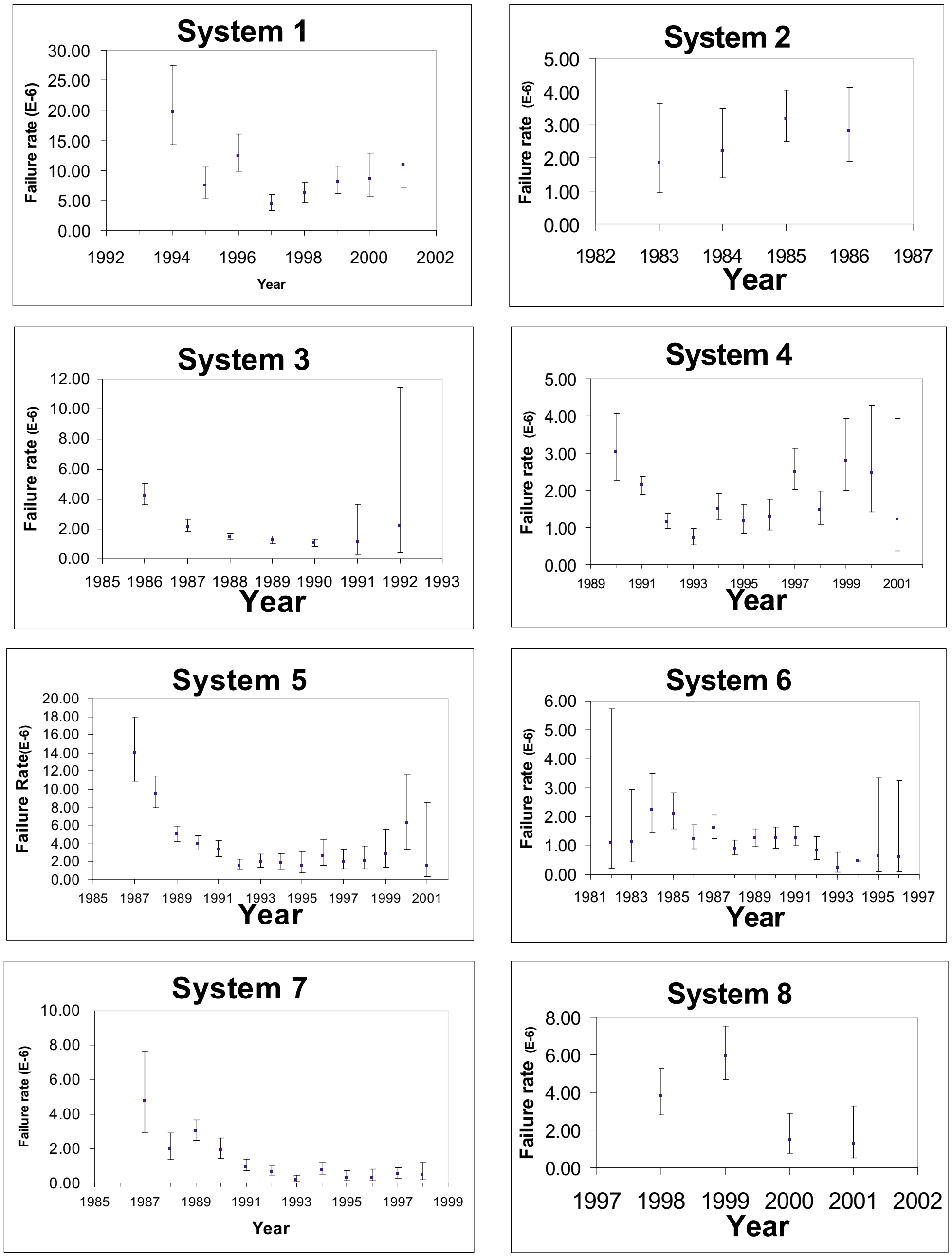


Figure 3. Failure Rates of Systems with 90% Confidence Intervals

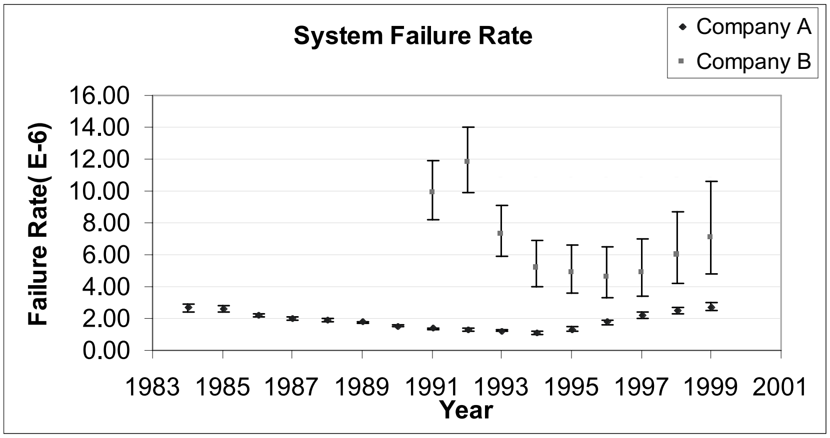


Figure 4. Overall System Failure Rates from Company A and B (90% Confidence Interval)

IC failure analysis. We can get the type and number of replaced ICs from company A's records but only the number of failed ICs from company B's records. Since no information was available for tracing down the failure mechanism, we simply calculated the overall failure rate of all ICs from company A and from Company B. For company B's records, we used the exponential distribution to analyze the moving five-year IC failure data because of the small number of failures in each year. Company A's IC failure records were analyzed in the same way. The results are shown in Figure 5.

Summary

Field data of microelectronic systems in the aerospace industry was collected and analyzed. Based on our statistical analysis results, we found that:

1. The exponential distribution is appropriate for most avionics' lifetime analyses because the IC chips and system structure are becoming more complex.
2. System reliability generally improves in the first several years after introduction and drops off later. It follows very well the known phenomena of "infant mortality" or "learning curve."
3. According to the analysis, the failure rate of several systems increases, almost constantly, after 1994-1996. The increase isn't large and not statistically significant. No one specific reason of this trend could be postulated due to the lack of information. It could be due to design problems in replacement military grade components by commercial or due to total redesign in introducing new technologies, inherent reliability of commercial components or manufacturing problems in introducing new for avionic system packaging standards, etc.

This work presents some practical observations. A future investigation, tracking of the failure data and failure analysis, is suggested.

For Further Reading

1. Abernethy, R.B., *The New Weibull Handbook, Third Edition*, page 3-3. North Palm Beach, Florida: R.B. Abernethy, 1998.
2. Abernethy, R.B., *Ibid,* page 3-14.
3. Alam, M., B. Weir, and P. Silverman, "A future of function or failure? (CMOS gate oxide scaling)," *IEEE Circuits and Device*, Vol. 18, pages 42-48, March 2002.
4. Degraeve, R., "New insights in the relation between electron trap generation and the statistical properties of oxide breakdown," *IEEE Transaction on Electron Devices*, Vol. 45, pages 904-911, April 1998.
5. Drenick, R.F., "The failure law of complex equipment," *Journal of the Society for Industrial and Applied Mathematics*, Vol. 8, pages 680-690, December 1960.

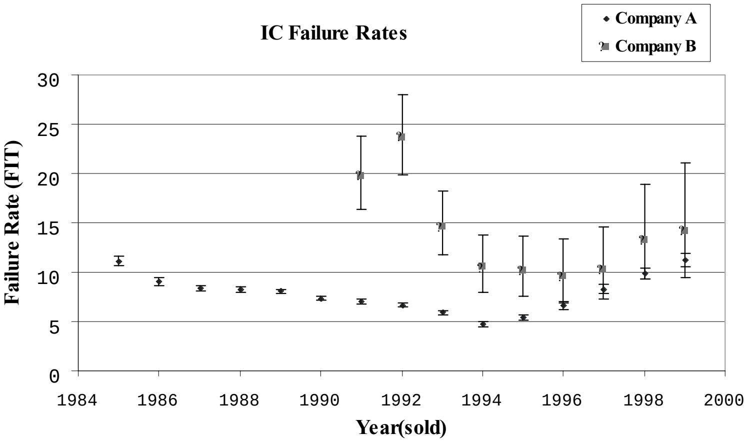


Figure 5. Overall IC Failure Rate (90% Confidence Interval)

6. Hnatek, E.R., *Integrated Circuit Quality and Reliability*, Marcel Dekker, Inc, 2nd Edition, 1995.
7. Stathis, J.H., "Percolation models for gate oxide breakdown," *Journal of Applied Physic*s, Vol. 86, pages 5757-5766, November 1999.

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JIN QIN is a PhD candidate of Reliability Engineering at the University of Maryland, College Park. His research topics include reliability testing, reliability data analysis, and microelectronic system reliability estimation. He holds a Master of Science in Reliability Engineering from the University of Maryland and a Master of Engineering in Management Science and Engineering from the University of Science and Technology of China.

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Reliability Theory Explains Human Aging and Longevity

Reprinted with permission of Dr. Leonid A. Gavrilov, Center on Aging, NORC/University of Chicago

Our bodies' backup systems don't prevent aging, they make it more certain. This is one offshoot of a new "reliability theory of aging and longevity" by two researchers at the Center on Aging, National Opinion Research Center (NORC) at the University of Chicago.

The authors presented their new theory at the National Institutes of Health (NIH) conference "The Dynamic and Energetic Bases of Health and Aging" (held in Bethesda, NIH). Their theory of aging has been published by the "Science" magazine department on aging research, Science's SAGE KE ("Science of Aging Knowledge Environment").

The authors say, "Reliability theory is a general theory about systems failure. It allows researchers to predict the age-related failure kinetics for a system of given architecture (reliability structure) and given reliability of its components."

"Reliability theory predicts that even those systems that are entirely composed of non-aging elements (with a constant failure rate) will nevertheless deteriorate (fail more often) with age, if these systems are REDUNDANT in irreplaceable elements. Aging, therefore, is a direct consequence of systems redundancy."

In their paper, "The quest for a general theory of aging and longevity" (Science's SAGE KE [Science of Aging Knowledge Environment] for 16 July 2003; Vol. 2003, No. 28, 1-10. <http://sageke.sciencemag.org>), Leonid Gavrilov and Natalia Gavrilova offer an explanation why people (and other biological species as well) deteriorate and die more often with age.

Interestingly, the relative differences in mortality rates across nations and gender decrease with age: Although people living in the U.S. have longer life spans on average than people living in countries with poor health and high mortality, those who achieve the oldest-old age in those countries die at rates roughly similar to the oldest-old in the U.S.

The authors explain that humans are built from the ground up, starting off with a few cells that differentiate and multiply to form the systems that keep us operating. But even at birth, the cells that make up our systems are full of faults that would kill primitive organisms lacking the redundancies that we have built in.

"It's as if we were born with our bodies already full of garbage," said Gavrilov. "Then, during our life span, we are assaulted by random destructive hits that accumulate further damage. Thus we age."

"At some point, one of those hits causes a critical system without a back-up redundancy to fail, and we die."

As the authors puts it, "Reliability theory also predicts the late-life mortality deceleration with subsequent leveling-off, as well as the late-life mortality plateaus, as inevitable consequences of *redundancy exhaustion* at extreme old ages."

All those who have achieved the oldest-old age have very few redundancies remaining when the next random shock hits a critical system. Hence, the mortality rates tend to level off at extreme old ages, and people all over the world die at relatively similar rates on average. The initial differences in body reserves (redundancy) eventually disappear.

In the authors' words, "The theory explains why relative differences in mortality rates of compared populations (within a given species) vanish with age, and mortality convergence is observed due to the exhaustion of initial differences in redundancy levels."

This fundamental theory of aging and longevity is grounded in a predictive mathematical model that accounts for questions raised by previous models addressing the mechanisms of aging, mortality, survival, and longevity.

The authors are research associates at the Center for Aging at the University of Chicago's National Opinion Research Center. Their research was sponsored by the National Institute on Aging. The authors are invited to present and discuss their theory at the forthcoming 10th Congress of the International Association of Biomedical Gerontology (England, September 2003), organized by Dr. Aubrey de Grey (<http://www.gen.cam.ac.uk/iabg10/abs/Gavrilov2.htm>).

Additional information on new theory is available at <http://longevity-science.org/> and <http://longevity-science.org/SAGE-KE-03.pdf>.

Medline abstract of this new publication follows (Sci Aging Knowl Environ. 2003 Jul 16; 2003 (28): RE5):

> **The quest for a general theory of aging and longevity. Gavrilov LA, Gavrilova NS**. Center on Aging, National Opinion Research Center/University of Chicago, Chicago, IL 60637, USA <lagavril@midway.uchicago.edu>.
>
> Extensive studies of phenomena related to aging have produced many diverse findings, which require a general theoretical framework to be organized into a comprehensive body of knowledge. As demonstrated by the success of evolutionary theories of aging, quite general theoretical considerations can be very useful when applied to research on aging. In this theoretical study, we attempt to gain insight into aging by applying a general theory of systems failure known as reliability theory. Considerations of this theory lead to the following conclusions: (i) Redundancy is a concept of crucial importance for understanding aging, particularly the systemic nature of aging. Systems that are redundant in numbers of irreplaceable elements deteriorate (that is, age) over time, even if they are built of elements that do not themselves age. (ii) An apparent aging rate or expression of aging is higher for systems that have higher levels of redundancy. (iii) Redundancy exhaustion over the life course explains a number of observations about mortality, including mortality convergence at later life (when death rates are becoming relatively similar at advanced ages for different populations of the same species) as well as late-life mortality deceleration, leveling off, and mortality plateaus. (iv) Living organisms apparently contain a high load of initial damage from the early stages of development, and therefore their life span and aging patterns may be sensitive to early-life conditions that determine this initial damage load. Thus, the reliability theory provides a parsimonious explanation for many important aging-related phenomena and suggests a number of interesting testable predictions. We therefore suggest adding the reliability theory to the arsenal of methodological approaches applied to research on aging. PMID: 12867663 [PubMed - in process; web link: <http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=12867663&dopt=Abstract>].

About the Author

Dr. Leonid Gavrilov earned his PhD and MSc degrees from the Moscow State University in Moscow, Russia in 1980 and 1976, respectively. Dr. Gavrilov is a Research Associate at the Center on Aging, NORC (National Organization for Research) and the University of Chicago. He specializes in biodemography of Human Longevity/Analysis of Human Mortality and Aging, Mathematical Modeling of Aging, and Mortality Genetics of Aging and Longevity. He currently has a grant from the National Institute on Aging for his work as Principal Investigator in biodemography of human longevity. Dr. Gavrilov is a member of many professional organizations, including the International Union for the Scientific Study of Population, Population Association of America, Gerontological Society of America, Social Science History Association, and the European Association for Population Studies. He is cited in "Who's Who in America" in *Marquis Who's Who*, 2002 and 2003 Editions: "Who's Who in Medicine and Healthcare," *Marquis Who's Who*, 4th Edition, 2002-2003, and "Who's Who in Science and Engineering" *Marquis Who's Who*, 7th Edition, 2003-2004.

Dr. Gavroliv's many publications include "The Biology of Life Span: A Quantitative Approach," Harwood Academic Publisher, NY, 1991; "Why We Fall Apart. Engineering's Reliability Theory Explains Human Aging," IEE*E Spectrum*, 2004, 41(9): 30-35; and "The Reliability-Engineering Approach to the Problem of Biological Aging," *Annals of the New York Academy of Sciences*, 2004, 1019: 509-512.

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Form, Fit, Function, and Interface - An Element of an Open System Strategy

By: *Ned H. Criscimagna, Alion Science and Technology*

Introduction

Parts obsolescence and diminishing sources of manufacturing are two problems that the commercial and defense sectors alike face on a daily and increasing basis. The problem has reached serious proportions over the past decade or so, as the pace of technological improvements and innovation has steadily accelerated. An approach to solving the problem that enjoys broad support within the defense management community is that of open systems. The term is bound to be heard at nearly every conference and symposium even remotely related to logistics and support.

What is the open systems approach? Federal Standard 1037C defines open system as follows:

> "A system with characteristics that comply with specified, publicly maintained, readily available standards and that therefore can be connected to other systems that comply with these same standards."

The Software Engineering Institute defines an open system in a similar fashion:

> "An open system is a collection of interacting software, hardware, and human components:
>
> - Designed to satisfy stated needs
> - With interface specifications of its components that are:
>   - Fully defined
>   - Available to the public
>   - Maintained according to group consensus
> - In which the implementations of the components conform to the interface specifications"

The Department of Defense (DoD) Open Systems Joint Task Force defines the Open System Approach (OSA) as:

> "A means to assess and implement when feasible widely supported commercial interface standards in developing systems using modular design concepts. It is a significant part of the toolset that will help meet DoD's goals of modernizing weapon systems, developing and deploying new systems required for 21st century warfare, and supporting these systems over their total life cycle. DoD 5000 series documents call for an OSA as an integral part of the overall acquisition strategy."

The Task Force goes on to state that an OSA is also an integrated technical and business strategy that defines key system or equipment interfaces by widely used consensus-based standards. According to the Task Force, the open systems strategy is an enabler to achieve the objectives listed in Table 1.

Table 1. Objectives of an Open Systems Strategy

- Promote transition from science and technology into acquisition and deployment
- Adapt to evolving requirements and threats
- Facilitate systems integration
- Leverage commercial investment
- Reduce the development cycle time/total life-cycle cost
- Ensure that the system will be fully interoperable with all the systems which it must interface, without major modification of existing components
- Enhance commonality and reuse of components among systems
- Enhance access to cutting edge technologies and products from multiple suppliers
- Mitigate the risks associated with technology obsolescence
- Mitigate risk of single source of supply over system life
- Enhance life-cycle supportability
- Increase competition

Form, Fit, Function, and Interface (F^3I)

Although the concept of open systems has become a top priority issue within DoD over the last 10-15 years, the military services were considering the use of form, fit, function, interface (F^3I)[1] standards in the 1970s and even earlier. F^3I supports but is not exactly equivalent to the open system concept. F^3I are types of essential technical requirements in a performance-based specification and are defined as follows.

Form. The term form addresses the physical characteristics of an end item. For hardware items, form includes the product envelope (which could include both internal and external envelopes), weight or mass, center of gravity, moments of inertia. The term has less significance for software items but could include memory storage requirements, throughput requirements, etc. For training materials, it would include characteristics such as the delivery media.

Fit. The term fit is primarily applicable to hardware end items and addresses the "mating" characteristics with other hardware items and with the user and operator. Fit includes such characteristics as the location relative to a defined datum of mating surfaces/features; the location relative to a defined datum of features designed to facilitate handling, assembly, and installation; and mating surface and feature requirements such as flatness or contour.

Function. Function addresses what the end item must be capable of doing under a defined set of conditions. Function includes power, speed, reliability, useful life, maintainability, supportability, and other "-ilities" in general.

Interface. Interface is defined as the functional and physical requirements and constraints at a common boundary between two

(Continued on page 10)

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[1] Often written as F3I.

Consider...

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Form, Fit, and Function . . . (Continued from page 7)

or more functions or items. Interfaces result from the interaction between functions, items, products of an item, or collateral effects of operating an item. Functional interfaces are the relationships between characteristic internal or external actions. Physical interfaces are the relationships between internal parts of the solution as well as between the solution and external elements.

Under the F^{3}I concept, only the form, fit, function, and interface requirements, most commonly at the Line Replaceable Unit (LRU) level, are stipulated; no requirements are levied below the LRU level. A supplier can use any approach for designing the internal workings of an LRU, and retain proprietary rights to the internal design, as long as the F^{3}I requirements are met. This approach allows suppliers to implement new technology as LRUs are returned for repair. These changes are transparent to the customer but the new technology may manifest itself as improved reliability, lower power consumption, lighter weight, etc. F^{3}I has the benefits listed in Table 2.

Table 2. Benefits of F^{3}I

- Promotes competition
    - Increases supplier base
    - Reduces cost
    - Leverages commercial investment
- Facilitates technology refreshment
- Eliminates need for customer repair of LRUs
- Supports standardization, thereby enhancing commonality and reuse of LRUs among systems
- Enhances life-cycle supportability
- Supports interoperability
- Eliminates parts obsolescence problems for customer

These benefits are similar to those listed in Table 1 because F^{3}I is similar to the open systems approach but the latter places more emphasis on specifying interfaces based on broadly accepted standards to allow for as many suppliers as possible over the long term.

The F^{3}I concept is an important consideration in Reliability-Based Logistics, Flexible Sustainment, and other processes and initiatives within the DoD.

Accepting the F^{3}I Concept

A common problem encountered in accepting the F^{3}I concept is the reluctance to yield configuration control of the inside of a “box” (i.e., below the LRU level) to the manufacturer. The reason? Logisticians and maintenance managers are accustomed to repairing boxes at the shop or depot level. To perform maintenance below the box level, one must have configuration control. Otherwise, keeping the maintenance people trained, the repair manuals and schematics up to date, and having the right test equipment available would be impossible. On the other hand, if the customer retains configuration control, then the manufacturer is not free to change the internal design as new or improved technology becomes available, to reduce costs, improve reliability, etc.

The ARINC Standards

Long before the military was debating the pros and cons of F^{3}I, the concept had found a home in the commercial airlines community. The first standards that were developed on an F^{3}I basis are known as the ARINC Standards. The standards are actually developed by the Airlines Electronic Engineering Committee (AEEC). The AEEC is an international standards organization, comprising major airline operators and other airspace users. The AEEC began developing standards in 1949. The AEEC establishes consensus-based, voluntary form, fit, function, and interface standards that are published by ARINC[2] and are known as ARINC Standards. ARINC Standards specify the air transport avionics equipment and systems used by more than 10,000 commercial aircraft worldwide.

A brief description of the three classes of ARINC Standards, Characteristics, Specifications, and Reports, follows.

1. ARINC Characteristics – Define the form, fit, function, and interfaces of avionics equipment.
2. ARINC Specifications – Principally used to define the physical packaging or mounting of avionics equipment, data communication standards, or a high-level computer language
3. ARINC Reports – Provide guidelines or general information found by the airlines to be good practices, often related to avionics maintenance and support

Example of an ARINC Standard: ARINC 429

The ARINC 429 specification defines how avionics equipment and systems should communicate with each other, interconnected by wires in twisted pairs. The specification defines the electrical and data characteristics and protocols,. ARINC 429 employs a unidirectional data bus standard known as Mark 33 Digital Information Transfer System (DITS). Messages are transmitted at a bit rate of either 12.5 or 100 kilobits per second to other system elements, which are monitoring the bus messages. Transmission and reception is on separate ports so that many wires may be needed on aircraft.

ARINC 429 has been installed on most commercial transport aircraft including Airbus A310/A320 and A330/A340; Bell Helicopters; Boeing 727, 737, 747, 757, and 767; and McDonnell Douglas MD-11. Boeing installed a newer system specified as ARINC 629 on the 777. The unidirectional ARINC 429 system provides high reliability at the cost of wire weight and limited data rates. Military aircraft generally use a high-speed, bi-directional protocol IAW Military Specifications MIL-STD-1553.

Source: Condor Engineering - <http://www.429-arinc.com/arinc-429-tutorial.html>

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[2] Incorporated December 2, 1929, Aeronautical Radio, Inc., was chartered by the Federal Radio Commission to serve as the airline industry’s “single licensee and coordinator of radio communication outside of the government.” Soon the company, widely known as ARINC, took on responsibility for all ground-based, aeronautical radio stations and for ensuring station compliance with FRC rules and regulations. Today, ARINC serves the aviation, airports, defense, government, and transportation industries with products and services.

The use of ARINC standards for purchasing their air transport avionics equipment and systems results in substantial benefits to airlines by allowing avionics interchangeability and commonality and reducing avionics cost by promoting competition. Furthermore, for new aircraft and avionics installations, ARINC standards provide the starting point for avionics development and allow aircraft manufacturers to pre-wire aircraft, thus ensuring that cost-effective avionics for air transport aircraft are ready when needed.

The airlines also benefit from suppliers transparently incorporating new technology, avoid the problems of parts obsolescence and diminishing manufacturing sources, and eliminate the need for any maintenance below the LRU level. Given the volume of avionics bought by the airlines and airliner manufacturers, avionics firms readily accept the ARINC standards and competition in this market is alive and well. This competition helps keep costs down and drives the competing companies to continually improve their products. According to Georgia State University in a 2000 study “The Economic Impact of Avionics Standardization on the Airline Industry,” use of ARINC Standards to foster a competitive avionics marketplace alone saves the airline industry nearly $300 million annually. An August 2002 article of Avionics Magazine, Reference 1, provides a current perspective on the ARINC standards.

Three Military Applications

The military has had some experience in applying the F^3I concept. Take the case of the AN/FPS-108 (COBRA DANE) ground radar system. When support of three components of the system became difficult and expensive, state-of-the-art F^3I replacements were developed. Development was accomplished using state-of-the-art design tools, leveraging the evolution of Commercial-Off-The-Shelf (COTS) microwave components and tools that have resulted from developments in the cellular communication and other microwave industries.

Using these replacements, the life cycle of the components and system has been increased and there has been a dramatic savings in cost, space, and downtime, and improved maintainability.

In another case, and in response to its strategy of Flexible Sustainment, the Air Forces implemented the F^3I Lifetime Contractor Sustainment (FLICS) program for the F-15 APG-63 V1 radar. Under the program, the radar developer, Raytheon, has systems engineering responsibility of the radar: and configuration control below the LRU level. Raytheon has the responsibility and authority to manage technology insertion and parts obsolescence. The Air Force’s responsibility is to remove and replace LRUs and ship bad LRUs to Raytheon within 24 hours of removal. Figure 1 illustrates the support concept for aircraft stationed at Base X.

Another F^3I application is the Generalized Emulation of Microcircuits (GEM). GEM technology was developed by the Defense Logistics Agency (DLA) as a long-term solution to the problem of diminishing manufacturing sources (DMS). DMS becomes a significant problem as systems are operated over ever-increasing life spans and a continually faster rate of change in technology. Using gate arrays and single line processing technology, F^3I microcircuits are manufactured to replace non-procurable microcircuits originally designed with RTL, NMOS, CMOS, and other technologies.

COTS and F^3I

A broad military application of the F^3I concept is the acquisition on COTS items as end products or to integrate into military systems. The decision to use a COTS item is essentially a decision

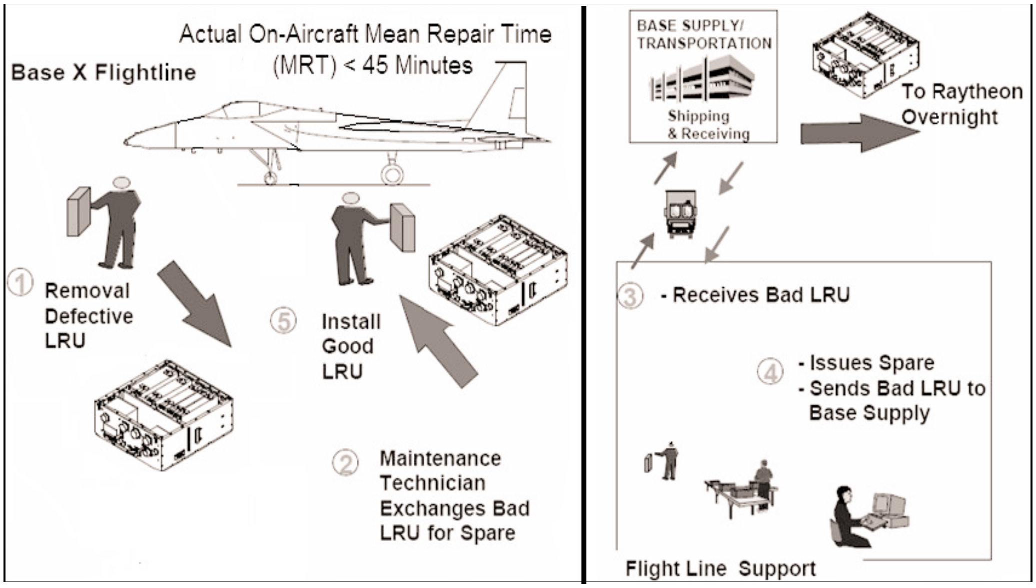

Figure 1. Support Concept for the F-15 APG-(63) V1 Radar

to make an F^{3}I purchase. The advantages of buying COTS are similar to those for buying F^{3}I and are shown in Table 2. If the item is modified in any way, then some of these advantages may be lost. These lost advantages can include warranty coverage and technology updates.

Table 2. Advantages of COTS

- Reduces cost
- Leverages commercial investment
- Facilitates technology refreshment
- Eliminates need for customer to repair LRUs
- Can support standardization
- Eliminates parts obsolescence problems
- Enhances life-cycle supportability
- Can support interoperability
- Usually warranted

When a COTS item must be modified, either to address a more severe environment or for some other reason, the item is no longer a pure COTS item. Terms such as Ruggedized-Off-the-Shelf (ROTS) and Militarized-Off-the-Shelf (MOTS) are used to refer to such modified COTS items. Definitions of COTS, MOTS, and ROTS follow.

COTS – A COTS product is one that is bought and used "as is." Nearly all software bought for a desktop or laptop computer is COTS, including Word, WordPerfect, Excel, and Windows.

MOTS – A MOTS product is a COTS product customized by the buyer or the supplier to meet customer requirements that are different from those of the original COTS market.

ROTS – A ROTS product is a COTS product customized to meet harsher or more severe environments than originally envisioned by the designers. Again, the customization may be performed by either the buyer or the supplier.

An important difference between a COTS item and one bought using an F^{3}I specification is that the form, fit, and function of a COTS item are determined by suppliers based on the needs of a commercial market. An F^{3}I specification can be tailored to the needs of a specific customer. Thus, although a COTS item may not meet all of the environmental and operating requirements of the user, an item bought using an F^{3}I specification will (or should, if the specification is accurate and complete). Table 3 compares COTS and F^{3}I items.

The Importance of Reliability to F^{3}I

A critical performance requirement for items bought on an F^{3}I basis is reliability. The reason is fairly simple as can be deduced from studying Figure 1. Note that organic maintenance consists of removal and replacement (R&R) of the failed unit. The failed unit is then shipped to Raytheon.

To make this maintenance concept viable, some minimum value of reliability is needed. That level is the one that will ensure that the supply pipeline is not constantly full of avionics boxes. If the reliability is insufficient, not only will a great number of boxes be required to keep a reasonable stock of good spares at the base, but availability will suffer. Even though R&R, as opposed to repair in place, is the fastest way to "repair" an aircraft, too many R&R actions will affect availability. They also increase the need for maintenance and, hence, increase ownership costs.

Obstacles to Implementing F^{3}I

Despite the long and successful history of F^{3}I in the airline industry, and the success with which it has been used in military systems, the concept has found limited application in military acquisition and modernization programs. Several related reasons could account for this limited application.

1. ***Tradition and Lack of Trust***. Traditional approaches to specifying requirements have involved customer oversight, if not specific control, of all aspects of design down to the part level.

Table 3. Comparing COTS and F^{3}I Items in Military Applications

Basis for Comparison	COTS[3]	F^{3}I
How bought	"As is"	To F^{3}I specification
Designed to	Satisfy commercial customers	Meet F^{3}I specification
Source	Original equipment manufacturer (OEM)	Any supplier who can design & build to F^{3}I spec
Configuration control	None	At F^{3}I ("box") level
Suitability	Buyer must assess to determine if item can meet requirements	Item must meet F^{3}I specification
Repair	Provided by OEM	Provided by supplier
Warranty:	Usually; may be voided by operation in different environment/for different application	Only if provided for by contract with supplier
Obsolescence	OEM can make technology updates transparently to user, but may choose to stop production of the item at any time	OEM can make technology updates transparently to user; production can continue as long as buyer willing to pay suppliers to "build to [F^{3}I] print"
Investment	No R&D or other up-front investment; purchase and repair costs	Some up-front investment may be needed plus purchase and repair costs
Market	Usually large depending on product and whims of commercial marketplace	Depends on military application; can be very small or very large

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[3] Un-modified. MOTS and ROTS items, as discussed in the text, are different from pure COTS items.

It is difficult for some to shift their thinking from a parts perspective to a box perspective. They question the wisdom of relinquishing control at lower indentures of design, fearing that doing so will compromise meeting requirements at the higher levels of design. For example, unless they know what is inside the box, how can they be sure reliability requirements for the LRU will be met?

Although relationships between customer and contractor have improved markedly in military acquisition over the past decade, a level of customer distrust of contractors still exists. Those who most have this distrust are unwilling to let the contractor dictate the internal specification and design of LRUs. They believe that only by controlling the design to the piece part level can they be assured that the end product will meet their requirements.

2. ***Vested Financial Interests***. The military services have developed an extensive logistics infrastructure. Military depots employ thousands of people. Managers of these depots control millions of dollars in assets. A considerable amount of the work done by depots involves repair and replacement of shop-replaceable units (SRUs) that make up the LRUs. The move to an F^3I concept means that repair of LRUs now becomes the sole prerogative of a contractor. The loss of work could mean that the depots need fewer people and smaller budgets. Although the benefits accruing to the military from F^3I may outweigh any negative impact on the depots, it is only natural for those directly affected to be less than enthusiastic about the concept.

3. ***Dominance of Legacy Systems***. It has become the norm for military systems to continue in operational use far beyond what was originally planned or even envisioned. Today, the bulk of the military's support dollars go to keep legacy systems up and running. Consequently, some may conclude that since embracing the F^3I concept in new system development will have little impact on total operating and support costs, why bother.

Overcoming the Obstacles

The obstacles just discussed are certainly not insurmountable. Let's look at the obstacles presented in the previous section, working from the last obstacle to the first.

Dominance of Legacy Systems. Consider the view that since the support of legacy systems dominates the budget, and will probably do so for years to come, why bother with F^3I for new systems. The fallacy of this line of reasoning is that F^3I is a perfect approach to modernizing and extending the life of legacy systems. The examples of the F-15 radar and COBRA DANE radar, discussed earlier, clearly substantiate this claim.

Legacy systems usually have size, space, power, cooling, and shape factor constraints. For these systems, the open systems approach provides F^3I solutions within existing packaging, power, and environmental constraints. In such cases, the open systems solution frequently requires less system resources by using newer, more efficient technologies. By replacing older technology legacy system LRUs, that are repaired by the military services, with F^3I LRUs, performance can be improved and costs reduced. In fact, the payoff for applying the F^3I concept to modernization and life extension programs is greater than for new system, due to the sheer number of legacy systems.

Vested Financial Interests. As for the affect of F^3I on depot workload, management and personnel policies can minimize the impact on the workforce. Given the impact of outsourcing and private competition for depot work, the effect of a wider application of F^3I should be less dramatic by comparison.

Tradition and Lack of Trust. This obstacle really boils down to the issue of requirements. Requirements, whether or not an open systems approach is being used in a specific program, must be realistic, achievable, and appropriate. They must be derived from the warfighter's needs. A program must start with good requirements and then have effective means of verifying if the requirements have been met. These means include analysis, simulation, and testing.

Certainly the government has the responsibility to ensure that a contractor is implementing good configuration management practices, an effective process for selecting parts and suppliers, and has effective design, analysis, and test methods for achieving the F^3I requirements. However, the government's focus must be on the F^3I requirements, whether the LRU has the required form, fit, and function, and can interface with the other elements of the system and not on the internal design, i.e., parts selection and specific design.

References

1. ANSI/EIA 649-1998, National Consensus Standard for Configuration Management, Approved July 10, 1998.
2. Charles, Richard A. and Arthur C. Brooks, "The Economic Impact of Avionics Standardization on the Airline Industry," Georgia State University, 2000.
3. Criscimagna, Ned H., "Commercial Off-the-Shelf Equipment and Non-Developmental Items," RAC START Sheet 98-4.
4. Hanratty, Michael, Robed H. Lightsey, and Arvid G. Larson, "Open Systems and The Systems Engineering Process," Acquisition Review Quarterly, Winter, 1999.
5. Jensen, David, "ARINC Standards: Where They Come From. Why We Need Them," Avionics Magazine, Access Intelligence, LLC, Potomac, MD, August 2002.
6. OS Computer Resources Acquisition Guide & Supportability Guide, Next Generation Computer Resources Document No. AST 003, Version 1.0 – 31, Space and Naval Warfare Systems Command, December 1996.

About the Author

Ned H. Criscimagna is a Science Advisor with Alion Science and Technology Corporation and Deputy Director of the Reliability Analysis Center. Prior to joining Alion, he worked for ARINC Research Corporation. Before entering industry, Mr. Criscimagna served for 20 years in the U.S. Air Force and retired with the rank of Lieutenant Colonel. Over his 39-year career, he has been involved in a wide variety of projects related to Department of Defense acquisition, reliability, logistics, reliability and maintainability (R&M), and availability. He led the development of the last version of MIL-HDBK-470 and the last update to MIL-HDBK-338. He has experience in project management, aircraft maintenance, system acquisition, logistics, R&M, and availability. He instructs the RAC's Mechanical Design Reliability Course.

Mr. Criscimagna earned his B.S. in Mechanical Engineering from the University of Nebraska-Lincoln in 1965 and his M.S. in Systems Engineering with an emphasis on reliability from the USAF Institute of Technology in 1971. In addition, he earned graduate credits in Systems Management from the University of Southern California in 1976-77. He is a member of the American Society for Quality (ASQ), the National Defense Industries Association (NDIA), and the Society of Automotive Engineers (SAE), and is a Senior Member of the International Society of Logistics (SOLE). He is a SOLE Certified Professional Logistician and an ASQ Certified Reliability Engineer. He is a member of the ASQ/ANSI Z-1 Dependability Subcommittee, the US TAG to IEC TC56, and the SAE G-11 Division. He is listed in the 27th Edition of Who's Who in the East, the 54th, 56th, and 57th, Editions of Who's Who in America, and in the 8th Edition of Who's Who in Science and Engineering.

System Level Clues for Detailed Part Issues

By: C. Richard Unkle, Senior Reliability Engineer, GE Transportation – Rail Division, Erie, Pennsylvania

Abstract

With the renewed emphasis on reliability within industry comes the desire to diagnose potential reliability problems of fielded systems, before they become either a warranty or life cycle cost issue. In the world of six-sigma, many techniques are available for determining the main issue or root cause of a problem, so it can be fixed. However, many such techniques are applied after a problem arises. This is especially true in the world of reliability, where the high-failure items tend to warrant most of the problem-solving focus. This article presents a drill-down method useful in the world of six-sigma for early detection of reliability issues in fielded systems. More specifically, the article describes research on a hypothesized relationship between a key parameter of the Weibull distribution and the Crow-AMSAA reliability growth model. This relationship has proven to be strong at both the component and functional levels of systems indenture. Actual data from GE Transportation Systems (GETS) were used in the research. Examples of how the relationship may be used to help detect upcoming reliability issues on GETS products are presented.

Introduction

One of the key objectives of a six-sigma company is to develop and maintain high quality products and processes, as measured using statistical methods. For products designed by General Electric's Transportation Rail Division (GE Rail) not only is it necessary to deliver high quality, but also to sustain high reliability over the full life cycle of the equipment. GE Rail currently has several long-term service agreements with many of its major North American customers. Because of the known impact that product reliability has on services and maintainability, GE Rail continuously monitors the reliability of its products that are maintained under such agreements.

GE Rail controls the management of product maintenance under the aforementioned service agreements, making it easier to collect field reliability data and store it in on-line database systems. GE Rail engineers use this reliability database system to track product performance for each customer, by product model and fleet. Whenever adverse trends in product reliability are detected in the data, project teams are created to determine the root cause of such trends and, if necessary, to develop improvements that are then cut in on the affected fleets. In all cases, six-sigma methods are used to determine the root cause and help develop a viable solution to the problem.

While this process has proven to be effective, project teams are too often reactive in nature. That is, problem investigation and resolution sometimes occur after the problem has become significant enough to be noticeable. To be more effective and to reduce the amount of time and dollars required to make improvements, proactive methods need to be developed. Such methods would include the ability to detect problems in their early stages, prior to the point in time that they are affecting an entire stage and prior to the point in time that they are affecting an entire fleet of locomotives. One such method being researched and proposed by the author involves the use of two well-known reliability analysis tools, Crow-AMSAA (CA) and Weibull.

Tracking Field Reliability

Several methods are used today in tracking and assessing the reliability of fielded systems. At GE Rail, many of the historical methods have included both Pareto analysis at the component level and trending of monthly mission failure rates. Projects are then created that target the poorest performing components for upgrades and improvement. More specialized techniques, such as Weibull analysis are also used on an as-needed basis.

While such techniques have been sufficient to improve the overall reliability of GE Rail products, other methods are being researched that can provide more advanced warning of reliability problems. Often, projects are defined after the problem is large enough to impact system reliability. It would certainly be better and less costly to find and fix such problems before they become large enough to be "felt" by the customer.

One method of accomplishing early detection of reliability problems would be to perform a Weibull analysis on each and every component in the system. Such analysis could be used to detect early wearout failure modes that could adversely impact a fleet of locomotives prior to overhaul, for example. However, even if such a process were automated, the amount of effort to review the plots for multiple failure modes, and to scrub the data for evidence of replacements, and not repairs, becomes a costly proposition. Another method would be to apply the CA model at the system-level. The CA model is similar to Weibull in that it provides a means to determine if reliability is increasing, decreasing or remaining constant in time. This is communicated via the CA β-value, which has a similar interpretation as the Weibull β-value. However, even if the CA β-value indicates decreasing reliability, additional analysis is required to determine which part, or parts of the system are contributing to the poor behavior. Further, at what value of β does one decide to take action? Most uses of this value have been primarily to characterize growth, constant failure rate, or deterioration.

The approach to be discussed in this article would be to use the CA model and Weibull model in concert with each other. The remainder of this article will briefly describe the proposed methodology, summarize research completed to-date, and provide an example of the methodology as applied to actual data from a fleet of GE Rail locomotives.

A Discussion of the Approach

In the paper, *Relationship between Weibull and AMSAA models in reliability analysis: a case study*, (Unkle and Venkataraman, 2002), a hypothesized relationship between the CA model β-value (referred to only as the AMSAA model in the referenced paper), and the Weibull β-value was described. The hypothesis was that whenever the CA β is shown to be 1.6 or higher, this is an indication that one or at most two dominating failure modes are driving the reliability behavior in the system. Furthermore, when the data is analyzed by the Weibull distribution, its β-value will be at least 2 or greater. (A Weibull β-value in the range of 2-4 is an indication of the onset of early wearout. Higher than 4 implies old age, or rapid wearout. Either case is an indication that action needs to be taken). This relationship was proven out at both the component and functional levels of indenture using empirical data.

A summary of the findings of this previous research is presented in Tables 1 and 2. Table 1 shows the component-level analysis results; Table 2 shows the functional-level analysis results. In a majority of the cases used in the analysis, the basic premise of the hypothesized relationship held true. That is, whenever the measured CA β-value was at least 1.6 or greater, the component or function contained at least one failure mode that had a measured Weibull β-value of greater than 2.0. Further work was done using Monte Carlo simulation techniques in an attempt to generalize this relationship. The authors concluded that in general, whenever the CA β-value was at least 1.3 or greater, one could expect a failure mode to exist that has a measured Weibull β-value of 2.0 or greater.

The significance of this relationship, in terms of detecting problems more proactively, is as follows. Because the CA model measures the frequency of events, regardless of the number of failure modes involved, tracking of reliability can take place at higher levels of indenture, without the details necessary to determine specific failure modes. Should a function indicate its reliability is starting to decrease, as measured by the CA β-value being between 1.3 and 1.6, say, then the analyst can feel confident that a failure mode exists that is in the wearout region, and needs to be considered as a potential improvement project. If the reliability of a function, as measured using CA, shows no degradation, then the analyst can feel confident that no adverse failure mode is evident in the system. In this fashion, the drill down approach to a proactive reliability tracking system can easily be digitized and set up to warn the right functional engineer, automatically. The engineer then has a clear picture of what analysis, using Weibull, needs to be performed to diagnose the failure mode of interest. Such a process is akin to the well-known six-sigma technique called a Solution Tree^{SM}, developed by Dorian Shanin.

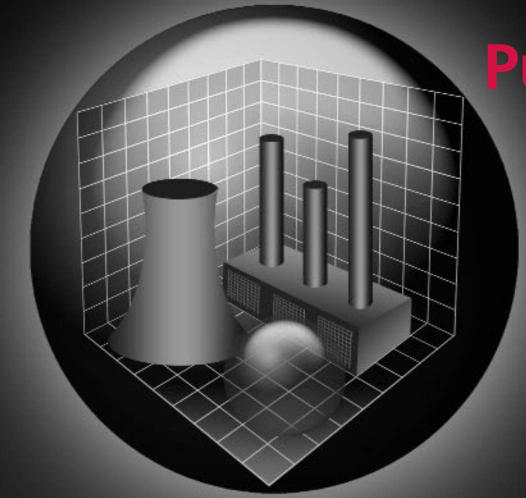
Table 1. Component-Level Results

Case	CA β	CA Model FIT	M	Conf. Range (%)	Weibull β	Weibull Model Fit
1	0.6	0.182	27	95-99	0.59	0.97
2	0.7	0.086	13	80-99	2.52	0.964
3	0.765	0.045	8	80-99	0.605	0.922
4	0.77	0.062	4	80-99	1.2	0.962
5	0.78	0.079	12	80-99	0.925	0.968
6	0.9	0.056	16	80-99	1.07	0.939
7	0.91	0.057	10	80-99	1	0.966
8	0.962	0.054	10	80-99	1.136	0.911
9	0.98	0.038	6	80-99	1.04	0.877
10	1	0.135	41	85-99	0.8	0.967
11	1.16	0.041	10	80-99	1.23	0.895
12	1.5	0.05	4	80-99	1.44	0.995
13	1.53	0.041	15	80-99	1.46	0.977
14	1.8	0.06	4	80-99	2.36	0.831
15	1.9	0.123	16	80-99	2.6	0.923
16	1.94	0.087	7	80-99	2.147	0.912
17	2.3	0.094	9	80-99	6.5	0.852
18	2.5	0.07	4	80-99	1.65	0.96
19	5.03	0.11	9	80-99	5.87	0.894
20	6.8	0.146 4	4	90-99	15.83	0.86

Table 2. Function-Level Results

Case	CA β	CA Model FIT	M	Conf. Range (%)	Weibull β	Weibull Model Fit
1	0.52	0.12	31	80-90	0.578	0.942
2	0.66	0.09	6	80-90	0.804	0.836
3	0.72	0.3	19	99	1.65	0.883
4	0.84	0.07	38	80-90	0.7	0.973
5	0.854	0.06	42	80-90	0.576	0.957
6	0.89	0.1	5	80-90	0.788	0.863
7	0.905	0.05	9	80-90	0.718	0.954
8	0.915	0.06	57	80-90	0.792	0.977
9	0.917	0.04	17	80-90	1.03	0.961
10	0.93	0.15	35	85-99	2.7	0.88
11	0.98	0.17	33	90-99	1.631	0.922
12	0.99	0.24	26	99	1.3	0.94
13	1.08	0.04	7	80-90	0.863	0.993
14	1.13	0.14	12	85-99	1.92	0.897
15	1.2	0.05	14	80-90	1.36	0.955
16	1.22	0.07	8	80-90	1.22	0.925
17	1.23	0.1	25	80-90	1.3	0.942
18	1.23	0.09	12	80-90	0.905	0.97
19	1.24	0.03	9	80-99	1.255	0.881
20	1.33	0.04	8	80-99	1.19	0.965
21	1.44	0.247	6	99	1.55	0.896

(Continued on page 17)



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System Level Clues ... (Continued from page 15)

Table 2. Function-Level Results (Cont'd)

Case	**CA β**	**CA Model FIT**	**M**	**Conf. Range (%)**	**Weibull β**	**Weibull Model Fit**
22	1.45	0.206	13	95-99	1.56	0.981
23	1.5	0.05	32	80-99	7.3	0.953
24	1.51	0.05	12	80-99	1.2	0.981
25	1.54	0.169	8	95-99	1.64	0.917
26	1.6	0.22	82	95-99	5.6	0.827
27	1.64	0.1	11	80-99	5.67	0.872
28	1.65	0.115	6	80-99	2.5	0.855
29	1.7	0.081	12	80-99	4.23	0.935
30	1.73	0.044	8	80-99	2.16	0.921
31	1.74	0.046	6	80-99	4.07	0.988
32	1.96	0.037	12	80-99	2.44	0.99
33	2	0.073	9	80-99	2.68	0.916
34	2.02	0.16	16	90-99	1.7	0.95
35	2.12	0.107	6	80-99	2.13	0.943
36	3.18	0.22	9	99	11.6	0.98
37	5.01	0.149	22	90-99	6.83	0.825

The author has continued to research the relationship between the two models at higher levels of indenture. While the relationship does appear to hold true at the subsystem level, the author has found that higher levels within the system tend to have more and more constant failure rates ($\beta = 1$), than not. Therefore, the preliminary conclusion is that this technique, due to the nature of systems reliability, may not be sensitive enough to detect problems early enough.

Applying the Method

As a demonstration of the potential of this new methodology to detect problems proactively, the author has applied it to one of GE Rail's product lines that contains multiple subsystems and functions. A proposed format for how the results of the analysis could be presented is shown in Table 3. Note that none of the actual names of the subsystems or the analyzed functions is shown for proprietary reasons. In reviewing Table 3, one can see

Table 3. Example Drill Down Approach Using the CA-Weibull Analysis Methodology

SS #	**Function #**	**CA β**	**Weibull β**	**RU Related to Weibull**	**Notes**
01	1	0.94	Not Evaluated		
	2	0.82	Not Evaluated		
03	1	0.93	Not Evaluated		
	2	1.15	Not Evaluated		
	3	0.72	Not Evaluated		
04	1	**1.27**	Should be Evaluated	Computer	Borderline CA beta value
	2	**1.60**	Needs Evaluation	Not yet determined	CA beta above threshold
	3	1.12	Not Evaluated		
06	1	**2.14**	**2.17**	Duct work	Unknown Failure Mode
	2	0.77	Not Evaluated		
	3	1.31	Needs Evaluation	Rotating Part	
	4	0.66	Not Evaluated		
07	1	0.97	Not Evaluated		
	2	0.93	Not Evaluated		
08	1	0.98	Not Evaluated		
	2	0.84	Not Evaluated		
	3	1.10	Not Evaluated		
	4	1.09	Not Evaluated		
	5	1.01	Not Evaluated		
	6	**1.53**	Needs Evaluation	Not yet determined	
09	1	**1.68**	Needs Evaluation	Battery	
	2	**1.29**	**2.71**	Power Supply	Unknown Failure Mode
	3	1.08	Not Evaluated		
10	1	**1.34**	Needs Evaluation	Comm Panel	
11	1	**1.49**	**1.98**	Mech. Equip.	Oil Leak Failure Mode
	2	1.02	Not Evaluated		
	3	0.90	Not Evaluated		
	4	1.00	Not Evaluated		
	5	1.08	Not Evaluated		
	6	1.19	Not Evaluated		
	7	0.91	Not Evaluated		
	8	0.43	Not Evaluated		
	9	0.95	Not Evaluated		
12	1	1.15	Not Evaluated		
	2	**1.60**	Needs Evaluation	Electronic Panel	Unknown Failure Mode
	3	**1.93**	Needs Evaluation		Potential Batch Issue
	4	0.68	Not Evaluated		

(Continued on page 19)

item Software

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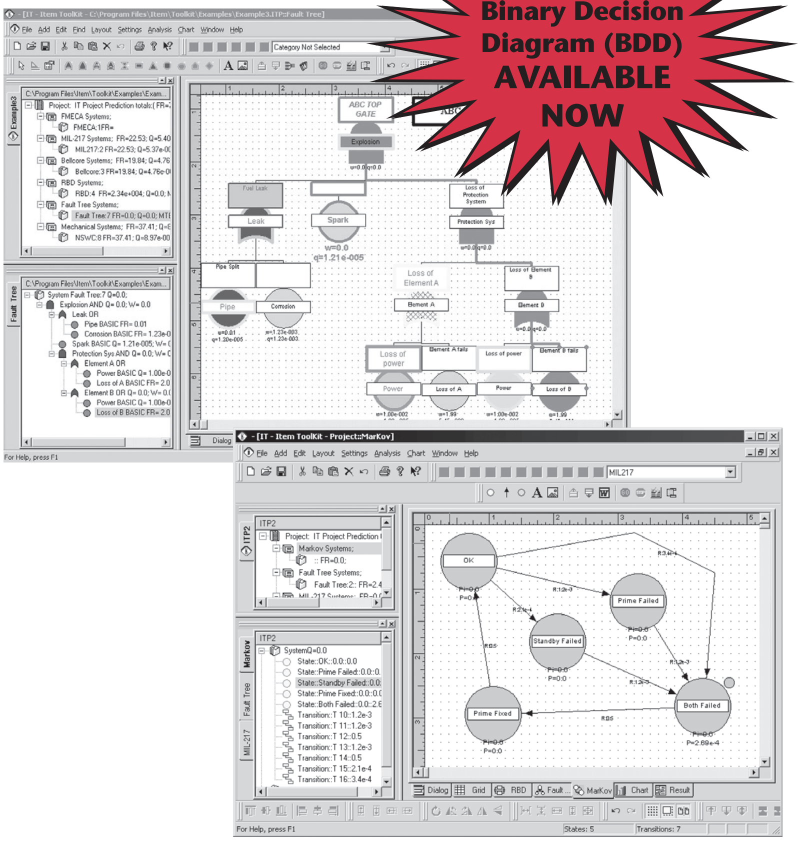

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System Level Clues ... (Continued from page 17)

that whenever engineering is presented with data in this format, they can now quickly see which functions and even which components require further analysis. Table 3 also points out where additional data collection activity may be needed to determine further specific failure mode information such that it can be analyzed using Weibull techniques. Much of this approach can be automated, and GETS is in the process of doing so for its field reliability database. One note of caution here is that even when these methods show potential problem areas, trade-off analyses may still be required. However, this method shows promise as a means to focus quickly and easily in on potential problems. Further, such methods can be applied at any time in a system's life cycle, and therefore has the potential of detecting problems early enough, before they become an issue with the customer. In this fashion, the design team can stay ahead of such problems, improving performance and customer satisfaction.

Conclusion

Proactive analysis of fielded system reliability is becoming a must for companies that are responsible for the life cycle management of large equipments. Current trending methods, while adequate for determining when problems may be arising in such systems, are reactive rather than proactive in nature. Because of this, other methods are required that will provide the needed early warning of failure modes that, if left unchecked, could develop into larger problems later on. One such method, as described in this paper, is to use two well-known reliability analysis techniques in concert to provide the noted proactive capability. One technique, known as Crow-AMSAA, is applicable at any system level. More importantly, it can be used to measure the impact of all failure modes at once. Using CA, the analyst can first determine if the system reliability, at least at the functional level of indenture, is increasing, decreasing, or remaining constant in time. If decreasing, as measured by the CA β-value being at least in the 1.3-1.6 range, then it is highly likely that one and possibly two wearout failure modes exist within the function. Detection and characterization of the failure mode is then possible using Weibull analysis techniques. Using this method in a drill down fashion will allow quick and focused identification of only those pieces of the system that require attention. This new methodology is significant in that the drill down nature of the approach, with the result being a focused problem definition, fits quite nicely within the six-sigma stable of analysis techniques.

References

1. Unkle, C. Richard and Venkataraman, Ray, *Relationship between Weibull and AMSAA models in reliability analysis: a case study*, International Journal of Quality & Reliability Management, Vol. 19, No. 8/9, 2002.
2. MIL-HDBK-189, "Reliability Growth Management," 13 February 1981.
3. Abernethy, Robert B., The New Weibull Handbook- Fourth Edition, Published and Distributed by Robert B. Abernethy, 536 Oyster Rd, N. Palm Beach, Florida 33408-4328, September 2000.

About the Author

Richard Unkle is a Six Sigma Black Belt and a Senior Reliability Engineer working for GE Rail in Erie, Pennsylvania. He earned a BSEE from RIT in 1981 and an MBA from The Pennsylvania State University in 2002. He has more than 20 years experience in systems reliability engineering, having worked at the USAF Rome Laboratory, ARINC Research Corporation, and the Reliability Analysis Center before joining GE Rail in 1997. In his current role, he provides reliability training, analysis, and tool development support to the engineering, quality, life cycle cost, and finance departments of GE Transportation's Rail division.

RMSQ Headlines

Wired for Success: Ensuring Aircraft Wiring Integrity Requires a Proactive Systems Approach, AMPTIAC QUARTERLY, published by the Advanced Materials and Processes Technology Information Analysis Center, Vol. 8, No. 3, 2004, page 17. Wiring integrity has become a highly visible aging aircraft issue in recent years, both for military and commercial aircraft. This article highlights some recent events that have resulted in an increased emphasis on wiring interconnection and power distribution, both of which are considered highly critical to the safe and successful operation of modern aircraft and space vehicles. It also looks at the emergence of proactive approaches designed to safeguard wiring system performance.

How Useful is QFD, Quality Progress, published by the American Society for Quality, January 2005, page 51. This article discusses an interesting application of Quality Function Deployment (QFD). The author, a quality engineer at Cincinnati-Lamb in Hebron, KY, tells how he used QFD in mentoring a high school team that was developing a robot for the FIRST Robotics Competition.

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From the Editor

Be Positive But Be Realistic

Having a positive outlook on life is an enviable trait. Now I don't mean positive in a Pollyanna sense, where everything will turn out rosy if we are only good and believe. I mean looking for possibilities where none seem to exist, and accepting problems as challenges and then working to find solutions. Having a positive outlook means that we do not easily give up but persistently pursue our goals and objectives.

Having a positive outlook is as healthy for people in their occupations as it is in their private lives. Everyone has days when they gripe about something that has happened at work, about the company for which they work, or about a co-worker. But overall, most of us like the profession we have chosen and gain some measure of self-satisfaction in the work we perform.

In system acquisition, as in any other endeavor, a positive outlook can be a healthy and desirable characteristic of the management and technical team. Unfortunately, this positive outlook sometimes slips into the world of self-deception and illusion. For example, when technical problems arise, and every tool available to the engineer, every management indicator, and common sense tell us that the challenge is insurmountable within the budget and schedule, we should be wise enough to call a timeout. During the timeout, we need to reassess and possibly relax the goals, examine less lofty alternatives, or even cancel the program. Too often, however, a "can-do" mentality and an overly positive outlook blind us to such practical actions.

All of us at least have heard anecdotal stories about programs in which requirements were doggedly chased, despite incontrovertible evidence that the requirements were unachievable, given program and technical constraints. Reliability is often one of these requirements. It seems that every new program asks for ever-higher levels of reliability, even as every other measure of performance is also expected to be improved significantly.

Now, striving for improvement is commendable, but only if the improvement is really needed and is within the realm of technical feasibility. All-too-often, an extremely high reliability requirement is imposed to compensate for restricted budgets that prevent the needed number of systems from being bought. Reliability and higher performance overall is expected to make up for the reduced number of systems. A rule of thumb, the origin of which escapes me, is that if the opponent has twice as many tanks (or planes, or men, etc.) as you, your tanks must be four times better. Whether or not this ratio is or ever was true. It is obvious that when outnumbered, you must have weapons of superior quality.

Ned H. Criscimagna

At other times, ridiculously high reliability requirements are called out because technology is available, or at least is touted as being available, to achieve the requirements. Unless the overall life cycle cost is minimized (or nearly so) by this level of reliability, and unless the technology can be incorporated within the budget and schedule for the program, the requirement is "gold plating" at its worst.

In system acquisition, rather than dreaming of what we want, we must be realistic and see things as they really are. We have the tools to help us do this for reliability. These include:

- Analysis – Using analytical tools like the Failure Modes and Effects Analysis and Fault Tree Analysis can help us assess whether or not we have a realistic opportunity to attain the required reliability.
- Tests – Testing parts to determine life and testing systems provides additional insight into the realism and achievability of a reliability requirement.
- The Reliability Case – A useful approach for organizing all available information and then using the information as the basis for assessing the level of reliability achieved.
- Engineering Judgment – Our experience and good sense are indispensable for evaluating the level of reliability that can reasonable be expected from a system.

A good reliability program can be an essential part of an overall risk management program. By selecting key criteria (e.g., fix effectiveness, occurrence of new failures, test results, etc.) and assigning a color code, we can assess the risk in meeting the reliability requirement. When all the indicators are red, perhaps we have a problem and not simply a challenge.

As engineers, we have an obligation to tell management how it "really is." Sugar-coating the truth may be easier than being the bearer of bad news, but in the long run, no one is well served by such a tactic. Managers always have the prerogative, of course, of ignoring bad news. It may be that some have even tried to manipulate the facts to avoid losing funding or political support for their program. Be that as it may, the engineer's responsibility is to use the available information and his or her best judgment in assessing the technical realities. It is then a matter of ethics not to be swayed by pressures to sacrifice reality for the unrealistically positive outlook others desperately seek.

PRISM Column

Environmental Profiles

A factor is included in PRISM to account for the environmental effects of vibration and temperature cycling at the system level. At the component level, the π and λ factors in PRISM account for temperature cycling, vibration, and relative humidity when RACRates models are used.

At the system level, if the specific environmental stresses to which the system will be exposed in field use are known, then the environmental correction factor is calculated using the formula:

$$\Pi_E = \frac{P_{TC} \bullet SS(TC_{use}) + P_{RV} \bullet SS(RV_{use})}{P_{TC} \bullet SS(TC_{G_b}) + P_{RV} \bullet SS(RV_{G_b})}$$

where,

P_{TC} = percentage of failures resulting from temperature cycling stresses
P_{RV} = percentage of failures resulting from random vibration stresses
SS = screening strength applicable to the application environmental values

If the actual values of these variables are unknown, the default values that should be used are $P_{TC} = 0.80$ and $P_{RV} = 0.20$. The SS value is the screening strength and has been derived from MIL-HDBK-344. It is an estimate of the probability of both precipitating a defect to failure and detecting it once precipitated by the test. Whenever possible, the actual values of delta T (ΔT) and vibration (G_{rms}) should be used for the intended application environment. The PRISM software tool includes default values for these values that are a function of the generic environment that can be used when the model user does not know the specific environmental stresses to which the system will be exposed.

Default values for environmental stresses can be found in the PRISM user's manual, Appendix B. Additionally, as with the operational profiles, custom profiles can be added to the system. For example, say that a ground communications system is operated in an environment with an operating temperature of 30°C, dormant temperature of 10°C, relative humidity of 50%, and a vibration of 0.5 G_{rms}. To use this profile in related systems and system reassessments, it is recommended that a custom profile be created. To add custom environmental profile or to review the default operational profiles, select "Environments" from the Libraries menu.

RAC is offering a two day **PRISM® Training Course** at the Turning Stone Conference Center in Verona, NY on May 10-11, 2005. Registration for this training course will be free of charge to licensed PRISM users. Individuals who are not currently licensed users will be able to purchase the PRISM software for $1,995 ($2,195 International) and attend the course at no charge.

For more information on PRISM feel free to contact the PRISM team by phone (315-337-0900) or by E-mail (<rac_software@alionscience.com>). To obtain additional information including a demo version of the software or to register for training go to (<http://rac.alionscience. com/prism>).

Upcoming June Training

Electronic Design Reliability

This intensive course is structured for all key participants in the reliability engineering process. Included are systems and circuit design engineers, quality engineers, and members of related disciplines having little or no previous reliability training. The course deals with both theoretical and practical applications of reliability; all considerations related to the design process including parts selection and control, circuit analysis, reliability analysis, reliability test and evaluation, equipment production and usage, reliability-oriented trade-offs, and reliability improvement techniques.

Reliability Engineering Statistics

The Reliability Statistics Training Course is a three-day, applications-oriented course on statistical methods. Designed for the practitioner, this course covers the main statistical methods used in reliability and life data analysis. The course starts with an overview of the main results of probability and reliability theory. Then, the main discrete and continuous distributions used in reliability data analysis are overviewed. This review of reliability principles prepares the participants to address the main problems of estimating, testing and modeling system reliability data. Course materials include the course manual and RAC's publication "Practical Statistical Tools for the Reliability Engineer."

Mechanical Design Reliability

This training course is a practical application of fundamental mechanical engineering to system and component reliability. Designed for the practitioner, this course covers the theories of mechanical reliability and demonstrates the supporting mathematical theory. For the beginner, the essential tools of reliability analysis are presented and demonstrated. These applications are further solidified by practical problem solving and open discussion. The objective of this extensive application of reliability principles is to leave the participants prepared to address reliability related to mechanical equipment and to provide competency in the predominant tools of mechanical system reliability analysis.

For more information <http://rac.alionscience.com/training>.

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