# Physics of Failure Durability Simulations Accelerate Development and Improve Reliability and Safety of Automotive Electronics

*Apr 5, 2012 10:25 AM*
*By James G. McLeish, DfR Solutions*

Automotive electronics systems are becoming increasing complex and essential to the proper and safe operation of cars and trucks as vehicle controls for basic operation and safety functions are increasingly being implemented by electronic modules. The ability of these electronic systems to function reliably is becoming a greater aspect of vehicle safety that was dramatically demonstrated by the 2009-2011 recall of over 9 million Toyota vehicles for unintended acceleration issues.

While electronic reliability issues were widely suspected but eventually ruled out as a root cause, the crisis revealed the challenges of evaluating, validating and investigating the reliability and safety assurance aspect of modern, distributed and interactive vehicle controls systems that are equally taxing on OEMs, electronic system suppliers and regulators.

As an aftermath of the incident, the U.S. National Academy of Science issued "Special Report #038 (record #13342) The Safety Challenge and Promise of Automotive Electronics - Insights from Unintended Acceleration" in January of 2012. The report cited that federal safety regulators in the National Highway Traffic Safety Administration (NHTSA) lack the expertise to monitor vehicles with increasingly sophisticated electronics as was demonstrated by the need for NHSTA to call in NASA electronic personnel to assist in the investigation.

Meanwhile, in Europe the new standard ISO 26262 "Road Vehicles -- Functional safety" defines an automotive-specific approach for determining risk classes and requirements for validation and confirmation measures to ensure a sufficient and acceptable level of safety and reliability is being achieved.

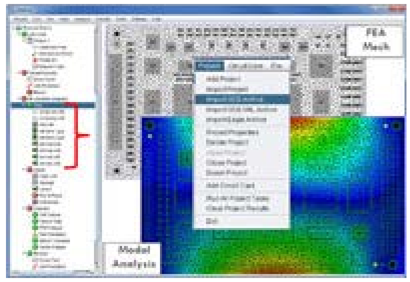


Figure 1. Sherlock ADA imports standard circuit board CAD/CAM Gerber files or ODB archives and uses them to automatically create and run finite element models for structural analysis and Physics of Failure durability simulations / reliability assessments.

There is now a new set of Computer Aided Engineering (CAE) tools that can help evaluate the safety and reliability of vehicular electronics models to meet these needs and support the new ISO standard. CAE modeling and simulation tools are now widely viewed as an automotive engineering core competency. It is needed to reduce new product development time, in order to get products to the market faster, at lower costs by helping to design them right on the first attempt.

In the mechanical, civil and structural engineering fields the use of CAE structural analysis tools for optimizing performance, durability and reliability requirements are a standard part of the engineering process. For automotive bodies, frame, suspensions, engines and all other structural elements, structural analysis is an essential procedure for verifying that usage condition stresses do not exceed the capabilities or fatigue limits of the material used in a product. By helping to design products and parts right on the first attempt, CAE analysis tools accelerate and improve the engineering process while reducing the need for physical prototype and durability testing which significantly reduces product development time and costs.

The primary issues being evaluated are overstress and wearout-related failures. Overstress failures such as yield and buckling occur when the stresses of the application exceed the strength or capabilities of a device's materials causing immediate or imminent failures. In items that are well designed for the loads in their application, overstress failures are rare and random. They occur only under conditions that are beyond the design intent of the device, such as acts of god or war, such as being struck by lightning or submerged in a flood. Overstress failures can be correlated to the traditional reliability concept of random failures. Load-stress analysis is used to determine if the strength limits of a design for stresses like mechanical shock events are adequate. Wearout failures are related to gradual stress driven damage accumulation of materials over time. This covers failure mechanisms such as fatigue.

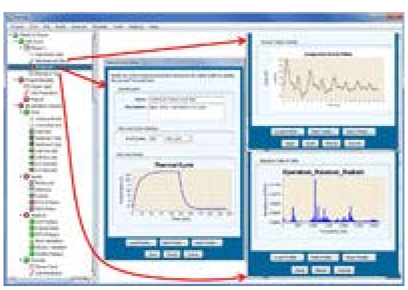

Figure 2. The user can define and save an unlimited number of test or field environmental and usage stress profiles to perform virtual test to field correlations and simulated aided testing studies.

By contrast, Electrical and Electronic (EE) engineers historically have gravitated to CAE tools for circuit, functional and software analysis with less emphasis on structural analysis tools that were viewed as less essential to their field. However, as advancements in electronic technology have produced smaller and smaller devices that handle ever increasing amounts of power and heat, the micro structural integrity of wire bonds, micro-terminals and solder joints becomes increasingly important especially in the auto industry where the ability to endure 10-15 years of harsh environmental conditions is needed. This is underscored by the fact that the majority of field failures of electronic modules are physical and structural in nature, related to items such as thermal over stress and fracture or fatigue of wires, solder joints, component terminals, wire bonds, circuit board through-hole vias and such.

Evaluating and achieving the structural integrity, durability and reliability of automotive electronic modules primarily remained dependent on traditional Design-Build-Test-Fix (D-B-T-F) reliability growth processes that employ a variety of environmental stress and usage durability testing of physical prototypes. The time and cost of building and testing prototype electronic components has been a limiting factor in efforts to accelerate the product development-validation process of automotive electronics.

As vehicular electronic content continues to climb into and beyond the range of 70 to 80 modules per vehicle (on internal combustion engine vehicles), the burden of integrity assurance / reliability / durability testing is becoming an even greater drain on the industry. The conversion to hybrid and electric vehicle bring with it even greater increase in electronic content. For example, the Chevy Volt Lithium Ion battery module requires seven circuit board assemblies for battery system management and safety. Each of these assemblies was required to be tested in accordance with an extensive durability profile.

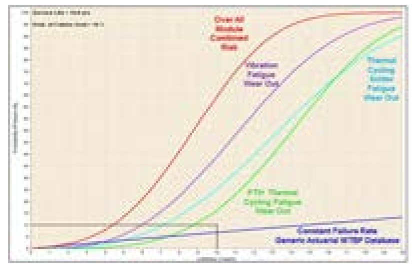

Figure 3. The Sherlock program plots individual and overall combined risk timelines curves for the failure mechanisms the device is susceptible to. This early identification of specific risks allows the design to be improved, at low cost, while the design is still on the CAD screen.

To address this situation, a new class of Knowledge Based, Automated Design Analysis (ADA) CAE tools for performing Physics of Failure (PoF) durability simulations and reliability assessments for ensuring structural integrity of electronic modules has been developed. This new CAE program is called Sherlock Automated Design Analysis (ADA) for its ability to investigate a design and identify if it is susceptible to failure mechanisms related to the intended usage environment of the application. The program works by performing a durability simulation in a virtual environment and calculating the durability life and reliability distribution of various failure mechanisms for the electronic component and structural elements on the circuit board(s) of an electronic module. This is similar to the way structural durability analysis is now performed for vehicle body, chassis and other mechanical systems and parts.

The Sherlock program, produced by DfR Solutions, is the result of years of Physics of Failure research to identify the failure mechanism of how and why different electronic components and materials fail, then develop and calibrate a math model of each failure mechanism that could be incorporated into the CAE analysis program. Previously, these PoF analyses were performed using tradition CAE tools such as Finite Element Analysis (FEA). This required a long, complicated, model creation process performed by a highly trained expert - a capability that was rarely available to most electronic engineers.

However, the Sherlock Automated Design Analysis™ program is designed to be used by non-CAE experts to quickly create and perform PoF durability simulations and reliability assessments. This is accomplished by a high degree of automation in the program that includes preloaded libraries of: component models, material properties, design templates, analysis wizards and environmental profiles for specific applications. The automation features enable electronic engineer, circuit board designers, and quality/ reliability personnel to use the analysis tool to incorporate reliability growth into the design process.

The creation of a virtual module of a circuit board assembly is greatly simplified by importing the same Computer Aided Design (CAD) files created during a typical circuit layout design process that are sent to a circuit board fabricator and a circuit board assembler for use in their Computer Aided Manufacturing (CAM) equipment. Once the CAD-CAM files in either a tradition Gerber format or the new ODB++ format are loaded, the Sherlock program automatically self generates the FEA models needed for structural analysis as shown in Figure 1. The environmental and usage conditions to be evaluated along with the durability time frame and reliability objectives of the application are then defined.

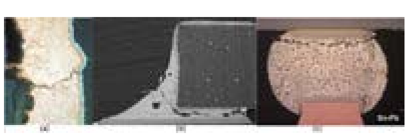

Figure 4. Examples of typical circuit board structural failures:

Next, the user selects the types of stress analysis to be performed which determines the types, intensity and loading frequency of the stresses the device is required to endure during its service life as shown in Figure 2. The stress conditions automatically become

(a) a cracked copper barrel wall in a signal carrying plated through hole via (left),
(b) a solder attachment crack at a surface mount resistor (center) and
(c) a solder ball crack in a BGA integrated circuit (right).

inputs to various PoF failure mechanism model to determine the susceptibility of the electronic assembly's devices, materials and components to various failure mechanisms which produces a projection of the time to mean failure and the failure distribution about the mean of each susceptible failure mechanism to each element in the design.

Figure 3 shows how the Sherlock program then tallies all the failure risks of each element to calculate a combined failure risk life curve for each failure mechanism and an overall risk life curve for the complete electronic module. It also produces an ordered Pareto list that identifies the components or features projected to have the greatest risk of failure for each failure mechanisms. This enables easy identification and prioritization of all the weak link items, most likely to fail within the desired service life. It also identifies why they are expected to fail so that corrective actions can be implemented while the design is still on the CAD screen, without the time and expense of building prototype modules for physical reliability growth durability testing.

The current version of the Sherlock program performs the following stress assessments, wearout or overstress failure simulations and risk assessments.

- FEA Vibration Modal Analysis – Stress Assessment
- FEA Shock Modal Analysis – Stress Assessment
- Thermal Cycling Fatigue of Solder Joints – Wearout Failure Mechanism
    - Traditional Tin/Lead Solders
    - SAC Family of RoHS Lead Free solder
- Thermal Cycling Fatigue of Plated Through Hole Vias – Wearout Failure Mechanism
- Mechanical Vibration Fatigue of Solder Joints – Wearout Failure Mechanism
    - Traditional Tin/Lead Solders
    - SAC Family of RoHS Lead Free solder
- Mechanical Shock Fracture of Solder Joints - Overstress Failure Mechanism
- Conductive Anodic Filament Formation – Risk assessment

Examples of real-world failures that this type of analysis can detect and prevent are shown in Figure 4.

**Conclusion**

The Sherlock Automated Design Analysis™ program is a powerful durability simulation and reliability assessment CAE tool suite that integrates Physics of Failure stress analysis and failure mechanism modeling to rapidly provide durability simulations capabilities for electronic products. The highly automated model creation capabilities were designed to allow it to be used by a wide range of engineering and design personnel interactively with the creation of a new design. This enables a physics based understanding of product reliability and optimization opportunities early in the design cycle.

**About the Author**

James G McLeish is a Senior Member of the ASQ Reliability Division, the IEEE Reliability Society and the SAE E/E Reliability and ISO-26262 Functional Safety Committees. He started his career as a practicing electronics product engineer who helped invent the first microprocessor based engine computer at Chrysler Corp. in the 1970's. He has since worked in systems engineering, design, development, product, validation, reliability and quality assurance of both E/E components and vehicle systems at General Motors and GM Military. He is credited with the introduction of Physics-of-Failure (PoF) methods to GM while serving as an E/E Reliability Manager and E/E QRD (Quality/ Reliability/Durability) Technology Expert. Since 2006 Mr. McLeish has been a partner and manager of the Michigan office of DfR Solutions, a QRD engineering consulting, failure analysis and laboratory services firm that is a leader in providing PoF expertise to the global electronics industry. For further information he can be contacted at jmcleish@dfrsolutions.com or askdfr@dfrsolutions.com.

Back to Top

Contact Us E-mail Webmaster For Advertisers For Search Partners Privacy Statement RSS Terms of Use