CAE Apps for Physics of Failure
Reliability & Durability Simulations

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Computer Aided Engineering (CAE)

- CAE involves using computers & software to perform engineering analysis tasks
  - Expedites the application of scientific principles to determine the properties or performance characteristics of a design, (a.k.a. CAA Computer Aided Analysis).
  - Developed and evolved to support many different engineering disciplines & industries:
    - Mechanical, Civil/Structural, Electrical/Electronics, Thermal, Hydraulics . . .
    - Automotive, Aerospace, Naval, Construction, Mining, Power Generation . . .

1. Stress analysis using FEA (Finite Element Analysis)
2. Computational Fluid Dynamics (CFD) for thermal & fluid flow analysis
3. Kinematics & Mechanical event simulation (MES)
4. Process simulation (casting, molding, and die press forming)
5. Product Optimization
6. Circuits & Electromagnetics Analysis
CAE Tools & Methods

**Most CAE programs are model “creation” tools**

- Like a blank spread sheet or word document they enable the user to first create every element and then run an analysis.
- But this requires a long model creation effort and requires the user to be:
  - Very experienced with the CAE modeling program.
  - Highly knowledgeable in the specific physics and engineering discipline of the item being analyzed.
  - PhD level expertise is often required.
  - Availability and cost of this level of expertise has sometimes limited the expansion of CAE methods from reaching many areas where they could be beneficial.

*A Blank Canvas*
An Emerging Trend - Application Specific CAE Apps

- Application Specific, Customized CAE Solutions.
- Auto guided, specific function, CAE Apps or analysis templates are created to provide a common, reusable semi-automated interface.
- Pre-programed, off the shelf ready, similar to smart phone or tablet Apps.
  - Regularly needed product optimization
  - Frequently encountered problems.
  - Allows product teams to perform expert level CAE analysis without a rare, costly, CAE expert
- See Article at:
  [http://www.sae.org/mags/SVE/10767](http://www.sae.org/mags/SVE/10767)
Physics of Failure Reliability Assessment

- Combines dynamic stress analysis of usage & environmental conditions with failure mechanism models to perform a durability simulation
  - Identifies failure susceptibilities & calculates reliability behavior over time.
  - Based on Physics of Failure Root Cause Research that identifies:
    - “CAUSE & EFFECT” Relationships in Failure Mechanisms &
    - The variable factors that makes them “APPEAR” to be Random Events.

- Failure of devices or structures (i.e. hardware) are due to:
  - The gradual degradation (wearout) or
  - Rapid disruption (overstress) due to encounters with “Excessive Stresses” that exceeds the capabilities/strength of a device or material.
  - Both are related to the stress(s) an item is exposed to
  - Failures can also occur prematurely due to fabrication or assemble defects, excessive variable factors or even design errors that weakens the items to reduced capability to endurance capabilities
3. Designing Reliability & Durability into Products with PoF Knowledge & CAE Failure Mechanism Modeling

- Starts With Understanding The Failure Mechanisms Your Product’s Technology Is Susceptible To and

- How It Will Be Exposed To The Stresses That Initiate and Propagate These Failure Mechanisms

Temperature Extremes & Cycling
Moisture & Humidity
Electromagnetic Noise
Vibration & Shock
PoF Durability Simulations & Reliability Assessments

- Finite Element Analysis (FEA) and Computational Fluid Dynamic (CFD) CAE program are regularly used to identify the stress conditions that products and systems will experience under various usage conditions.
  - A standard practice in mechanical and structural products.

- Combining CAE Stress Analysis with Failure Mechanism Models enables: “Virtual Durability Simulations” that can Calculate Stress Driven Reliability Performance Over Time.
  - PoF Research has enable the migration of this technology to the materials and micro structures of E/E components and circuit board assemblies.
4. A Tool Suite of CAE Apps for PoF Durability Simulations & Reliability Assessments of Electronic Equipment

- Fast, Semi-Automated
  - Enables CAE durability simulations to be interactively with design creation
  - Durability/Reliability impact of design choices rapidly determined

It is not at the Iphone or Droid App store. But yes there is now a Physics of Failure Durability Simulation App

Sherlock is the backbone to one of the most powerful reliability tools to be released for use not just by the reliability group, but by the entire engineering design and management team. Sherlock is the future of Automated Design Analysis (ADA), the integration of design rules, best practices and a return to a physics based understanding of product reliability.
Key Characteristics of the Sherlock ADA PoF CAE App

- A Semi-Automated CAE knowledge based tool suite for:
  - PoF durability simulation & reliability assessments on electronics
  - Semi-Automated features simplifies model creation and analysis

- Designed to be used by non-CAE experts to quickly create and perform PoF durability & reliability analysis.
  - Eliminates the long, complicated, model creation process & the need for a PhD level expert in PoF, FEA and CFD numerical modeling.
  - The “Knowledge Based” features customized for E/E component and materials includes customizable, preloaded libraries of:
    - Component geometry models
    - Material properties
    - Design templates
    - Analysis wizards
    - Environmental profiles for various applications.
4 Steps of a PoF CAE App Analysis

1) **Design Capture** – Circuit board CAD files provides the inputs to the modeling software & calculation tools.

2) **Life-Cycle Definition** – define the reliability/durability objectives and expected environmental & usage conditions (Field or Test) under which the device is required to operate.

3) **Load Transformation** – auto creates a Finite Element Analysis to calculate and distribute the environmental and operational loads across a circuit board to the individual parts and features.

4) **PoF Durability Simulation/Reliability Analysis & Risk Assessment** – Failure Mechanisms algorithms applied to the model & stress conditions created in steps 1, 2 & 3 to performs a design & application specific durability simulation to calculates life expectations, reliability distributions & prioritizes risks.
Step 1: Design Capture - Import PCBA Layout
(Gerber, ODB++, Eagle & Valor CAD & BOM Part Lists)
Step 1: Design Capture - Mech. Stack up Analysis define PCB Laminate & Layers to Calculate Substrate Performance

- Calculates
- Thickness
- Density
- CTE x-y
- CTE z
- Modulus x-y
- Modulus z
- From the material properties of each layer
- Using the Built in Laminate Data Library
Step 1: Design Capture - Mech. Stack up Analysis Determines How the PCB Transmits Stress the the EE Components

- All PCB Laminates are NOT ALIKE!
  - FR-4 Only Defines Flame Resistant Grade 4
  - Many other Electrical, Mechanical & Thermal Material Properties that Affect Performance & QRD that Need to be Considered

- The Sherlock ADA Laminate Library
  - Defines 48 Categories Of Material Properties And Characteristics
  - For over 400 Circuit Board Laminates Materials
  - From 22 Global Producers
  - New Entries Can be Added as New Laminate Materials Are Introduced to the Market.
Step 1: Parts ID, Management & Linkage to Built In PoF Component Model Library

- Minimizes data entry through intelligent parsing and embedded electronic components package and material databases
Step 2: Define Life Cycle - Field or Test Environment & Usage Condition – Use Pre-Programs Standards or Define Your Own

- Define Detail Lifetime Thermal, Vibration & Shock Stress Profiles
Step 2: Life Cycle Characterization - Need to Develop Life Time Environmental Loading Profiles

Time At Temperature Hours Over 10 Years at Phoenix Az.

Number of Thermal Cycles Over 10 Years At Phoenix Az.
Step 3: Load Transformation - Automated FEA Mesh Generation to Calculate Stress Distribution Across the PCBA
Step 3) Load Transformation Automated FEA Meshing & Analysis
Determines Stress Distribution Across the PCB & to Components

- Automatic Mesh Generation
  - Days of FEA modeling and calculations, executed in minutes
  - Without a FEA modeling expert.

1st Natural Frequency

2nd Natural Frequency

Calculates PCB Stress Distribution for use in Fatigue/Fracture Analysis
- Harmonic Vibration
- Random Vibration
- Shock
Step 4: PoF Durability Simulation & Reliability Risk Assessments - Thermal Cycling Solder Fatigue Example

- N50 fatigue life calculated for each of 705 components (68 unique part types), with risk color coding, prioritized risk listing and life distribution plots based on known part type failure distributions (analysis performed in <30 seconds) after model created.
  - Red - Significant portion of failure distribution within service life or test duration.
  - Yellow - Lesser portion of failure distribution within service life or test duration.
  - Green - Failure distribution well beyond service life or test duration.

(Note: N50 life - # of thermal cycles where fatigue of 50% of the parts are expected to fail)

### Parts With Low Fatigue Endurance Found In Initial Design

- ~84% Failure Projection Within Service Life, Starting at ~3.8 years.

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<th>RefDes</th>
<th>Package</th>
<th>Part Type</th>
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Step 4: PoF Durability/Reliability Risk Assessment Enables Virtual Reliability Growth

- Identification of specific reliability/durability limiting or deficiencies, of specific parts in, specific applications
- Enables the design to be revised to meet reliability/durability objectives
  - **WHILE STILL ON THE CAE SCREEN**

- Failure Risk Plot of the same project after fatigue susceptible parts replaced with electrically equivalent parts in component package suitable for the application.

- Life time failure risks reduced from \(~84\%\) to \(~1.5\\%\)
Step 4: PoF Durability/Reliability Capabilities
Plus Optional MIL-STD-217 Random Failure Rate Calculator

- Thermal Cycling Solder Attachment Fatigue
- Thermal Cycling PCB PTH Via Barrel Cracking Fatigue
- Vibration Solder Fatigue
- Shock Solder Fracture
- MIL-HDBK-217 Actuarial (Constant Failure Rate/MTBF-Probabilistic)
- Conductive Anodic Filament Risk Assessment
- Stress load in Fracture Risk Assessments
  - ICT Test Stress Analysis
  - Compliant Pin Connector Insertion
- ISO-26262 Functional Safety FMECA
Step 4: PoF Durability Simulations/Failure Risk Life Curves for each Failure Mechanism Talled to Produce a Combined Life Curve

- Detailed Design & Application Specific PoF Life Curves are Far More Useful that a simple single point MTBF (Mean Time Between Failure) estimate.
Using an Improved PoF Reliability Metrics

PoF Modeling uses a Combined Life & Reliability Metric

- **Bx/Lx** - the Life Point (hrs., days, yrs. or cycles) When No More Than x% of Failures Have Occurred.

  A Time to “Early-First Failure” Focus
  - Evolved from the B10 Bearing Life metric (also used in Machinery & Auto Industries)
  - Minimum Life of (1-x)% of a population (R ≥90% by the specified life point)
  - Defines the max. allowable % failures/min acceptable reliability AND the durability life.
  - Failure values other than 10% can be used (i.e. 5%, 2%, 1%, 0.5% . . . )

Improvement over the Traditional (MTBF/MTTF) Reliability Metric

- Mean Time Between Failure / Mean Time To Failure
  - Represents when 50% of the failures in a diverse population have occurred during only the useful life phase (assumes wearout does not occur)
  - Arithmetic mean is a poor metric since it is greatly influenced by outliers and the spread/distribution of the population.

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3 Failure Distributions (with the same Mean) But Vastly Different Times to 1st Failure
Step 4: PoF Durability/Reliability Risk Assessment Results Available in 6 Different Output Options
Step 4: PoF Durability/Reliability Risk Assessment - Automated Report Generation

- Comprehensive reports generated in PDF format
  - Key summary points
  - Detailed inputs and findings
  - Result plots and tables
  - User control over contents

- 50-100 page professionally formatted document produced in seconds

![Sherlock Analysis Results](image)
In Conclusion: the Sherlock ADA CAE App is a New, Revolutionary, Awarding Winning Tool Suite for Virtual Durability/Reliability Risk Assessments of Electronic Equipment
Questions

Thank you for your attention.

Any questions?

For More Information or Copies of the Presentation Slides Contact:

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