An electronics assembly is a complex electromechanical system
There are many competing failure mechanisms in micro-electronic components.

Die delamination, Electromigration, Wire bond corrosion and fracture.

There are many competing failure mechanisms in electronic assemblies:

Conductive Filament Formation, Dendritic Growth, PTH Barrel Cracking.

Trace Fracture, Solder Fatigue, Lead Wire Fracture.
Simulation Assisted Reliability Assessment (SARA) of Electronic Equipment?

- Reliability assessment of electronic equipment requires modeling physical hardware under anticipated life cycle loads.
- Electronic equipment is a complex system that requires a systematic approach for identifying failure mechanisms and ranking potential failures.
- Reliability is based on failure sites and mechanisms precipitated in hardware under life cycle loading conditions.
- Simulation software can be used to facilitate this process.

Simulation Assisted Reliability Assessment (SARA)

Virtual Qualification:
- Design Capture
- Failure Risk Identification
- Load Transformation
- Failure Quantification
- Ranking of Potential Failure Sites and Mechanisms

Physical Verification: Test Setup, Specimen Characterization, Accelerated Stress Test
Failure Models

Models which describe failure process at the material level are called *physics-of-failure* models.

Models which are based on curve-fitting of product level test data are called *empirical models*.

Failure models have the form

$$t_f = F(x_1, \ldots, x_n)$$

where $x_i$ are the parameters obtained from design capture, life cycle load characterization, and load transformation (stress analysis).

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Examples of Failure Mechanism Models

<table>
<thead>
<tr>
<th>Failure Mechanism</th>
<th>Failure Sites</th>
<th>Relevant Stresses</th>
<th>Sample Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue</td>
<td>Die attach, Wire bond/TAB, Solder leads, Bond pads, Traces, Vias/PTHs, Interfaces</td>
<td>Cyclic Deformations ($\Delta T$, $\Delta H$, $\Delta V$)</td>
<td>Nonlinear Power Law (Coffin-Manson)</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Metallizations</td>
<td>$M$, $\Delta V$, $T$, chemical</td>
<td>Eyring (Howard)</td>
</tr>
<tr>
<td>Electromigration</td>
<td>Metallizations</td>
<td>$T$, $J$</td>
<td>Eyring (Black)</td>
</tr>
<tr>
<td>Conductive Filament Formation</td>
<td>Between Metallizations</td>
<td>$M$, $\nu V$</td>
<td>Power Law (Rudra)</td>
</tr>
<tr>
<td>Stress Driven Diffusion Voiding</td>
<td>Metal Traces</td>
<td>$\sigma$, $T$</td>
<td>Eyring (Okabayashi)</td>
</tr>
<tr>
<td>Time Dependent Dielectric Breakdown</td>
<td>Dielectric layers</td>
<td>$V$, $T$</td>
<td>Arrhenius (Fowler-Nordheim)</td>
</tr>
</tbody>
</table>

$\Delta$: Cyclic range  
$V$: Gradient  
$T$: Temperature  
$H$: Humidity  
$
u$: Moisture  
$J$: Current density  
$\sigma$: Stress

Fatigue curve (shown above) is one form of failure model that may be applicable to electronic hardware.
# Design Capture

- **Import Electronic Layout (CAD files)**
  - PADS, Protel, Cadence, Mentor Graphics
  - Correlates component number with board location
- **Acquire Bill of Materials (BOM)**
  - Correlates part ID to component number
- **Review Part Manufacturer Datasheets**
  - Provides part dimensions and materials

---

# Importing CAD Data

- ODB++
- Veribest
- PADS 1.0, 3.5, 4.0 text files
- Mentor Neutral File
- Cadence IDF file
- Zuken-Recal (CADIF) text files
- PCAD

Importing typically provides board outline, part list, component list, and component positions referenced to the board outline. Other information such as pad size, traces, power dissipation, die size are not imported.
The Materials used in the construction of electronic devices are key building blocks and need to be characterized so that changes such as those that occur based on temperature can be considered.

The packages and parts used in electronic assemblies are key building blocks and need to be available for rapid model construction and life assessment.
Life Cycle Loads
(Information to develop the design, analysis, and test criteria)

- operation
  - modes of operation
  - on-off cycles
- manufacturing / assembly
- rework
- test
- storage
- transportation/handling
- repair / maintenance

Example: Aircraft Environment Guidelines
The Institute for Interconnecting and Packaging Electronic Circuits (IPC*) has defined worst case operating temperature requirements for an aircraft:

<table>
<thead>
<tr>
<th>Temperature Cycle Environment</th>
<th>IPC 1992 Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Temperature</td>
<td>-55 °C</td>
</tr>
<tr>
<td>Maximum Temperature</td>
<td>95 °C</td>
</tr>
<tr>
<td>ΔT for Temperature Cycle</td>
<td>20 °C + Power Dissipation</td>
</tr>
<tr>
<td>Dwell Time at Extremes</td>
<td>12 hrs</td>
</tr>
<tr>
<td>Number of Cycles</td>
<td>365 per year</td>
</tr>
<tr>
<td>Temperature Ramp Rate</td>
<td>&lt; 20 °C/min</td>
</tr>
<tr>
<td>Required Life of the Aircraft</td>
<td>20 yrs</td>
</tr>
</tbody>
</table>

Commercial aircraft requirements (DO-160C)

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Worst Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabin Altitude</td>
<td>8000 feet</td>
<td>Ground</td>
</tr>
<tr>
<td>Cooling Air Temperature</td>
<td>30 °C</td>
<td>70 °C</td>
</tr>
<tr>
<td>Cooling Method</td>
<td>Forced Air</td>
<td>Fan Off</td>
</tr>
</tbody>
</table>

Example: Actual Aircraft Temperature Profile


* Measured by an Aircraft Equipment Monitor (AEM) fitted in a commercial aircraft

Cycle Extraction

Cycle extraction data analysis modules can:

- Import temperature history
- Extract parameters from history
- Eliminate small ranges from history
- Bin cycles into an output CSV file

This is needed to convert time based field loading to usable life analysis inputs.
Monitored Conditions Vs Local Condition

Outside Environment
- Ambient temperature
- Ambient pressure
- Box mounting
- Air velocities

Inside Environment
- Component heat losses
- Geometry and layout
- Damping
- Cooling method

Local Environment

Load Transformation

Based on the response of the structure to applied and internally generated loading conditions, stresses for use in the failure models are calculated.

Housing Fixture

Global Simulation Model

Local Simulation Model

Temperatures

Mode Shape and Frequencies

Curvatures and Displacements

Load Transformation

Relay strain gage PSD @ 25c

Anticipated Loads
Failure Assessment

- Determine time-to-failure for each applicable failure mechanism at each identified failure site
- Often involves multiple scenarios
  - Both accelerated test and field environment
- Conducted using physics-of-failure based models
- Determines damage accumulation per cycle as each failure site.
- Displays in results in multiple formats

SARA for Test

2 mm thick board contained PBGA, TSOP, TQFP, CLCC packages. The simulation model was based on a test vehicle used under the JGPP/JCAA Pb-free Solder Test Program. Test assemblies were subjected to a -55 to 125°C temperature cycle and a -20 to 80°C cycle condition.
SARA for Product Development (Body Module Control)
Design-Build-Test-Fix vs. Simulation Assisted Design

- Product development using simulations produced a more robust design, faster
- First pass issue reductions: 100% E/E circuits, 83% permanent failures, 75% EMI, 63% total
- The more complex module using the simulated assisted design achieved higher quality durability and reliability by beta version in a faster period.

<table>
<thead>
<tr>
<th>Program Comparison:</th>
<th>Moderate</th>
<th>More Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>E/E Technology:</td>
<td>Proven Tech/Compts - No Electromech.</td>
<td>Proven Tech/Compts+4 Onboard Relays</td>
</tr>
<tr>
<td>Functional/Software Complexity:</td>
<td>Moderate</td>
<td>More Functions, More Complex</td>
</tr>
<tr>
<td>Power/Internal Heat:</td>
<td>Low Power/Heat</td>
<td>High Power &amp; Thermal Challenges</td>
</tr>
<tr>
<td>Packaging:</td>
<td>I.P. Mounted Snap Fit, 1 conn.</td>
<td>Console Mnt., Integ’t’d w/Fuse (NEW)</td>
</tr>
<tr>
<td>Supplier:</td>
<td>Supplier A - Highly Capable</td>
<td>Supplier A - Highly Capable</td>
</tr>
</tbody>
</table>

Results:
- # of Total Test Issues Identified:
  - Pontiac Grand Am: Completed 1/98
  - Pontiac Aztek: Completed 8/99

Testing Results:
- 20 pin Leadless Chip Carrier (LCC) was weak in design
- Estimated life under operating conditions - 6.5 years
- Developed Log Case Study for Potential Improvements
  - Module Level - 5,000 units fielded - 20 years field life

Analysis Results:
- Testing of CCAs demonstrated failures predicted by CalcePWA Analysis. Redesign of module results in an estimated savings of $27 mil in avoided cost.

SARA for Product Assessment (Radio System)

Objectives:
- Assess reliability of Control Module in the military environment
- Improve reliability of Control Module

Testing Results:
- Aluminum Backplane
- Board 1 Frame
- Board 2
- Board 3
- Aluminum Backplane

Developed Log Case Study for Potential Improvements
- Module Level - 5,000 units fielded - 20 years field life

References:
Flight was discretized into events and each event was characterized by vibration loading based on structural simulation and measured data.
## Life Cycle Environment Specification

<table>
<thead>
<tr>
<th>Environment</th>
<th>Load Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>Thermal and vibration conditions</td>
</tr>
<tr>
<td>Storage</td>
<td>Thermal and humidity conditions</td>
</tr>
<tr>
<td>Transportation</td>
<td>Thermal and vibration conditions</td>
</tr>
<tr>
<td>Acceptance Test</td>
<td>Temperature cycling and random vibration conditions</td>
</tr>
<tr>
<td>Pre Launch Operations</td>
<td>Vibration, thermal, humidity conditions</td>
</tr>
<tr>
<td>Flight Operations</td>
<td>Random vibration, shock and thermal conditions</td>
</tr>
<tr>
<td>Recovery Operations</td>
<td>Thermal conditions</td>
</tr>
</tbody>
</table>

## Usage Condition

<table>
<thead>
<tr>
<th>Usage Condition</th>
<th>Load Type and Duration</th>
<th>Exposures To Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration Acceptance Test</td>
<td>Random Vibration (60 sec)</td>
<td>15</td>
</tr>
<tr>
<td>Thermal Acceptance Test</td>
<td>Temperature Cycling</td>
<td>27</td>
</tr>
<tr>
<td>Flight (Non Vibration-Isolated)</td>
<td>Random Vibration and Shock (~ 7 min)</td>
<td>1</td>
</tr>
<tr>
<td>Flight (Vibration Isolated)</td>
<td>Random Vibration and Shock (~ 7 min)</td>
<td>7</td>
</tr>
</tbody>
</table>

## Remaining Life of Test Article

<table>
<thead>
<tr>
<th>Component</th>
<th>Total damage accumulation to date $D_{TD}$</th>
<th>Damage per future mission $D_M$</th>
<th>Remaining life in number of missions $N_M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.292</td>
<td>3.18E-02</td>
<td>22</td>
</tr>
<tr>
<td>CR14</td>
<td>0.207</td>
<td>2.08E-02</td>
<td>40</td>
</tr>
<tr>
<td>CR6</td>
<td>0.167</td>
<td>1.64E-02</td>
<td>52</td>
</tr>
<tr>
<td>CR10</td>
<td>0.153</td>
<td>1.52E-02</td>
<td>57</td>
</tr>
<tr>
<td>Tb</td>
<td>0.130</td>
<td>1.31E-02</td>
<td>68</td>
</tr>
<tr>
<td>CR2</td>
<td>0.123</td>
<td>1.20E-02</td>
<td>75</td>
</tr>
<tr>
<td>Ta</td>
<td>0.117</td>
<td>1.18E-02</td>
<td>76</td>
</tr>
<tr>
<td>Q15</td>
<td>0.0143</td>
<td>1.59E-03</td>
<td>619</td>
</tr>
<tr>
<td>Q11</td>
<td>0.0143</td>
<td>1.58E-03</td>
<td>621</td>
</tr>
<tr>
<td>Q3</td>
<td>0.0142</td>
<td>1.58E-03</td>
<td>623</td>
</tr>
</tbody>
</table>

\[
N_M = \frac{(D_f - D_{TD})}{D_M}
\]

$D_f$ is the damage failure criteria (usually equal to 1.0).

1. Since P1 (connector) is secured to the circuit board with screws, the remaining life of CR14 (diode) is used as the baseline estimate of the remaining life of the circuit card.

2. It was estimated that the test article card could survive over 20 more missions.

---

Summary

- Estimating reliability of electronic assemblies depends on understanding the physical failure mechanisms.

- PoF Models are available for common mechanisms that produce failure in electronic assemblies.

- Software is available to simulate life expectancy of stress levels and evaluate PoF models. Life expectancies can be estimated and results can be used to develop effective tests.

- Determining actual use conditions likely to lead to the most uncertainty in life assessment.

- Modeling approach can also be used to develop prognostic strategies by identifying monitoring points and allowing for the design of prognostic canaries.
What is CALCE?
Center for Advanced Life Cycle Engineering (founded 1987) is dedicated to providing a knowledge and resource base to support the development and sustainment of competitive electronic components, products and systems. Focus areas:
- Physics of Failure
- Design of Reliability
- Accelerated Qualification
- Supply-chain Management
- Obsolescence
- Prognostics

Center Organization
16 research faculty
5 technical staff
40+ PhD students
20+ MS students
11 visiting scholars

http://www.calce.umd.edu

Resources
- calceSARA
- MOCA
- PHM Toolkit
- Webbooks

Education
- MS and PhD programs
- International visitors
- Web seminars
- Short courses for industry

Lab Services
- Small to medium scale
- Rapid response
- Examples: Failure analysis, measurement, design review, supplier assessment

Research Contracts
- Large scale programs
- Medium to long-term durations
- Contractual agreements
- Examples: Software development, testing, training programs

Standards
- Putting CALCE research to work for industry
- Examples: IEEE IPC SAE

A special thanks to CALCE research sponsors!

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- Advanced Biosics
- Aerotech Systems
- Agilent Technologies
- American Competitiveness Inst.
- Ankor
- Arbortron
- Arcelik
- ASC Capacitors
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- Park Advanced Product Dev.
- Penn State University
- PFI Integrated Warfare
- Petra Solar
- Philips
- Philips Lighting
- Pole Zero Corporation
- Pressure Biosciences
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- Rendell Sales Company
- Research in Motion
- Resin Designs LLC
- RNT, Inc.
- Roadtrack
- Rolls Royce
- Rockwell Automation
- Rockwell Collins
- Saab Avionics
- Samsung Mchtronics
- Samsung Memory
- S.C. Johnson Wax
- Sandia National Labs
- Sandisk
- Schlumberger
- Schweitzer Engineering Labs
- Selux-SAS
- Sensors for Medicine and Science
- SiliconExpert
- Silicon Power
- Space Systems Loral
- SolarEdge Technologies
- Starkey Laboratories, Inc
- Symbol Technologies, Inc
- Symc
- Team Corp
- Tech Film
- Triarima
- Teradyne
- Testron Systems
- The Bergquist Company
- The M&T Company
- The University of Michigan
- Toyota
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- United Technologies Aerospace
- U.S. Air Force Research Lab
- U.S. AMSAA
- U.S. ARL
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- U.S. Army Picatinny/UTRS
- U.S. Army RECOM/ARDEC
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