Solder Fatigue Evaluation
with High Fidelity PWB Assembly Model

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Outline

- Background of Solder Fatigue Evaluation
- Assembly Model and Component Library
- Fidelity and Efficiency
- Actual Design Cases*

*: Certain Numbers Are Omitted for Security Reason
Background of Solder Fatigue Evaluation

- Some PWB May Contain Hundreds of Electronic Components, and Thousands of Solder Joints
- Solder Fatigue in Dynamic Environments Has Been a Major Failure Mode
- Fatigue Evaluation Is Based on
  - Solder Stress in Dynamic Environment
  - Solder Material’s Fatigue Strength (S-N Curve)
- The Challenge Is to Determine Solder Stress – Reliably, and For Thousands of Them!
Assembly Model and Component Library

- It is well understood that an assembly model has the following advantages:
  - Captures component interaction
  - Captures system load path
  - And thus provides fidelity prediction on solder joint response

- But an assembly model would be very costly
  - Can the problems be solved?
Assembly Model and Component Library (Cont’d)

- The Reason for Complexity: Numerous Electronic Components
- Aerojet Solution: Electronic Component Library
  - Component Structural Models Are Pre-Built by Macros with Parameters as Arguments

  BGA:
  IC:
  Capacitor:
  ...

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Then PWB Assembly Models Is Generated by A Series of Function Calls

```
&ael,a,,76,79,3
cm,atopclea,area
!For u19,u25,u34,u43,u52,u61:
weight=0.00077
bga,88,0.018,14,14,0.019,0.04,weight,ex2,3
bga,87,0.018,14,14,0.019,0.04,weight,ex2
bga,89,0.018,14,14,0.019,0.04,weight,ex2
bga,90,0.018,14,14,0.019,0.04,weight,ex2
bga,86,0.018,14,14,0.019,0.04,weight,ex2
bga, 1,0.018,14,14,0.019,0.04,weight,ex2
a1lse
!For j1,j5,j19,j17,
weight=0.0001
chipresist4,11,0.04,0.07,weight,ex2
chipresist4,10,0.04,0.07,weight,ex2
chipresist4,43,0.04,0.07,weight,ex2
esel,s,type,,3
cm,sel,u,etopclea
cm,etopbglead,elem
```
Fidelity and Efficiency

- With the Scattered Components Taking More Than 50% of the PWB Assembly Weight, Such An Assembly Model Captures The Structural Dynamic Characteristics with High Fidelity
  
  1. Components Modeled with Solids,
     - Representing Component Stiffness, Inertia and Contributions to the Assembly
  2. Leads Modeled by Beams
     - Adequate Force and Stress Responses for Fatigue Evaluation
  3. Board and Supports Modeled with Shell and Solids as Appropriate

- First Model Completed in A Couple of Days
  - Design Mod Completed in Minutes
Actual Design Cases: Controller

- A PWB Design in a Propulsion System Contains 500+ Electronic Components
- The Objectives Are to Evaluate Displacement, Strength and Solder Fatigue in the Harsh Dynamic Environments
- Structural Evaluation Is Performed with An Assembly FEA

Bottom View of A PWB
(>500 Components)

FEM of the Assembly
(>38000 Nodes, with Beam/Shell/Solid Elements)
Controller Natural Frequencies and Modes

- Modal Analysis Is Done First to Verify the Frequency Requirements
  - Realistic Stiffness/Mass Distribution Renders High Fidelity to the Results
Controller Deflection

- Then Deformation from a Random Vibration Response Is Used to Verify Deflection Requirements

RMS (1-σ) Displacement

Response Accl. PSD

\[ D_{RMS} = 0.000786 \text{ in} \]

\[ A_{RMS} = 4889 \text{ in/s}^2 \]

\[ F_0 = \sqrt{\frac{A_{RMS}}{2\pi}} = 397 \text{ Hz} \]
Solder Joint Force, Stress and CDI

- Then the Forces of All Solder Joints Are Processed, Deriving Solder Stress and Cumulative Damage Index (CDI)
  - Forces, Stresses, and CDI Are Presented in 3-D Graph

Solder Joint Stresses on the 2300+ Joints

Max. Solder Joint Stress: 9

Stress Distribution Details

Max. Solder Joint Stress: 9

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Conclusions

- PWB Assembly Analysis Provides High Fidelity Structural Dynamic Responses
- Component Library Makes Assembly Analysis Efficient
- Solder Joint Results Presented in 3-D Graph Are Very Informative
- Much Yet to Be Done to Improve, and Correlate with Tests
Additional Info

- **Analysis Approach**

  - **Modeling**
    - CAD
    - Board Layout
    - Datasheet & Library
    - Housing Model
    - TCCA Model
    - TCCA Assembly Model

  - **Strength Evaluation**
    - G-Loads
    - Flight PSD
    - Static Analysis
    - Random Vibration
    - Strength Evaluation

  - **Solder Fatigue Evaluation**
    - Launch Environment
    - Flight Environment
    - Random Vibration
    - TDAC Op Environment
    - Accumulated Damage & Solder Fatigue Evaluation
More of Component Library

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1. BGA Component FEM Model
2. BGA Component output

3. Chip resistor with surface mounts
4. Chip with heat sink

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Solder Joint Forces on the 2300+ Joints

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Solder Joint CDI

Solder CDI on 2500+ Joints

BGA CDI Details

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Solder Fatigue Evaluation (Steinberg)

- Fatigue Life Consumption in Dynamic Environments Is Measured by “Cumulative Damage Index” (CDI), Calculated with The “3-Band” Technique that Implements Miner’s Rule

\[
CDI = \sum \frac{n_i}{N_i} = f_c T \left( \frac{0.6831}{N_1} + \frac{0.271}{N_2} + \frac{0.0433}{N_3} \right)
\]

- Stress Frequency:

\[
f_c = \frac{1}{2\pi} \left[ \int \omega^2 D(\omega) d\omega \right]^{1/2} / \int D(\omega) d\omega
\]

- Solder S-N Curve: