National Aeronautics and Space Administration

Components to Assembly: Role of Model Based Physics-of-Failure (PoF) Reliability Assessment

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Reliability and Risk Assessment Branch

SAFETY and MISSION ASSURANCE DIRECTORATE Code 300

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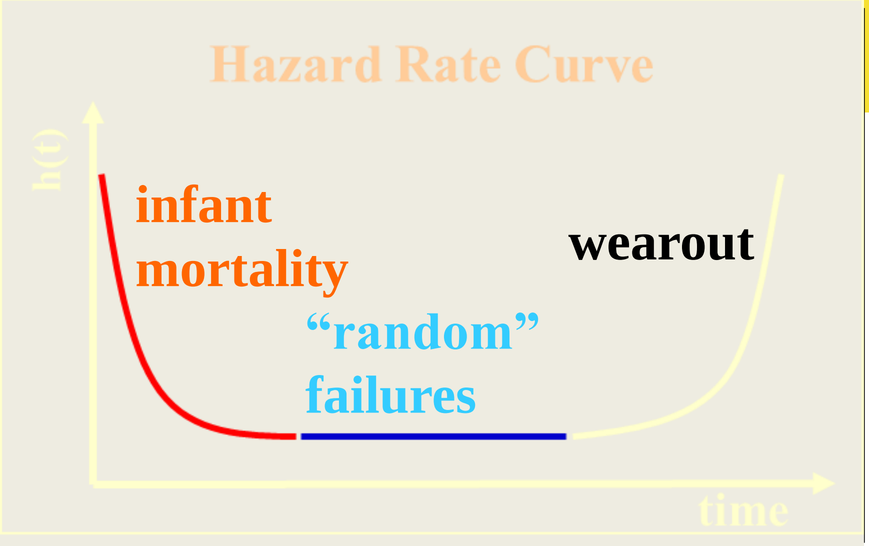
Reliability – a PoF Perspective

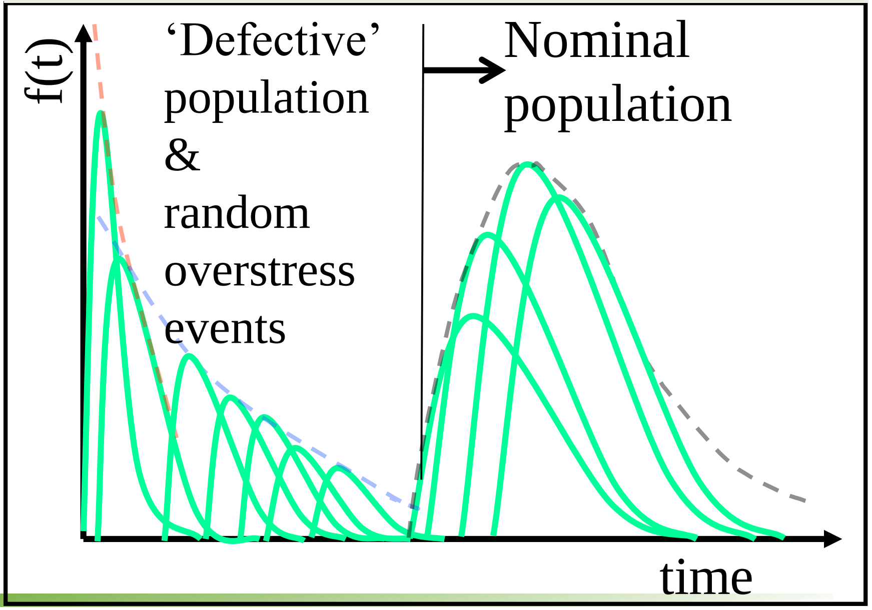


Reliability statisticians are interested in:

- Tracking system level failure data during the service life for logistical purposes.
- Determining the hazard rate curves.

PoF reliability engineers are interested in:

- Understanding the individual failures.
- Controlling the causes.



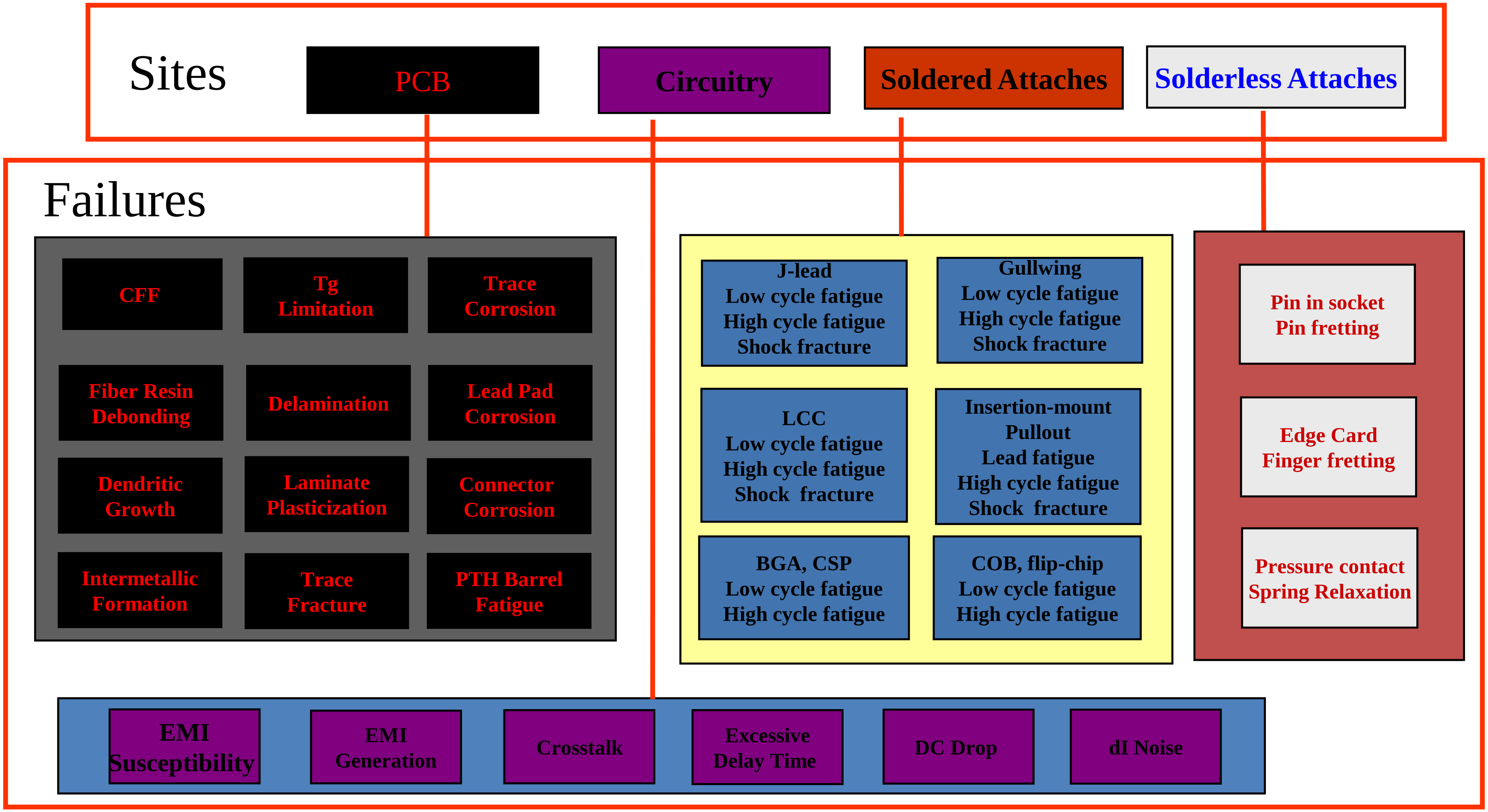
This is done by:

1. Assessment of influence of hardware configuration.
2. Systematic and detailed study of life-cycle stresses on root-cause failure mechanisms.
3. Influence of materials at potential failure sites.

PoF Fundamentals: Terminology

Failure………………	product no longer performs the intended function
Failure Mode…………	the effect by which a failure is observed
Failure Mechanism…..	physical, chemical, thermodynamic or other process that results in failure
Failure Site……………	location of the failure site
Fault/Defect………….	weakness (e.g., crack or void) that can locally accelerate damage accumulation and failure
Load……………………	application/environmental condition (electrical, thermal, mechanical, chemical...) that can precipitate a failure mechanism
Stress…………………..	intensity of the applied load at a failure site

Failure Mechanisms in Printed Wiring Assemblies

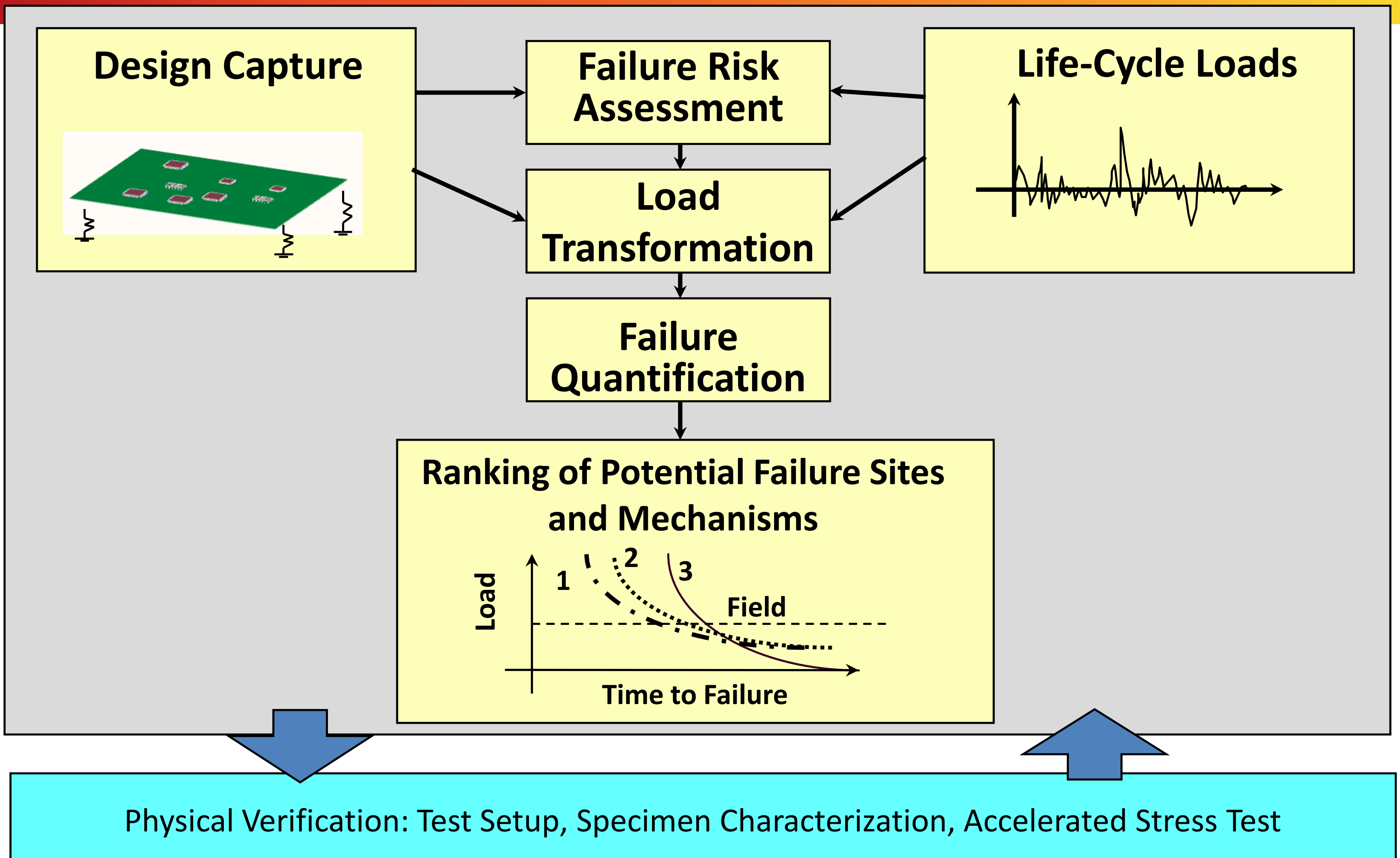


Virtual Qualification: A Method to Apply PoF in Electronic Design

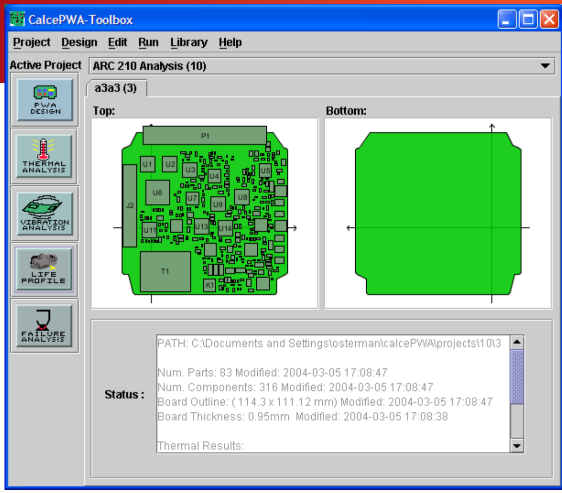
- VQ is a simulation-based methodology that assesses whether a system can meet defined life cycle requirements based on its materials, geometry, and operating characteristics.

- Virtual qualification is based on physics-of-failure (PoF) principles and focuses on the dominant wear-out mechanisms in electronic products
  - Focus on interconnect materials such as solder joints.
  - Printed circuit board features such as plated through-holes (PTH).

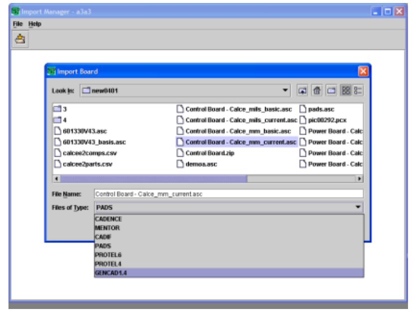
Steps in Virtual Qualification



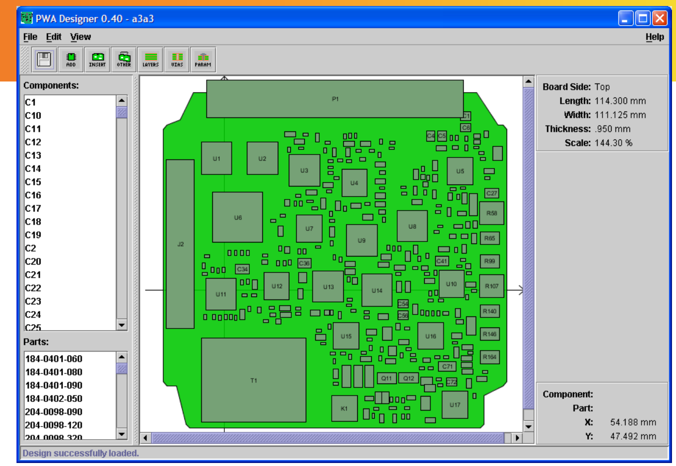
Virtual Qualification Software



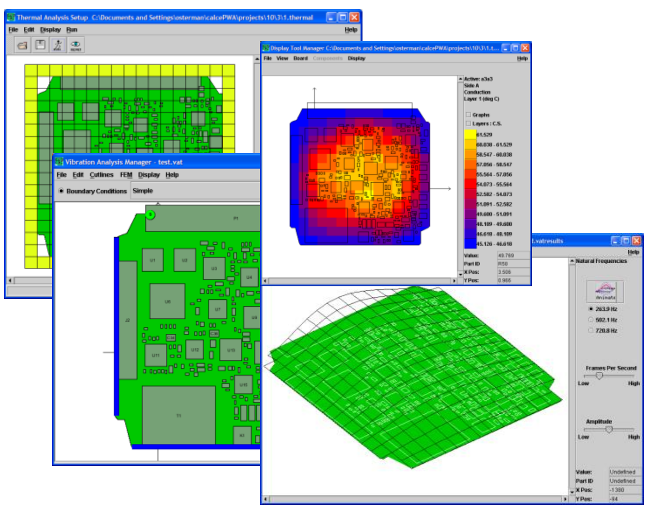
Assessment Management



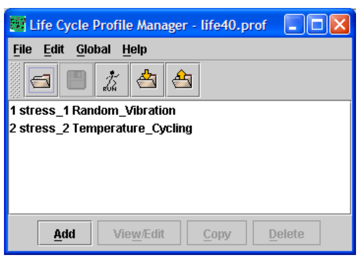
Interface to CAD



Design Capture



Stress Assessment



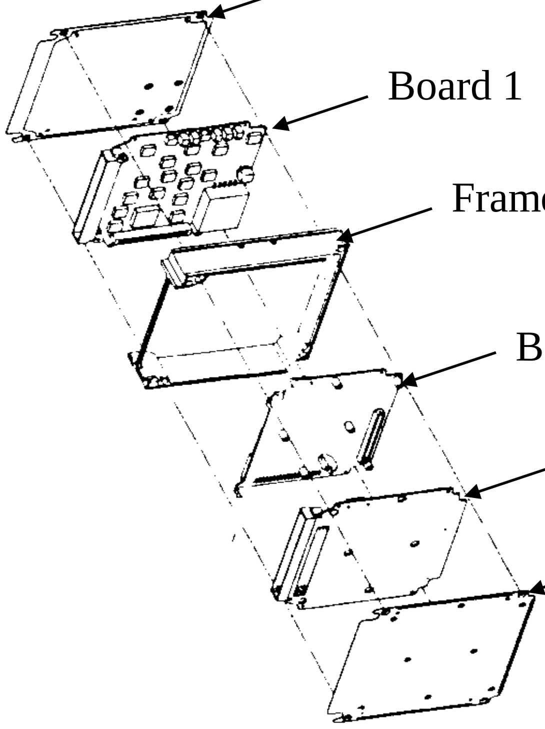
Life Cycle Characterization

Life Expectancy and Failure Assessment

Case Study: Virtual Qualification of Radio Control Module

RT 1556 Control Module

- Consists of 3 CCA's with 6 layer PWB's
- Ceramic and plastic microcircuits
- SMT and PTH technology
- Commercial and military components
- Approx. Cost $5k/module



CCAs
Approximately 4.5x4.5"
40 mils thick laminated BT backed with 25 mil Al Plate

Components
- 50 microcircuits
- 7 connectors
- 22 inductors
- 44 semiconductors
- 241 capacitors
- 222 resistors

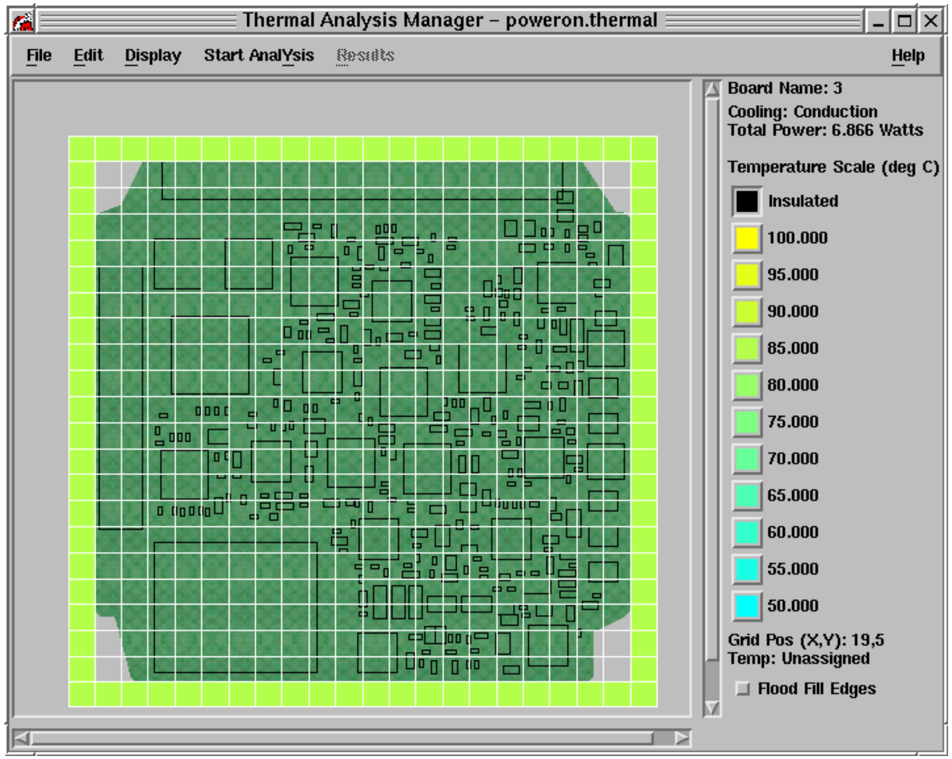
Life Cycle Loading Conditions

Life Expectancy: 20 years

- Power-On Time = 10,080 hours
  30 flight hours per month, ratio on time vs flight time = 1.4
- Thermal Cycles = 7,200 cycles
  one cycle per flight hour, 30 flights per month
- Vibration Cycles = 3.6×10^6 to 70.8×10^6 cycles
  Maximum PSD $0.04 G^2/Hz$
  100-1000 Hz (Absolute worst case, 10% of flight hours ~ 10^9 cycles)

Thermal Analysis

Thermal simulation of the circuit card was performed to obtain operating temperatures and temperature gradients between board and components.



Boundary Conditions

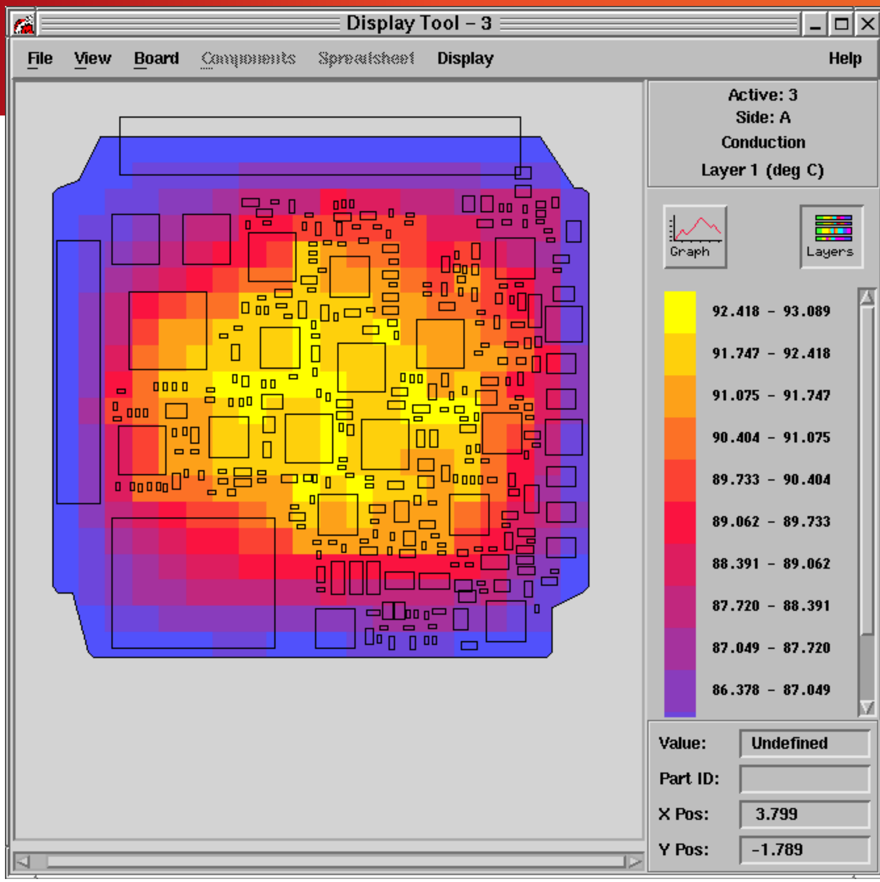
Component Data

- Component interconnect geometry and material
- Component standoff height
- Thermal vias
- Thermal paste

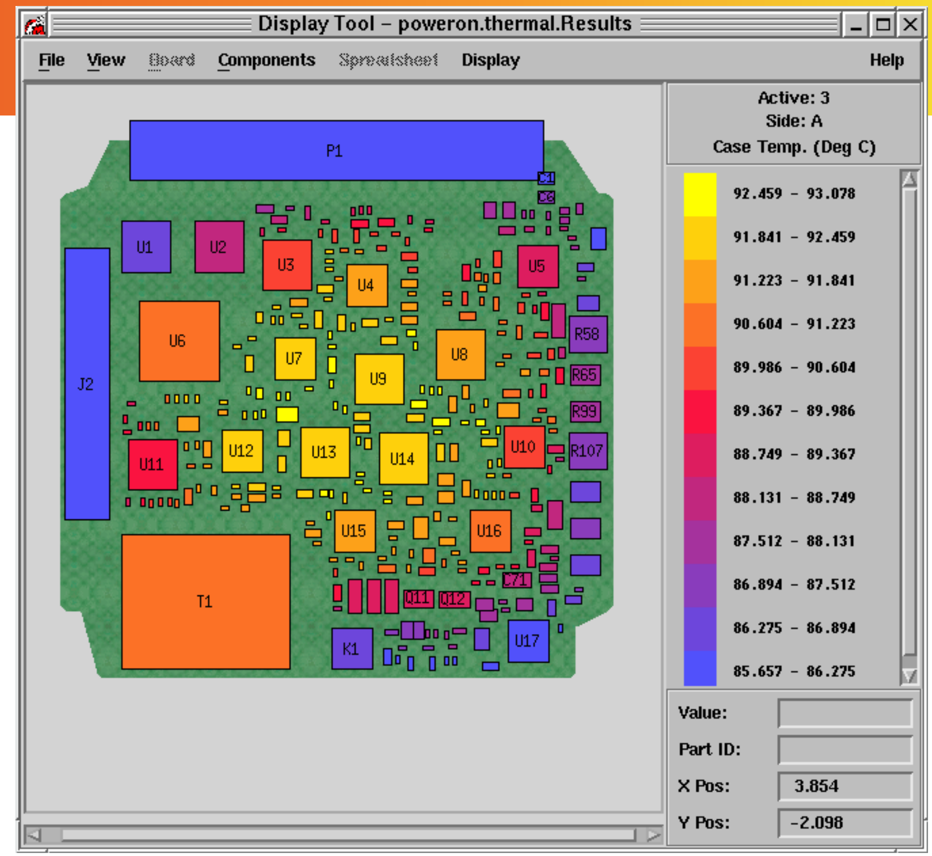
Board Data

- Material composition of board layers
- Thermal conductivity of board material

Thermal Analysis – Results



Layer 1 Temperature

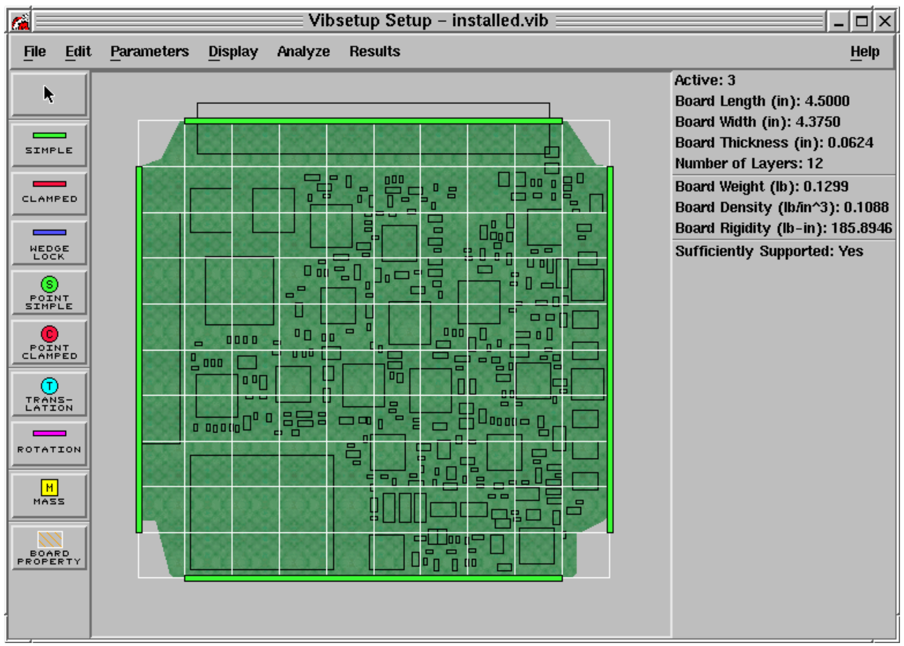


Component Temperature – Case Temperature

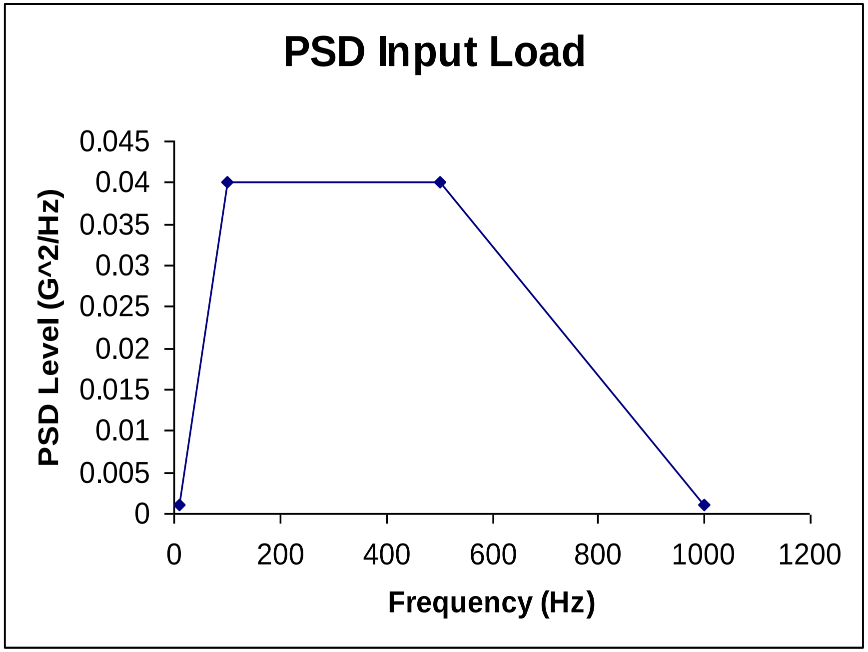
Board and component temperatures are used to confirm that parts will operate below temperature limit and in developing a life cycle loading scenario. Simulation indicated an 8°C rise above ambient during operation which was confirmed in test.

Vibration Analysis – Problem Definition

Vibration simulation of the circuit card was performed to obtain the natural frequency and board response to the anticipated loading condition.

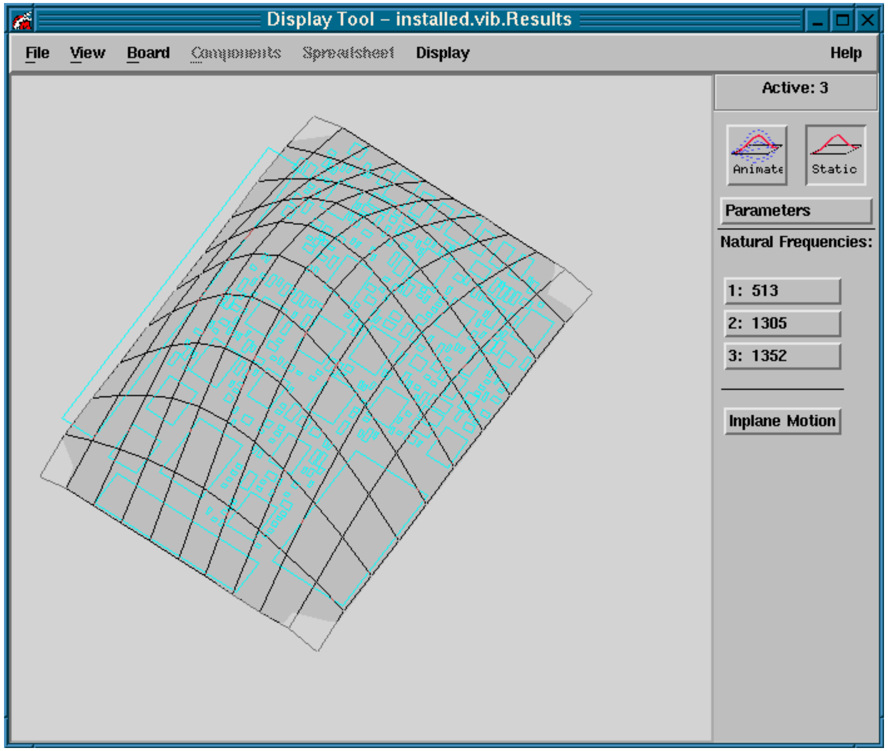


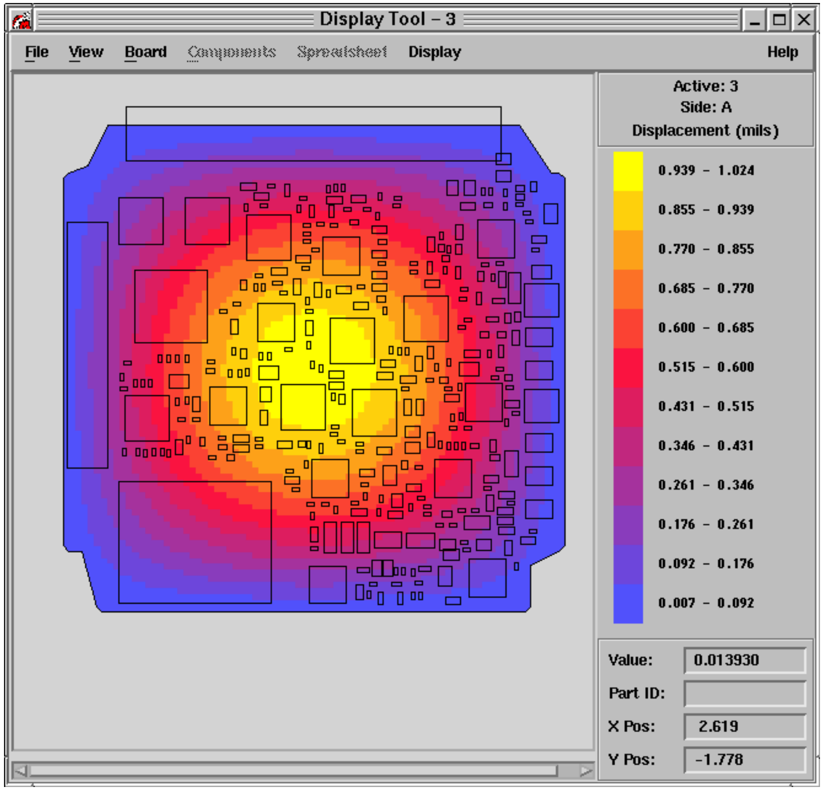
Boundary Conditions



Input Loading

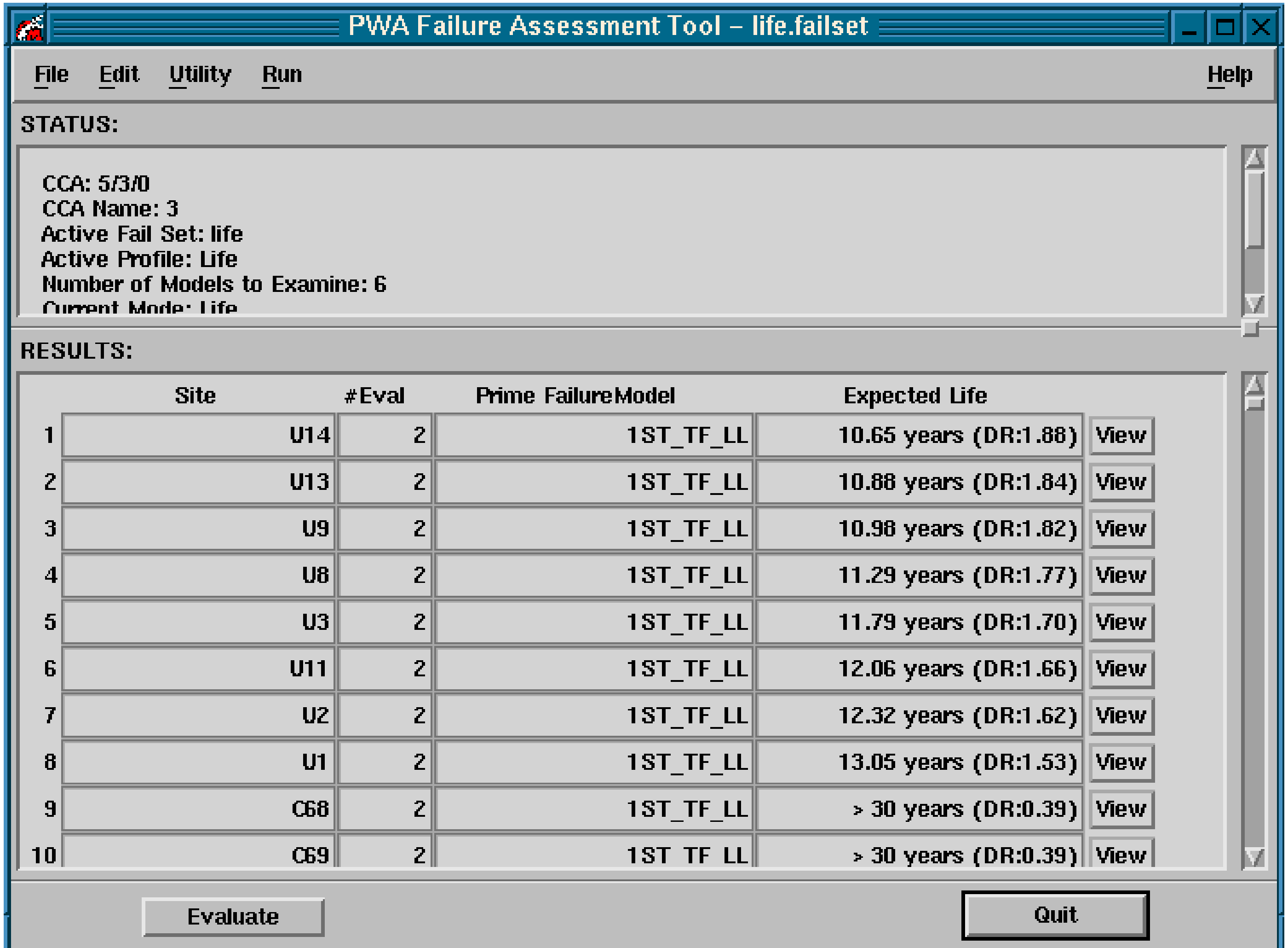
Vibration Analysis – Results





- Natural Frequency > 500 Hz
- Maximum curvature at board center

Failure Assessment For Life Cycle Loading



The failure assessment of the life cycling loading scenario and database indicates that the module will not meet its 20 year design requirement. The life is equivalent to 3800 thermal cycles.

Virtual Testing

Using the simulation model, a physical test was developed to precipitate failures.

Test conditions:

Temperature cycling: -50 to 95°C, dwell, 2 hours per cycle

Vibration: 0.04 G^2/Hz, 6.10 Grms, 10 hours

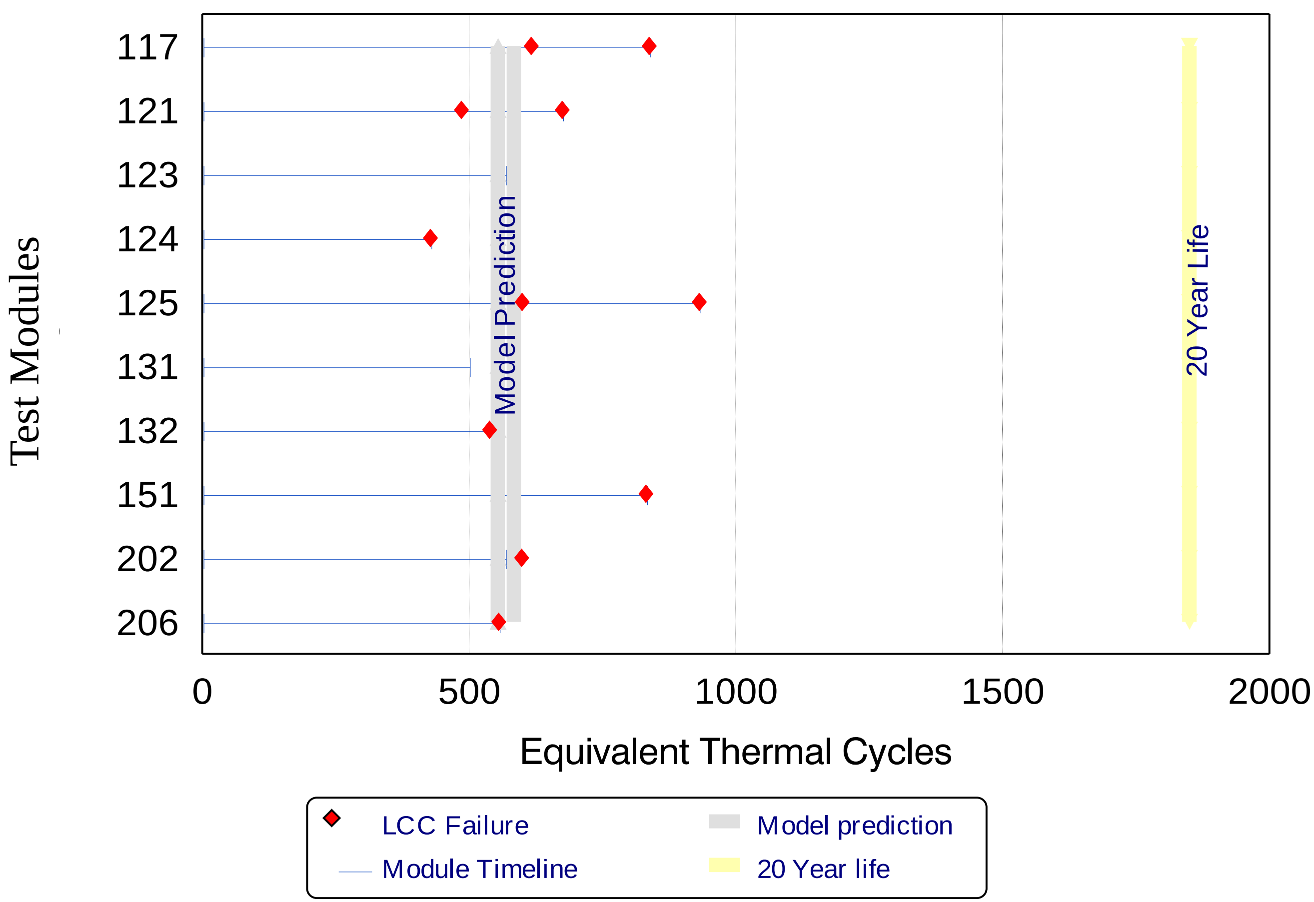
RESULTS:

	Site	#Eval	Prime FailureModel	Expected Life	
1	U14	2	1ST_TF_LL	62.38 days (DR:1.04)	View
2	U1	2	1ST_TF_LL	62.38 days (DR:1.04)	View
3	U2	2	1ST_TF_LL	62.38 days (DR:1.04)	View
4	U9	2	1ST_TF_LL	64.96 days (DR:1.00)	View
5	U13	2	1ST_TF_LL	64.96 days (DR:1.00)	View
6	U8	2	1ST_TF_LL	64.96 days (DR:1.00)	View
7	U3	2	1ST_TF_LL	64.96 days (DR:1.00)	View
8	U11	2	1ST_TF_LL	64.96 days (DR:1.00)	View
9	C69	2	1ST_TF_LL	312.84 days (DR:0.21)	View
10	C29	2	1ST_TF_LL	312.84 days (DR:0.21)	View

Simulation Results

Test would require approximately 63 days or 750 thermal cycles.

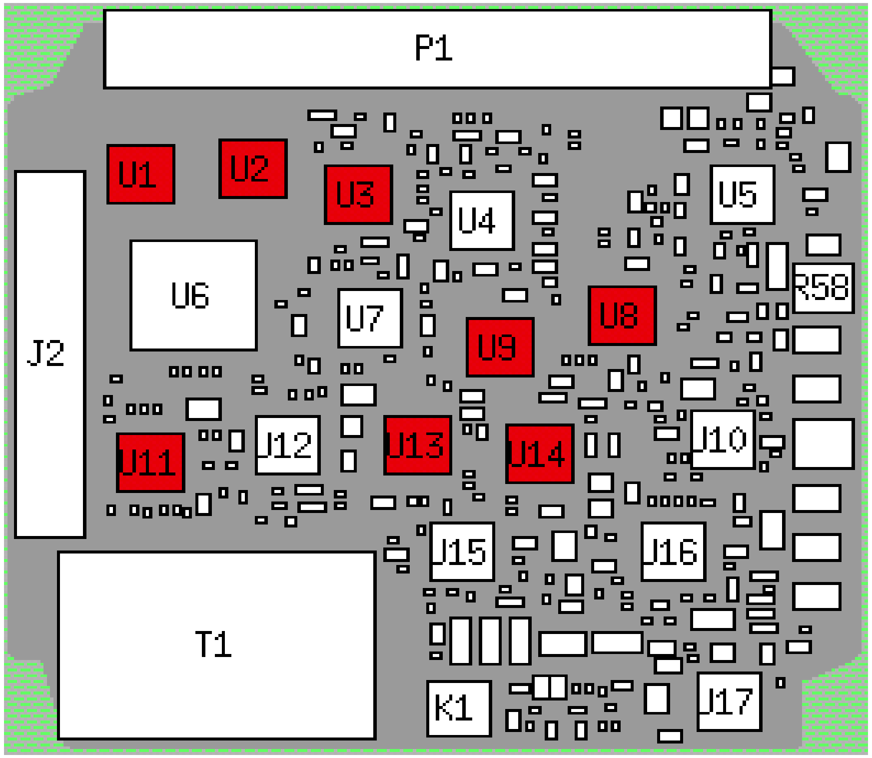
Testing Results



Test conditions:
Temperature cycling: -50 to 95°C, dwell, 2 hours per cycle.

Vibration: 0.04 G^2/Hz, 6.10 Grms, 10 hours

Summary of Radio Module VQ



Virtual Qualification Results:

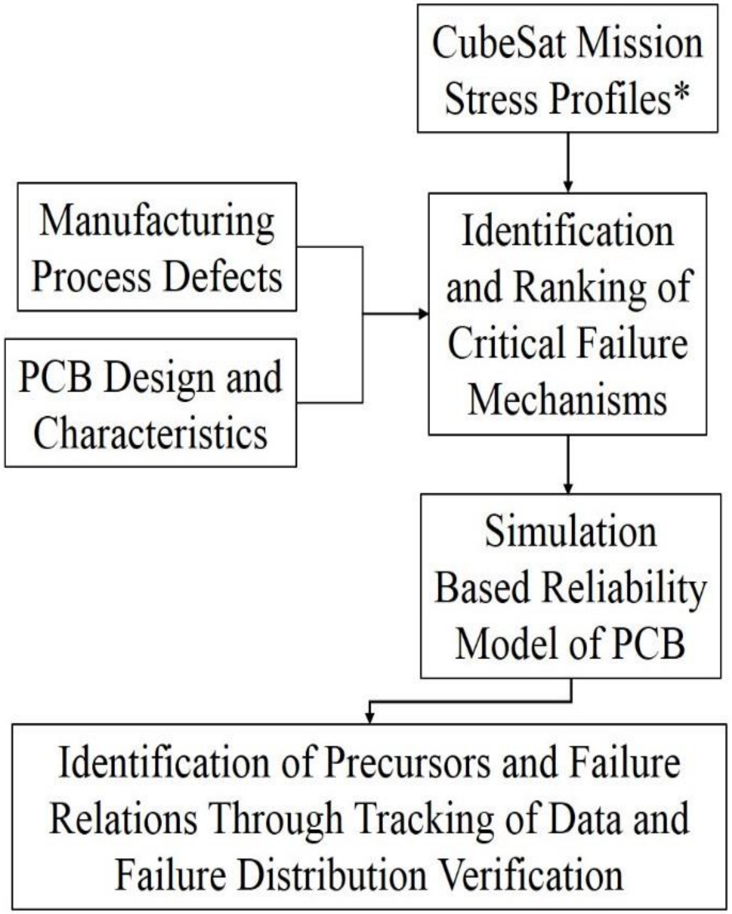
- Identified 20 pin Leadless Chip Carrier (LCC) as a weak link in the CCA design
- Estimated time-to-failure during accelerated life test cycle
- Estimated life under operating conditions - 6.5 years

- Changed design to remove the 20 pin LCC
- Improved reliability of modules - 5,000 units fielded - 20 years field life
- Avoided potential cost of $27M in operation and sustainment.

Case Study: SpaceCube Processor Card

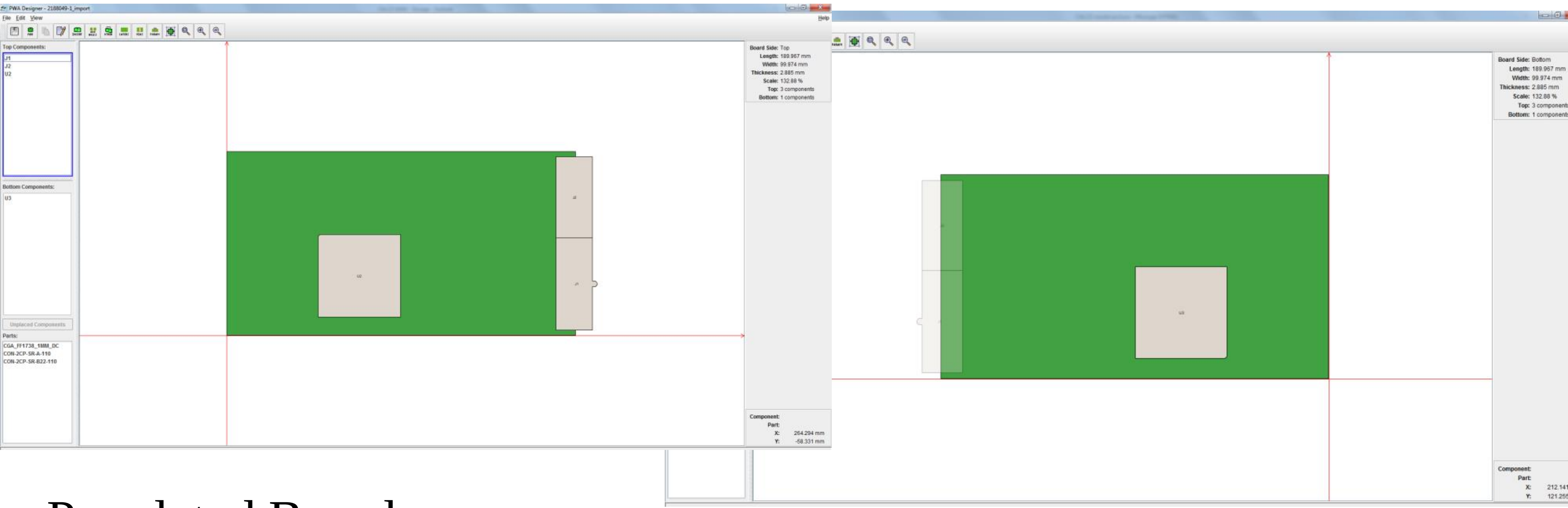
- Identified candidate PCBA

- Life cycle stress profiles
- Computer model of the PCBA
- PCB inspection data, design inputs - corresponding “safe” characteristics



** - Partial Input from Historical Review of on-orbit CubeSat Performance*

Overview of the SpaceCube Processor Card



Populated Board

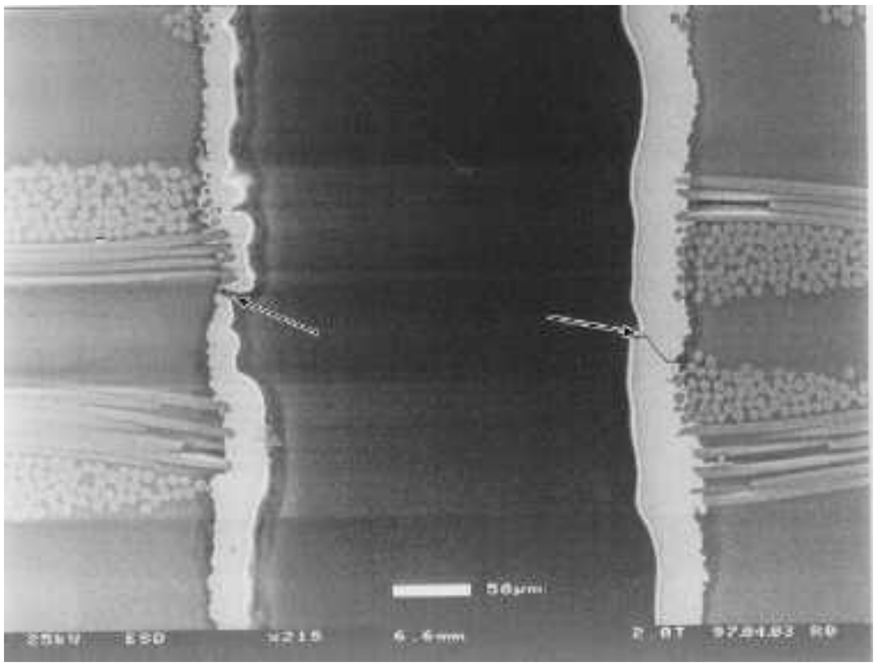
Expected stress conditions:

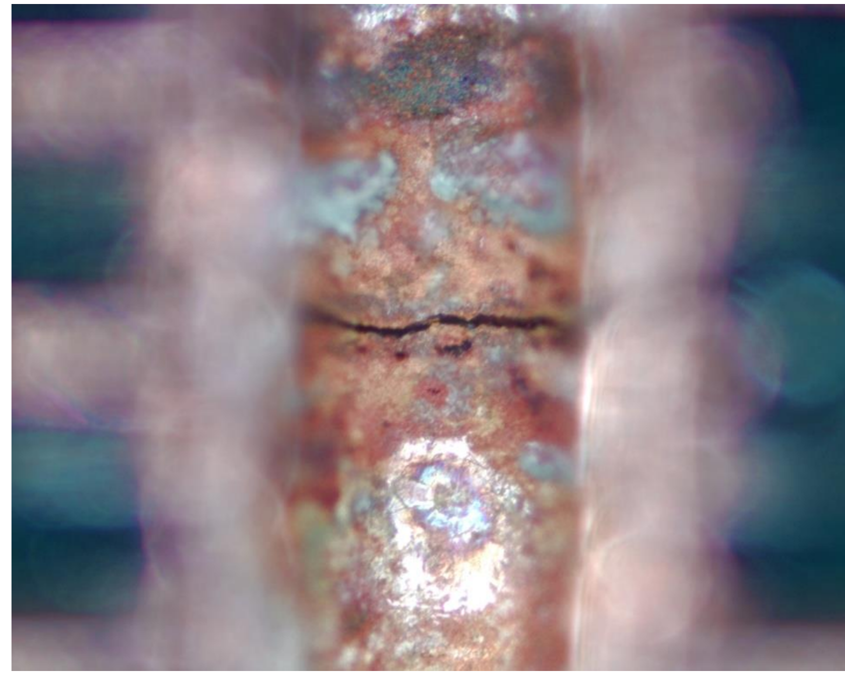
- -7°C to 48°C
- Limits set at -30°C to +55°C
- 14.1 GRMS

BOM:

- CGA package 1752 pin, 1mm pitch, 20mil diameter, 90/10 solder with eutectic
- MLCCs, SMD resistors, diodes, connectors, actives and power MOSFETs

Printed Wiring Board Failure Mechanism Plated Through Hole Circumferential Cracking

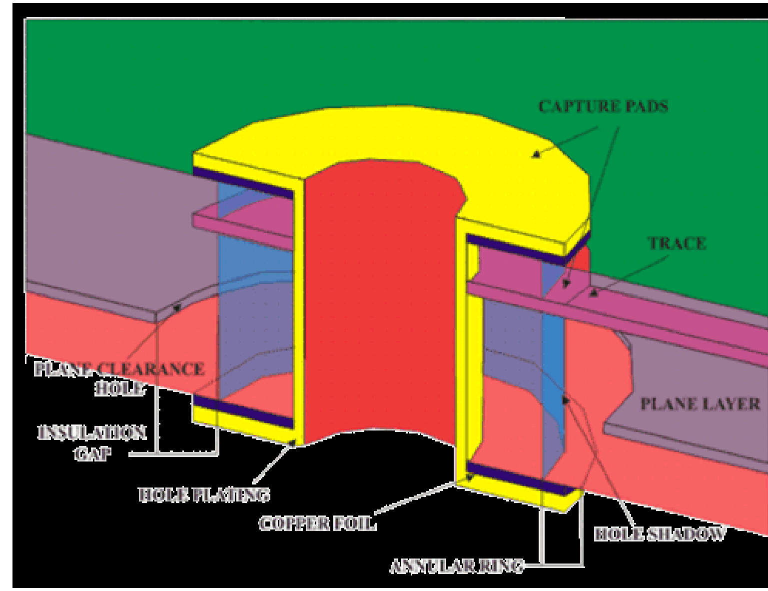


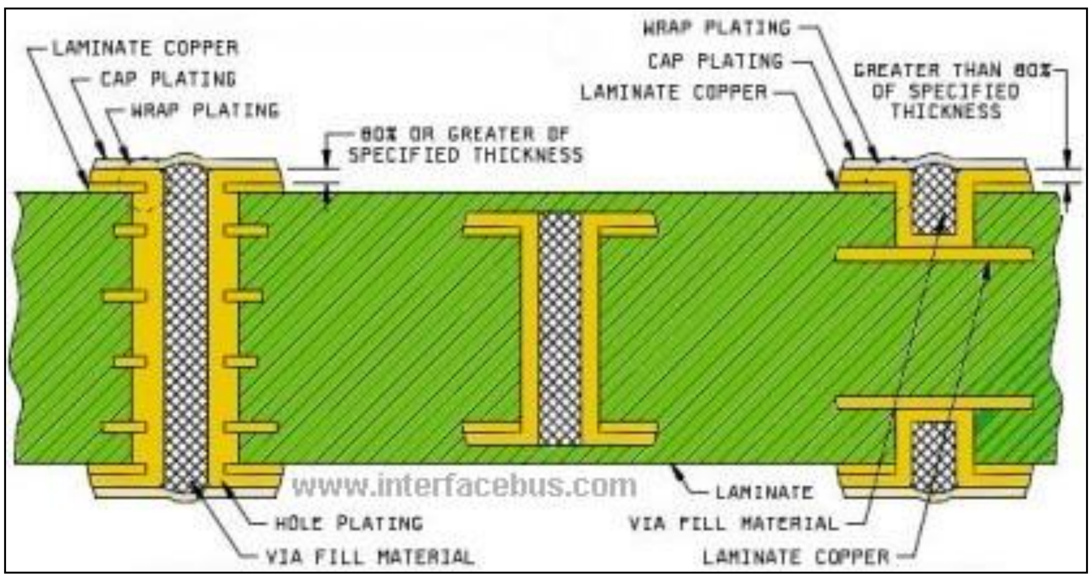


The difference in the “z” coefficient of thermal expansion (CTE) of the copper plating and the resin system in the PWBs is usually greater than a factor of 10. Higher reflow temperature will induce greater damage on large aspect ratio PTHs.

PTH Low-Cycle Fatigue in PWBs

PWB-CTE in thickness (z) direction: ~50-90 E-6 /^{o}C and Cu-CTE in plating: ~20 E-6 /^{o}C





Thermal excursions cause thermal expansion mismatch in the thickness direction

Feature	Variant	Effect on PTH Stress	Reason
Location	Spacing between PTHs	More closely spaced PTHs associated with a reduction in stresses	Out of plane constraints reduced and more readily shared between adjacent PTHs.
Barrel	Stress variation with respect to midplane	Stress increases closer to mid plane; maximum barrel stress at mid plane.	Results of thermally induced stress analysis.
Innerplanes	Polyamide boards	• Local stress concentration at innerplane (could exceed midplane stress depending on location wrt midplane) • Overall reduction (10%) in barrel stress outside concentrations (vs no innerplanes)	In plane CTE between Cu and Polyamide have a larger delta than FR-4 and Cu
Aspect Ratio	MLB Thickness/Hole Diameter	High aspect ratio associated with high stresses.	0.030" boards are most robust according to IPC TR-579; 0.090" boards are less robust all other dimensions being equal.
Plating	Thickness	2 mils variation (1-3 mils thickness) can change stress levels by 25%	More metal, less stress
Solder Filling PTHs	Solder Filled	Reduction in overall barrel stress 3%-9%	More metal (solder); small effect due to properties of solder

Summary

- Multifaceted PoF tools are being used in the SmartCube development process:
  - Adoption of PoF approaches allows the team to understand the product degradation processes and account for degradation during the design.

- Simulation based failure assessment is ongoing, stresses include
  - thermal analysis
  - vibration analysis
  - virtual failure assessment

- Algorithms are based on PoF knowledge assembled through the review of published literature and on the basis of research conducted at the University of Maryland.

Acknowledgements:

- John Evans/OSMA for supporting PoF Based VQ Efforts.
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