CALCE Simulation Assisted Reliability Assessment (SARA™) Software

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https://calce.umd.edu/calce-sara-software

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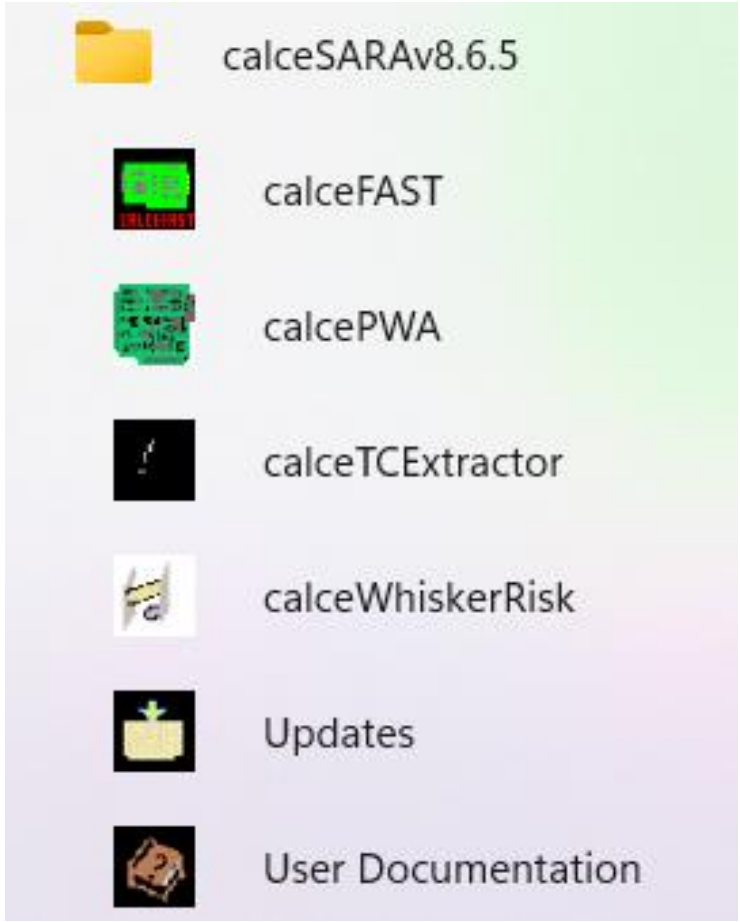
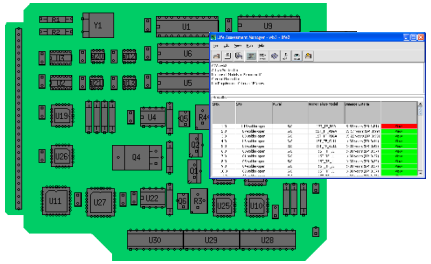
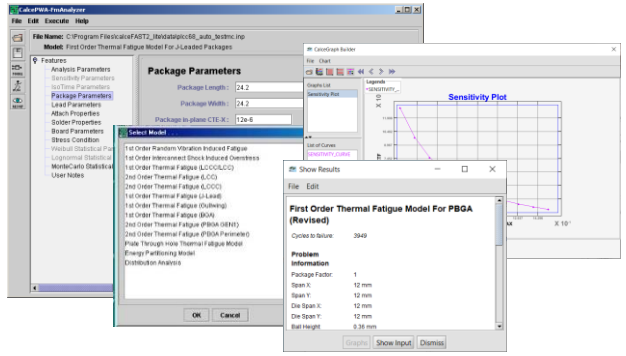


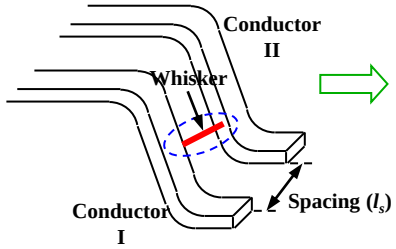


calcePWA
Circuit Card Assemblies

Thermal Analysis
Vibrational Analysis
Shock Analysis
Failure Analysis



calceFAST
Failure Assessment Software Toolkit

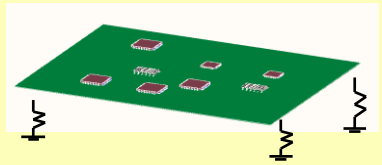


calceTinWhisker
FailureRiskCalculator

Simulation Assisted Reliability Assessment

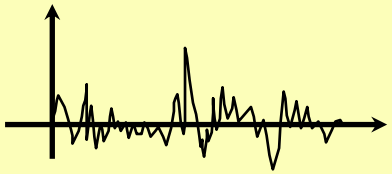
Virtual Qualification

Design Capture



Load Transformation

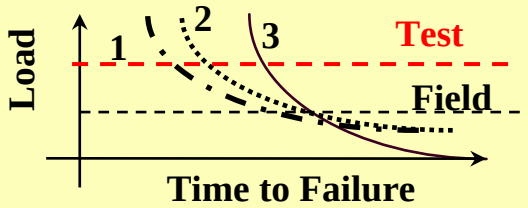
Life-Cycle Loads



Failure Risk Assessment

Failure Quantification

Ranking of Potential Failure Sites and Mechanisms



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

Uses of Virtual Qualification

- Life assessment under anticipated loading conditions
- Design trade-offs
- Accelerated test planning
- Interpretation of accelerated test results with respect to field life
- Remaining life assessment
- Prognostics development

CalcePWA Software Assessment (Military Radio)

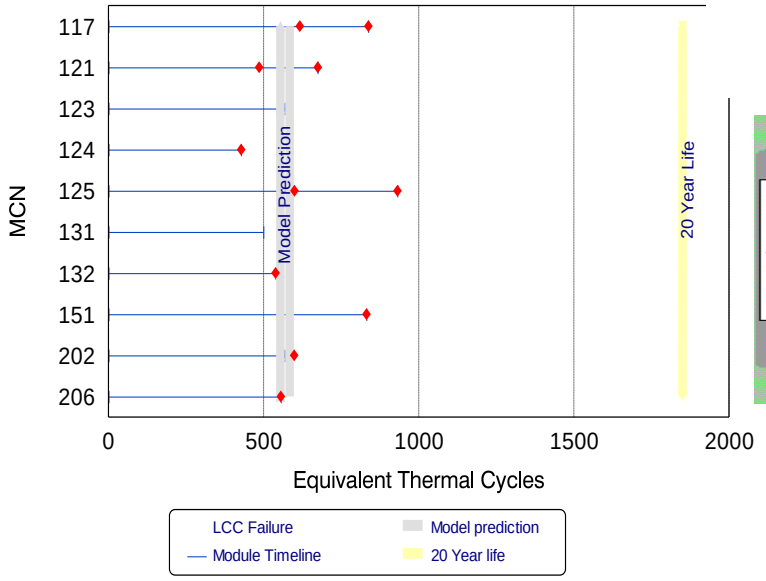
Objectives:

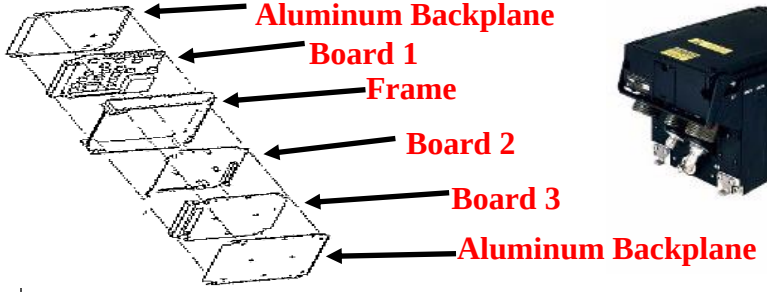
- Assess reliability of Control Module in the military environment
- Improve reliability of Control Module

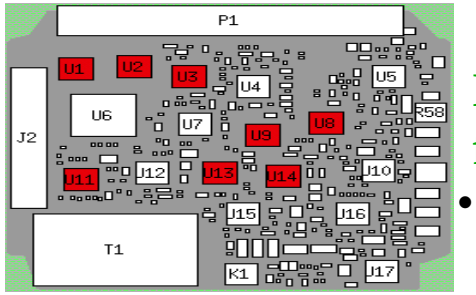
Analysis Results:

- 20 pin Leadless Chip Carrier (LCC) was weak in design
- Estimated life under operating conditions - 6.5 years

Testing Results:





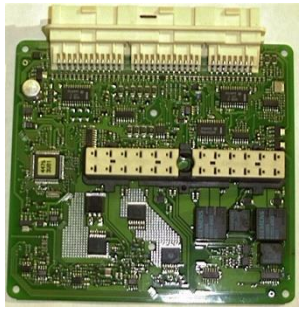


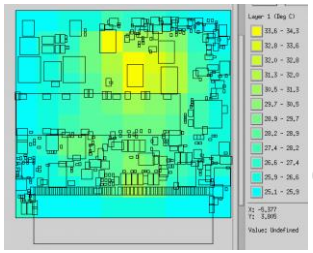
Developed Log Case Study for Potential Improvements

- Module Level - 5,000 units fielded - 20 years field life

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

Successful Application of calceSARA
Design-Build-Test-Fix vs. Simulation Assisted Design





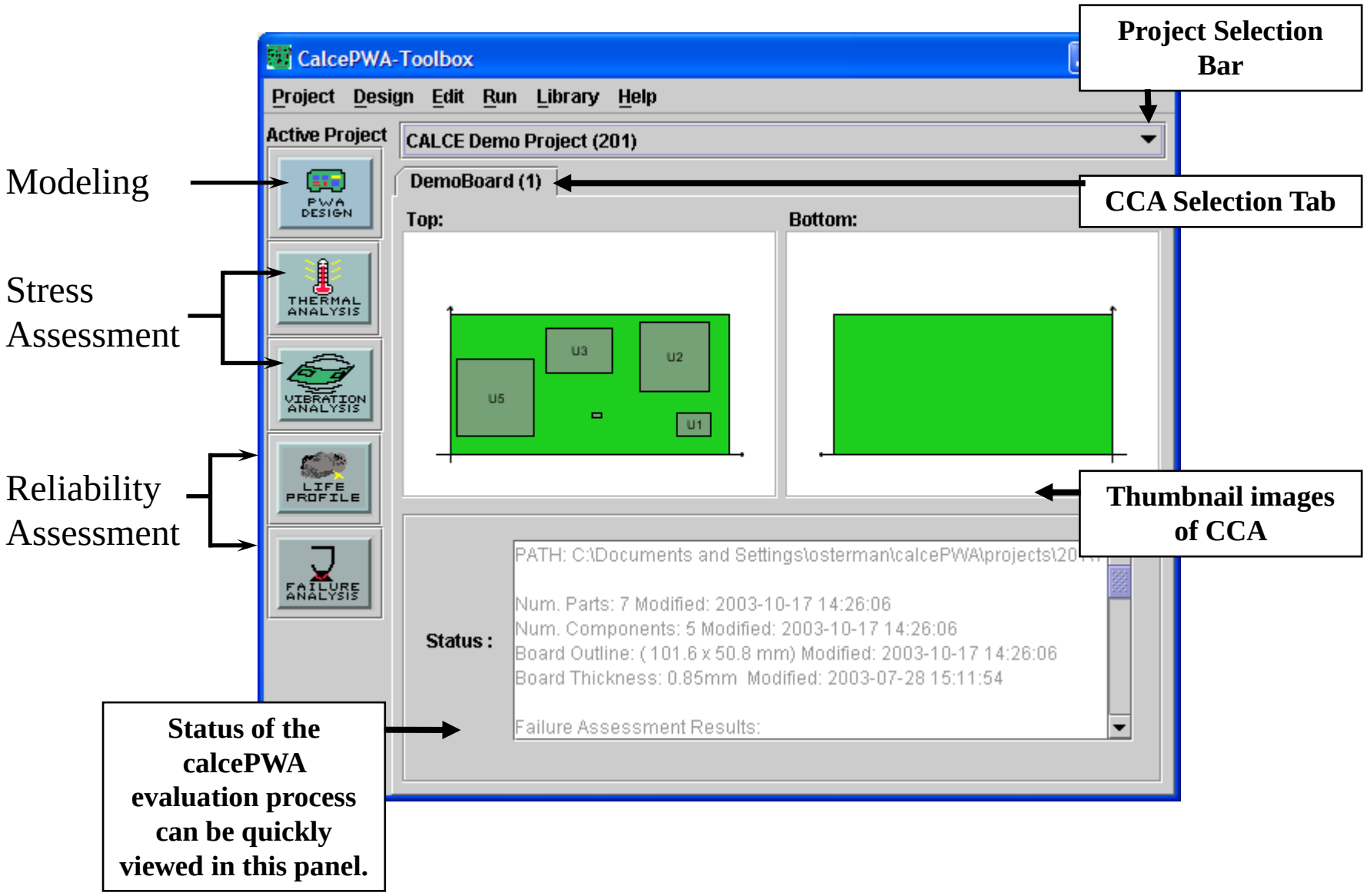
Pontiac Grand Am

Pontiac Aztek

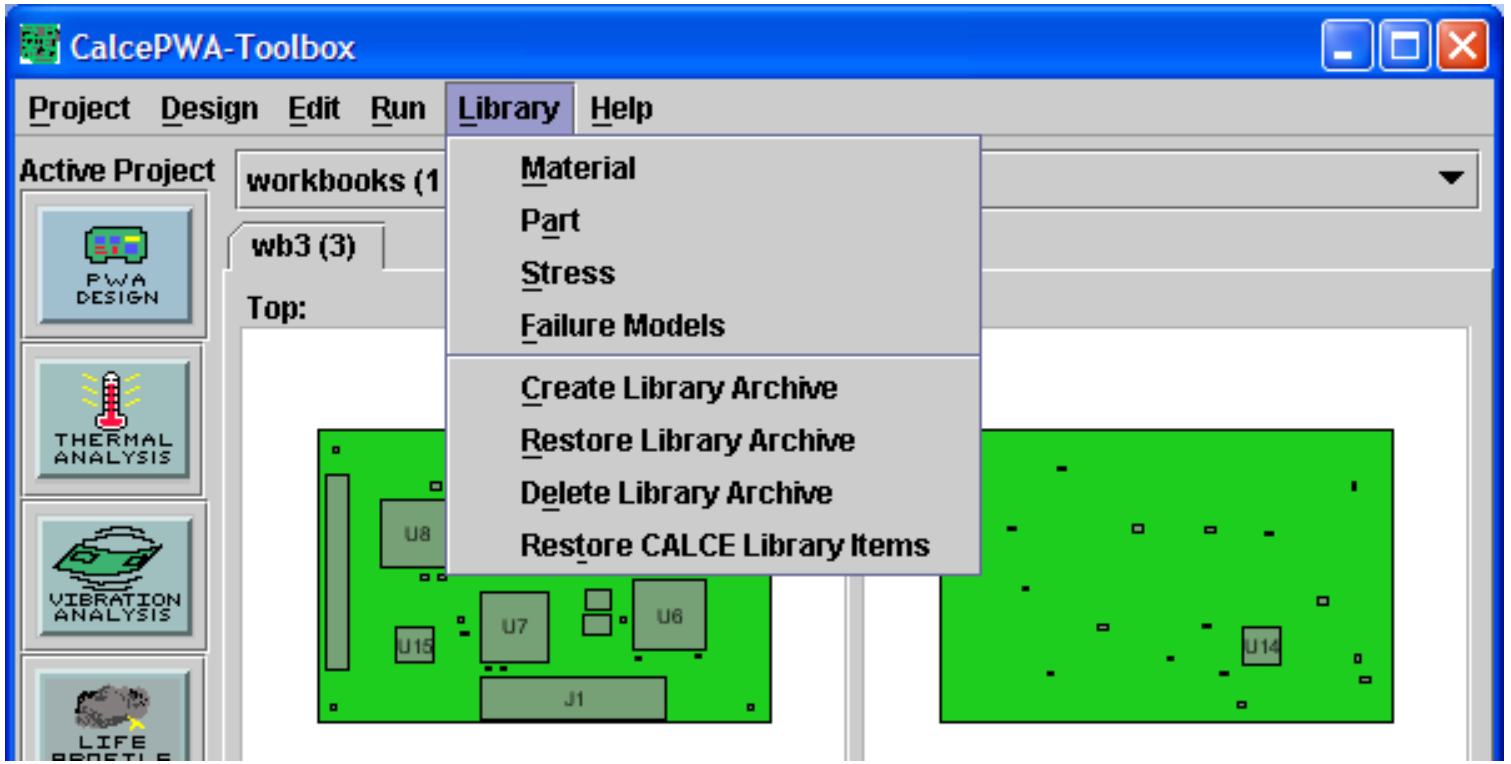
	(Development Period - 130 Wks)	(Development Period - 109 Wks)
Program Comparison:	Moderate	**More Complex**
E/E Technology:	Proven Tech/Compts - No Electromech.	Proven Tech/Compts+**4 Onboard Relays**
Functional/Software Complexity:	Moderate	**More Functions, More Complex**
Power/Internal Heat:	Low Power/Heat	**High Power & Thermal Challenges**
Packaging:	I.P. Mounted Snap Fit, 1 conn.	Console Mnt., **Integ'd w/Fuse (NEW)**
Supplier:	Supplier A - Highly Capable	Supplier A - Highly Capable
Results:	Completed 1/98	Completed 8/99
# of Total Test Issues Identified::	**16** ----------→	**6**

- 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.

Managing the CCA Virtual Qualification Process

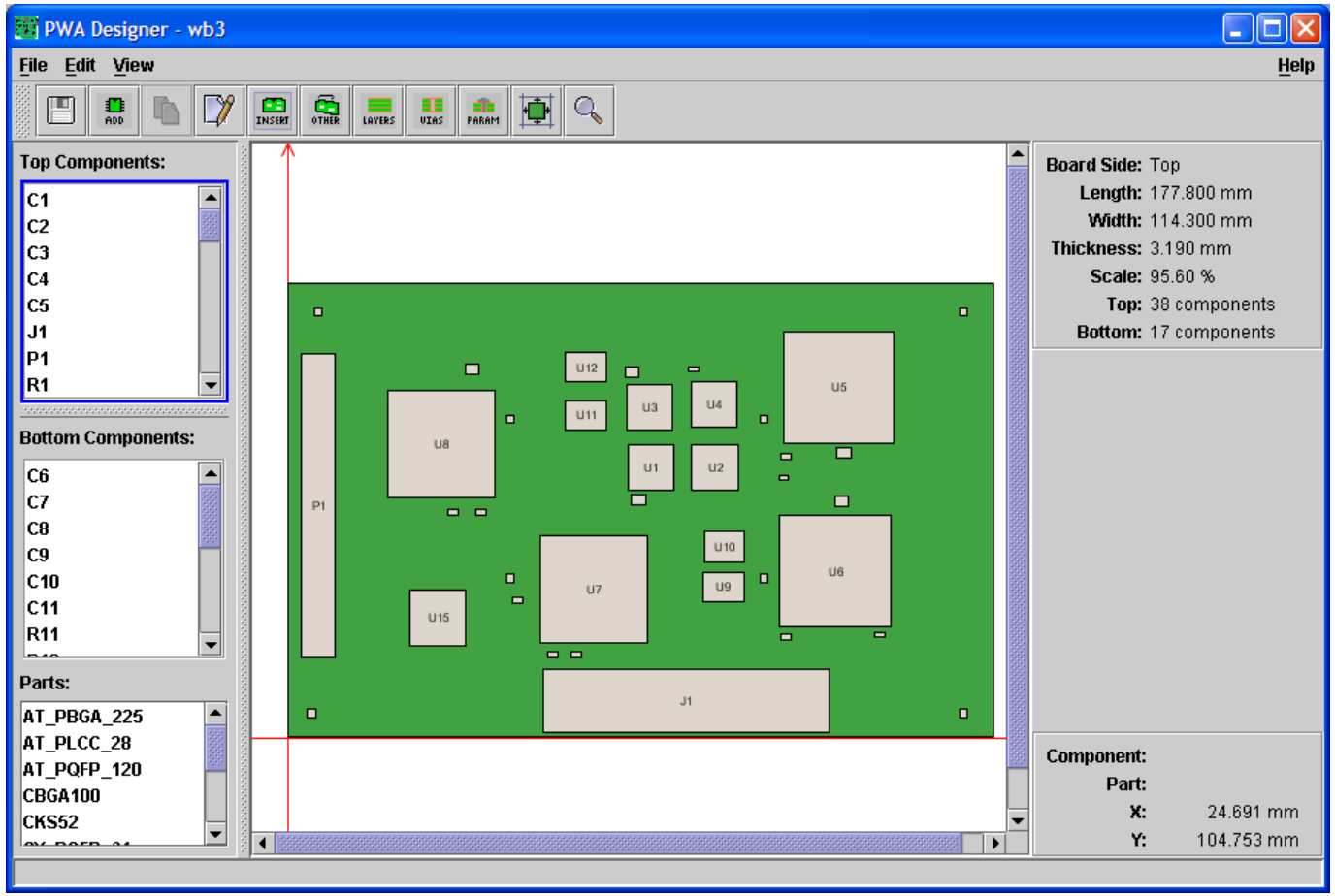


calcePWA Libraries



To promote reuse of data, the calcePWA software has the following database libraries. Libraries can be build either top down and bottom up.

Printed Wiring Assembly Design Manager



The PWA design manager provides the ability to define and/or modify the PWA model. Model items include board outline, material inserts, layer stack-up, vias, component, part, and materials.

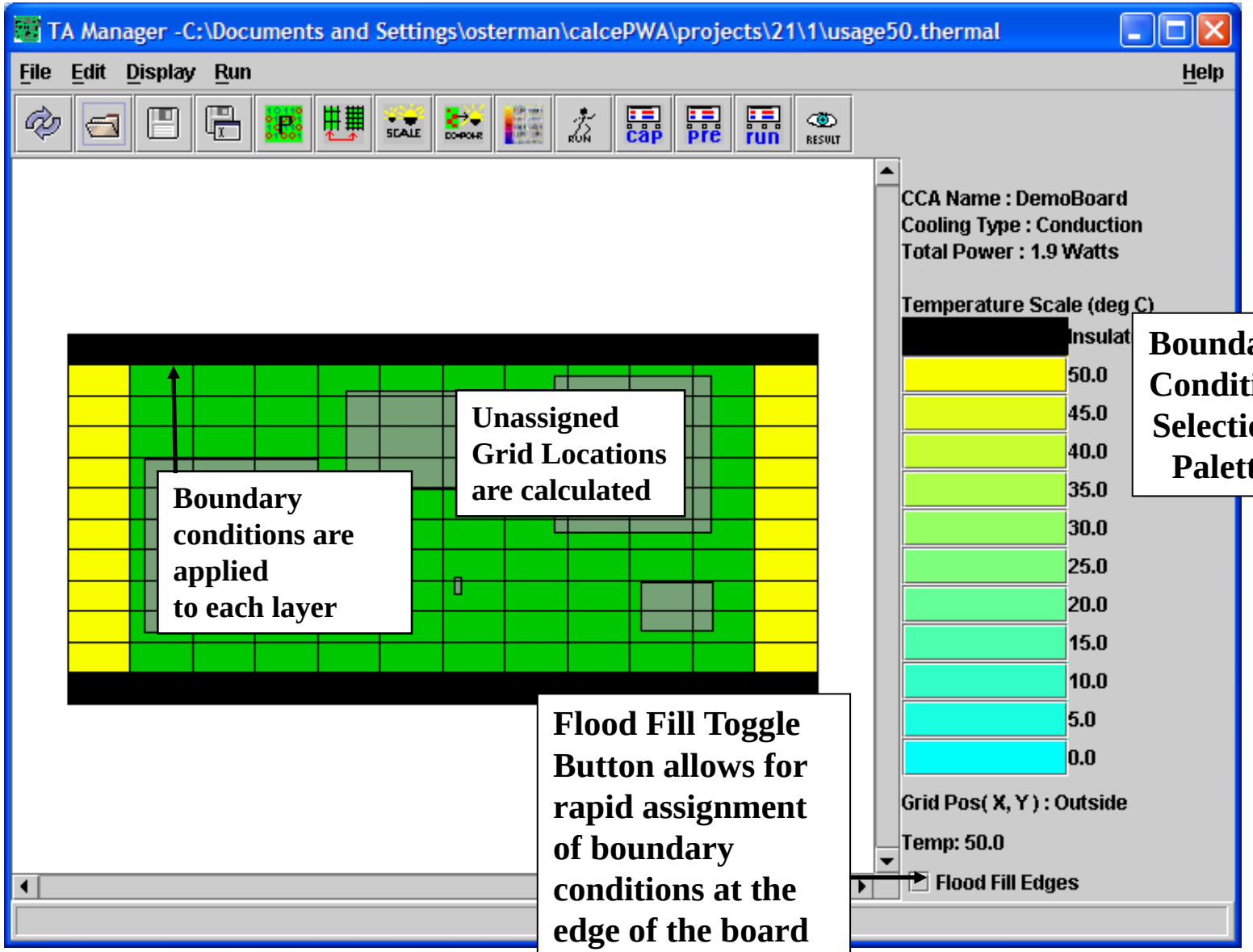
Supported CAD Text File Imports

Import currently available for

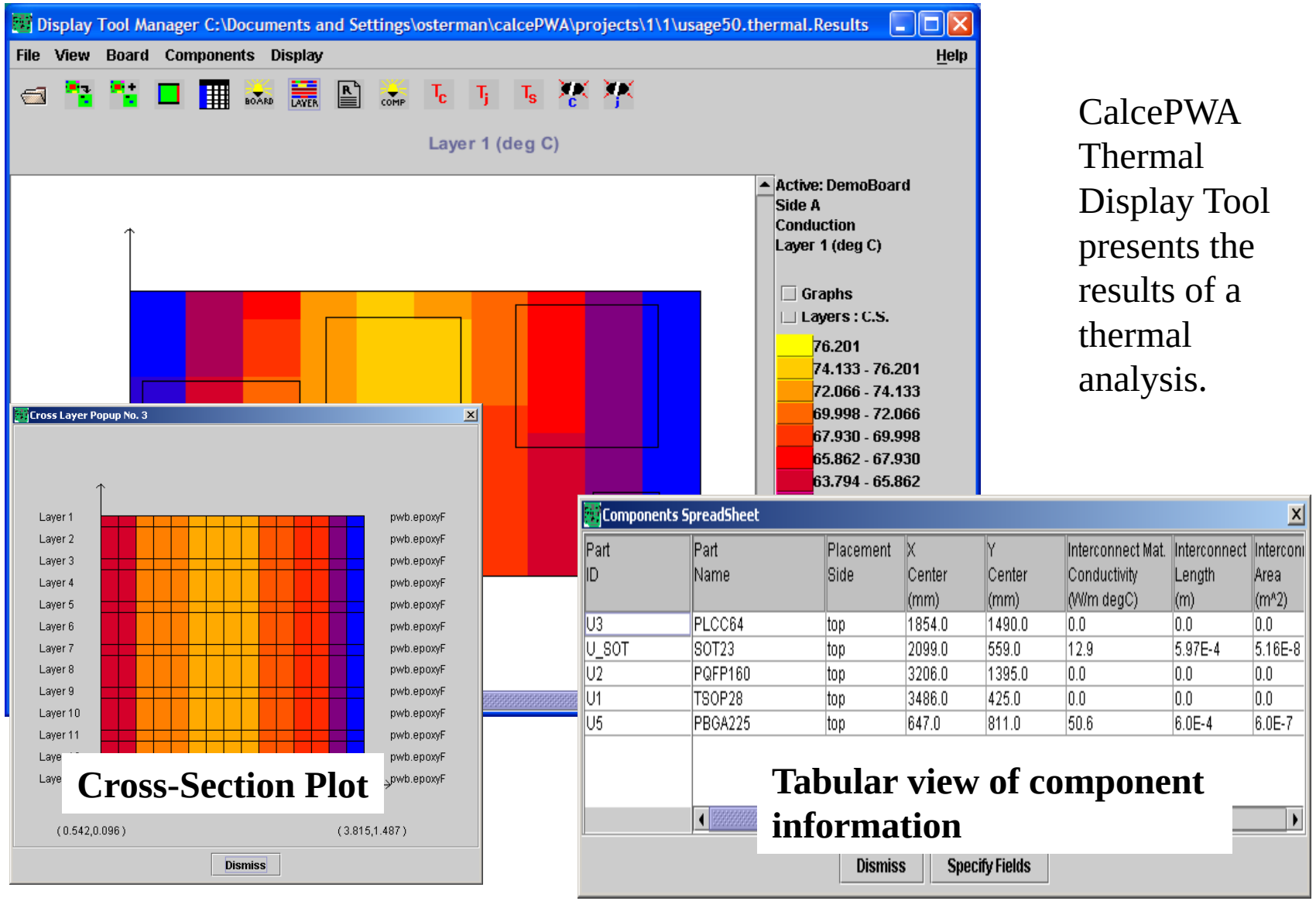
- ODB++
- P-CAD
- Veribest
- GENCAD 1.4
- Mentor Neutral File
- Cadance IDF file
- PADS 1.0, 3.5, 4.0 text files
- Zuken-Recal (CADIF) text files

Import typically provides board outline, part list, component list, and component positions referenced to the board outline. The import procedure was developed by extracting data from example text files.

Thermal Assessment

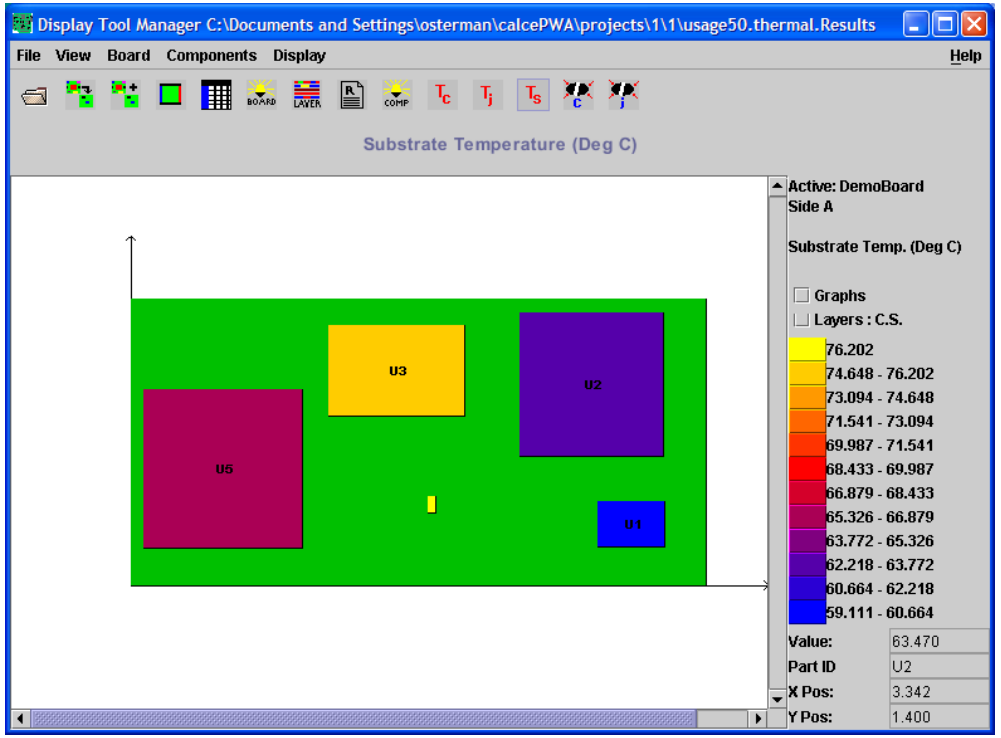


Display of Thermal Analysis Results



CalcePWA Thermal Display Tool presents the results of a thermal analysis.

Determining Component Temperatures



The display tool shows component temperatures calculated from the thermal analysis.

Substrate Temperatures

$$T_{sub} = T_{layer} + QR_z$$

T_{layer} -- Layer temperature below component

R_z -- $\frac{0.5\Delta Z}{K_z A_c}$

A_c -- Planar component area

Case Temperatures

$$T_{case} = T_{sub} + QR_{case}$$

R_{case} -- Parallel resistance of leads and case to substrate

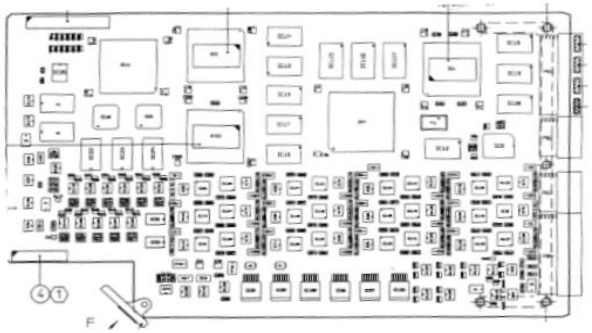
Junction Temperatures

$$T_{junction} = T_{case} + Q\Theta_{jc}$$

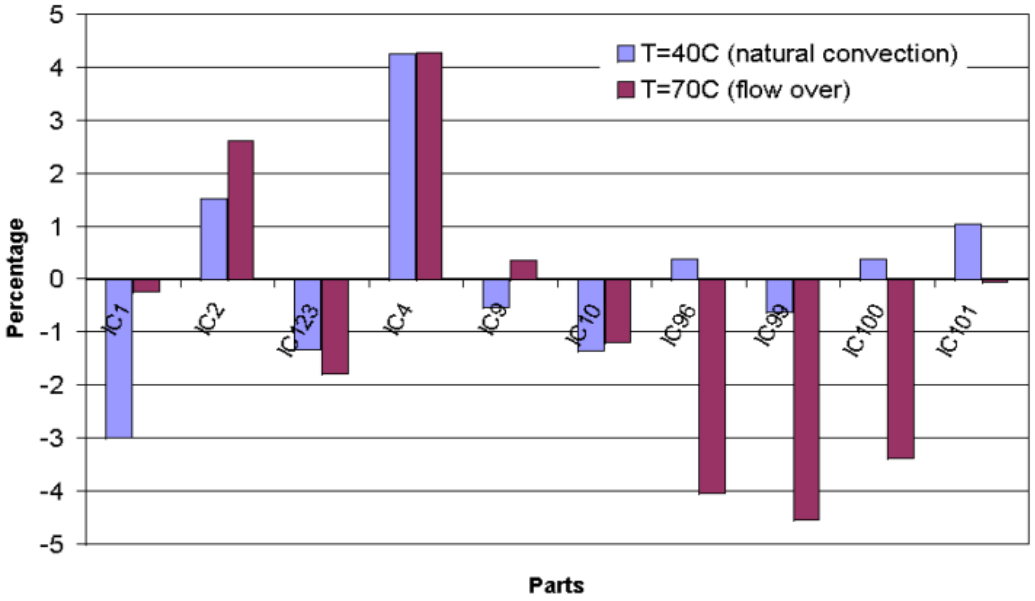
Θ_{jc} --User specified

CalcePWA Thermal Analysis Module Demonstrated for Avionics Printed Wiring Board Assembly

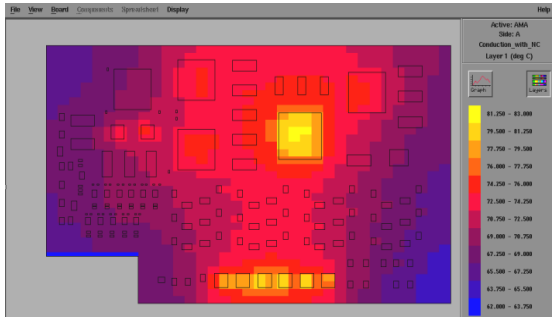
Flight Equipment Board



Percentage error between the case temperature predicted by CalcePWA and the experimental data



CalcePWA Thermal Results

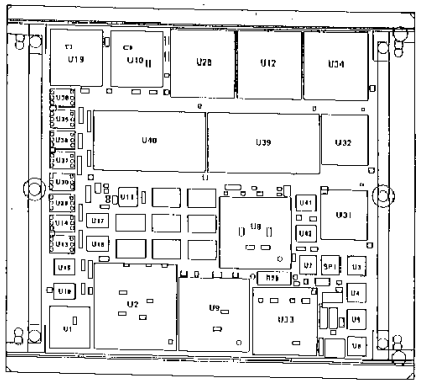


***Analysis results*: Thermal analysis software in CalcePWA has been validated against experimental data.**

→

***Benefit for the EADS*: Development of an optimized plan for accelerated qualification testing**

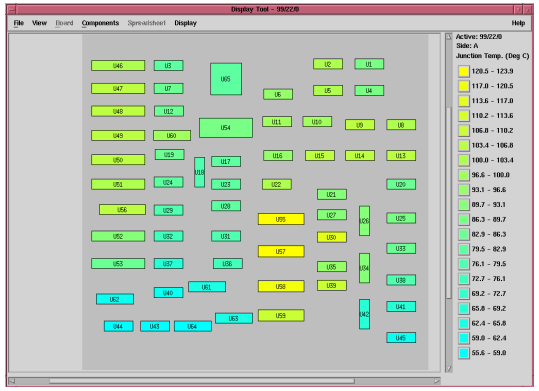
Validation of calcePWA Thermal Analysis



Validation of Conduction Analysis

The thermal analysis software in calcePWA has been extensively validated against experimental test data and accepted numerical simulations.

CalcePWA Thermal Software Found to be within 5% of experimental test data



Comparison of Component junction temperature (^{o}C) for natural convection case study

Component type and power dissipation	calcePWA	Program "PCB EXPLORER"
24 lead DIP (1.56 W) (U55)	124	134
16 lead DIP (0.32 W) (U38)	79	75

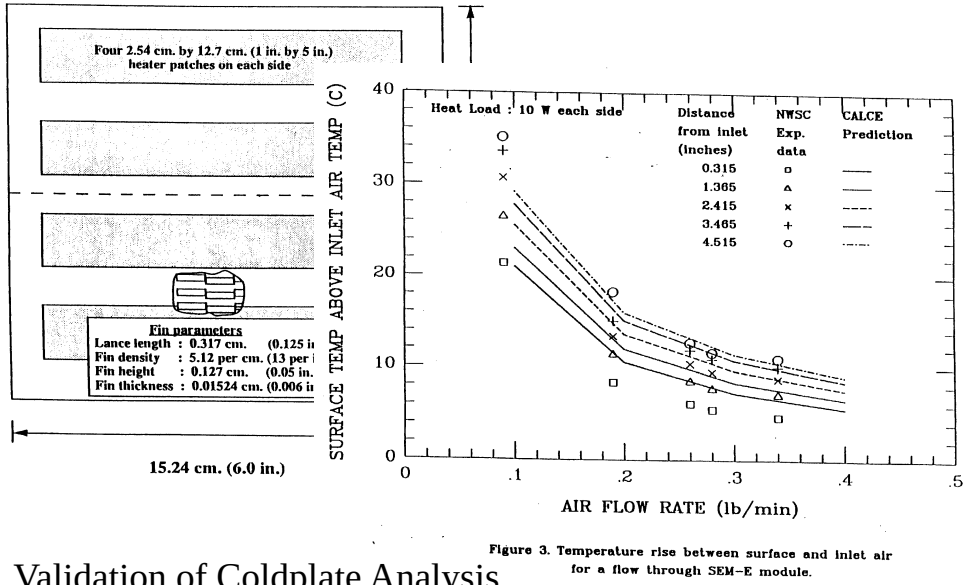


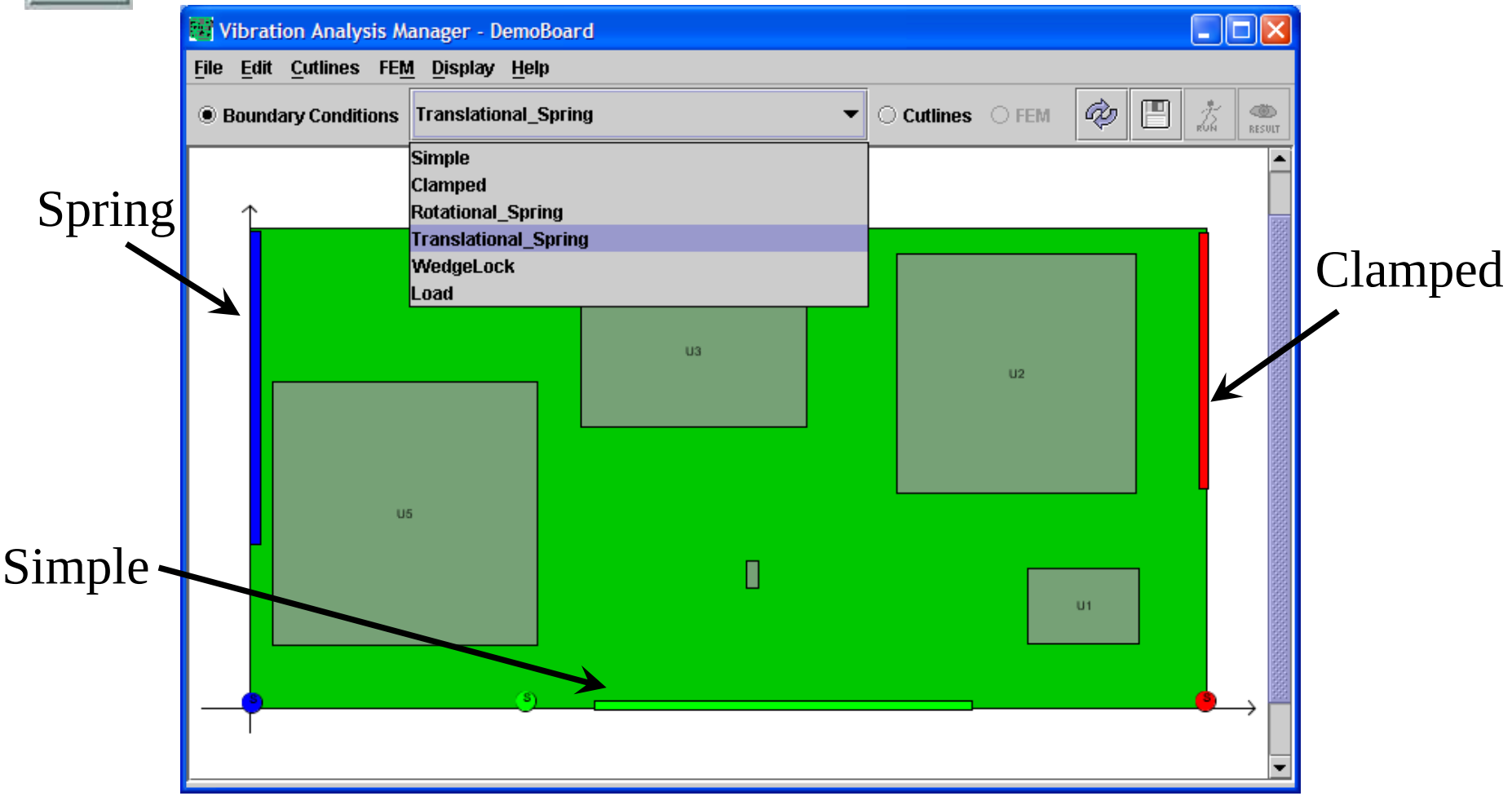
Figure 3. Temperature rise between surface and inlet air for a flow through SEM-E module.

Validation of Coldplate Analysis

Comparison of Component junction temperature (^{o}C) for flow over case study

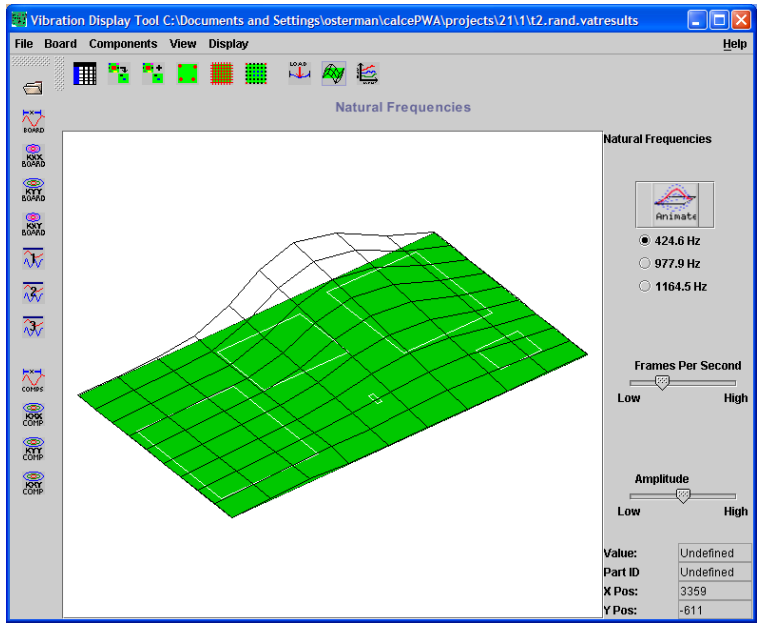
Component type and power dissipation	calcePWA	Program "PCB EXPLORER"	MRCs SUPERPOSITION METHOD
24 lead DIP (1.56W) (U55)	101	110	108
16 lead DIP (0.32W) (U38)	67	62	59

Vibration Analysis Manager

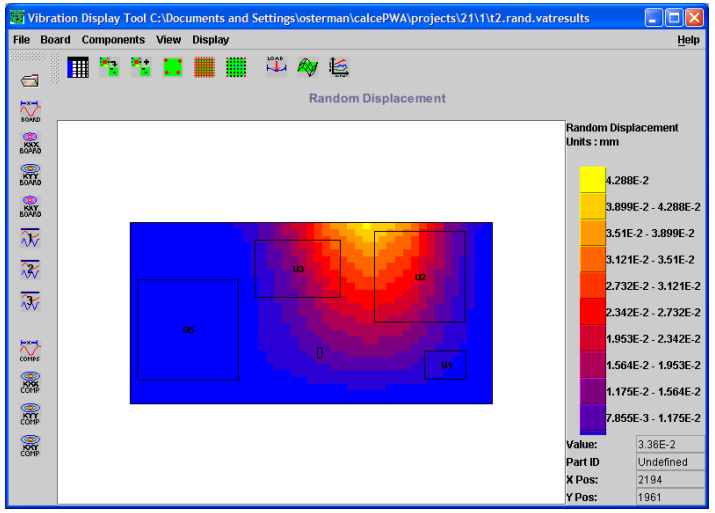


Vibration Analysis Manager allows you to assign supports to the board for consideration in the modal analysis and dynamic response. Additional options have been added to toolbar to facilitate use of the software.

Displaying Advanced Vibration Analysis Results

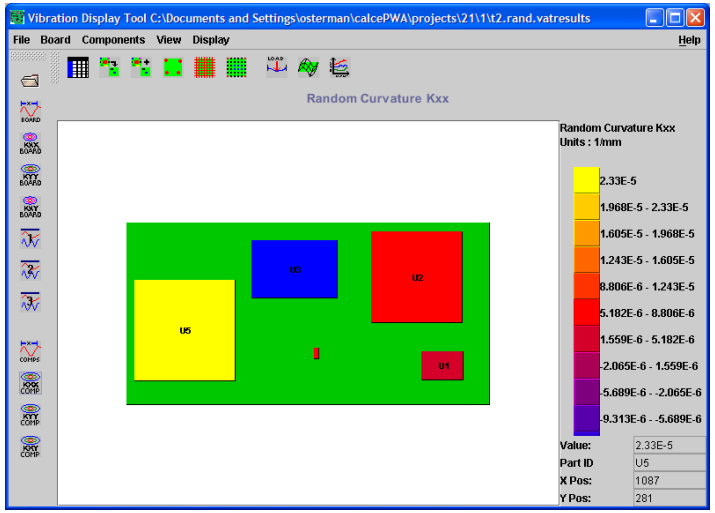


Mode Shapes



Displacement

Analysis results include:
Mode Shapes,
Natural Frequencies,
Board Displacement,
Board Curvature,
Component Displacement, and
Component Curvatures

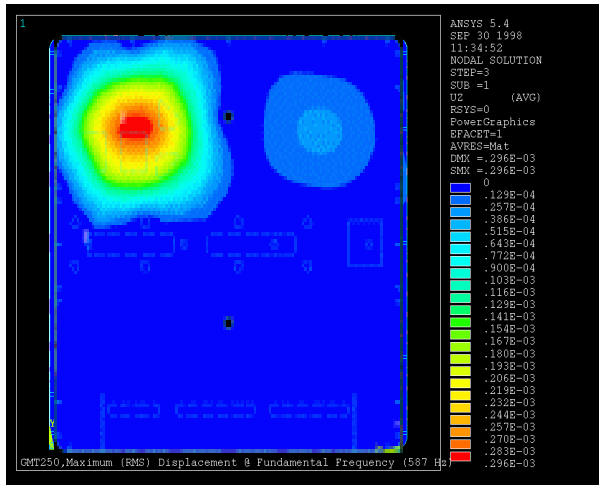


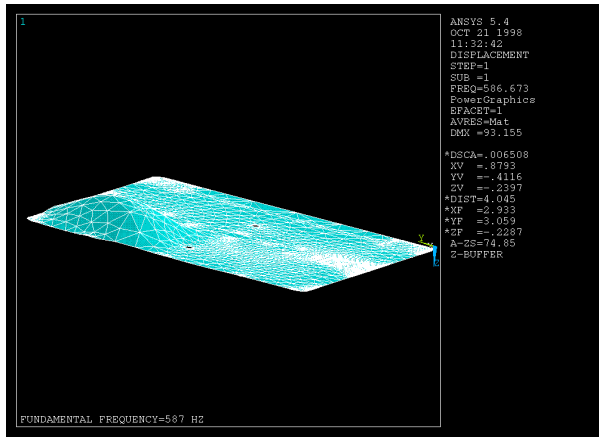
Component Curvature

Validation of CalcePWA Vibration Analysis

Modal Analysis & Displacement

ANSYS

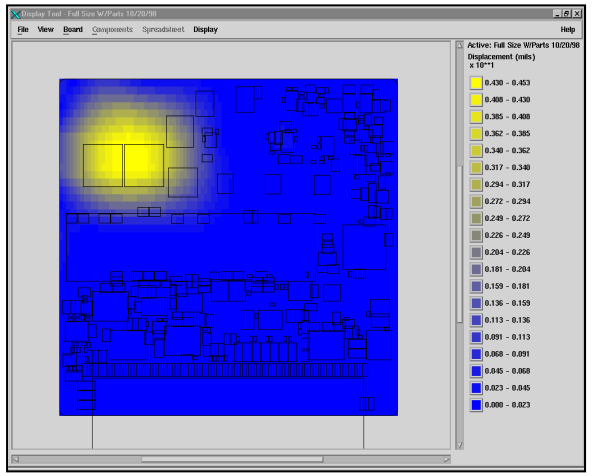


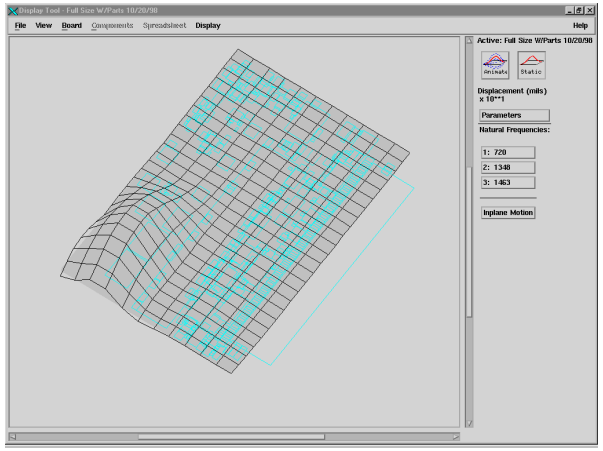


ANSYS
Resonant Frequencies
710 Hz
1331 Hz
1444 Hz

calcePWA
Resonant Frequencies
724 Hz
1348 Hz
1399 Hz

calcePWA





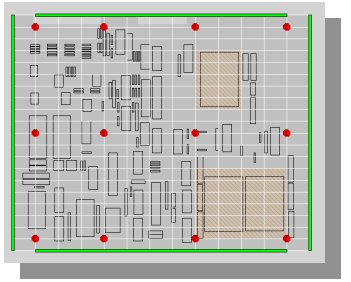
Validated against Measured Test Results

BFIST - XM7
Vibration Analysis Results

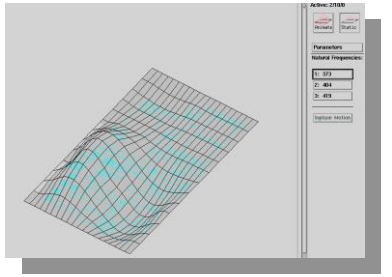
Input frequency to Solder Joint Fatigue is lowest value of CALCE results and ESS test results

	1st Natural Frequency (Hz) *CALCE*	1st Natural Frequency (Hz) *SEI ESS Test Data*	Max. Displacement (mils) *CALCE*
Video Processor CCA	372	510	.33
Power Filter CCA	226	230	13.5
Processor CCA	248	265	.47
Interface CCA	303	265	.66
Serial I/O CCA	261	N/A*	.61
Backplane CCA	417	410	.04

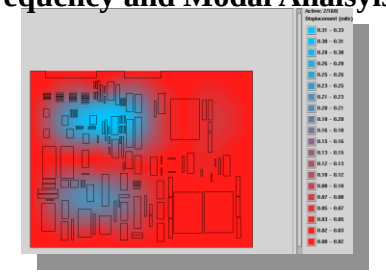
VEU Video Processor CCA



Applied Boundary Conditions

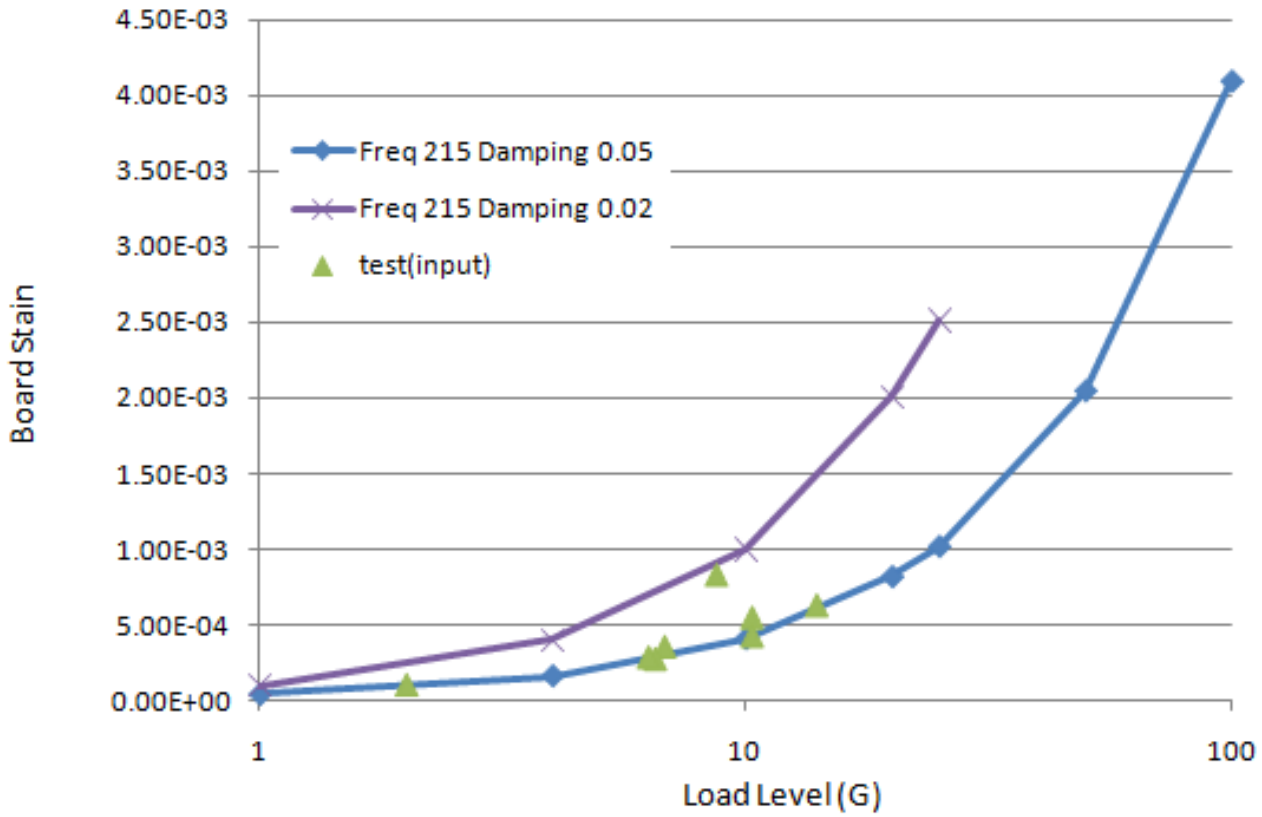


Frequency and Modal Analsyis



The vibration analysis software in calcePWA has been extensively validated against experimental data and numerical simulations.

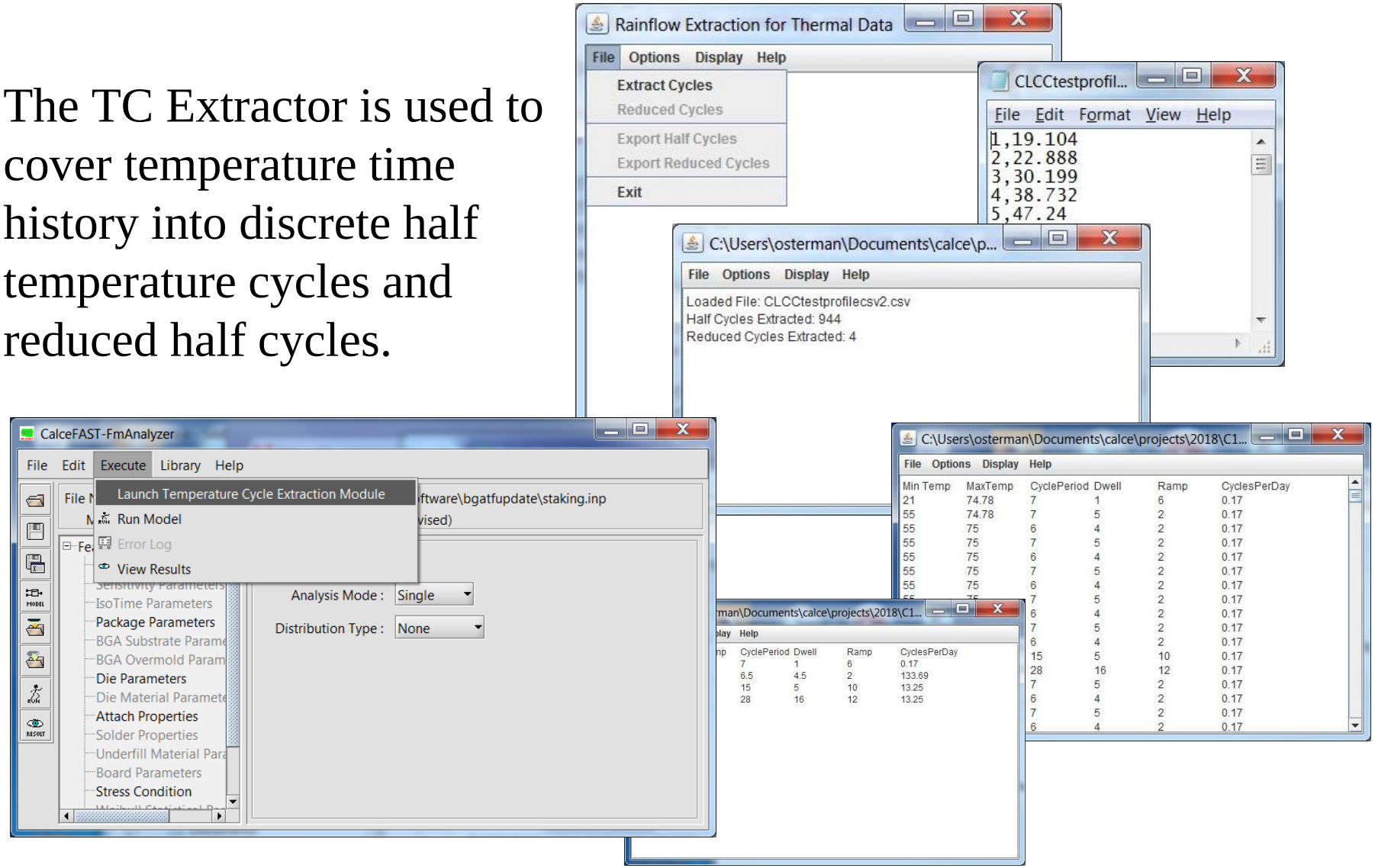
Comparison of Board Strain versus Input with calcePWA Vibration Module and Test Data



Comparing test strain to measured strain shows good correlation.

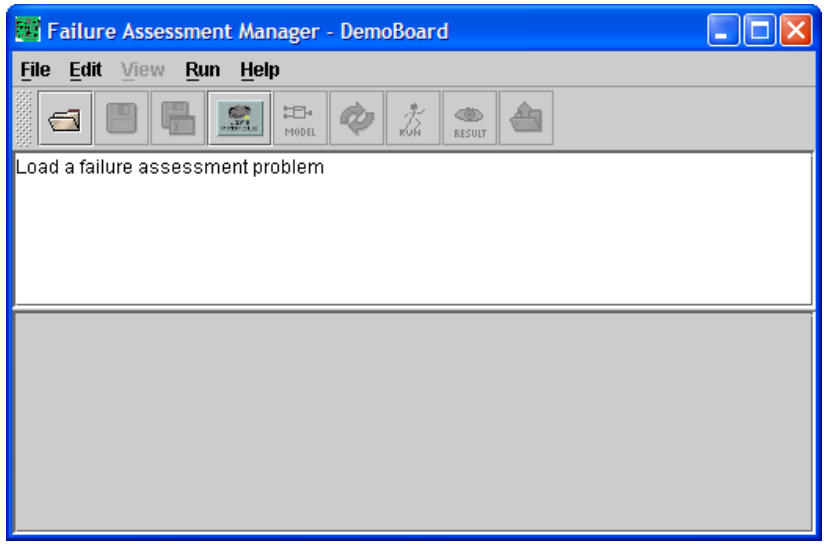
CalceTCExtractor

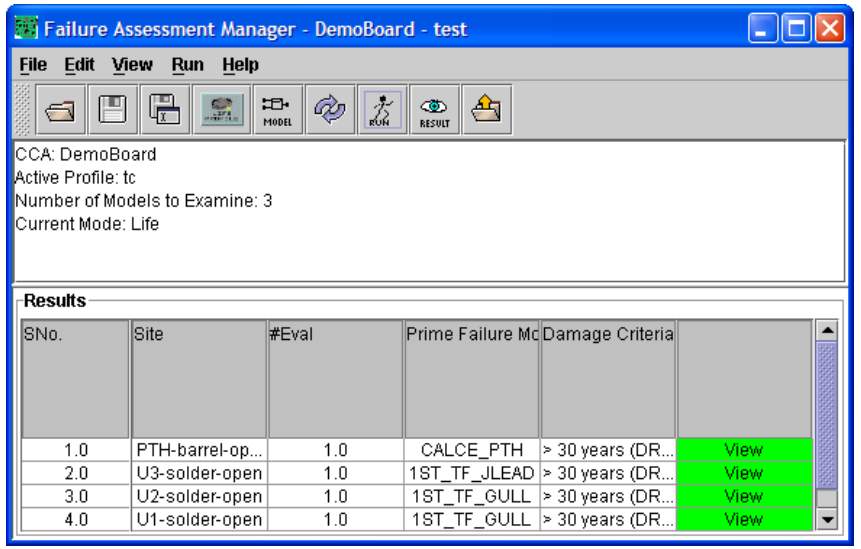
The TC Extractor is used to cover temperature time history into discrete half temperature cycles and reduced half cycles.



Life Assessment

Life assessment in calcePWA is conducted predefined a life cycle profiles



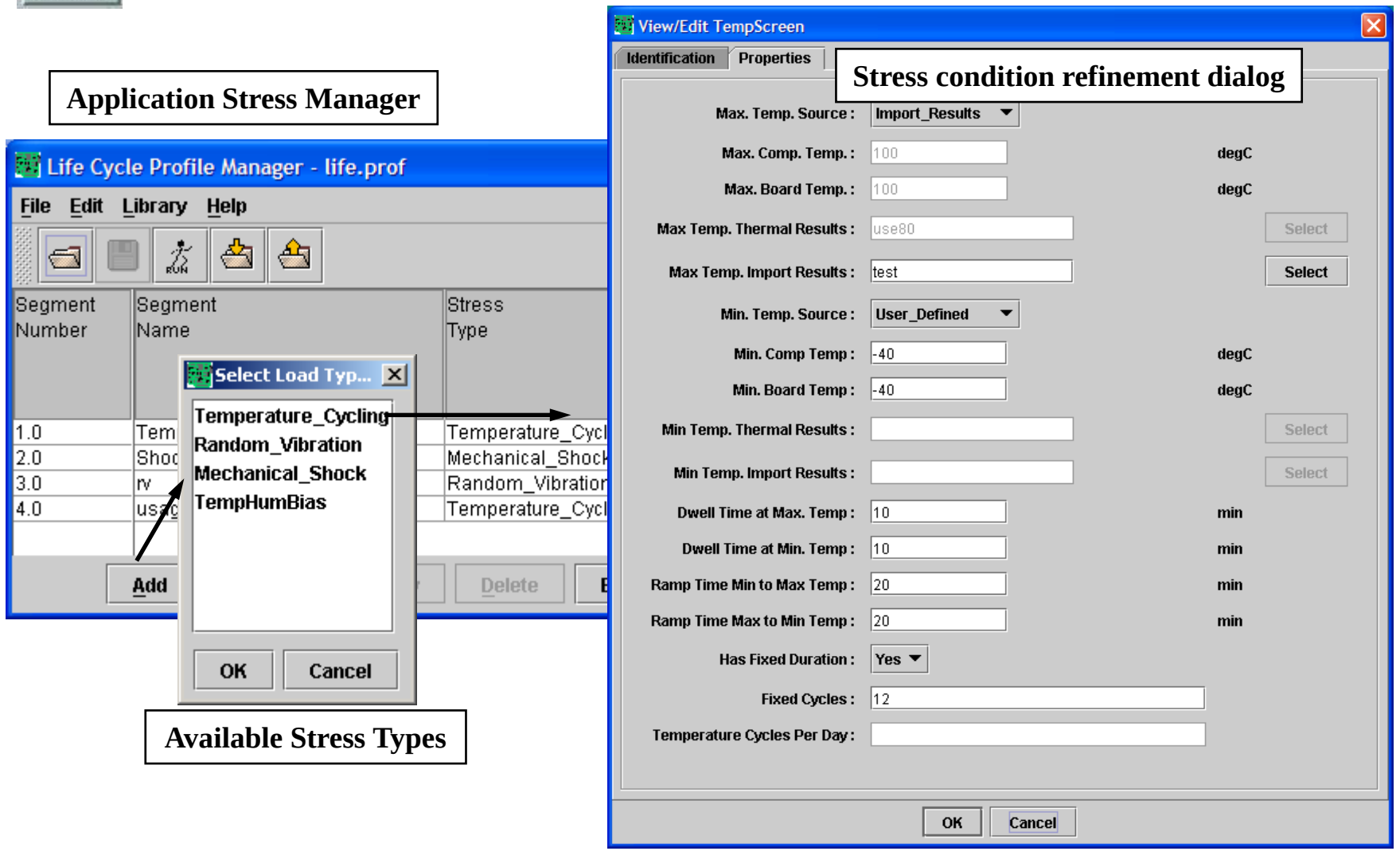


1. Select a predefined life cycle profile 

2. Save life assessment problem, 

3. solve life assess 

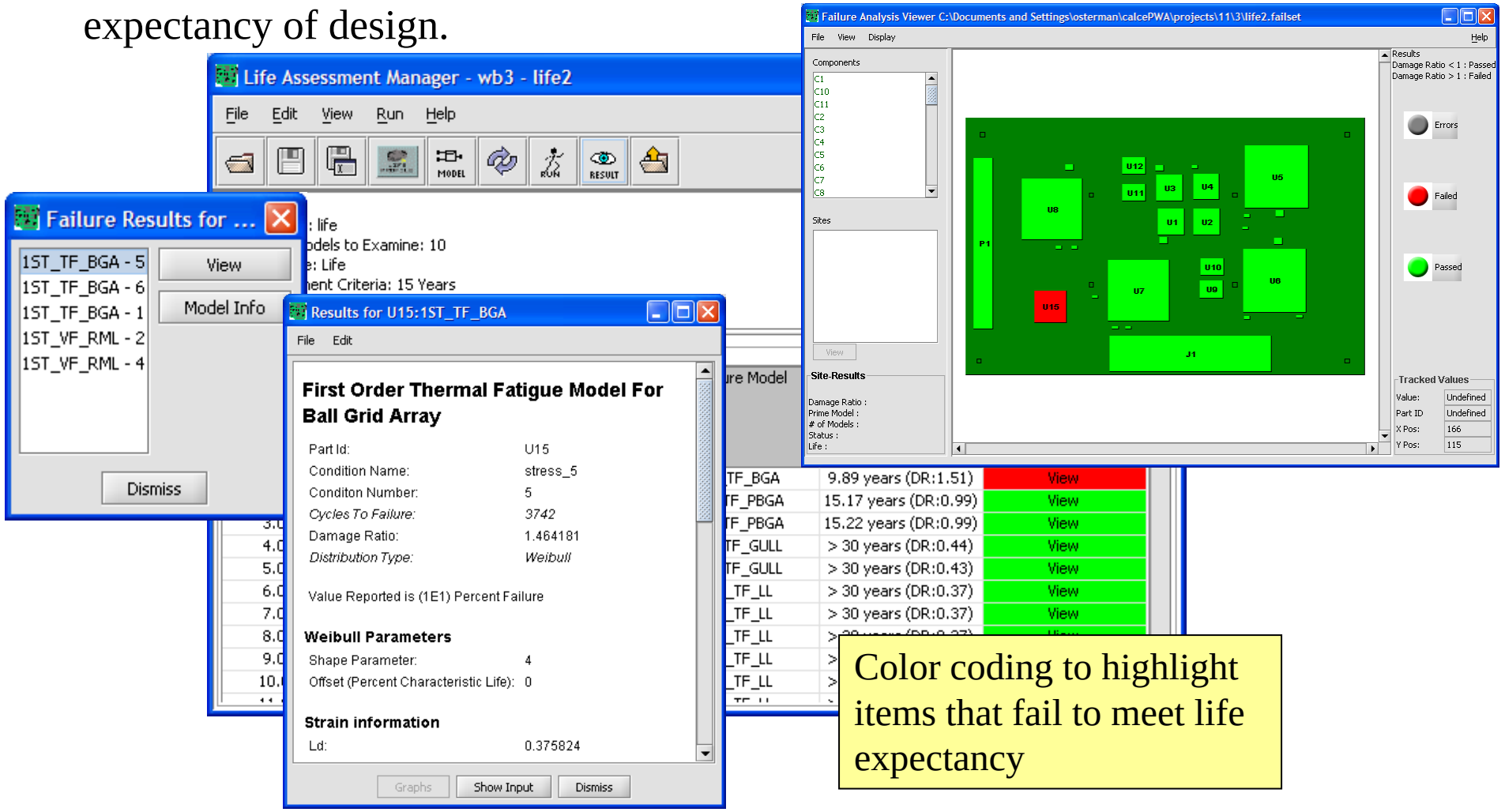
Defining the Life Cycle Profile



The Life Cycle Profile Manger allows you to define multiple loading conditions over which that PWA can be analyzed.

PWA Life Assessment

The life assessment module uses the PWA model, results of thermal and vibration simulations defined in a life cycle scenario to determine life expectancy of design.

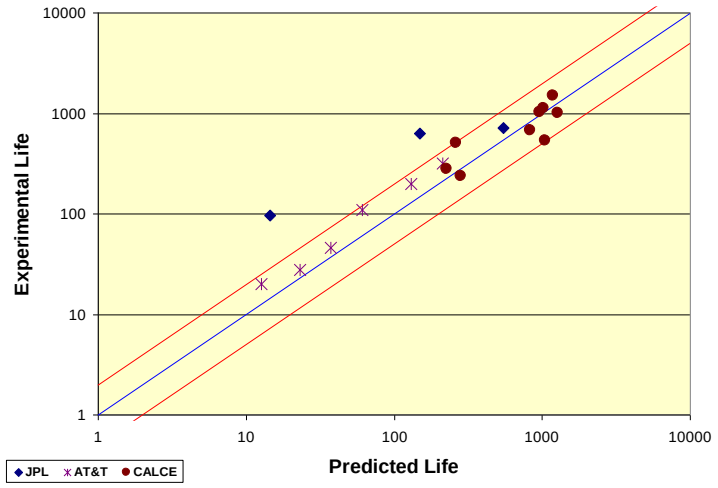


Available Failure Models

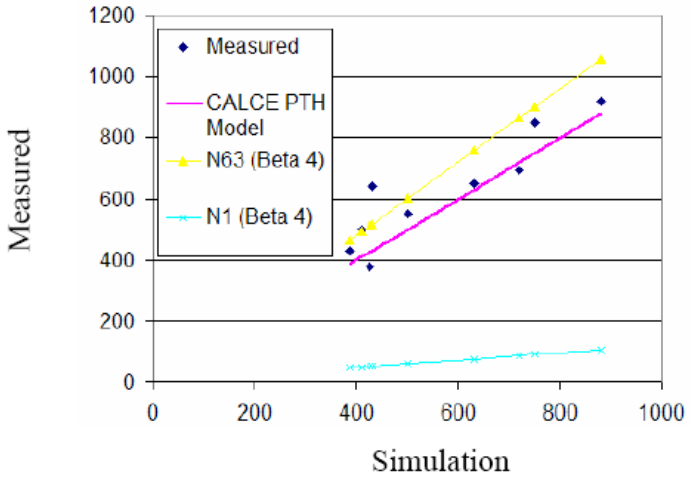
- Thermal Fatigue of Solder Interconnects
  - Most conventional package styles (SOIC, PLCC, QFP, BGA, SOT, HSOP, HSLCC, PGA, DIP, LCCC, LCC)
- Thermal Fatigue of PTH
- Thermal Fatigue of Die to Package Interface
- Vibration Induced Fatigue of Package to Board Interconnects
  - Most conventional package styles (SOIC, PLCC, QFP, BGA, SOT, HSOP, HSLCC, PGA, DIP, LCCC, LCC)
- Mechanical Shock Induced Failure of Package to Board Interconnects
  - Most conventional package styles (SOIC, PLCC, QFP, BGA, SOT, HSOP, HSLCC, PGA, DIP, LCCC, LCC)
- Die Level Electromigration
- Die Level Metallization Corrosion
- Die Level Dielectric Breakdown

Modeling Validation

1st Order Thermal Fatigue Leadless Chip Carrier Model Validation

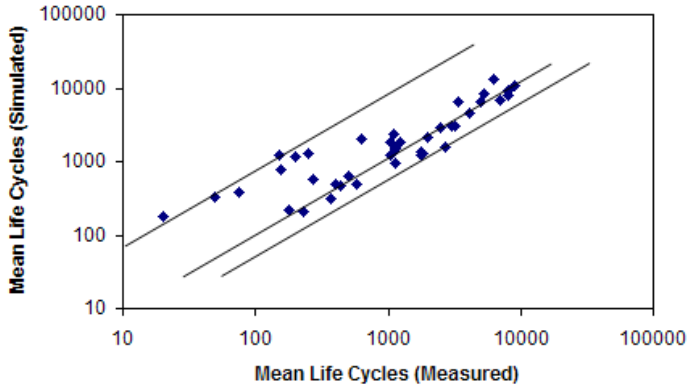


CALCE PTH Thermal Fatigue Model



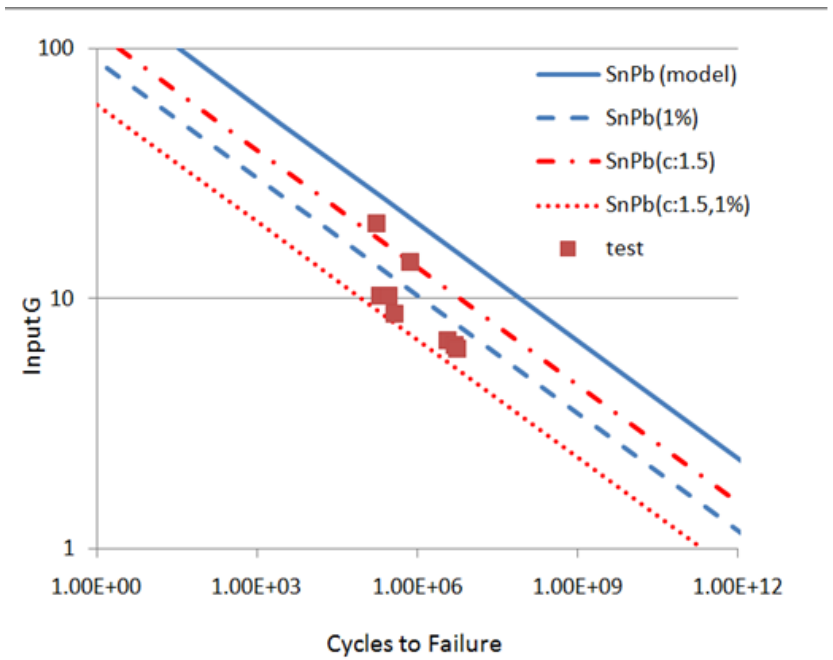
Interconnect fatigue failure models have been validated though experimental data and detailed numerical simulation. These models are reviewed on a continual basis and updated as necessary.

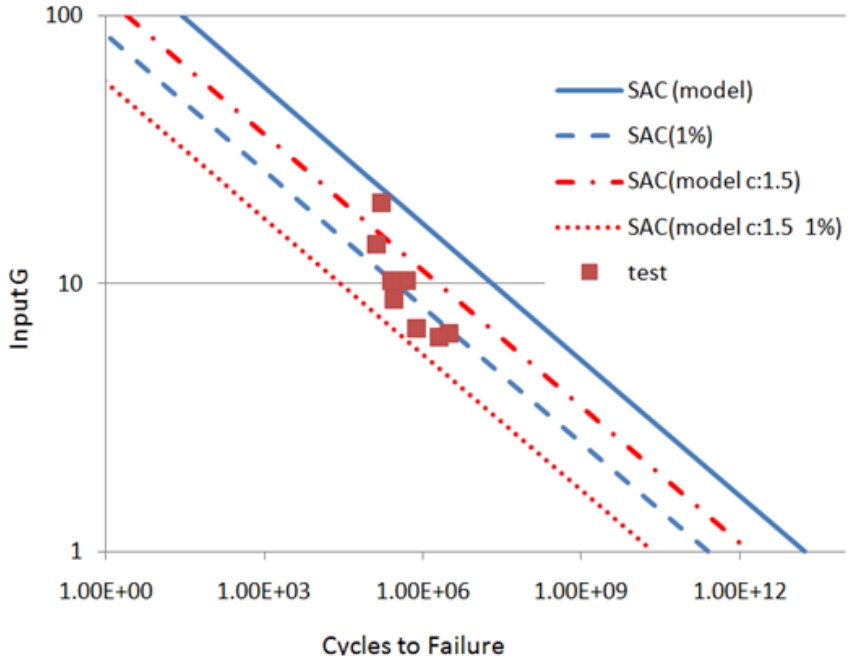
1st Order Thermal Fatigue PBGA Model Validation



BGA model has been compared against over 40 measured results obtained from the published papers, conference articles and experiments.

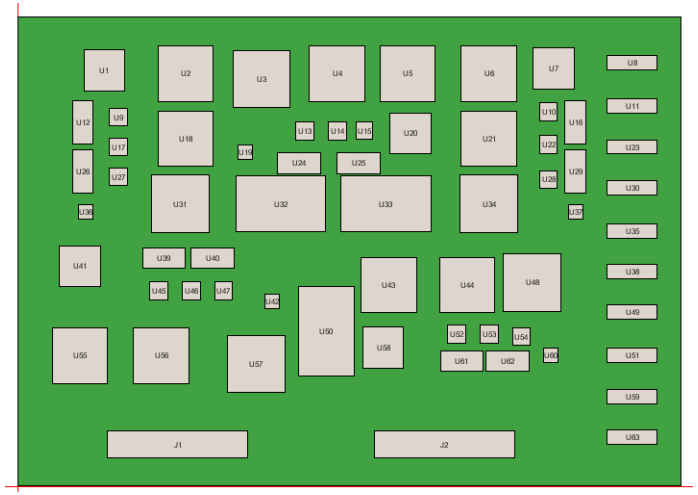
Comparison of CTF





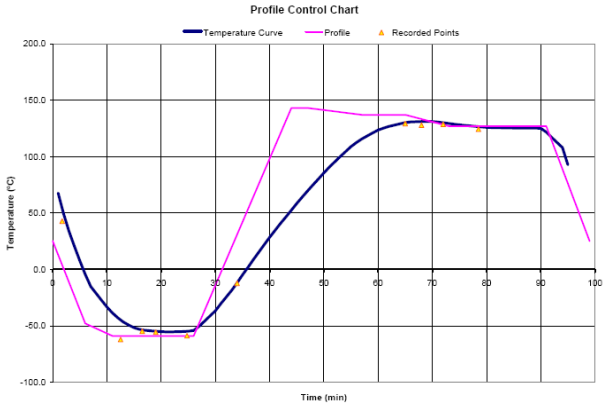
These plots contain curves for life expectancy of lead-free (SAC) and SnPb solder interconnects under harmonic load conditions at varying input accelerations generated by the calcePWA software for the CABGA test board. Test results plotted against these curves reveal good agreement.

Validated Temperature Cycle Induced Solder Interconnect Fatigue Model for SAC

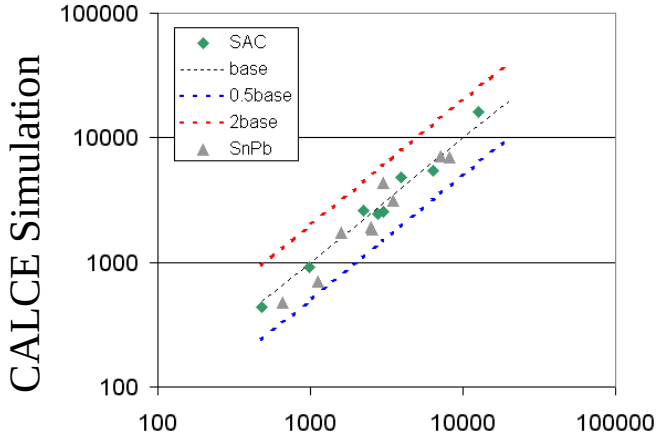


calcePWA Model

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

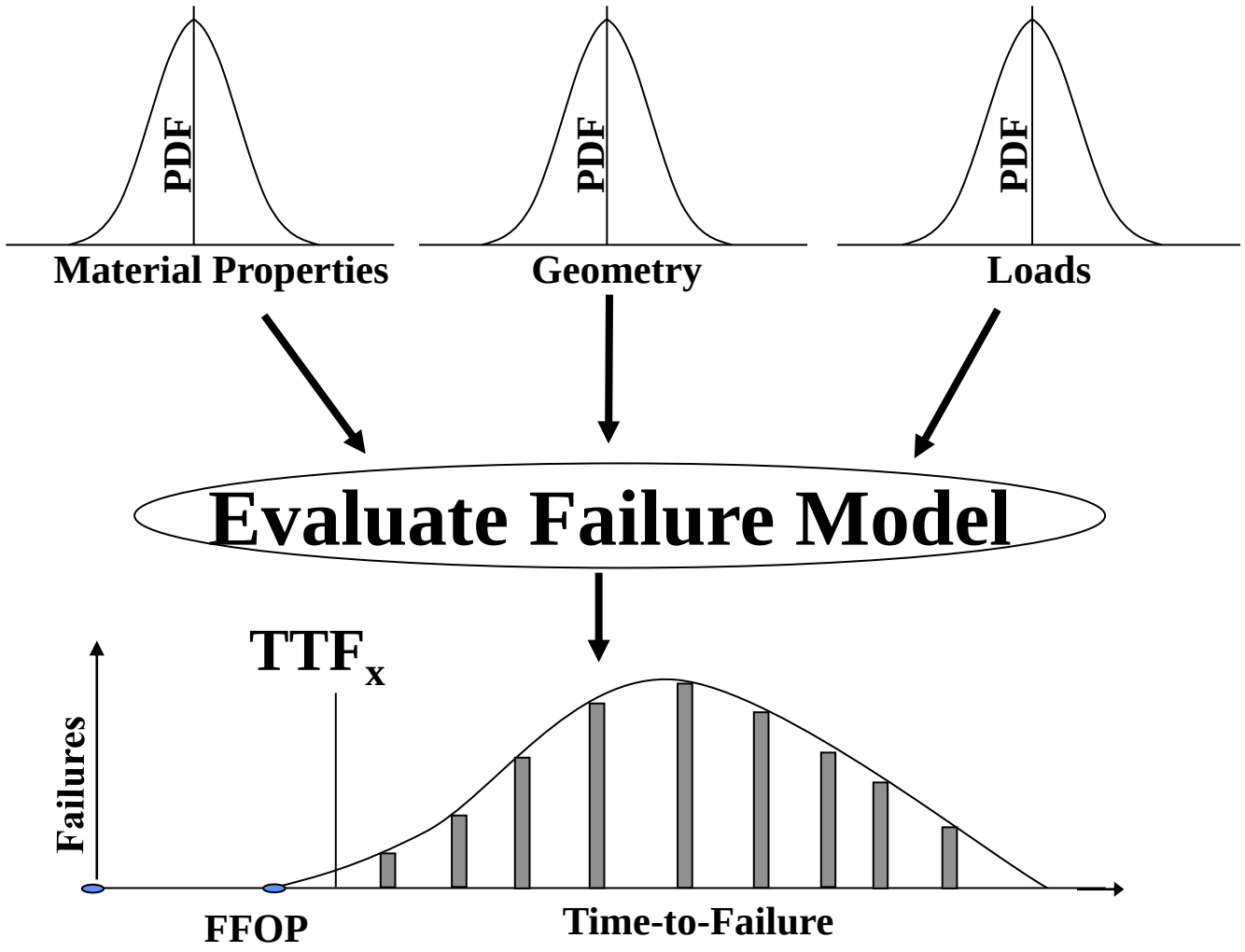


-55 to 125 C test



M. Osterman and M. Pecht, Strain Range Fatigue Life Assessment of Lead-free Solder Interconnects Subject to Temperature Cycle Loading, *Soldering & surface Mount Technology*, Vol. 19, No. 2, pp. 12-17, 2007.

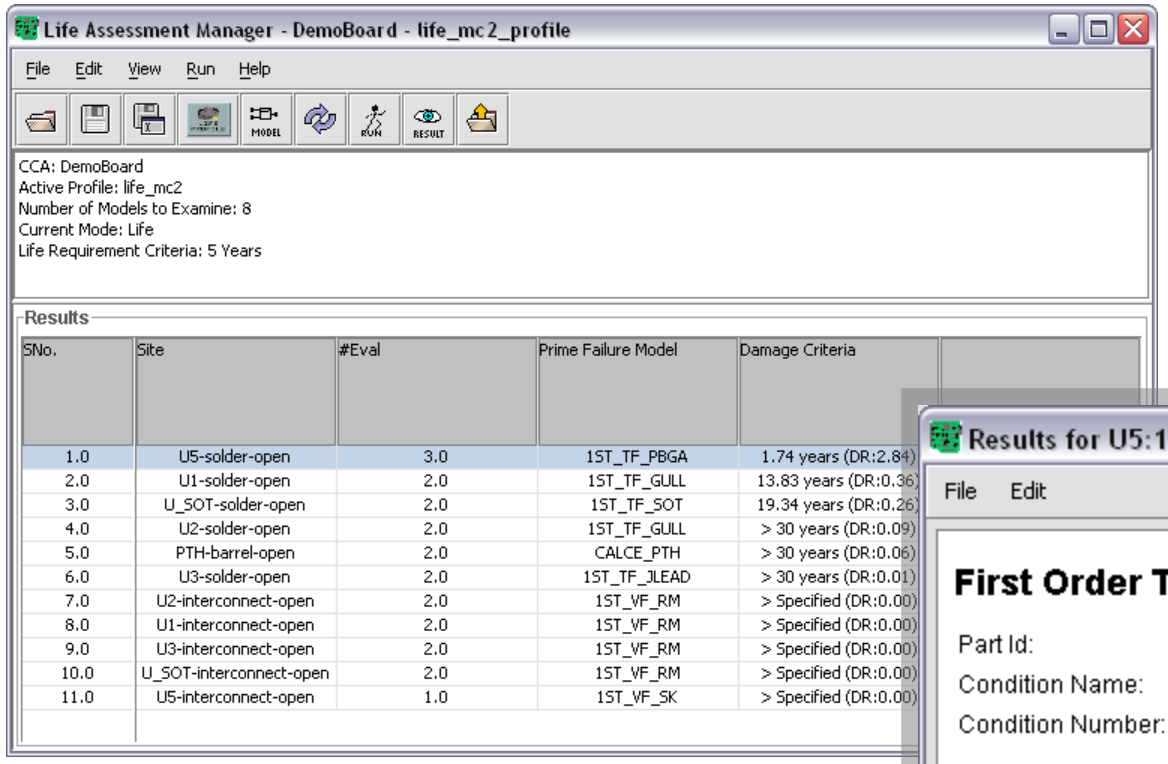
Probabilistic Physics of Failure (PPOF) Assessment in calcePWA



Probability Physics of Failure (PPOF)

- The default failure assessment process in calcePWA is to use nominal values for all parameters with the assumption that the failure assessment results represent time to 50% failure.
- To assess the effect of input variations, you can directly vary inputs and re-run the assessment. This requires modifying model data, regenerating the LCPDB, and re-running the failure assessment.
- The PPOF capability within the calcePWA failure assessment module offers two alternatives: assigned distributions and calculated distributions.
  - Assigned distributions include Weibull and Lognormal which can be applied on a model-by-model basis.
  - Calculated distributions are established by defining distributions to input parameters and using a Monte Carlo technique to establish the failure distribution.

Example of Monte Carlo Analysis



SNo.	Site	#Eval	Prime Failure Model	Damage Criteria
1.0	U5-solder-open	3.0	1ST_TF_PBGA	1.74 years (DR:2.84)
2.0	U1-solder-open	2.0	1ST_TF_GULL	13.83 years (DR:0.36)
3.0	U_SOT-solder-open	2.0	1ST_TF_SOT	19.34 years (DR:0.26)
4.0	U2-solder-open	2.0	1ST_TF_GULL	> 30 years (DR:0.09)
5.0	PTH-barrel-open	2.0	CALCE_PTH	> 30 years (DR:0.06)
6.0	U3-solder-open	2.0	1ST_TF_JLEAD	> 30 years (DR:0.01)
7.0	U2-interconnect-open	2.0	1ST_VF_RM	> Specified (DR:0.00)
8.0	U1-interconnect-open	2.0	1ST_VF_RM	> Specified (DR:0.00)
9.0	U3-interconnect-open	2.0	1ST_VF_RM	> Specified (DR:0.00)
10.0	U_SOT-interconnect-open	2.0	1ST_VF_RM	> Specified (DR:0.00)
11.0	U5-interconnect-open	1.0	1ST_VF_SK	> Specified (DR:0.00)

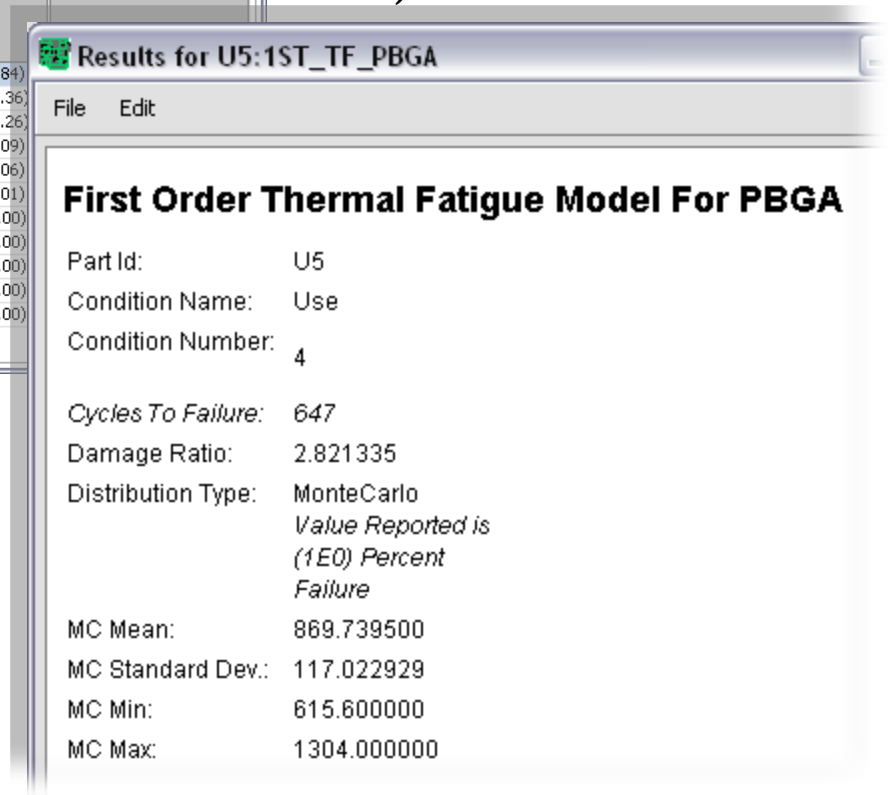
Life Cycle Profile:

1.Temperature Cycle –40 to 100°C (1 CPH) – 12 cycles

2. Shock 20G .5s Half-Sine

3. Random Vib: 0.2 G/Hz (100 to 500 Hz) – 100 hrs

4. Temperature Cycle 0 to 80°C (1 CPD)



Expected life is calculated based on the defined life cycle and assumes that the loading condition persists until failure. The total damage (DR) is based on the defined life cycle loading condition.

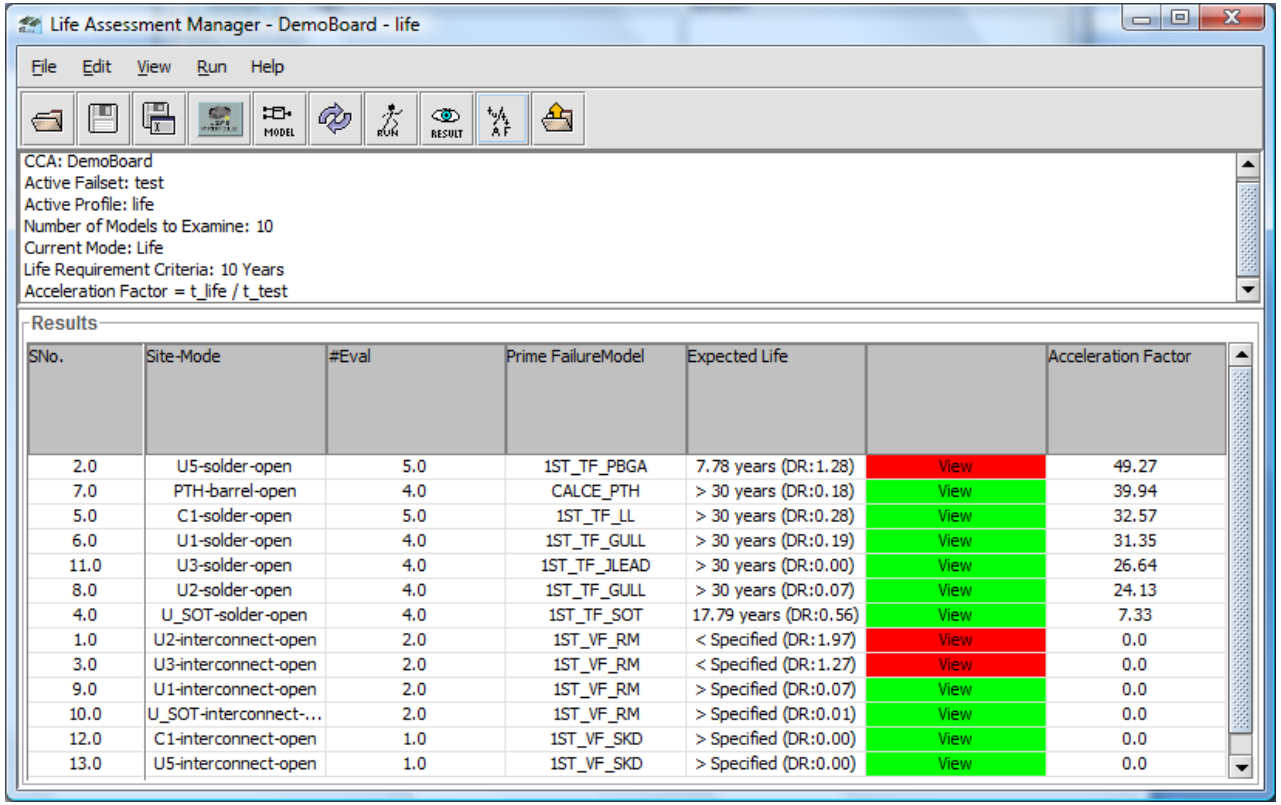
Acceleration Factors

In product qualification, it is often impractical to test the system for its full expected lifetime. As a result, high load frequency and load levels may be used. In order to relate the test condition to the anticipated use condition, a failure assessment under both conditions must be completed. If the same failure mechanisms and sites are produced under both conditions, the test and use condition can be related. An acceleration factor is the term used to relate the test and use condition.

$$AF_{cycle} = \frac{N_{use}}{N_{test}} \qquad AF_{time} = \frac{t_{use}}{t_{test}}$$

The ability to present acceleration factors has been recently added to the calcePWA software. In calcePWA, the acceleration factor is presented in the time domain.

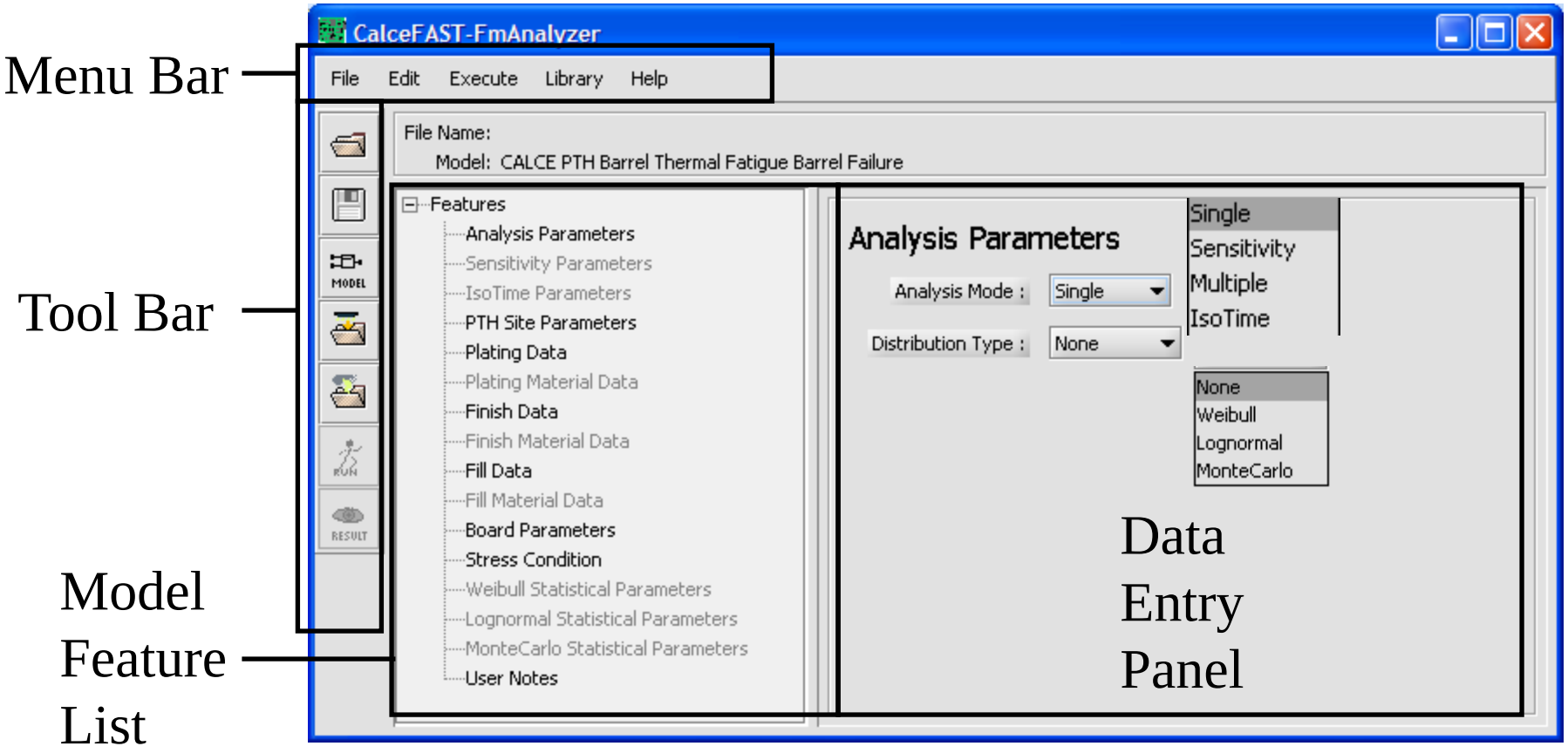
Time Domain Acceleration Factors



SNo.	Site-Mode	#Eval	Prime FailureModel	Expected Life		Acceleration Factor
2.0	U5-solder-open	5.0	1ST_TF_PBGA	7.78 years (DR:1.28)	View	49.27
7.0	PTH-barrel-open	4.0	CALCE_PTH	> 30 years (DR:0.18)	View	39.94
5.0	C1-solder-open	5.0	1ST_TF_LL	> 30 years (DR:0.28)	View	32.57
6.0	U1-solder-open	4.0	1ST_TF_GULL	> 30 years (DR:0.19)	View	31.35
11.0	U3-solder-open	4.0	1ST_TF_JLEAD	> 30 years (DR:0.00)	View	26.64
8.0	U2-solder-open	4.0	1ST_TF_GULL	> 30 years (DR:0.07)	View	24.13
4.0	U_SOT-solder-open	4.0	1ST_TF_SOT	17.79 years (DR:0.56)	View	7.33
1.0	U2-interconnect-open	2.0	1ST_VF_RM	< Specified (DR:1.97)	View	0.0
3.0	U3-interconnect-open	2.0	1ST_VF_RM	< Specified (DR:1.27)	View	0.0
9.0	U1-interconnect-open	2.0	1ST_VF_RM	> Specified (DR:0.07)	View	0.0
10.0	U_SOT-interconnect-...	2.0	1ST_VF_RM	> Specified (DR:0.01)	View	0.0
12.0	C1-interconnect-open	1.0	1ST_VF_SKD	> Specified (DR:0.00)	View	0.0
13.0	U5-interconnect-open	1.0	1ST_VF_SKD	> Specified (DR:0.00)	View	0.0

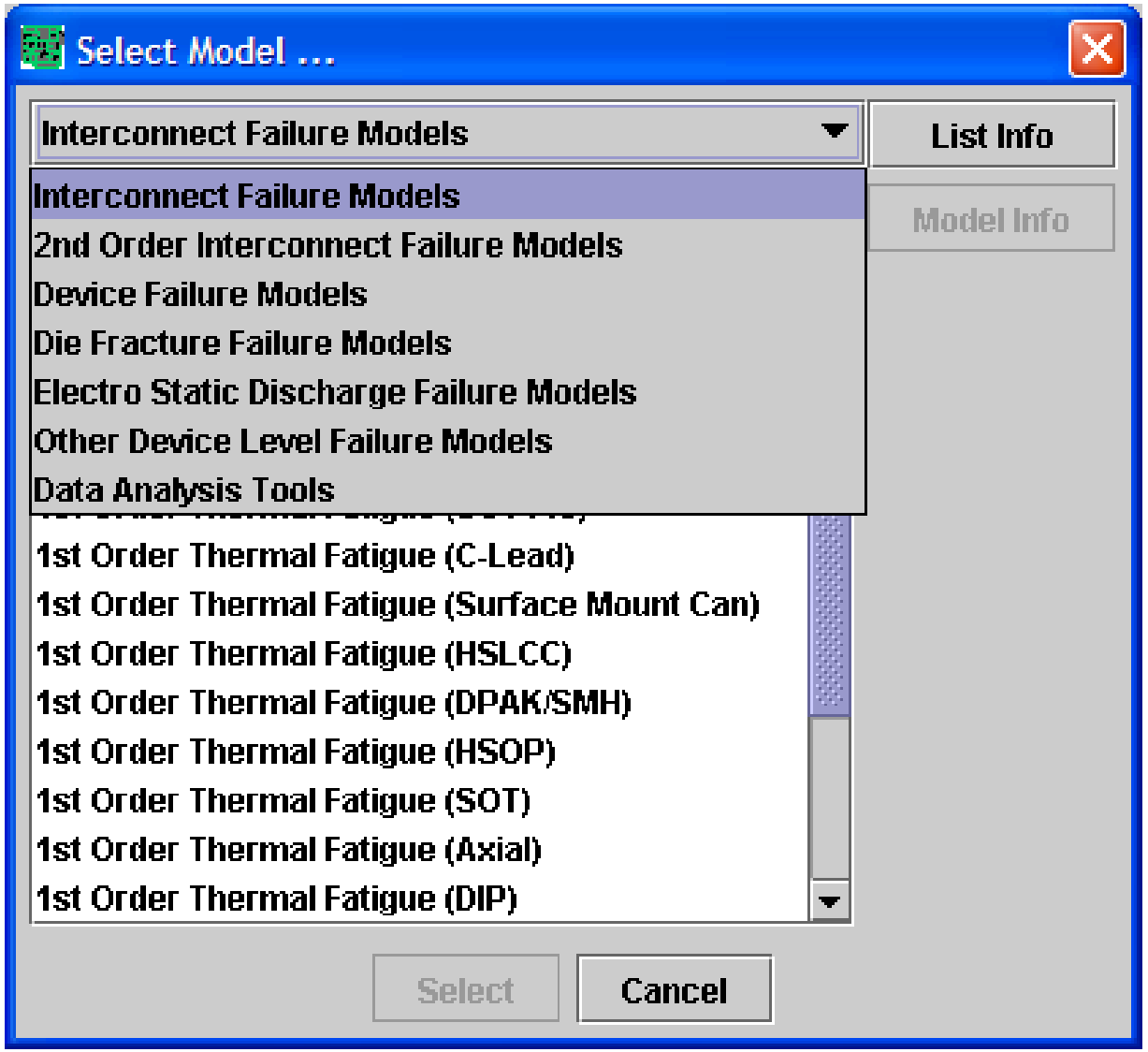
The acceleration factors determined in calcePWA are presented in the time domain. As such, the time in test is related to the time under the use condition. Therefore, an acceleration factor of 50 means that a part requiring 2 months for failure under the test would required 100 months to fail under the prescribed use condition. Alternatively, if a part can survive 2 months in test, it should be expected to survive 100 months in the field.

CalceFAST Software Interface



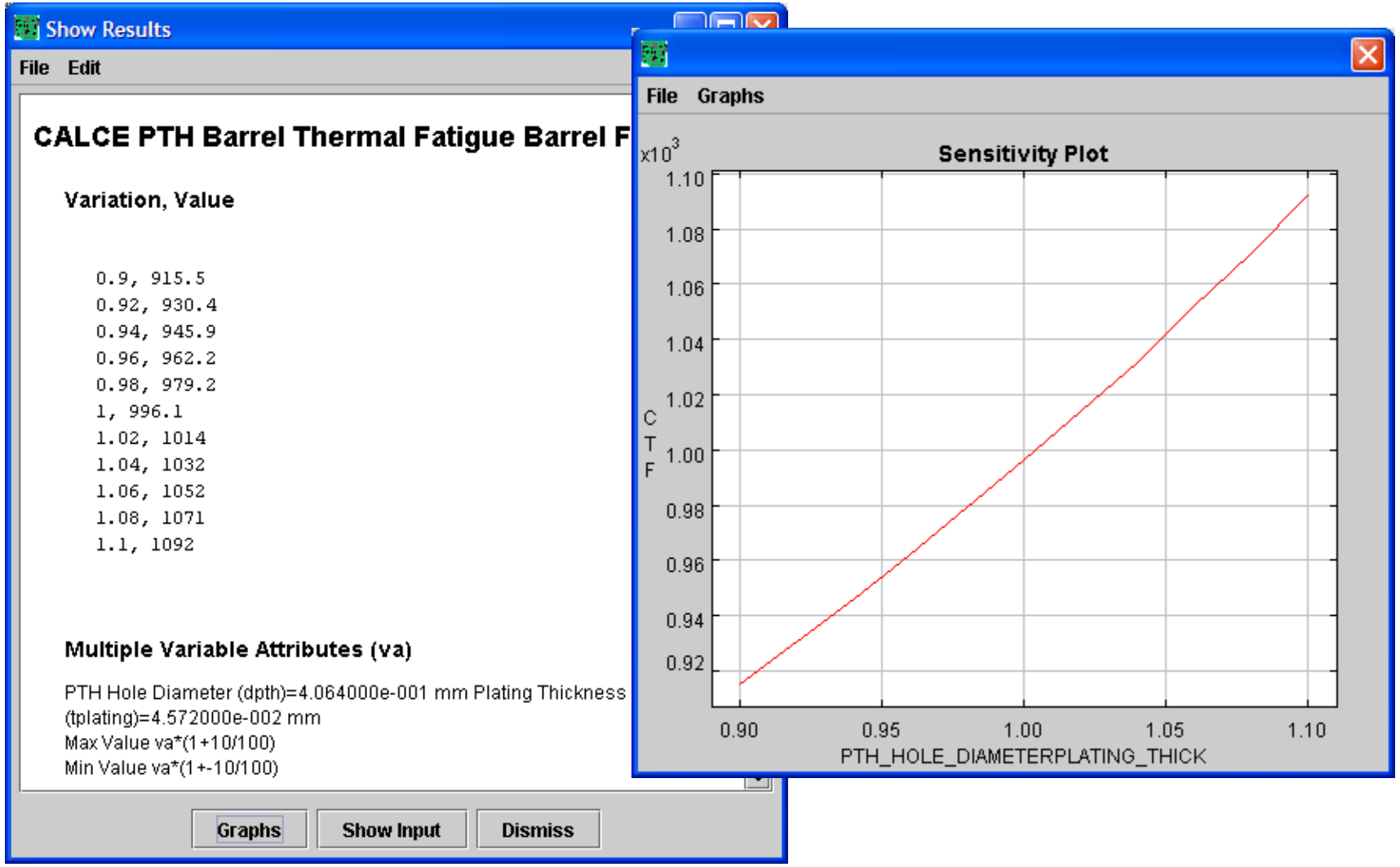
CalceFAST 5.0 (Failure Assessment Software Toolkit) software provides the capability to bypass full scale design modeling and conduct failure assessment using individual failure models. The software implements a failure model plug-in interface and allows the failure model software to be used in calcePWA 5.0 and on the CALCE Web Site.

Expanded Models in calceFAST



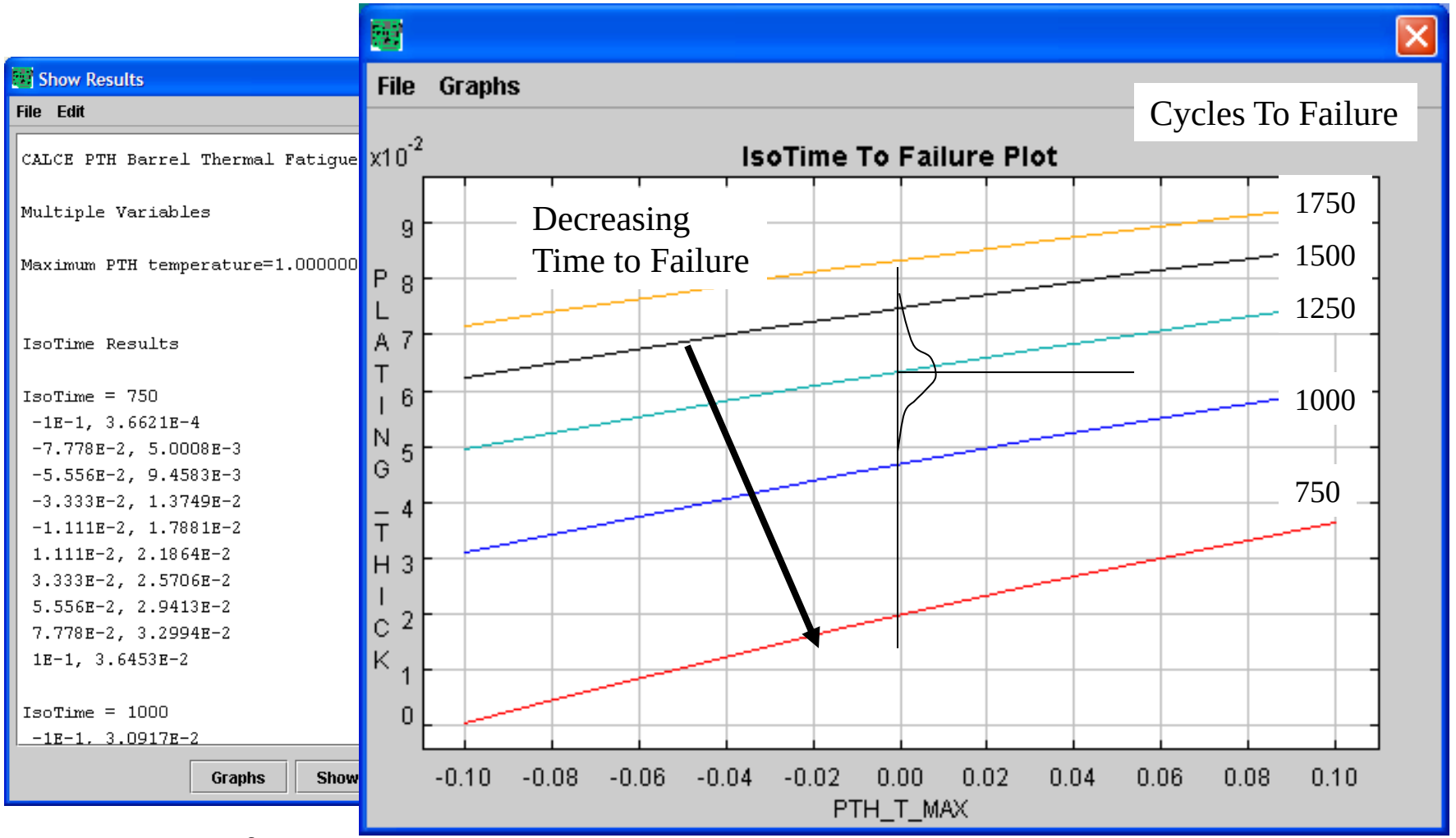
Package and device models from CADMP-II are now available in calceFAST.

Sensitivity Analysis Results



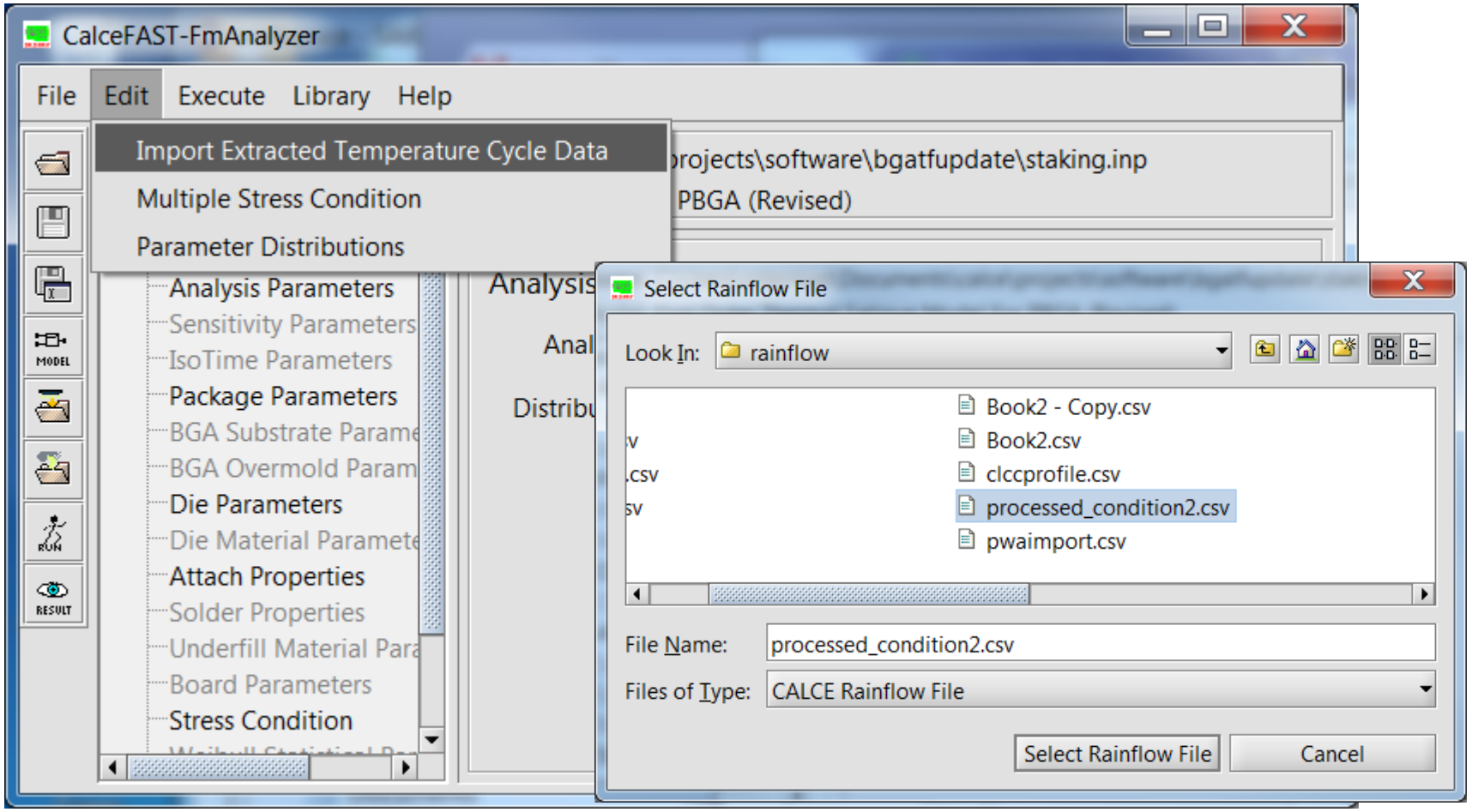
In the case of multiple attribute sensitivity, the attributes and their assigned values are presented in the text report. The X-axis of the graph defines the percent values over which the selected attributes were varied.

Iso-Time To Failure Results



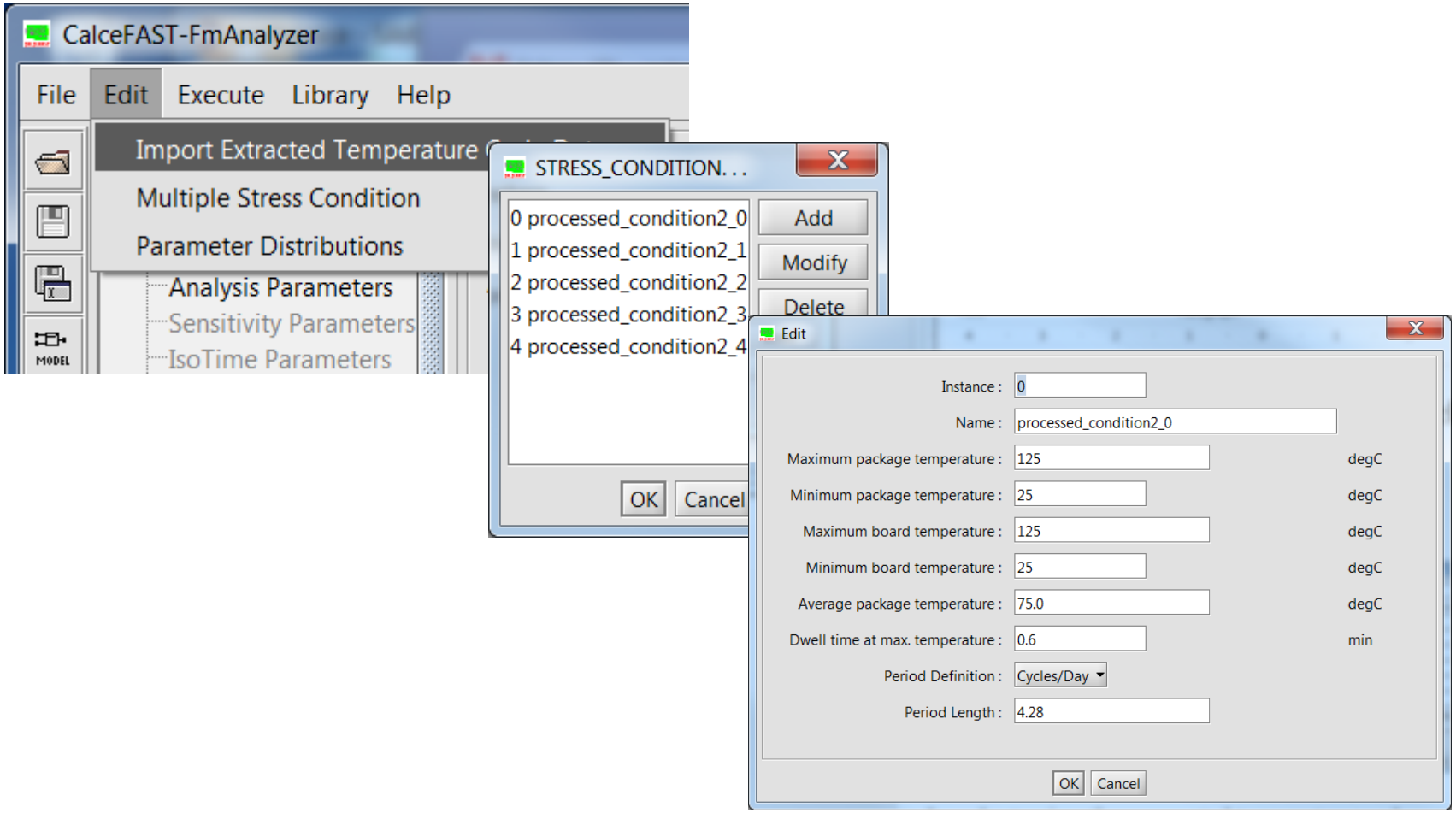
Iso-time to failure assessment provides you with plots that can be used to examine the effect of changes in environment loading conditions versus design parameters. From the example above, a reduction in plating thickness by 0.01mm can reduce the life by 44%.

calceFAST Implementation



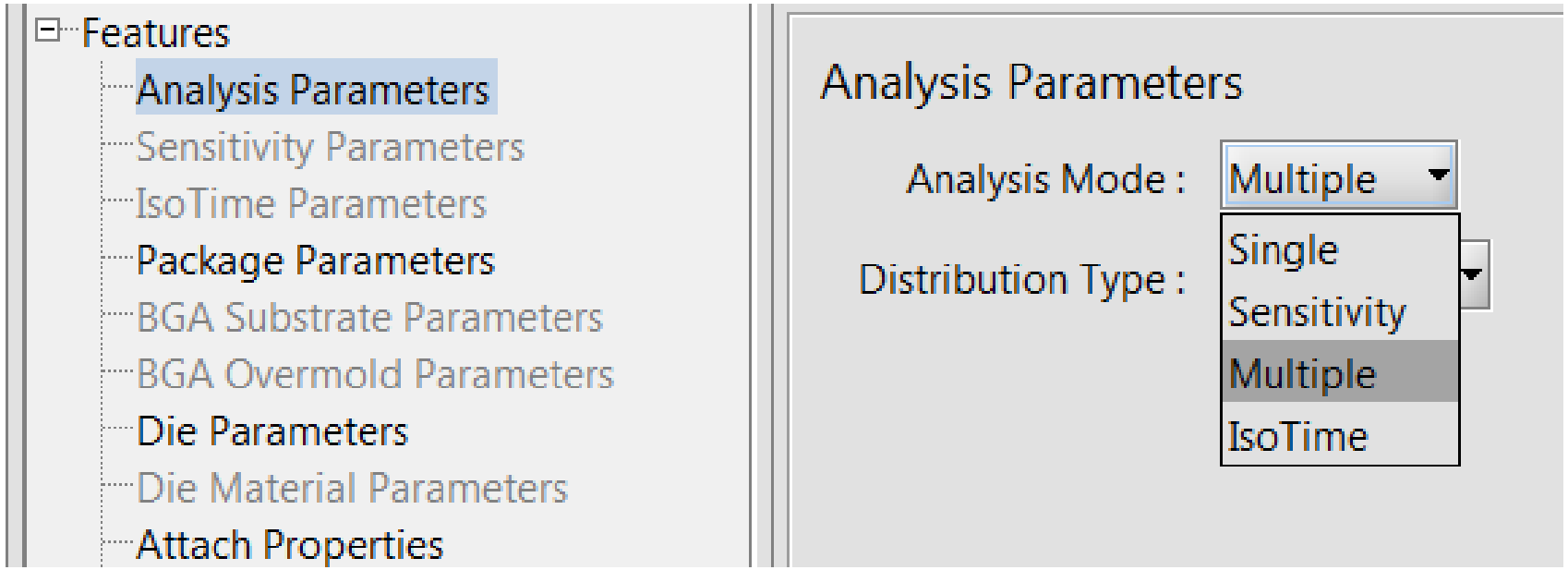
The calceFAST implementation assumes the user has already processed a time history file and "Import Extracted Temperature Cycle Data" option allows the user to select a processed output file.

Segmented Temperature Cycles



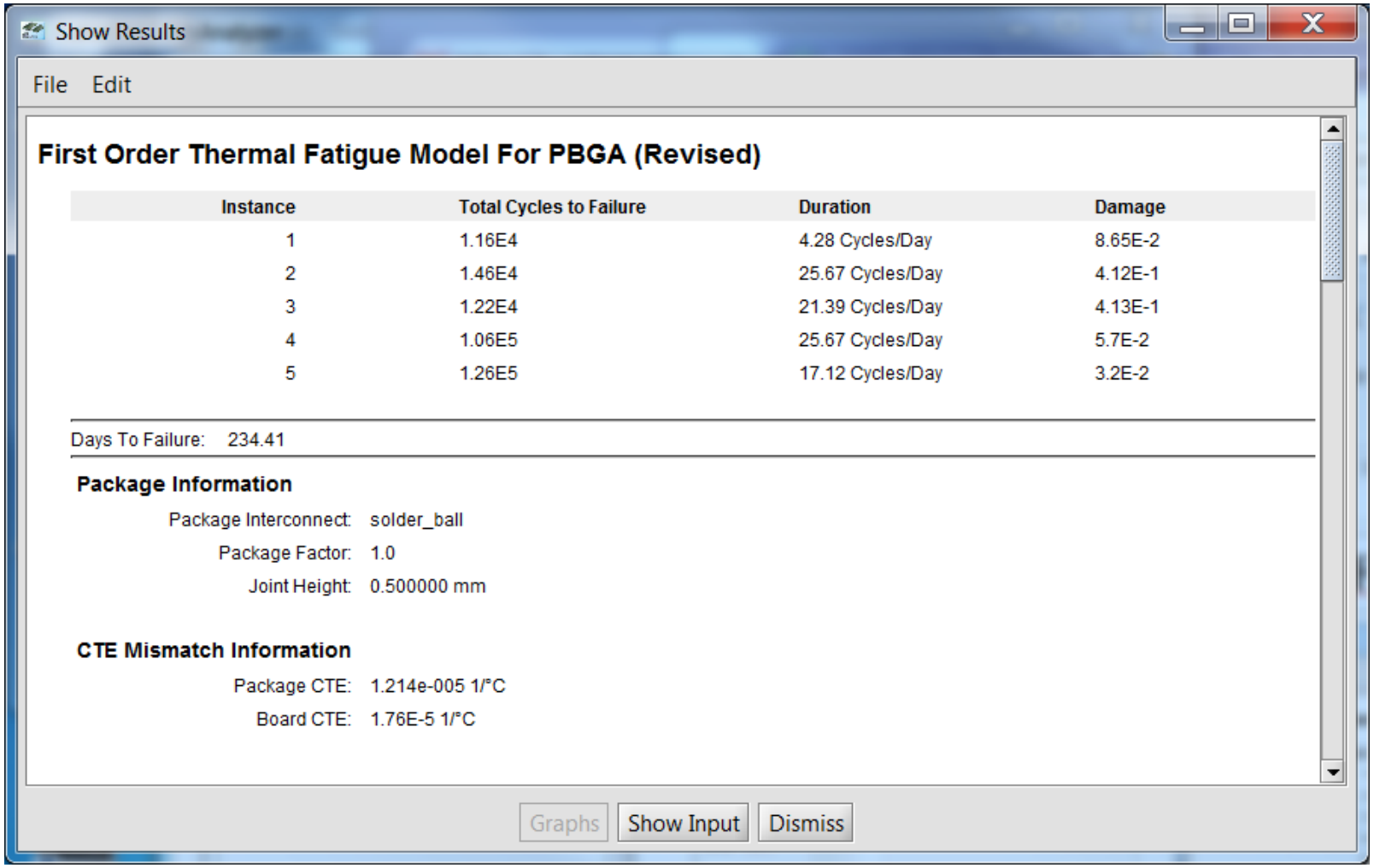
In order to view the segmented temperature cycles, you will need to select the **Multiple Stress Condition Options**.

Segmented Temperature Cycles



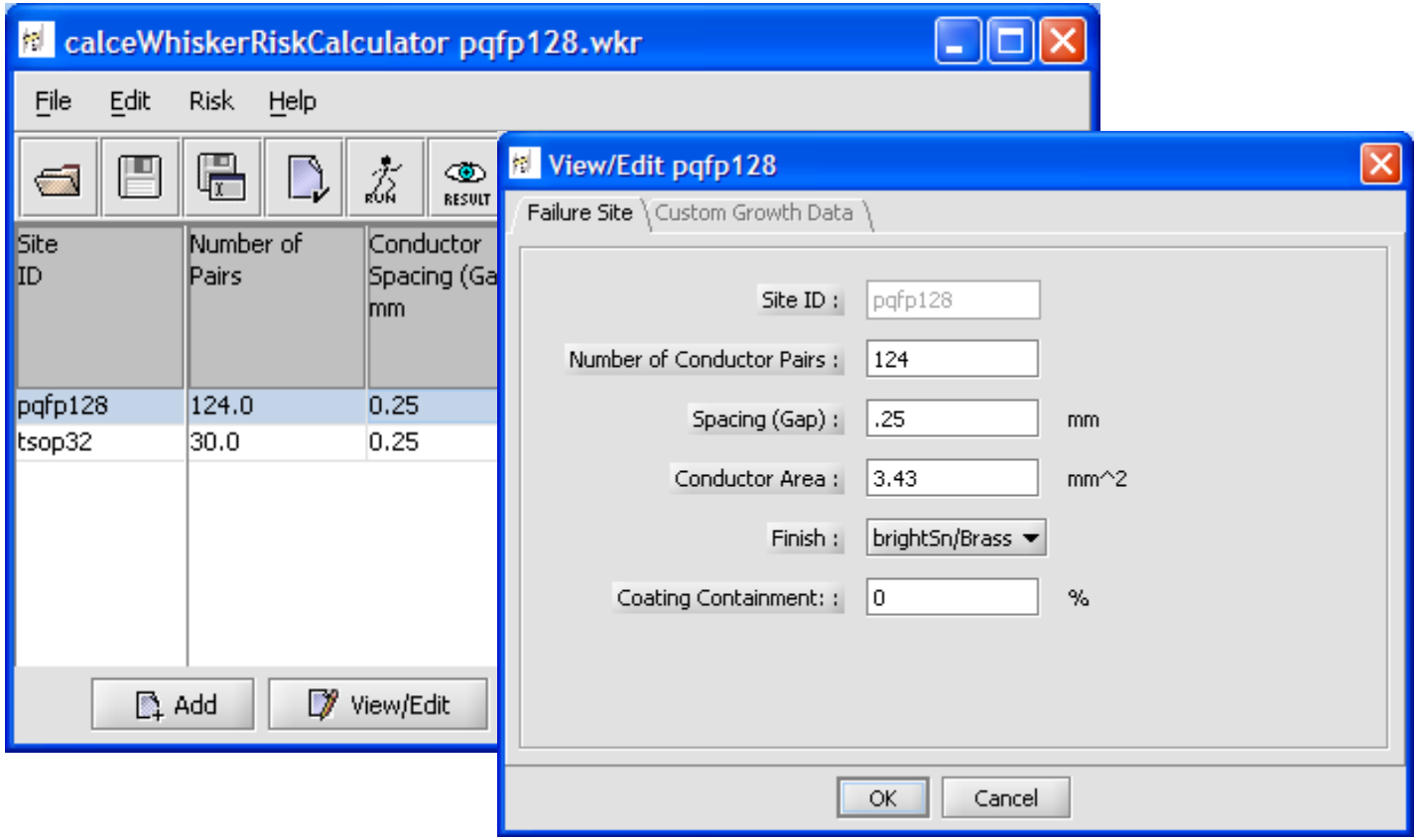
In order to conduct an assessment with the segmented temperature data, you will need to assign the ***Analysis Mode*** to *Multiple* under the **Analysis Parameters** Feature Panel.

calceFAST Fatigue Model Output Example



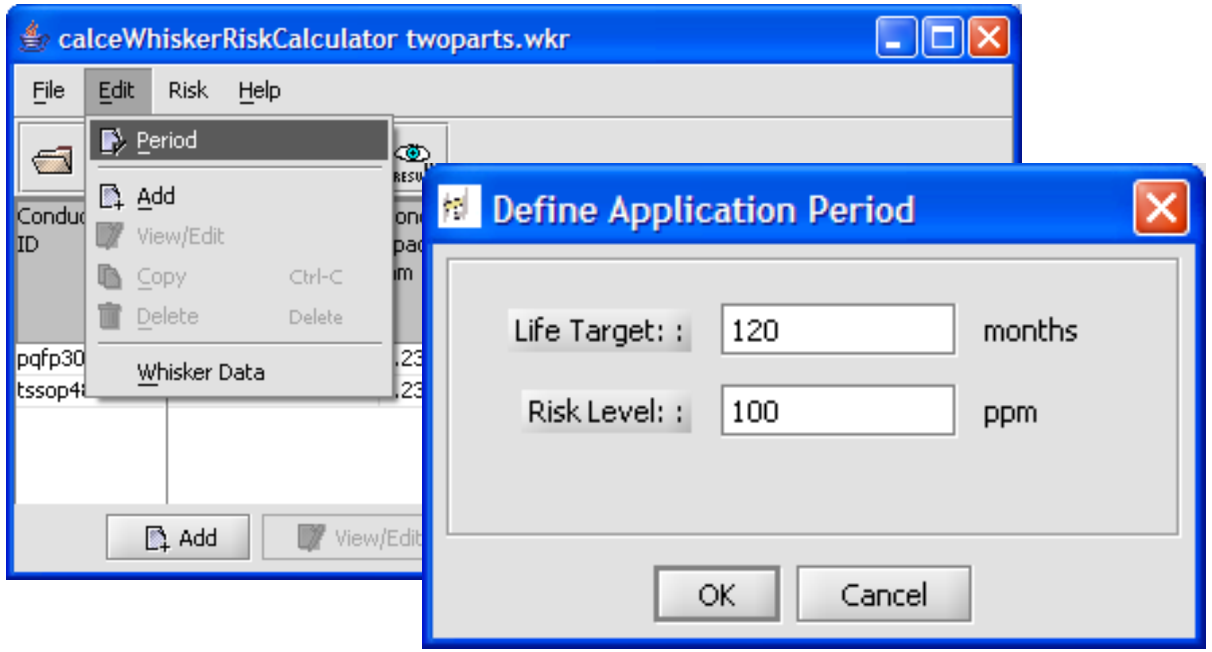
After saving and executing the analysis, the results are presented with damage ratios for each segment.

Whisker Risk Assessment Software



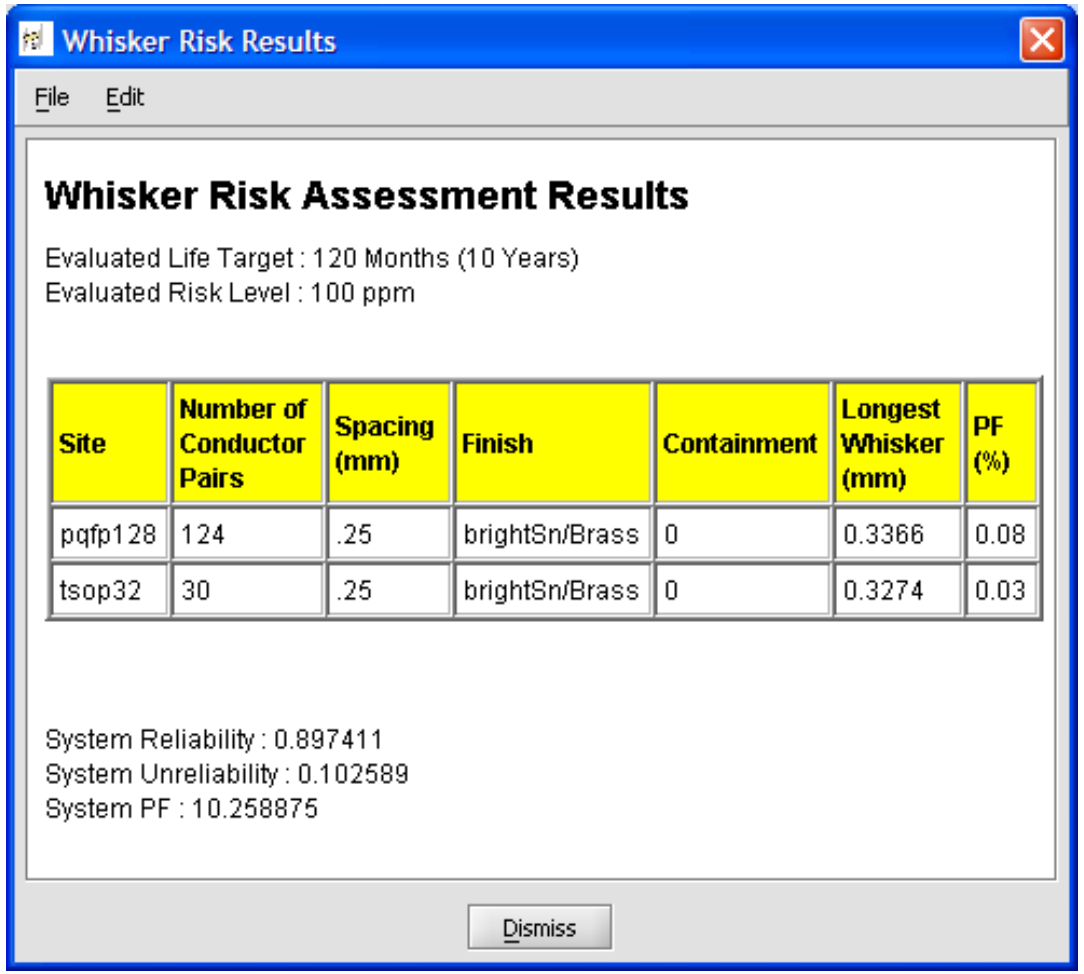
A software package that implements the fixed risk assessment algorithm has been developed. Software allows you to define conductor pairs and select finish type to look up whisker growth or directly define whisker growth parameters.

Conducting A Risk Assessment



The software allows you to define the target life time of the system, desired risk level in parts per million, and the percentage of whisker containment afford by the application of a conformal coat. The target life is used in combination with the database of whisker growth tables to determine the whisker growth characteristics. The risk level is used to define the sample size (i.e. the number of Monte Carlo iteration).

Risk Assessment Results



The software outputs the probability of whisker failure for each conductor pair considered. The probability of failure for each conductor pair is then rolled up to provide the total whisker reliability of the system.

Applications of CALCE Software

Comanche

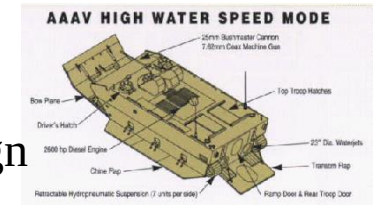
- Commonality w/ AF F-22
- Commercial ICs Inserted
- $50M O&S savings

JSTARS Ground Station

- PoF Analysis on circuit cards
- Recommended commercial processor circuit card
- $12M Savings

AAAV

Virtual Qualification of circuit cards



GM

83% reduction in design issues

>10% reduction in time to markert

Seagate

•Virtual Qualification

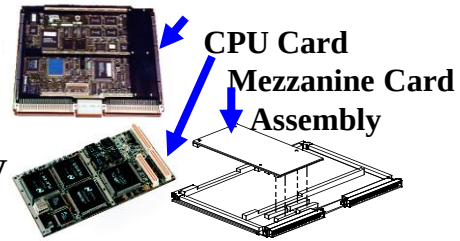
Emerson

•Virtual Qualification of CCA

•Failure assessment of a individual component.

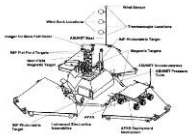
VISTA Controls

Conducted virtual qualification of military CCA



Mars Path Finder

Verified robustness of flight CCA



Bradley Fire Support Vehicle

- Identified potential problems
- Increased Reliability

Honeywell

Virtual qualification of engine controller

Life Cycle PoF Analysis Provides Considerable ROI