Cascade Engineering Services, Inc.

Viscoplastic Solder Fatigue Life Analysis

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Solder Fatigue Life Analysis

Test Objective

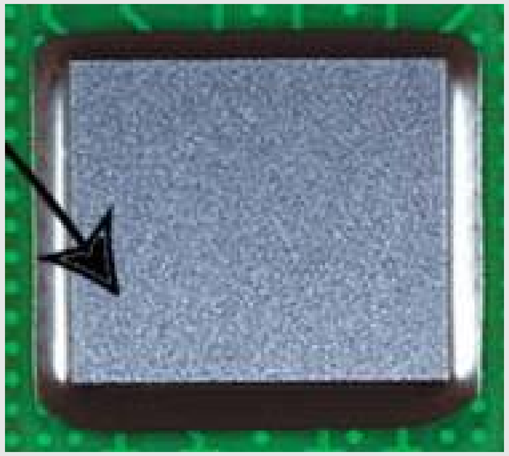
- To evaluate Solder joint fatigue life under thermal cycle loading

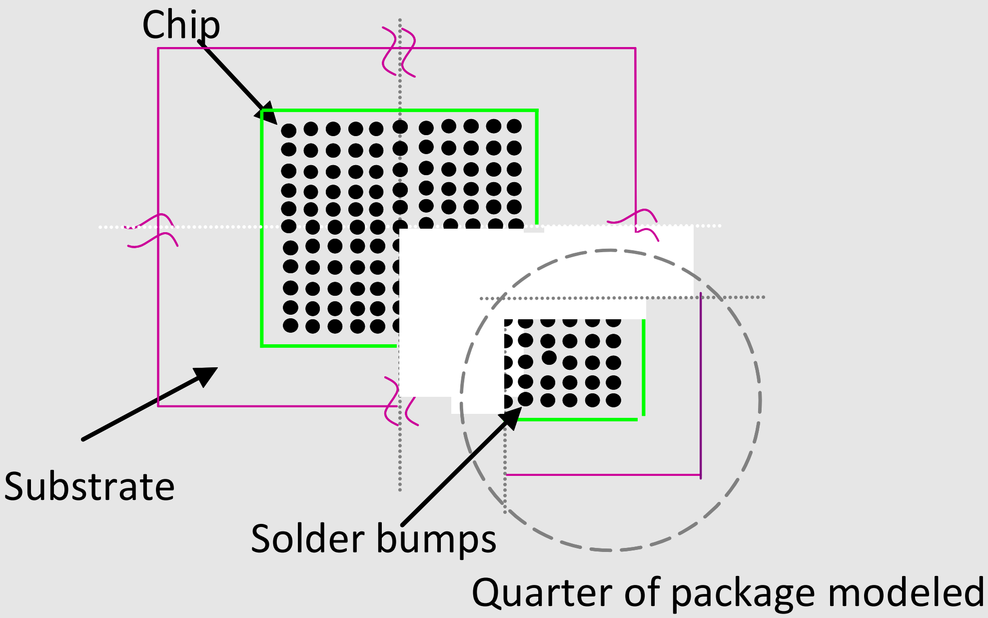
Methodology

- Step 1: Geometry and Material Properties - Constitutive Material Models
- Step 2: Loads and Boundary Conditions
- Step 3: FEA Results
- Step 4: Fatigue Life Estimation
- Case Study Benefits

Step 1: Geometric Model & Material Properties

Flip-Chip Electronic Package





Structure Dimensions

Components	Length (inch)	Width (inch)	Thickness (inch)
Chip	0.118	0.118	0.005315
Substrate	0.177	0.177	0.002756
Solder	Pitch: 0.009843	Max Dia: 0.003937	Standoff: 0.003543

Step 1: Geometric Model & Material Properties

Components	Young's Modulus (Psi)	Poisson's Ratio	CTE (PPM / C)
Die	**2.36e7**	**0.278**	**3.2**
Substrate	**3.5e6**	**0.3**	**16/16/35**
Underfill	**7.36e5**	**0.34**	**33**
Solder	**4.4e6**	**0.35**	**24.5**
Passivation	**4.7e7**	**0.24**	**2.9**
Copper	**1.7e7**	**0.3**	**16**
Aluminum	**1.01e7**	**0.24**	**23.2**
Nickel	**2.9e7**	**0.31**	**12.7**

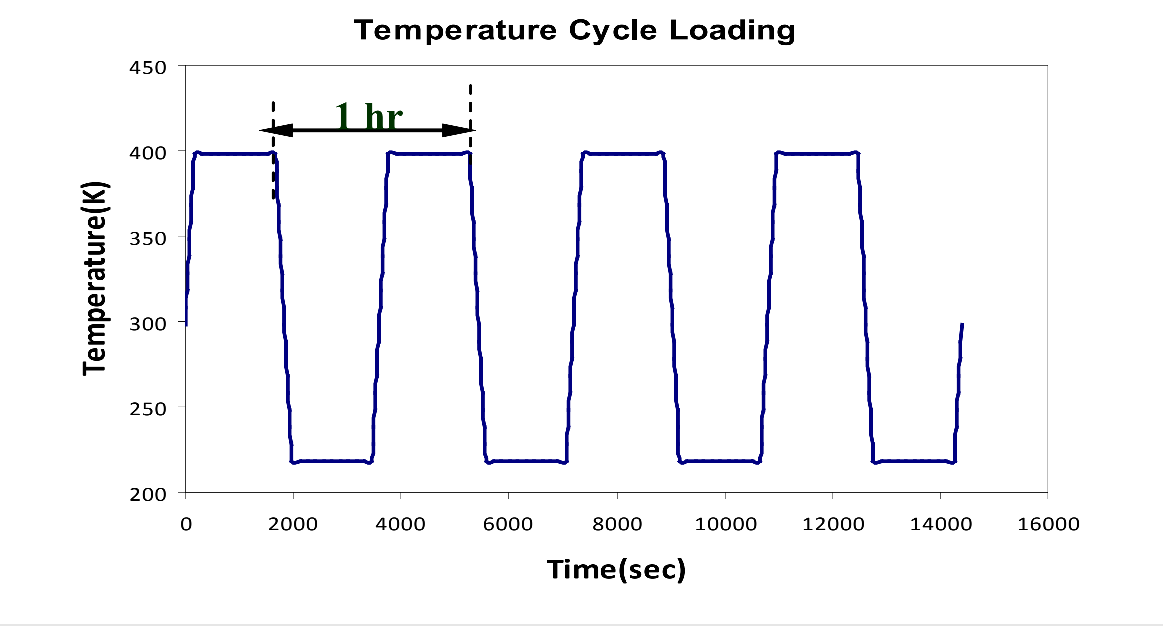
ANSYS	Parameter	Values	ANSYS	Parameter	Values
C1	**S_0(psi)**	1800	**C6**	**h_0(psi)**	2.0e5
C2	**Q/k(1/K)**	9400	**C7**	**S^ (psi)**	2.0e3
C3	**A(1/Sec)**	4.0e6	**C8**	**n**	0.07
C4	ε	1.5	**C9**	**a**	1.3
C5	**m**	0.303			

Solder: Anand Viscoplastic Constitutive Material Model

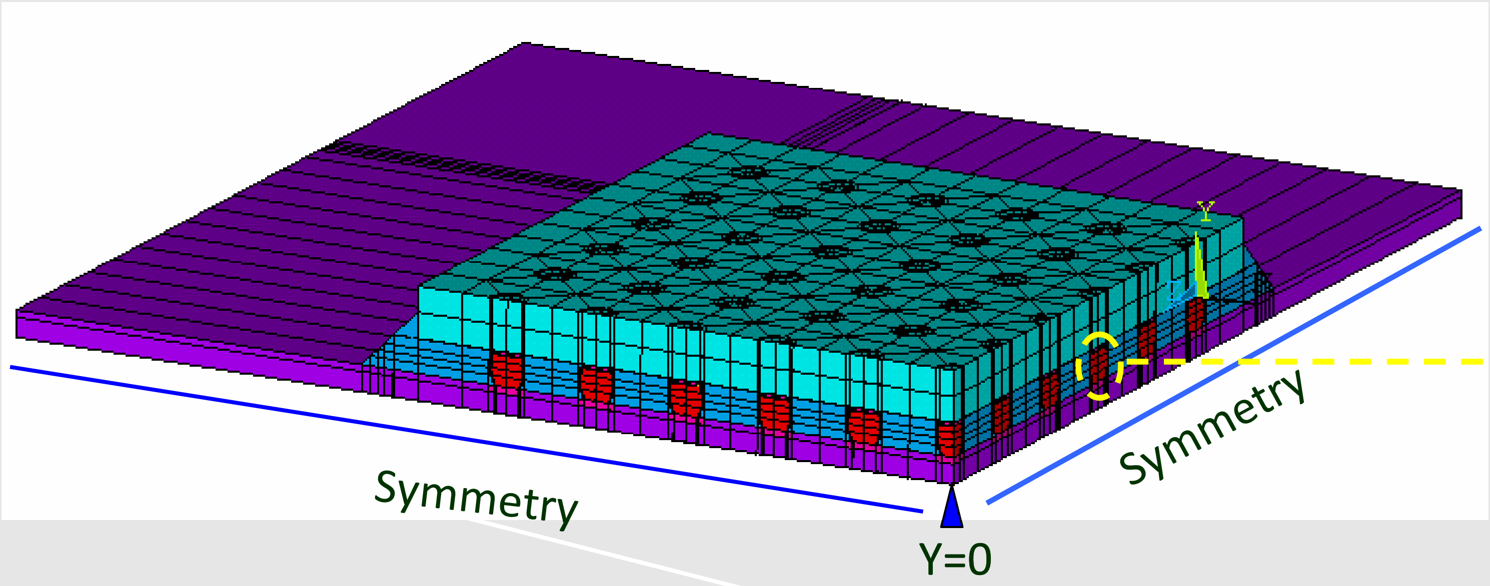
Step 2: Loads & Boundary Conditions

Thermal Loading

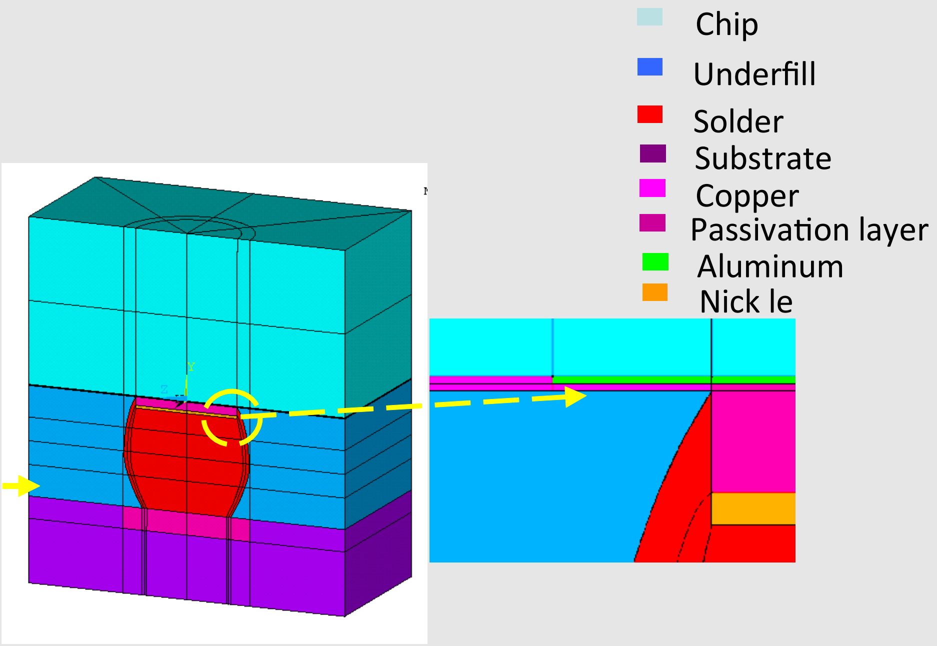
- Temperature limits: -55C to 125C
- Ramp rate: 36C / min
- Dwell time: 25 minutes



3-D Quarter Symmetric Model

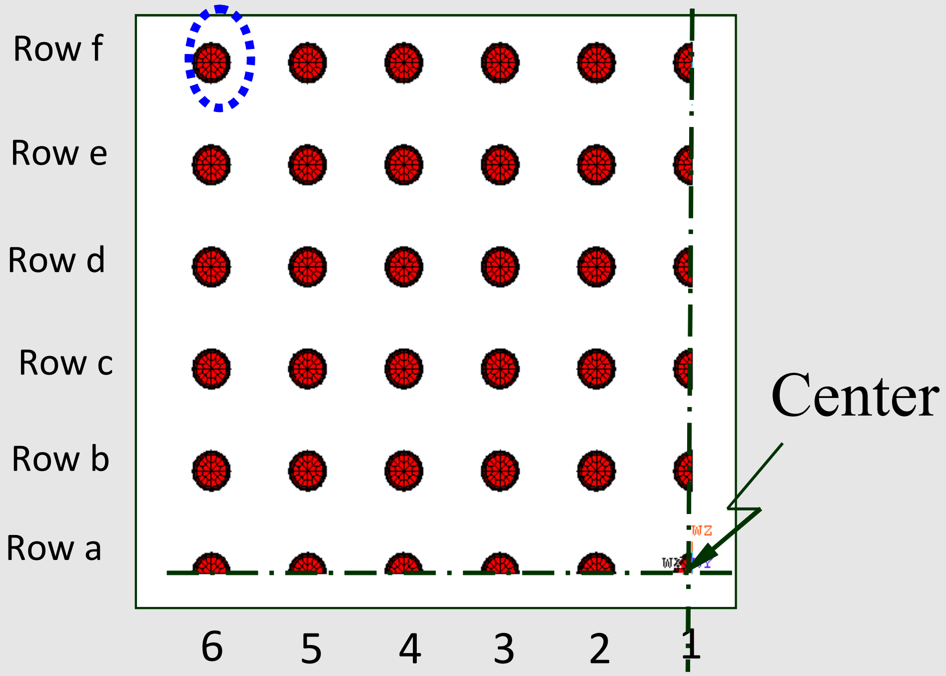


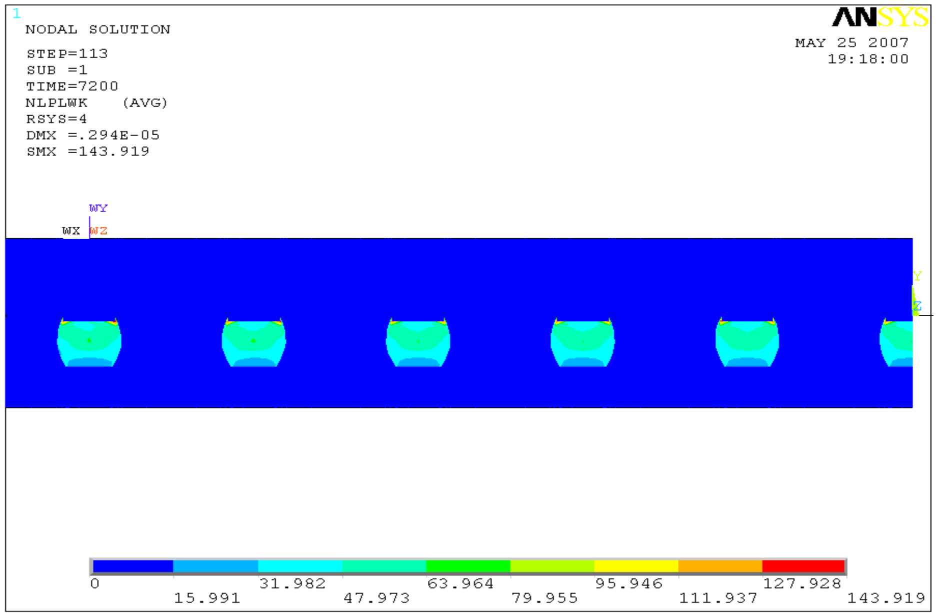
Meshing and Boundary Conditions



Unit Model

Step 3: FEA Results





```
NODAL SOLUTION

STEP=113
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TIME=7200
NLPLWK    (AVG)
RSYS=4
DMX =.294E-05
SMX =143.919
```
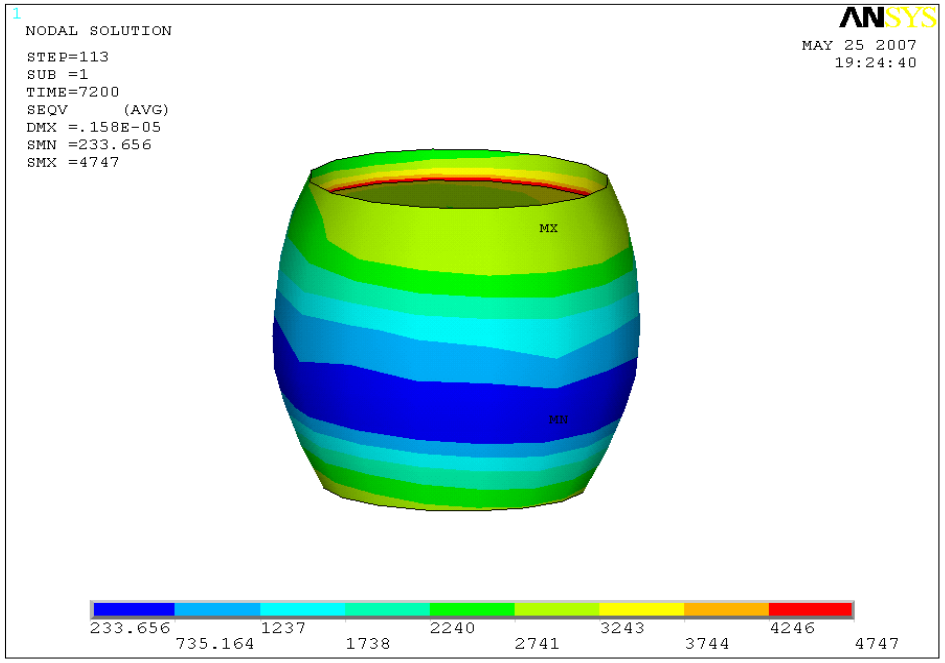

Plastic work for “row f”



```
NODAL SOLUTION

STEP=113
SUB =1
TIME=7200
SEQV      (AVG)
DMX =.158E-05
SMN =233.656
SMX =4747
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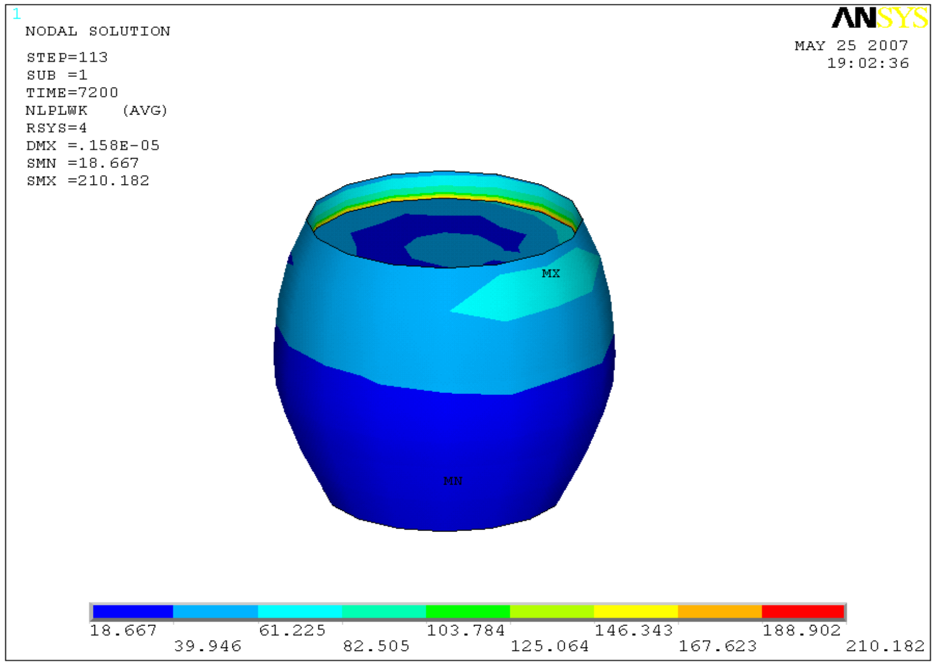
Von Mises stress “f6”



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NODAL SOLUTION

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SUB =1
TIME=7200
NLPLWK    (AVG)
RSYS=4
DMX =.158E-05
SMN =18.667
SMX =210.182
```

Plastic work for solder “f6”

Step 4: Fatigue Life Estimation

Solder Fatigue Life Model: Darveaux's Crack Growth Correlations

Characteristic life of the joint

$$\alpha = N_o + \frac{a}{{da}/{dN}}$$

Where,

ΔW_{avg} =Accumulated plastic work per cycle

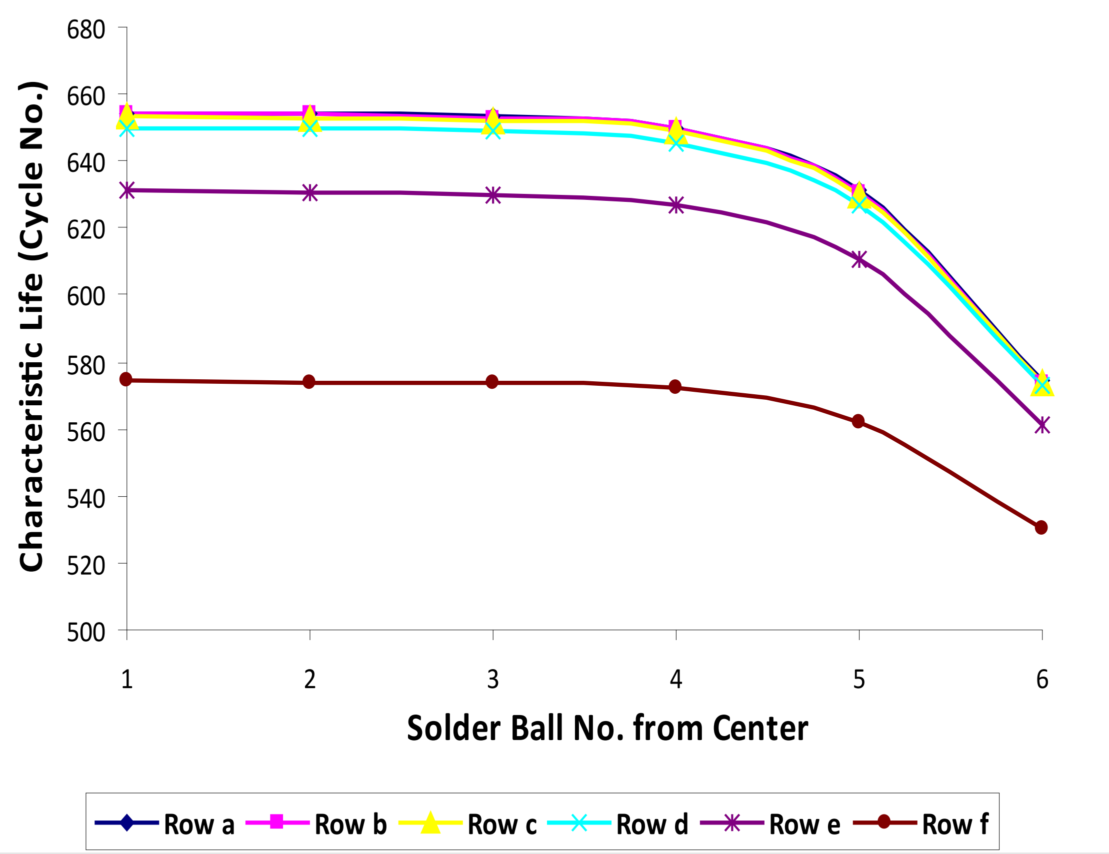
$N_o = K1(\Delta W_{avg})^{K2}$ = No. of cycles to crack initiation

$\frac{da}{dN} = K3(\Delta W_{avg})^{K4}$ =Crack growth rate

K1 , K2 , K3 , K4 = Crack growth constants

(for this case,K1=5.63e4, K2=1.62, K3=3.34e-7, K4=1.04)

a= the length of crack to propagate through the entire solder ball



Characteristic life of solders at different locations

Case Study Benefits

Summary

- Potential failure site: top of solder ball and below UBM layer
- Critical Solder Location: The corner solder ball “f6” is the most dangerous one with the shortest characteristic life of 530 cycles.
- Life Trends: Solder ball characteristic life decreased with increasing distance from center and life varied from 575-650 thermal cycles

Benefits

- Thermal-mechanical stress analysis identified reliability risk areas
- Cost effective parametric studies assisted with a more robust and reliable product design
- Fast and economic way to evaluate solder fatigue life to complement time and cost in tensive accelerated life tests
- Proven methodology for comparing different IC packaging styles, different suppliers for subsystem or system integration