Automotive E/E Environmental and Reliability Validation – Future Trend in Virtual Validation

C. Julius Wang

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Executive Summary

- **Trend**
  - ✓ Virtual Verification gains momentum
- **What does it do?**
  - ✓ Virtually prove life before physical testing
- **Benefits**
  - ✓ Resource saving – parts and test time
  - ✓ Less iteration/trial-and-error
  - ✓ Faster product development cycle

Agenda

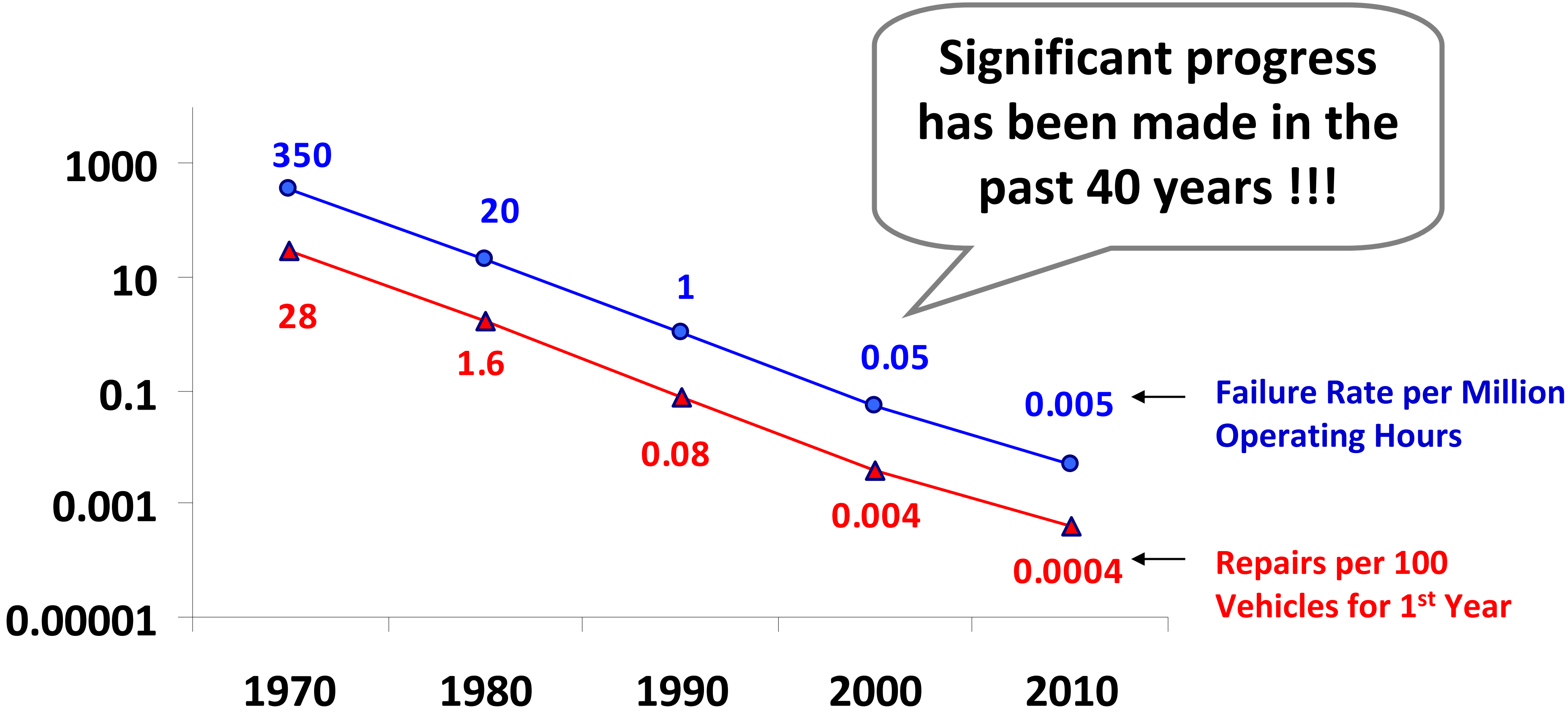
- E/E Reliability Test Evolution
- Virtual Verification
- Examples
- Limitations
- Benefits
- Recommendations
- Case Study

How Do We Use Vehicles?

Electrical/Electronics Demands High Reliability

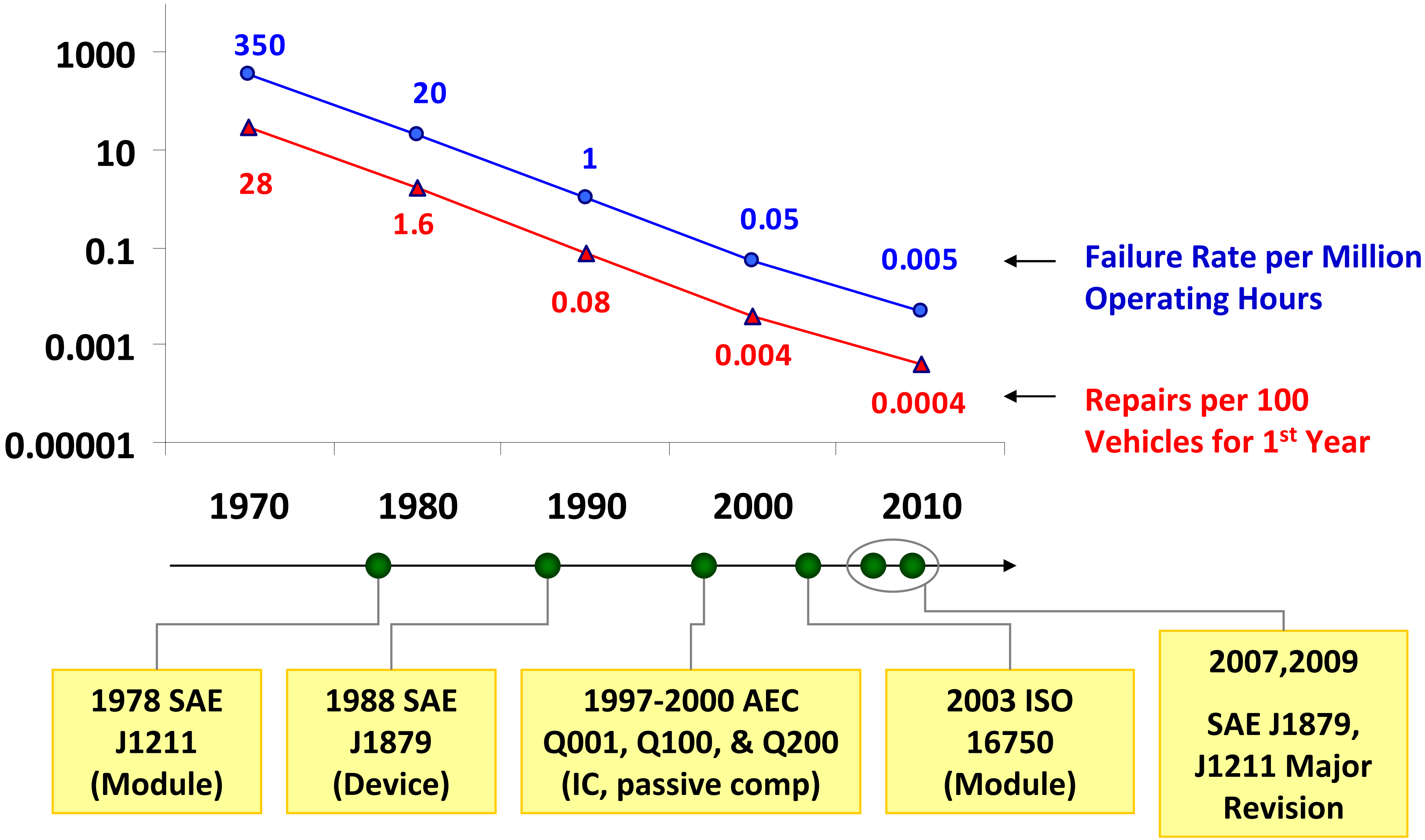
- **Design Life**
  - ✓ 10 to 15 years
  - ✓ 150K to 200K miles
- **Environmental Survivability**
  - ✓ hot, cold, rain, snow,dust
- **Customer Usage**
  - ✓ frequent stop & go
  - ✓ high mileage/long idling &parking
  - ✓ Road conditions - paved/ unpaved roads
  - ✓ passing through water/mud puddles
  - ✓ car wash
  - ✓ trailer tow

Automotive E/E Modules Reliability Trend

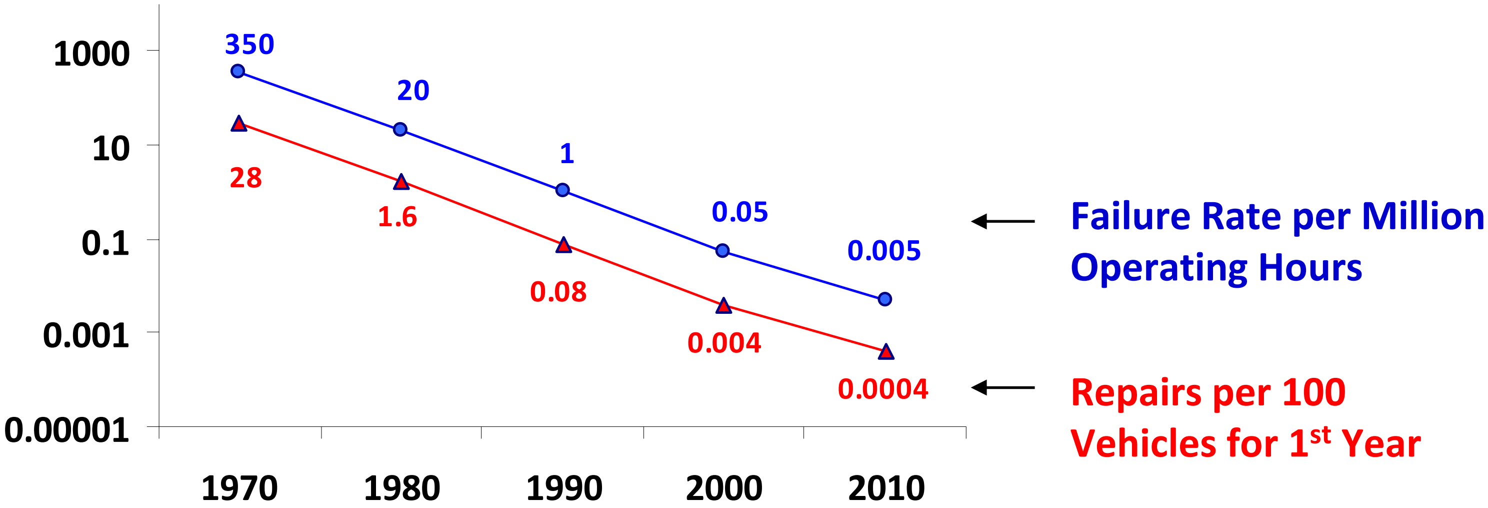


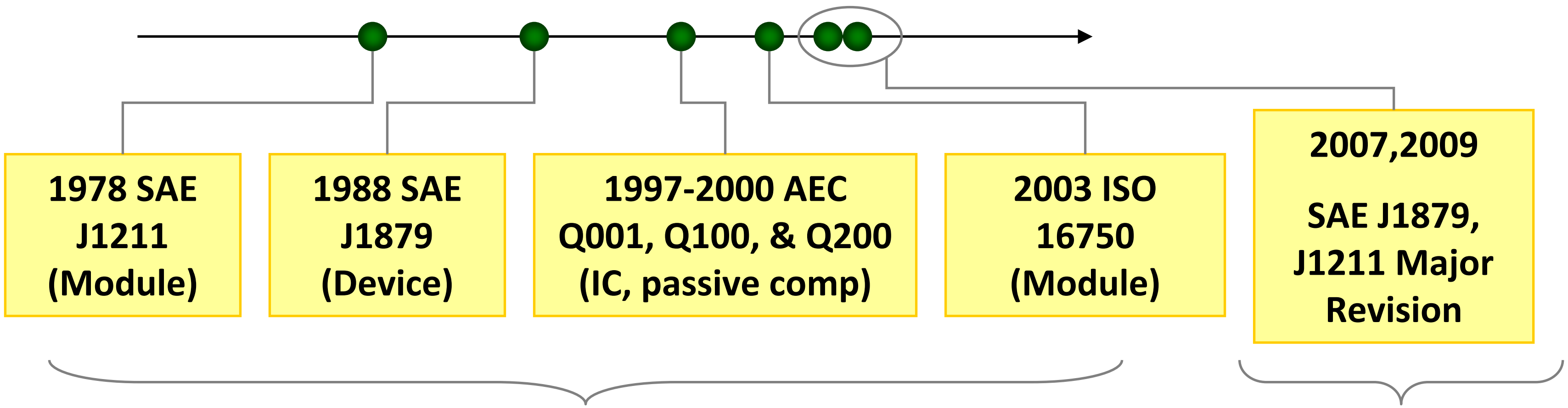
How was that achieved?

Major Events in Automotive E/E Testing Specs



E/E Reliability Testing Paradigm Shift





Test-to-Pass → **Test-to-Failure**

What Have We Observed?

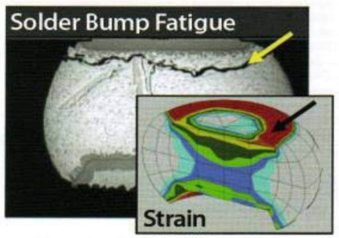
- Testing has matured in the past 40 years (incl. HALT/HASS)
- Shortened product development cycle due to technology advancement and forced by competition
- Must find a way to do more with less
  - ✓Shorter Development Time
  - ✓But Need High Reliability
  - ✓**How to align these two contradictory goals?**

Possible Strategy

Test to Failure

+

Virtual Verification



What is Virtual Verification?

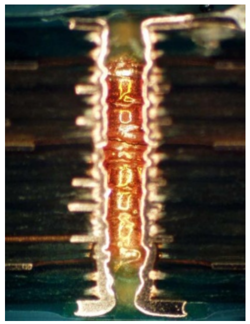
- The use of science (physics, chemistry, etc.) to capture the modeling of failure mechanisms so it could be used to predict life estimations under operational conditions. (*simply said: computer-aided-engineering tool used to verify design*)

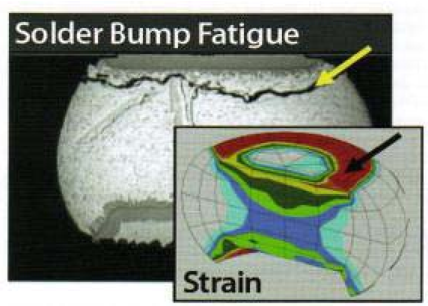
- Used in many areas in Auto Industry
  - structure, safety, thermal
  - aerodynamics, safety
  - noise/vibration/harshness, etc.

- With more research in Physics-of-Failure (PoF), Electrical/Electronics can focus on more than just circuit analysis, thermal analysis, and some EMC

Wearout Failure Mechanism is Major Focus

- A study* in 2006 pointed that
  - The majority of hardware electronic failures are thermo-mechanically related
  - By thermally induced stresses and strains
  - Root caused to excessive differences in coefficient of thermal expansion

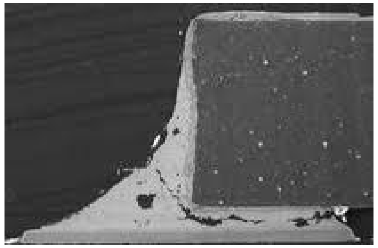




* Wunderle, B. and B. Michel, "Progress in Reliability Research in Micro and Nano Region", Microelectronics and Reliability, V46, Issue 9-11, 2006

Scope

- The current commercial CAE software* addresses five major fatigue/wearout failure mechanisms



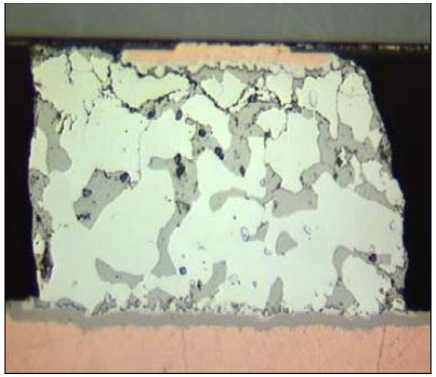
  - ✓ Solder joint fatigue life under thermal cycling
  - ✓ Solder joint fatigue life under vibration
  - ✓ Interconnect failures under mechanical shock
  - ✓ Plated through hole fatigue
  - ✓ Conductive anodic filament formation

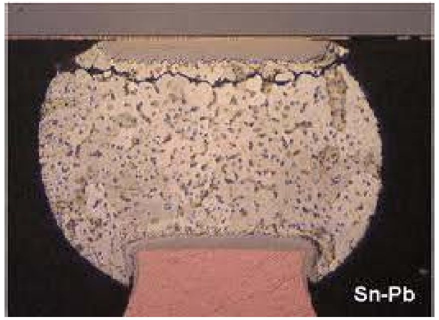
- It also calculated MTBF (mean time between failures)

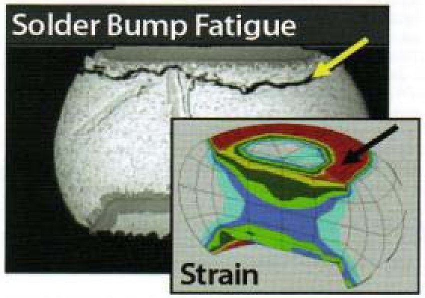
* Sherlock, DfR Solutions , 2011

Example - Ball Grid Array (BGA) Thermal-Mechanical Solder Joint Fatigue

- **Parameters affecting Fatigue**
  - Max temperature
  - Min temperature
  - dwell time
  - component design (size, number of I/O, etc.)
  - component material properties (CTE, elastic modulus, etc.)
  - solder joint geometry
  - solder joint material (SnPb, SAC305, etc.)
  - PCB thickness
  - PCBin-plane material properties (CTE, elastic modulus







Strain Energy Life Model – the Physics and Empirical Modeling Behind

$$(\alpha_2 - \alpha_1)\Delta T\, L_D = F\left[\frac{L_D}{E_1 A_1} + \frac{L_D}{E_2 A_2} + \frac{h_s}{A_s G_s} + \frac{h_c}{A_c G_c} + \left(\frac{2-\nu}{9 G_b a}\right)\right]$$

CTE (Coefficient of Thermal Expansion)

E: elastic modulus; A: effective solder area; G: shear modulus; L: ½ comp length; h: thickness…..

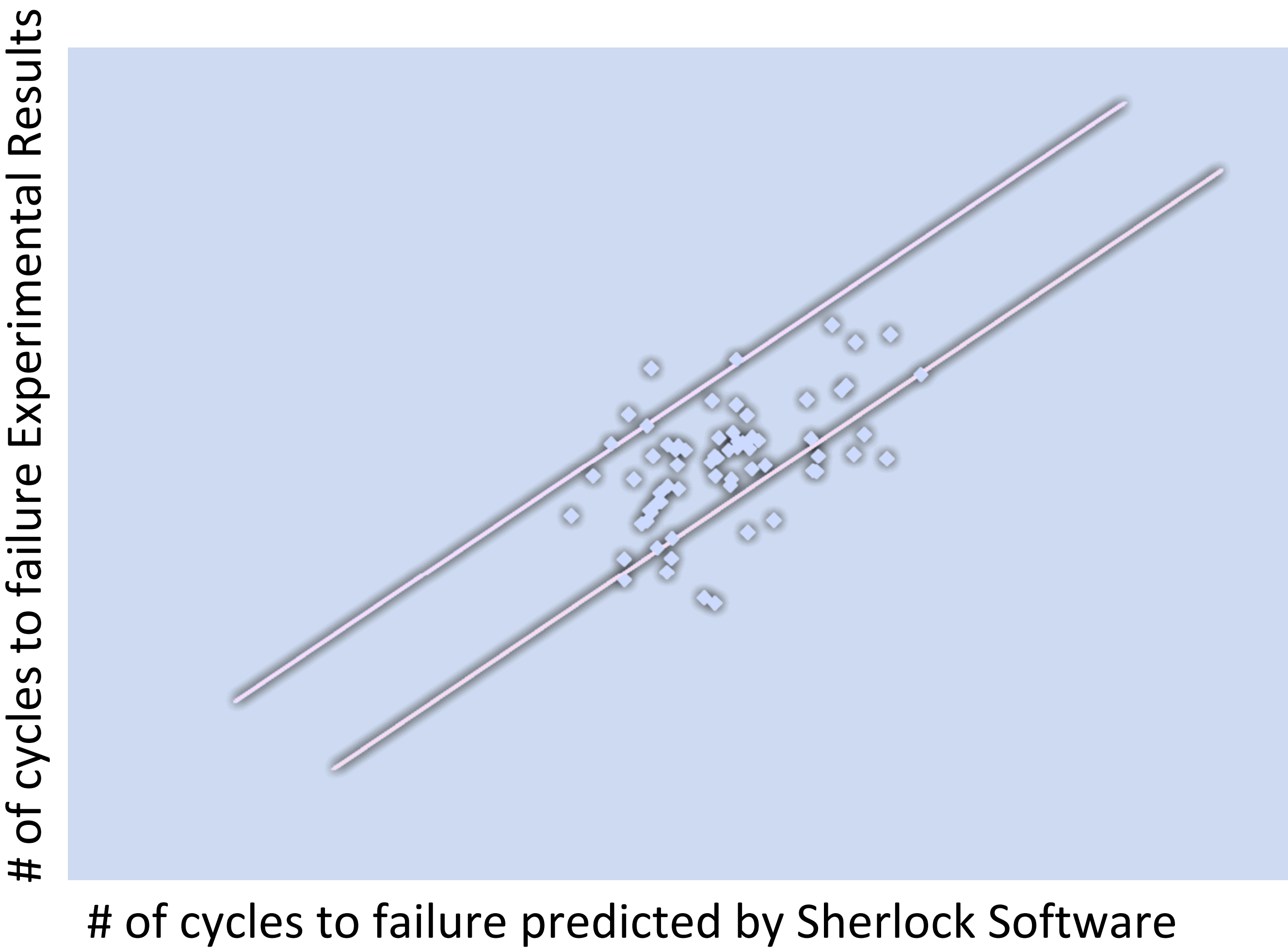
Strain Range →

$$\Delta\gamma = C\frac{L_D}{h_s}\Delta\alpha\Delta T$$

Life = # of cycles to failure →

$$N_f = 1/\left[(0.0006061)\left(0.5\Delta\gamma\frac{F}{A_s}\right)\right]$$

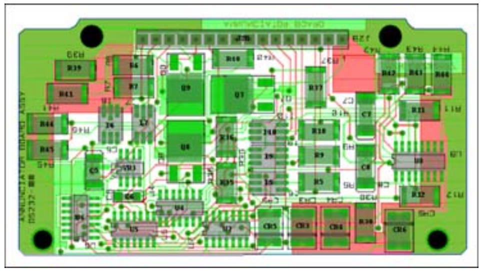
Correlation – Model to Experimental Results

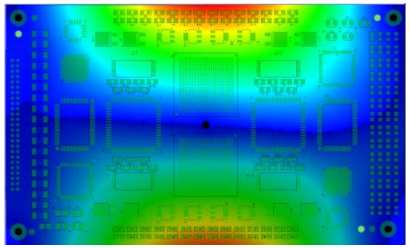


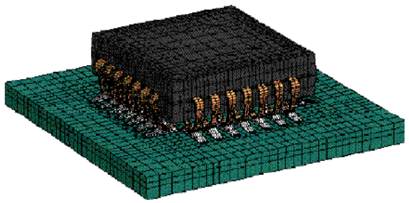
Data taken from Sherlock Validation Document, DfR Solutions , 2011

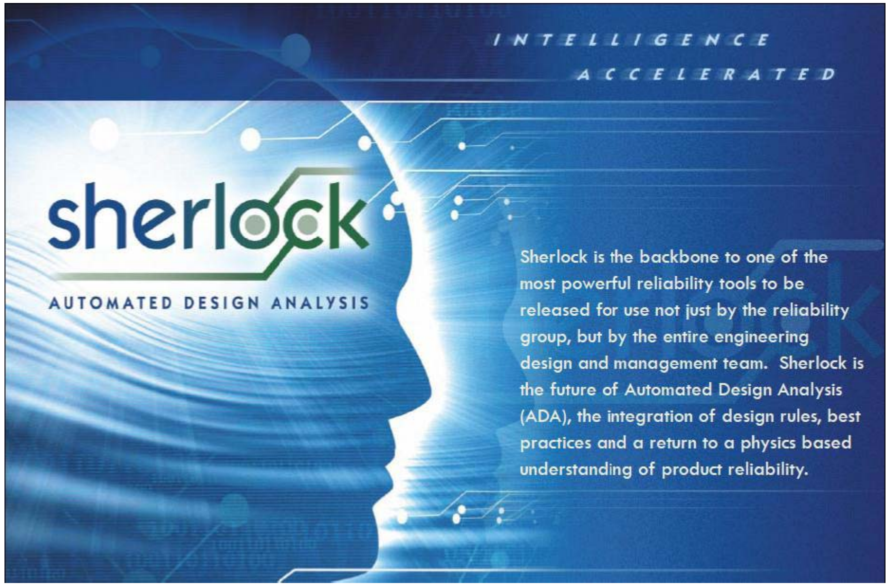
Virtual Verification – using a commercial software

- The software was build from the Physics-of-Failure mechanisms knowledge
- Validated with the physics-math model
- Added in statistical tool to account for variation









Note: Sherlock is from DfR Solutions

Limitations

- Correlation is fairly accurate in most situations
- Help reduce testing (*but **can not** replace all testing*)
  - Virtual tools can address overstress, wearout, fatigue issues
  - Virtual tools **can not** address if components and materials are built to design specs
  - Virtual tools **can not** predict what's unknown or new issues
  - Virtual tools **can not** predict software issues

Benefits

- Focus on effective and efficient test planning
- Reduce testing parts with design changes
- Identify application specific and packaging issues early
- Reduce resources in testing
- Reduce resources in test issue resolution
- Reduce resources in late problem discovery
- Reduce iteration/trial-and-error

Future is Already Here!!

The use of Physics-of-Failure (PoF) continues to grow

- U.S. Army requires PoF
- VITA-51.2 requires PoF
- GEIA-STD-0009 requires PoF
- MIL-HDBK-217H will require PoF (in process of changing)
- IEC-TS-62239 will require PoF (in process of changing)
- Under revision in SAE J2820 (in writing)
- Under consideration at FAA and Boeing (expected 2012)

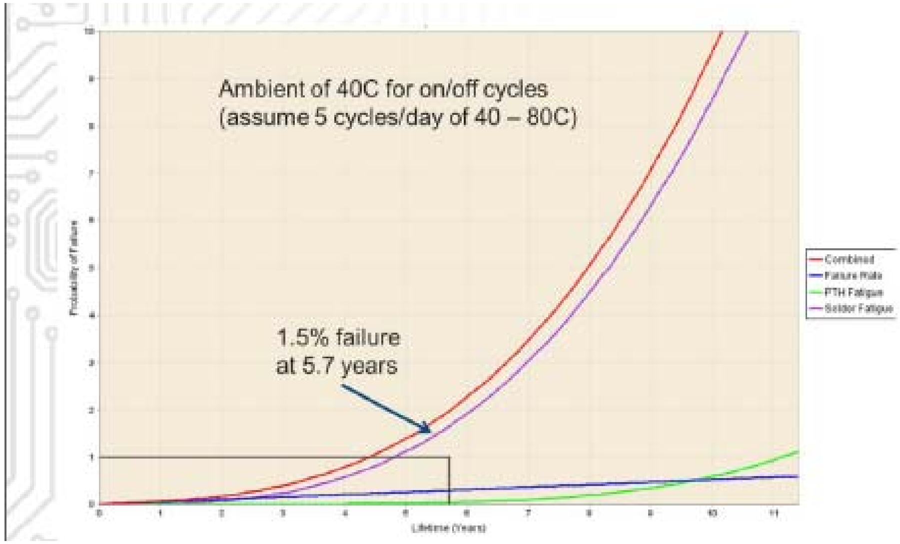
For Auto Industry,

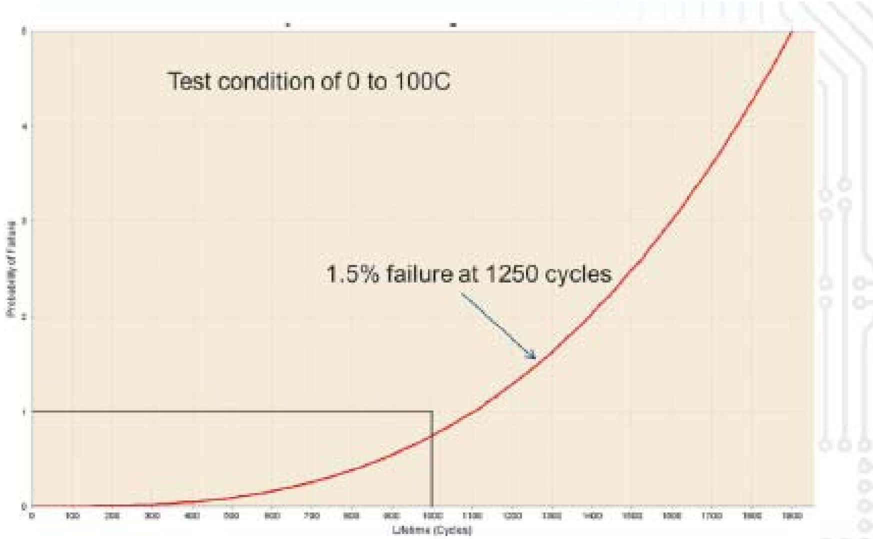
- Delphi and TRW Automotive already used the software
- Conti and Bosch are piloting
- GM expected to use by early November
- GM/Ford have asked suppliers to try it in a limited base
- Chrysler is studying the process

Recommendations

- Good investment
- Try a pilot if in doubt
- Design change should be virtually verified before engaging in physical reliability/life testing
    - ✓ If it doe not pass the virtual verification, less chance to pass the physical testing… do not waste time… go and change your design!!

Case Study A – Test Plan Development

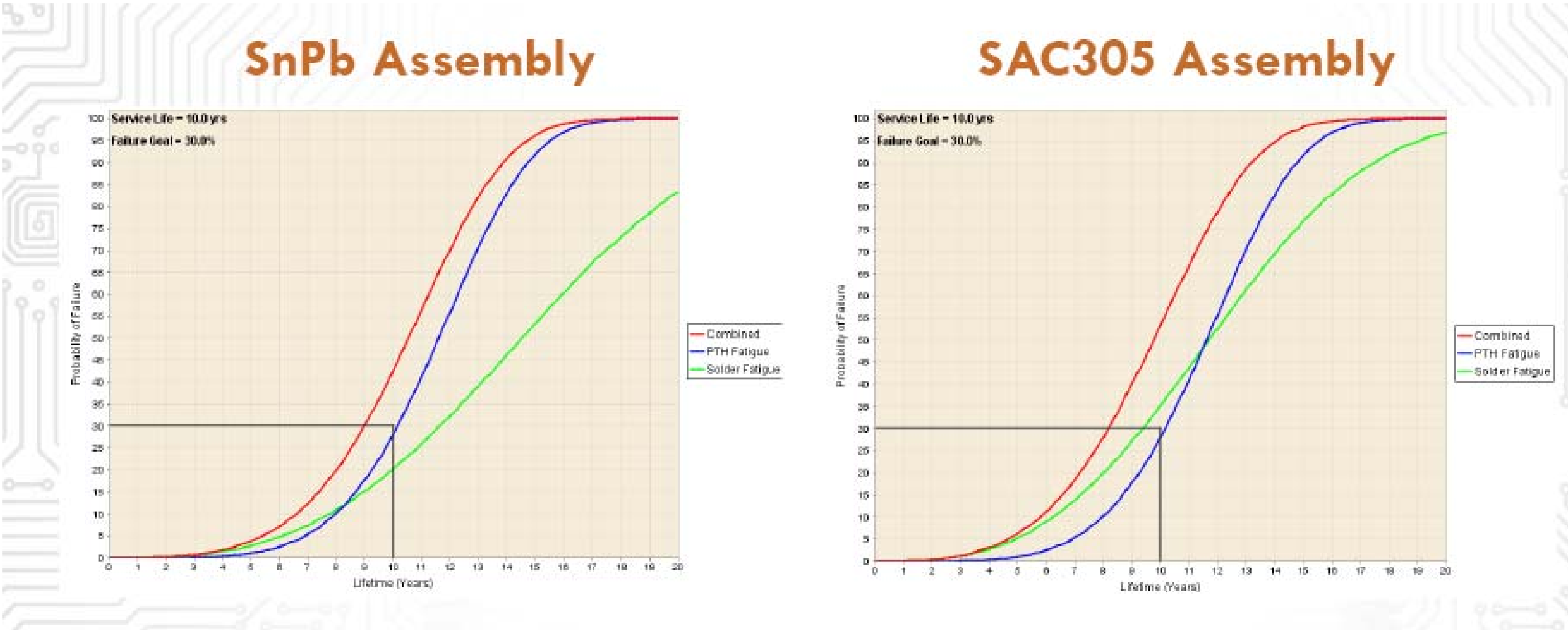




- A lighting component qualification plan.
- The Sherlock software identified test time and test condition based upon the field environment and likely failure mechanism.

Data taken from “Predicting the Future”, DfR Solutions , 2011

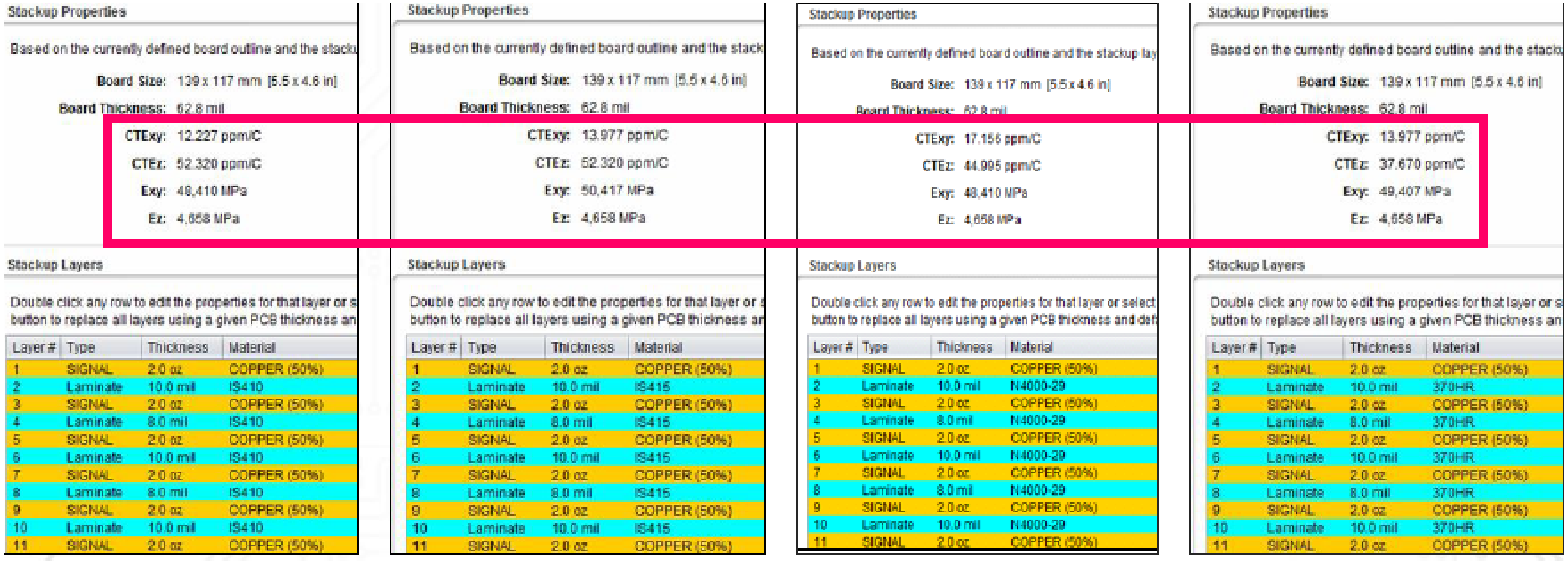
Case Study B – Pb-free Transition



- An avionics module planned to transitioned to Pb-free.
- Sherlock showed that the product performance will be negatively impacted due to severe environment.

Data taken from “Predicting the Future”, DfR Solutions , 2011

Case Study C – Design Change Management



Stackup Properties

Based on the currently defined board outline and the stacku

Board Size: 139 x 117 mm [5.5 x 4.6 in]

Board Thickness: 62.8 mil

CTExy: 12.227 ppm/C

CTEz: 52.320 ppm/C

Exy: 48,410 MPa

Ez: 4,658 MPa

Stackup Layers

Double click any row to edit the properties for that layer or s
button to replace all layers using a given PCB thickness an

Layer #	Type	Thickness	Material
1	SIGNAL	2.0 oz	COPPER (50%)
2	Laminate	10.0 mil	IS410
3	SIGNAL	2.0 oz	COPPER (50%)
4	Laminate	8.0 mil	IS410
5	SIGNAL	2.0 oz	COPPER (50%)
6	Laminate	10.0 mil	IS410
7	SIGNAL	2.0 oz	COPPER (50%)
8	Laminate	8.0 mil	IS410
9	SIGNAL	2.0 oz	COPPER (50%)
10	Laminate	10.0 mil	IS410
11	SIGNAL	2.0 oz	COPPER (50%)

Stackup Properties

Based on the currently defined board outline and the stack

Board Size: 139 x 117 mm [5.5 x 4.6 in]

Board Thickness: 62.8 mil

CTExy: 13.977 ppm/C

CTEz: 52.320 ppm/C

Exy: 50,417 MPa

Ez: 4,658 MPa

Stackup Layers

Double click any row to edit the properties for that layer or s
button to replace all layers using a given PCB thickness an

Layer #	Type	Thickness	Material
1	SIGNAL	2.0 oz	COPPER (50%)
2	Laminate	10.0 mil	IS415
3	SIGNAL	2.0 oz	COPPER (50%)
4	Laminate	8.0 mil	IS415
5	SIGNAL	2.0 oz	COPPER (50%)
6	Laminate	10.0 mil	IS415
7	SIGNAL	2.0 oz	COPPER (50%)
8	Laminate	8.0 mil	IS415
9	SIGNAL	2.0 oz	COPPER (50%)
10	Laminate	10.0 mil	IS415
11	SIGNAL	2.0 oz	COPPER (50%)

Stackup Properties

Based on the currently defined board outline and the stackup lay

Board Size: 139 x 117 mm [5.5 x 4.6 in]

Board Thickness: 62.8 mil

CTExy: 17.156 ppm/C

CTEz: 44.995 ppm/C

Exy: 48,410 MPa

Ez: 4,658 MPa

Stackup Layers

Double click any row to edit the properties for that layer or select
button to replace all layers using a given PCB thickness and def

Layer #	Type	Thickness	Material
1	SIGNAL	2.0 oz	COPPER (50%)
2	Laminate	10.0 mil	N4000-29
3	SIGNAL	2.0 oz	COPPER (50%)
4	Laminate	8.0 mil	N4000-29
5	SIGNAL	2.0 oz	COPPER (50%)
6	Laminate	10.0 mil	N4000-29
7	SIGNAL	2.0 oz	COPPER (50%)
8	Laminate	8.0 mil	N4000-29
9	SIGNAL	2.0 oz	COPPER (50%)
10	Laminate	10.0 mil	N4000-29
11	SIGNAL	2.0 oz	COPPER (50%)

Stackup Properties

Based on the currently defined board outline and the stack

Board Size: 139 x 117 mm [5.5 x 4.6 in]

Board Thickness: 62.8 mil

CTExy: 13.977 ppm/C

CTEz: 37.670 ppm/C

Exy: 49,407 MPa

Ez: 4,658 MPa

Stackup Layers

Double click any row to edit the properties for that layer or s
button to replace all layers using a given PCB thickness an

Layer #	Type	Thickness	Material
1	SIGNAL	2.0 oz	COPPER (50%)
2	Laminate	10.0 mil	370HR
3	SIGNAL	2.0 oz	COPPER (50%)
4	Laminate	8.0 mil	370HR
5	SIGNAL	2.0 oz	COPPER (50%)
6	Laminate	10.0 mil	370HR
7	SIGNAL	2.0 oz	COPPER (50%)
8	Laminate	8.0 mil	370HR
9	SIGNAL	2.0 oz	COPPER (50%)
10	Laminate	10.0 mil	370HR
11	SIGNAL	2.0 oz	COPPER (50%)

- Procurement recommends a lower cost laminate supplier.
- The Sherlock software (used by Engineering) determines the change negatively impact the product performance before engaging any test.

Data taken from "Predicting the Future", DfR Solutions , 2011