Pitfalls of Accelerated Testing

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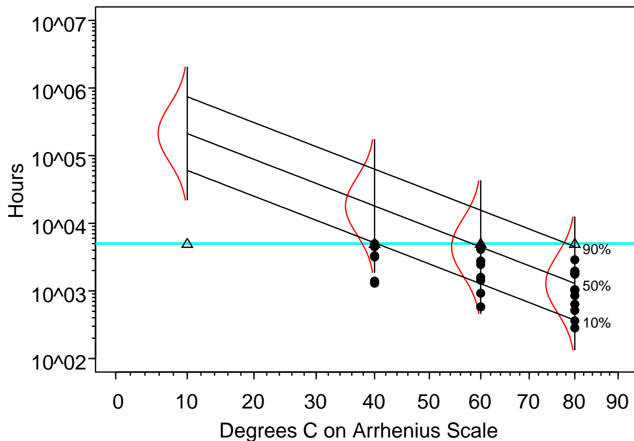
Overview

- Accelerated test overview
- Pitfalls and more pitfalls
- Different kinds of pitfalls
- Examples illustrating particular pitfalls
  - GE Refrigerator Compressor: Faulty accelerated test almost caused GE Appliances to go out of business
  - AT&T Bell Cells: Increased-voltage accelerated test inhibited failures that cost millions of dollars.
  - Electronic component: Accelerated test did not detect a masked failure mode that caused a reliability disaster.
  - Incandescent light bulb: A failure mode generated at high voltage led to a faulty comparison.
  - Insulating structure: Too much voltage stress caused extraneous failures and incorrectly optimistic lifetime predictions.
  - Appliance B: Industry-standard accelerated test led to incorrect predictions of field lifetime.
- Concluding Remarks

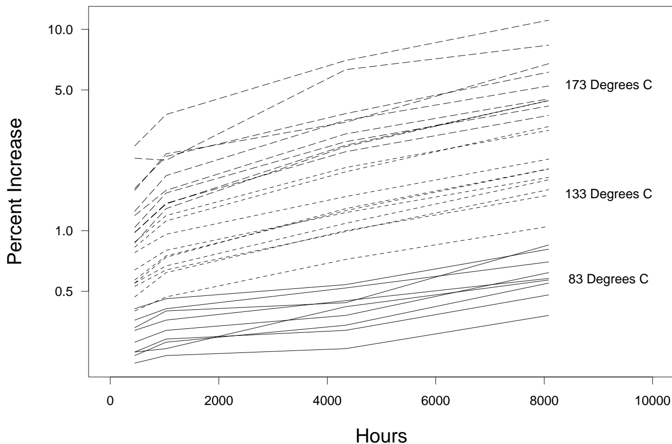
Types of Accelerated Tests

- There are three different kinds of quantitative accelerated tests, depending on what one is able to observe.
  - Accelerated life tests (ALT)
  - Accelerated repeated measures degradation tests (ARMDT)
  - Accelerated destructive degradation tests (ADDT)
- These different kinds of ATs have different data structures and thus **different** statistical models and methods of analysis.

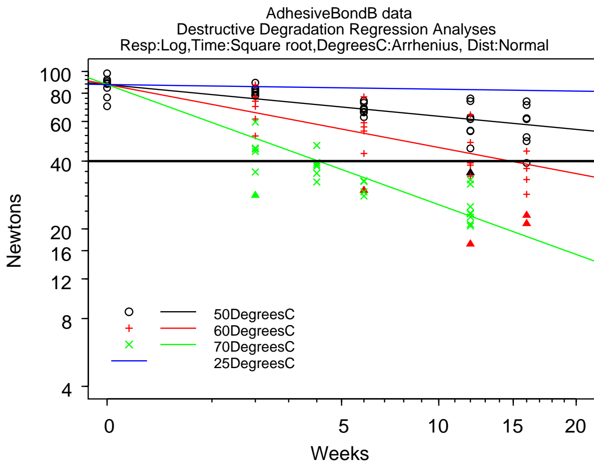
Typical Temperature-Accelerated Life Test



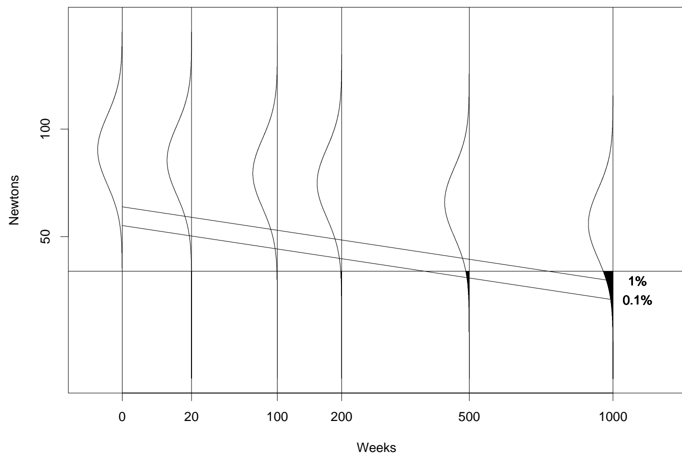
Accelerated Repeated Measures Degradation Test of Carbon-Film Resistors



Accelerated Destructive Degradation Test of an Adhesive



Proportion Failing as a Function of Time at from a Degradation Model



Methods of Acceleration

Three fundamentally different methods of accelerating a reliability test:

- Increase the use-rate of the product (e.g., test a toaster 200 times/day). Higher use rate reduces test time.
- Use elevated temperature or humidity to increase rate of failure-causing chemical/physical process.
- Increase stress (e.g., voltage or pressure) to make degrading units fail more quickly.

Use a **physical/chemical** (preferable) or **empirical** model relating degradation or lifetime to **use** conditions.

Accelerated Test Pitfalls References

- Meeker, W.Q. and Escobar, L. A. (1998). *Statistical Methods for Reliability Data*, John Wiley & Sons, Inc.

  Pitfalls 1-8 described in Chapter 19

- Meeker, W.Q. and Escobar, L.A. (1998). Pitfalls of Accelerated Testing. *IEEE Transactions on Reliability* R-47, 114-118.

  Pitfalls 1-9 described

- Meeker, W. Q., Sarakakis, G., and Gerokostopoulos, A. (2013). More Pitfalls in Conducting and Interpreting the Results of Accelerated Tests. *The Journal of Quality Technology* (with discussion), 45, 213-222.

  Pitfalls A-R described

Different Kinds of Pitfalls

Pitfalls are generally the result of **statistical misconceptions** or the **naive application** of accelerated test methods.

In the recent JQT paper, we categorized pitfalls according to

- Pitfalls that occur during the **planning** of an accelerated test More Pitfalls of Accelerated Tests
- Pitfalls that occur during the **execution** of an accelerated test
- Pitfalls that occur during the **analysis and interpretation** of accelerated test data

GE Refrigerator Compressor Problem

WALL STREET JOURNAL MONDAY, MAY 7, 1990

1

Chilling Tale

GE Refrigerator Woes Illustrate the Hazards In Changing a Product

Firm Pushed Development Of Compressor Too Fast, Failed to Test Adequately

Missing: the 'Magical Balance'

GE Refrigerator Compressor Problem

- Early 1980s, GE was losing market share to competitors—Jack Welch was unhappy
- 1983-1986 GE designed, tested, and began to produce a new higher efficiency, lower cost “rotary” compressor
- Stopped accelerated testing after one year and no failures
- One million + in service by 1987
- First failure after 1.5 years; virtually all would have eventually failed early.
- GE replaced all compressors in refrigerators that it could find. Total cost was more than $450 Million
- What went wrong?

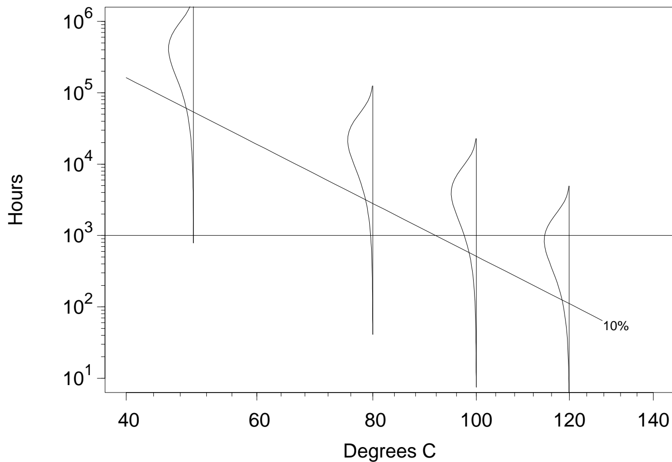
Pitfall I
Not Properly Using Information From Inspected Test Units

- Although there were no failures in the ALT, those who ran the test detected discoloration in the test units, indicating a lubrication issue
- Test units were well on their way to failure
- The bad news did not flow upward to higher management, as it should have

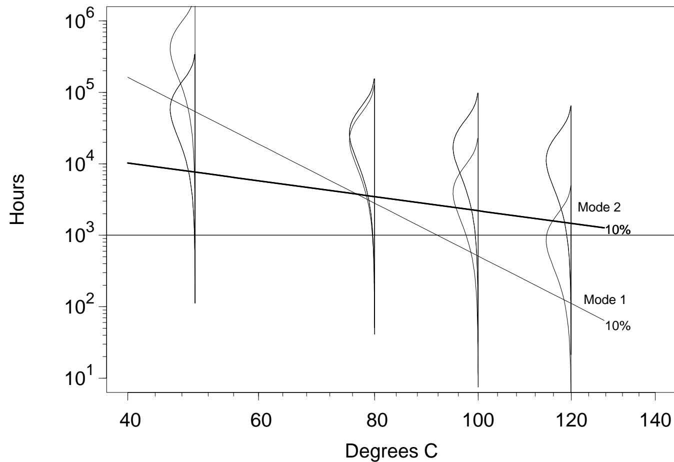
GE Refrigerator Compressor Reference

- O'Boyle, T. F. (1990). "Chilling Tale: GE Refrigerator Woes Illustrate the Hazards in Changing a Product." *Wall Street Journal* (Eastern edition). New York, N.Y.: May 7, 1990, page 1.

Temperature-Accelerated Life Test for an IC Device



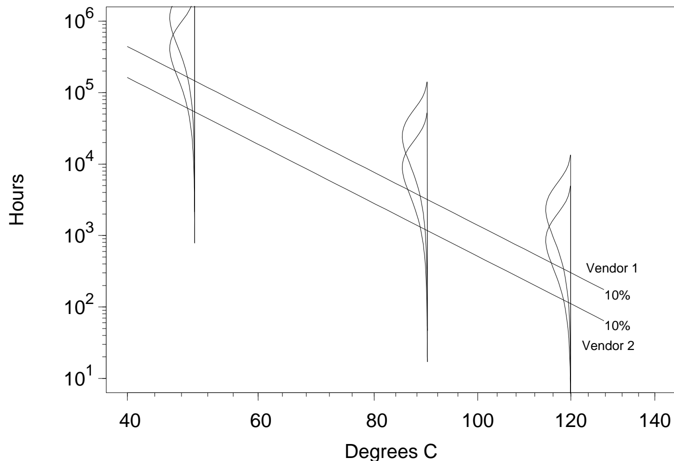
Lower Activation Energy Can Be Masked



Pitfall 4
Masked Failure Mode

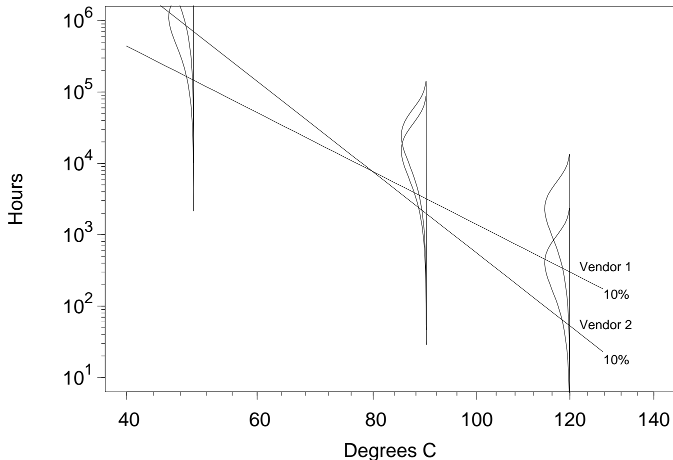
- Accelerated test may focus on one known failure mode, masking another!
- Masked failure modes may be the first one to show up in the field.
- Masked failure modes could dominate in the field.
- Suggestions:
  - Know (anticipate) different failure modes.
  - Limit acceleration and test at levels of accelerating variables such that each failure mode will be observed at two or more levels of the accelerating variable.
  - Identify failure modes of all failures.
  - Analyze failure modes separately.

ALT Simple Comparison



8in

ALT Questionable Comparison



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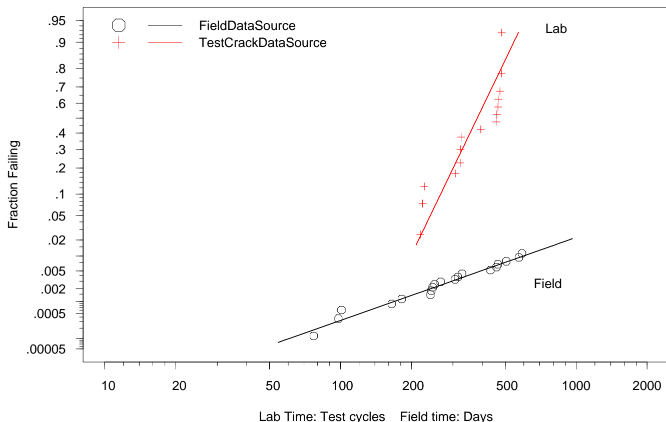
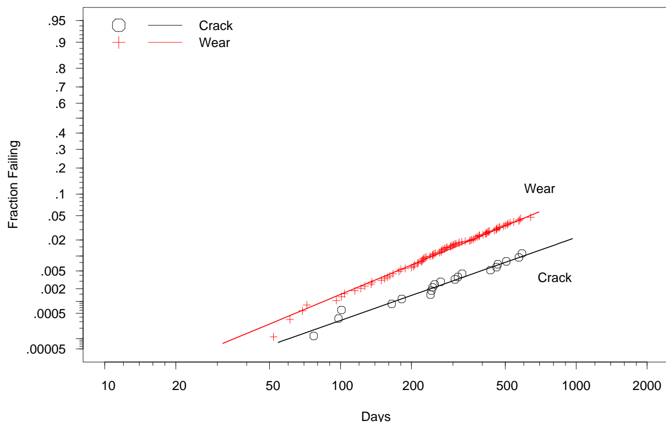
Pitfall 5
Faulty Comparison

- It is sometimes claimed that Accelerated Testing is not useful for predicting reliability, but is useful for comparing alternatives.
- Comparisons can, however, also be misleading.
- Beware of comparing products that have different kinds of failures.
- Suggestions:
  - Know (anticipate) different failure modes.
  - Identify failure modes of all failures.
  - Analyze failure modes separately.
  - Understand the physical reason for any differences.

Appliance B Comparison of **Laboratory** and **Field** Data for the **Crack** Failure Mode

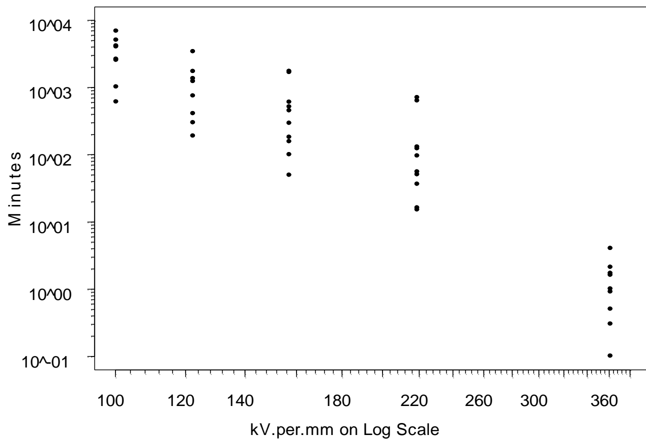


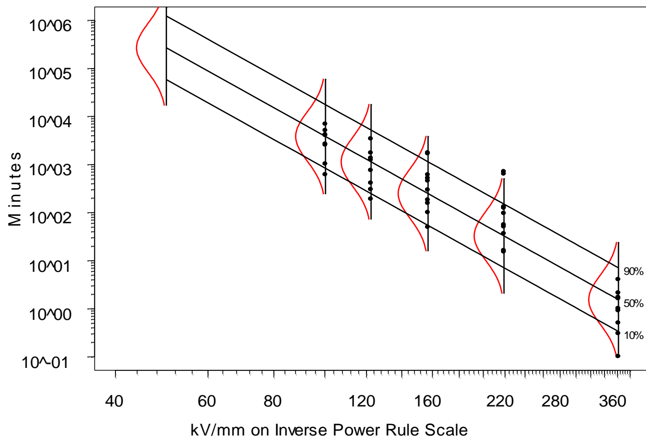
Appliance B Warranty-Return (Field) Data
Wear and **Crack** Failure Modes

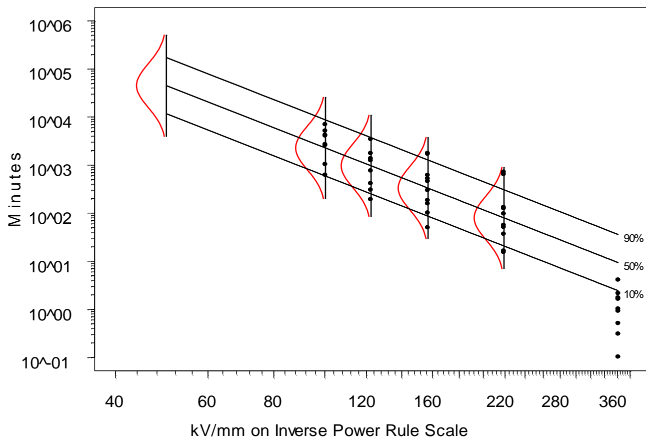


Pitfall Q
Not comparing failure modes in the field with failure modes in the laboratory

- Accelerated tests must generate failures in the same manner that they will be generated in actual use
- Often doing physical failure mode analysis is required
- When the mechanism is due to chemical change, analytical chemical measurements can be used to assure that AT and actual use have the same chemistry.


Mylar-Polyurethane Insulating Structure
10^04
10^03
10^02
10^01
10^00
10^-01
Minutes
100
120
140
180
220
260
300
360
kV.per.mm on Log Scale


Mylar-Polyurethane Insulating Structure
kV.per.mmInverse Power Rule , Dist:Lognormal
Minutes
10^06
10^05
10^04
10^03
10^02
10^01
10^00
10^-01
90%
50%
10%
40
60
80
120
160
220
280
360
kV/mm on Inverse Power Rule Scale

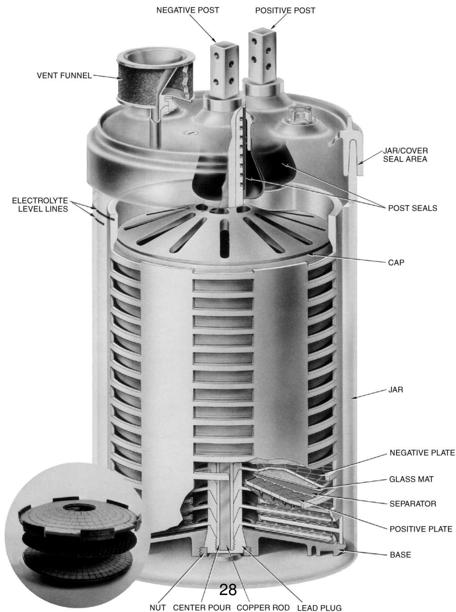


Mylar-Polyurethane Insulating Structure
kV.per.mmInverse Power Rule , Dist:Lognormal
Minutes
10^06
10^05
10^04
10^03
10^02
10^01
10^00
10^-01
90%
50%
10%
40
60
80
120
160
220
280
360
kV/mm on Inverse Power Rule Scale

Pitfall E
Testing at High Levels of Accelerating Variables That Cause New Failure Modes

- Using too much acceleration, generating new failure modes, is one of the most common AT pitfalls
- Early failures from a new failure mode at high levels of the accelerating variable will cause incorrectly optimistic predictions of lifetime at the use conditions.
- Knowledge of failure mechanisms and physical failure mode analysis can help avoid problems.

AT&T Round Cell (aka “Bell Cell”)



AT&T Round Cells (aka “Bell Cells”)

- Radical new design of a lead-acid battery in 1972
  - Longer life (70 years predicted from an accelerated test)
  - Lower maintenance cost
- Hundreds of thousands installed during the 1970s
- Positive post corrosion problems started in 1978
- A large proportion of the batteries had to be replaced.

Pitfall 6
Attempted Acceleration Can Cause Deceleration!

- Increased temperature in an **accelerated** circuit-pack reliability audit resulted in fewer failures than in the field because of lower humidity in the **accelerated** test.
- Higher than usual use rate of a mechanical device in an accelerated test inhibited a corrosion mechanism that eventually caused serious field problems.
- Automobile air conditioners failed due to a material **drying out** degradation, lack of use in winter (not seen in continuous accelerated testing).
- Inkjet pens fail from infrequent use.
- **Suggestion**: Understand failure mechanisms and how they are affected by experimental variables.

- Cannone, A., Cantor, W.P., Feder, D.O., and Stevens, J.P. (2004). “The Round Cell: Promises vs. Results 30 Years Later.” *Proceedings of the 26th Annual International Telecommunications Energy Conference*, Chicago, IL, 19-23.
- Cannone, A.G., Feder, D.O., and Biagetti, R.V. (1970). “Positive Grid Design Principles.” *The Bell System Technical Journal*, 49,1279-1303.
- Sharpe, J.R., Shroff, J.R., and Vaccaro, F.J. (1970). “Post Seals for the New Bell System Battery.” *The Bell System Technical Journal*, 49, 1405-1417.

Other References

- Nelson, W. (1990), *Accelerated Testing: Statistical Models, Test Plans, and Data Analyses*, New York: John Wiley & Sons.

  Important reference; also describes some pitfalls.

- Escobar, L.A., Meeker, W.Q., Kugler, D. L. and Kramer, L. L. (2003). “Accelerated Destructive Degradation Tests: Data, Models, and Analysis.” Chapter 21 in *Mathematical and Statistical Methods in Reliability*, B. H. Lindqvist and K. A. Doksum, Editors, World Scientific Publishing Company.

  Modeling and analysis methods of ADDT data (also see Chapter 11 of Nelson 1990).

- Escobar, L.A., and Meeker, W.Q. (2006). “A Review of Accelerated Test Models.” *Statistical Science*, 21, 552-577.

  Overview of commonly-used AT models (also see Chapter 2 of Nelson 1990).

Other References

- Meeker, W. Q., Escobar, L. A., and Hong, Y. (2009), “Using Accelerated Life Tests Results to Predict Field Reliability.” *Technometrics* 51, 146-161.

  Describes the Appliance B example.

- Kalkanis, G., and Rosso, E. (1989), “The inverse power law model for the lifetime of a mylar-polyurethane laminated DC HV insulating structure,” *Nuclear Instruments and Methods in Physics Research*, A281, 489¡V496.

  Original source for the mylar-polyurethane insulating structure example, which is also discussed in Chapter 19 of Meeker and Escobar (1998).

Concluding Remarks

- Accelerated tests are an important part of product development processes and are often needed to achieve high reliability.
- Accelerated testing requires extrapolation in several dimensions. **Extrapolation is dangerous.**
- It is important, when possible, to understand the physics/chemistry behind failure mechanisms.
- Knowledge of the potential pitfalls can help in avoiding serious mistakes.

The End

Thank You