Opportunities in Research Related to Reliability Engineering

Prof. M. Modarres
Reliability Engineering Group
Department of Mechanical Engineering

27 November 2006

Presentation to
CMC Technology Planning Group
Toshiba Corp

Mechanical Engineering Department
University of Maryland

Why Study Formal Engineering-Based Reliability and Performance Assessment?

- Technology and products evolve very fast, hence the need for ***shorter*** life tests
- Predict long-term ***performance*** of ***highly-reliable*** products
- Assess and demonstrate component reliability in the ***design stage***.
- Certify components, detect failure modes so that they can be ***corrected***.

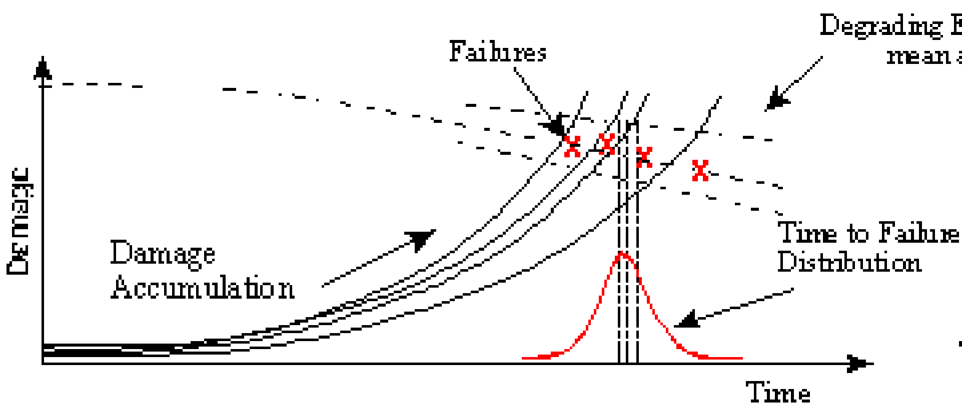
Mechanical Engineering Department
University of Maryland

RESEARCH OBJECTIVES

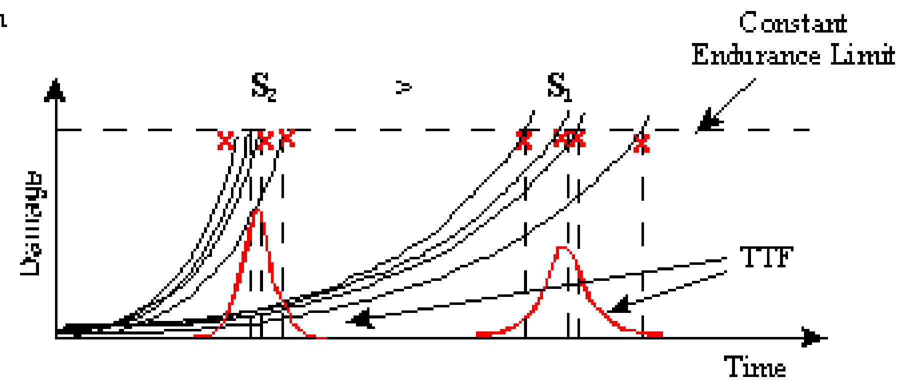
- Develop an appreciation for how life of materials, structures and components correlates with applied stresses induced by their working environment through the study of the applicable underlying physical phenomena of failure
- Understand common methods and important issues to consider when planning and performing accelerated tests to establish such models
- Investigate methods for statistically and/or probabilistically analyzing data gathered from such tests
- Use the results of the tests to infer reliability and other performance characteristics of components, systems and structures

Mechanical Engineering Department
University of Maryland

DAMAGE-ENDURANCE MODEL



Overlap of endurance limit distribution with the damage accumulation distribution leads to TTF distribution



Note: $S_2 > S_1$ implies that $TTF_2 < TTF_1$ Ψ

Examples:

- Fatigue corrosion cracking and growth in piping and components
- Vessel, piping and other structural corrosion
- Wear in key components, compressor seals and bearing

Assumption:

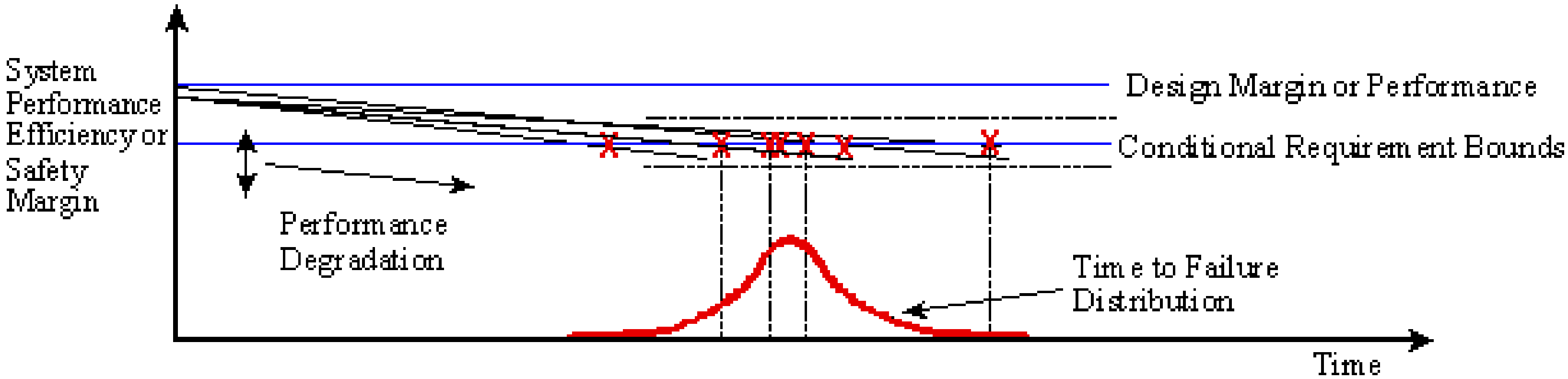
- Permanent damage occurs due to applied stresses and loads

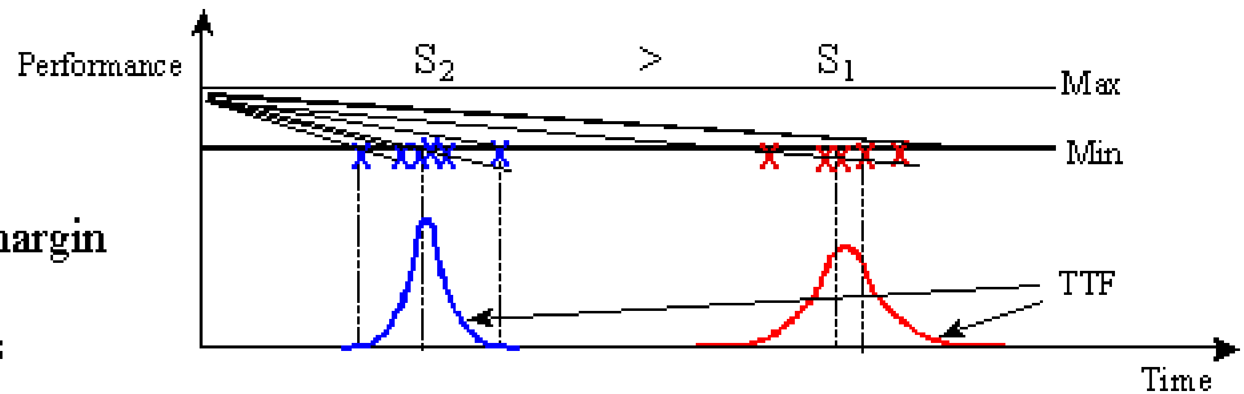
Implication:

- Used to model life of components and structures (favored by several industries)
- Engineering-based models of damage accumulation needed

Mechanical Engineering Department
University of Maryland

PERFORMANCE-REQUIREMENT MODEL





Examples:

- Degradation of safety margin
- System success criteria
- Efficiency requirements

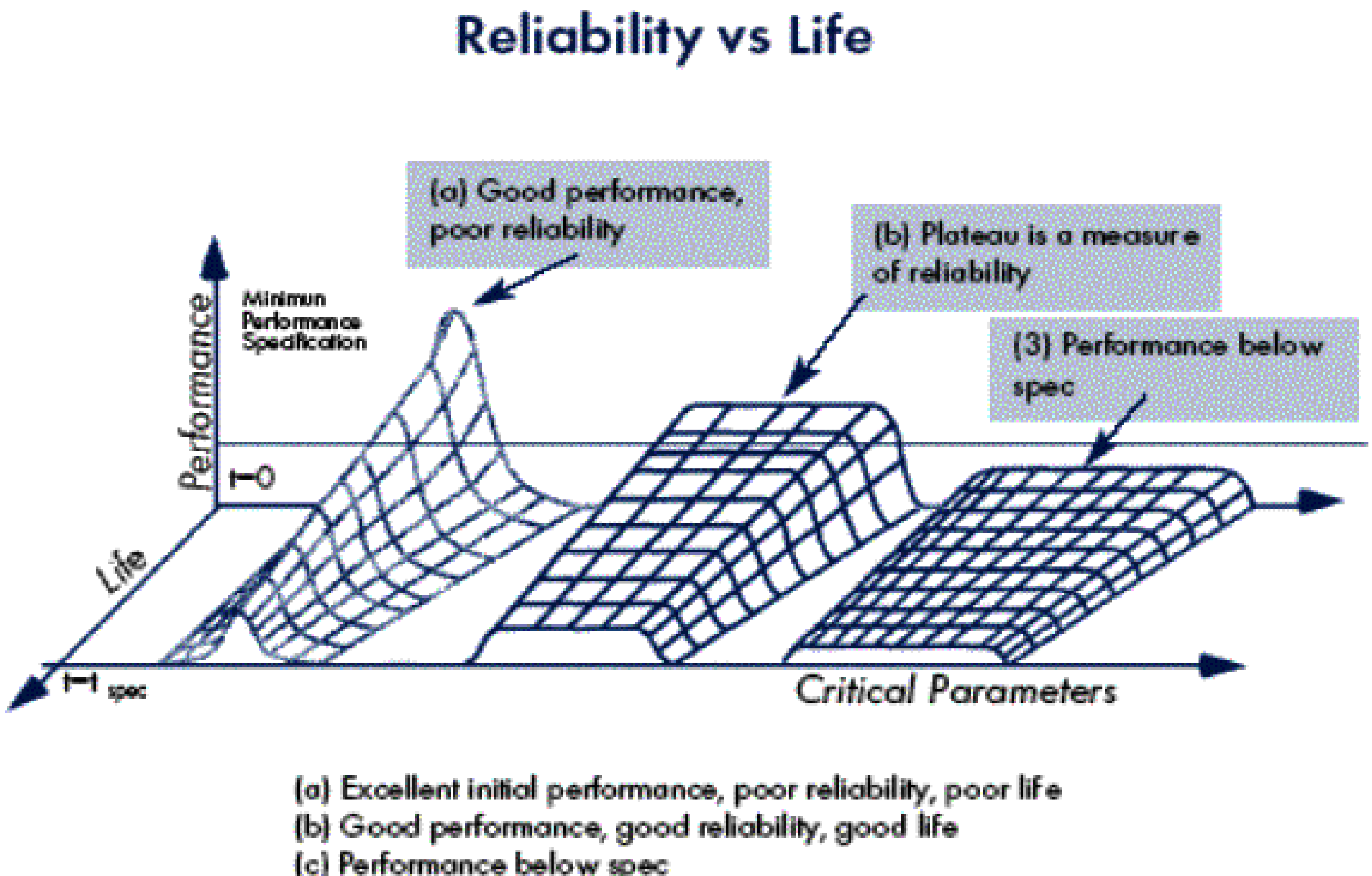
Assumption:

- Degradation due to normal aging and routine operational changes adversely affect performance, efficiency or safety margin

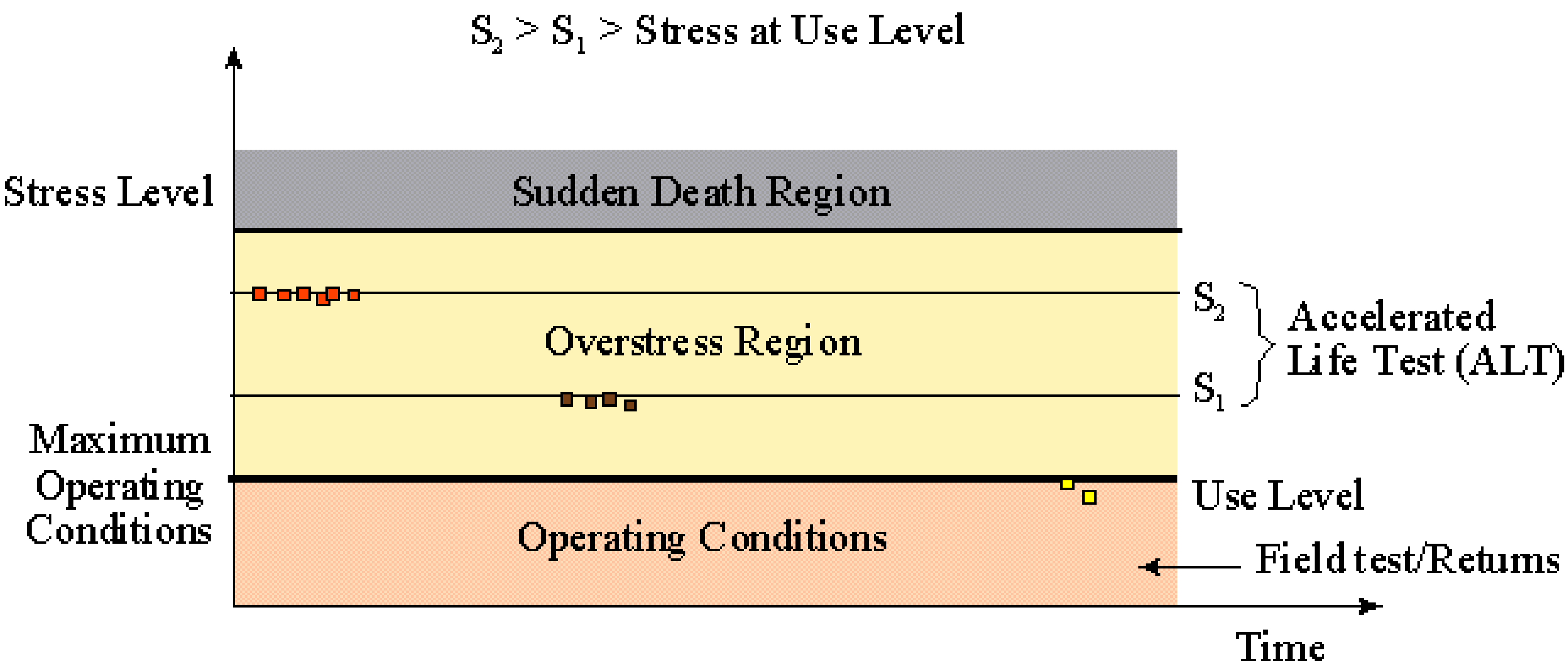
Implication:

- Measuring decline of safety margins
- Establishing performance-based warranties

LIFE DAMAGE AND PERFORMANCE

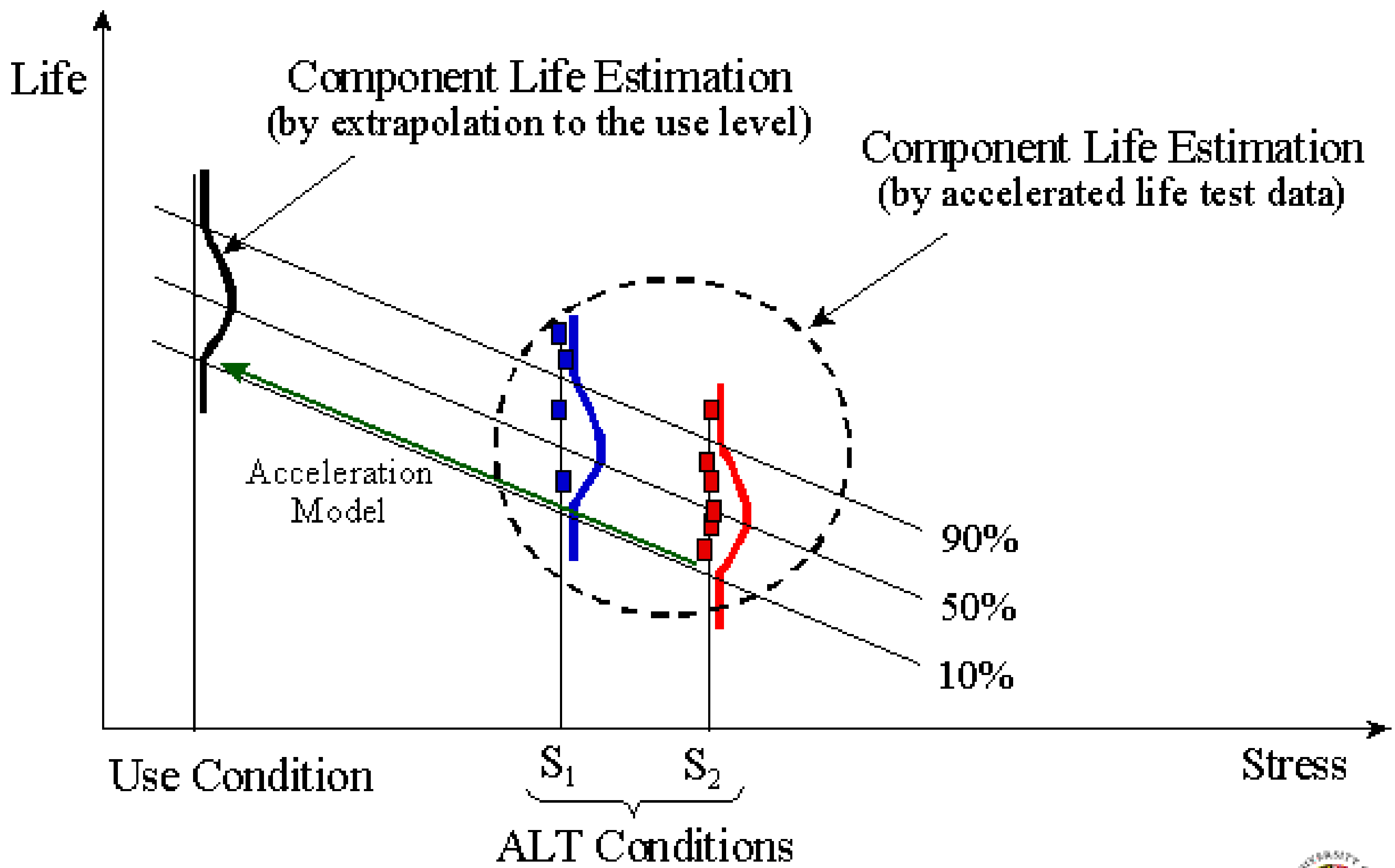


ACCELERATED LIFE TEST APPROACH



AT Provides **more** failures within **shorter** test durations

ALT MODELING



27 November 2006

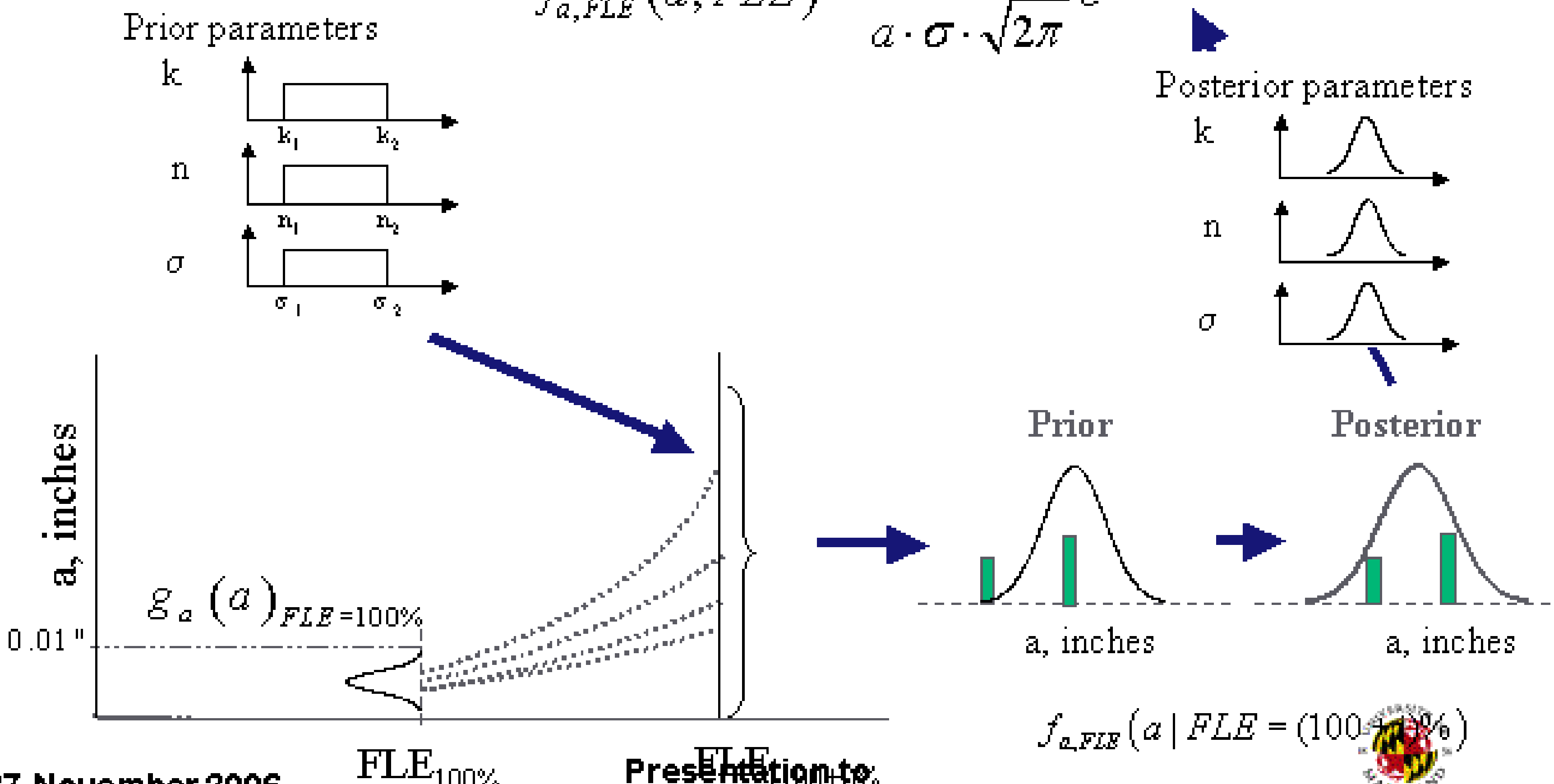
Presentation to
CMC Technology Planning Group
Toshiba Corp

Mechanical Engineering Department
University of Maryland

Joint Probability Density Function

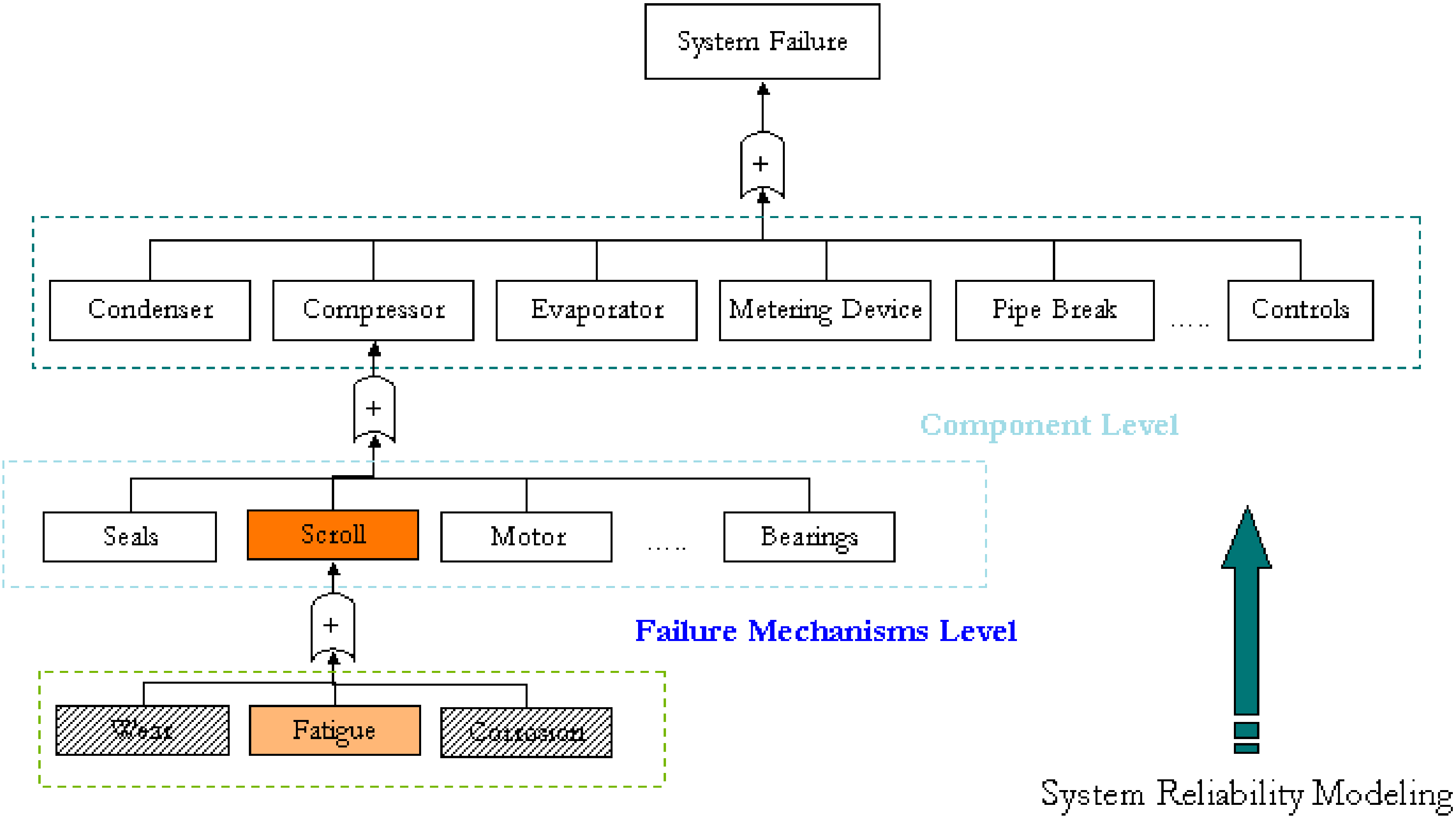
For an inspected aircraft at FLE=(100+i)%, generate random crack growth with known loads and random material properties.
Fit a joint probability density function.

$$f_{a,FLE}(a, FLE) = \frac{1}{a \cdot \sigma \cdot \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln(a)+\ln(k)+n \cdot \ln\left(\frac{1}{FLE}\right)}{\sigma}\right)^2}$$



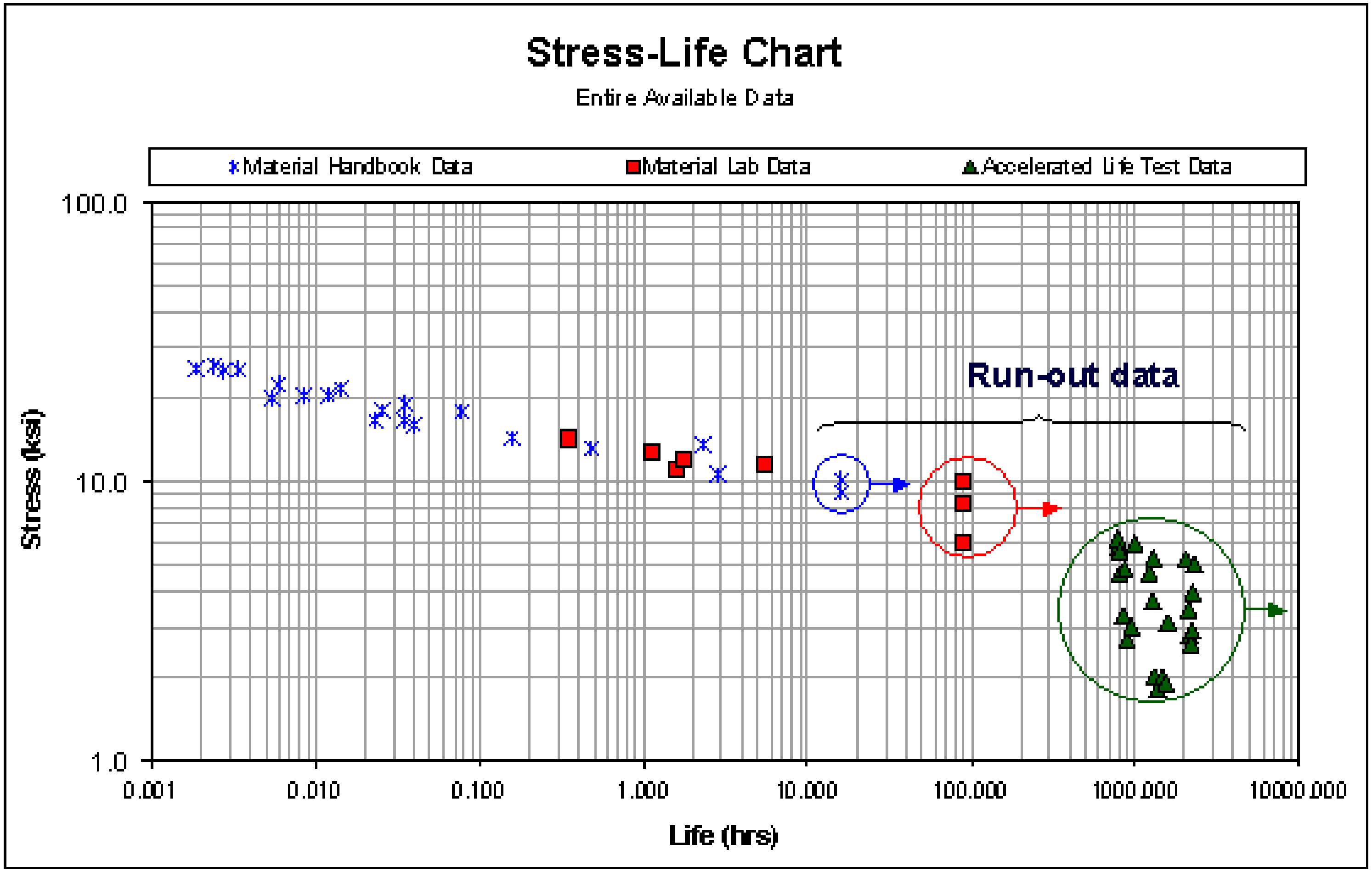
Mechanical Engineering Department
University of Maryland

RELIABILITY MODEL OF THE SYSTEM



Mechanical Engineering Department
University of Maryland

AVAILABLE AND TEST DATA



27 November 2006

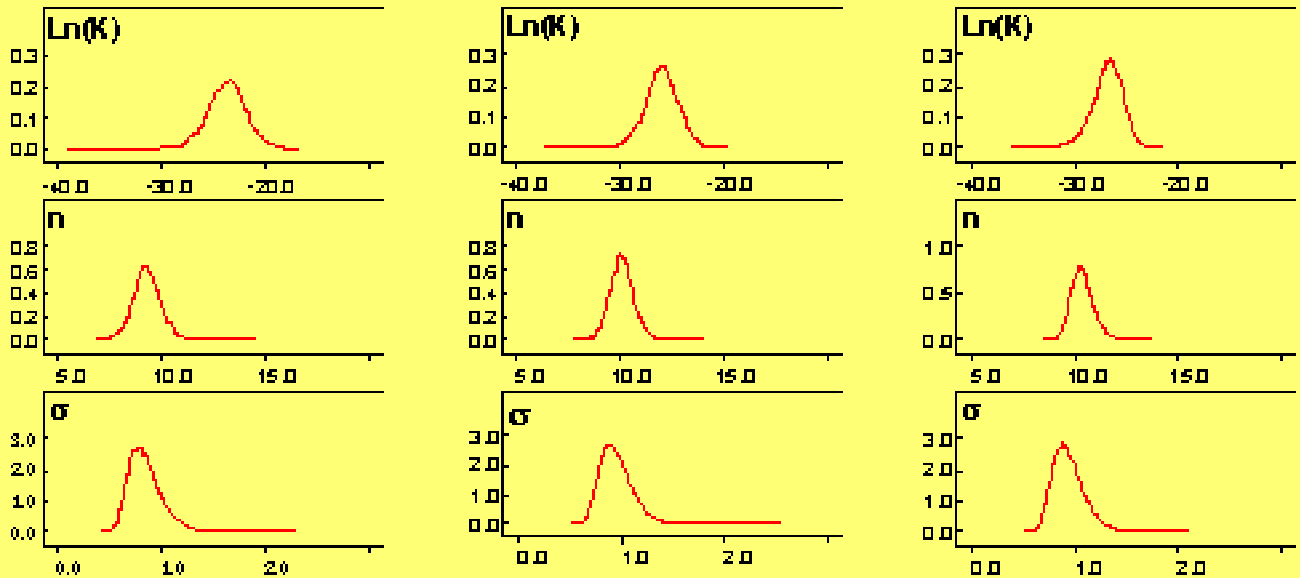
Presentation to
CMC Technology Planning Group
Toshiba Corp

Mechanical Engineering Department
University of Maryland

EVOLUTION OF MODEL PARAMETERS

Generic Data from Handbooks | Generic Data from Handbooks + Fatigue Test-Material Samples | Generic Data from Handbooks +Fatigue Test-Material Samples + ALT Data

Bayesian



Generic Data from Handbooks

	Mean	2.60%	60%	87.60%
Ln(K)	-23.73	-28.22	-23.61	-19.77
n	9.36	7.987	9.321	10.92
σ	0.8985	0.6043	0.8301	1.258

Generic Data from Handbooks + Fatigue Test-Material Samples

	Mean	2.60%	60%	87.60%
Ln(K)	-25.97	-29.38	-25.93	-22.86
n	10.12	8.995	10.1	11.33
σ	0.9699	0.7051	0.936	1.327

Generic Data from Handbooks + Fatigue Test-Material Samples + ALT Data

	Mean	2.60%	60%	87.60%
Ln(K)	-26.84	-30.38	-26.89	-24.22
n	10.42	9.452	10.37	11.68
σ	0.9489	0.7012	0.9274	1.32

MLE

Generic Data from Handbooks

	Mean	2.60%	60%	87.60%
Ln(K)	-23.46	-26.774	-23.46	-20.147
n	9.2714	8.122	9.2714	10.4209
σ	0.7447	0.539	0.7447	1.0288

Generic Data from Handbooks + Fatigue Test-Material Samples

	Mean	2.60%	60%	87.60%
Ln(K)	-25.989	-28.811	-25.989	-22.927
n	10.0822	9.0275	10.0822	11.1389
σ	0.8805	0.6442	0.8805	1.1493

Generic Data from Handbooks + Fatigue Test-Material Samples + ALT Data

	Mean	2.60%	60%	87.60%
Ln(K)	-26.397	-28.972	-26.397	-23.822
n	10.2862	9.3367	10.2862	11.1988
σ	0.8542	0.641	0.8542	1.1386

Mechanical Engineering Department
University of Maryland

Conclusions

- The underlying failure mechanisms are limited
- Models can be developed that rely on the physical/chemical phenomena that drive real causes of degradation, failure and performance deficiency
- Advanced testing technologies available
- Physical Models are directly used for simulation and automatic computation
- Available failure and performance data can be combined with small (accelerated) tests, field or expert judgment data in advanced Bayesian framework
- Fast computing allows simulations of multiple interacting failure mechanisms using autonomous agent-based computing