

# **ENRE 641**

## **Probabilistic Physics of Failure and Accelerated Testing (Fall 2021)**

### **Important Dates:**

**Midterm Exam: 27 October 2021.**

**Final Take Home Exam: Assigned at 12:01 AM 14 December 2021, Due 11:59 16 December 2020.**

**Instructor: Prof. M. Modarres, [modarres@umd.edu](mailto:modarres@umd.edu), Office Hours: TBA, Telephone: 301-405-5226.**

### **Grading:**

<b>Midterm (open book):</b>	<b>25%</b>
<b>Six Homework:</b>	<b>20%</b>
<b>Project:</b>	<b>25%</b>
<b>Final Exam (Take home):</b>	<b>30%</b>

### **Required Textbook:**

“Probabilistic Physics of Failure Approach to Reliability: Modeling, Accelerated Testing, Prognosis and Reliability Assessment”, M. Modarres, M. Amiri, and C. Jackson, Univ. of Maryland, Scrivener-Wiley Publishing (2017).

Also, the entire class notes will be posted at the beginning of the class, and you need to regularly check for updates, assignments, and announcements on CANVAS.

### **Additional Recommended References:**

- Accelerated Testing: Statistical Models, Test Plans, Data Analyses, W. Nelson, John Wiley and Sons, 1990.
- Statistical Methods for Reliability Data, W.Q. Meeker, L.A. Escobar, Wiley and Sons, 1998.
- Failure of Materials in Mechanical Design, 2<sup>nd</sup> Ed., J. Collins, Wiley & Sons, 1993
- Mechanical Behavior of Materials, 2<sup>nd</sup> Ed. N. Dowling, Prentice Hall 1999

- Metal Fatigue in Engineering, 2nd Edition, Ralph I. Stephens, Ali Fatemi, Robert R. Stephens, Henry O. Fuchs, Wiley and Sons, 2000
- Fundamentals of Metal Fatigue Analysis, Julie Bannantine, Jess Comer, James Handrock, Prentice Hall, 1989
- HALT, HASS, and HASA Explained: Accelerated Reliability Techniques, H. W. McLean, ASQC Press, 2009.
- Accelerated Reliability and Durability Testing Technology, L. M. Klyatis, Wiley, 2012.
- Accelerated Testing and Validation, A. Porter, Elsevier, 2012.
- Accelerated Testing: A practitioner's Guide to Accelerated Reliability Testing, B. Dodson, H. Schwab, SAE Int., 2006.

**ENRE641**  
**Curriculum**

**Overview of Probabilistic Physics-of-Failure Approach to Reliability**      Error! Bookmark not defined.

- Introduction
- Overview of Physics-of-Failure Modeling
- Important Forms of PoF Models **Error! Bookmark not defined.**
- PPoF Approach to Life Assessment
- Accelerated Testing in PPoF Model Development
- Organization of the Book

**Summary of Mechanisms of Failure and Associated PoF Models**

- Introduction
- Fatigue
  - Life-stress
    - The S-N Diagram **Error! Bookmark not defined.**
    - Mean Stress Effects **Error! Bookmark not defined.**
    - Combined Loading **Error! Bookmark not defined.**
  - Strain-Life **Error! Bookmark not defined.**
    - Monotonic Stress-Strain Behavior **Error! Bookmark not defined.**
    - Cyclic Stress-Strain Behavior **Error! Bookmark not defined.**
    - Strain-Life Relationship **Error! Bookmark not defined.**
    - Mean Stress Effects **Error! Bookmark not defined.**
  - Variable Amplitude Loading **Error! Bookmark not defined.**
    - Non-Linear Damage Models **Error! Bookmark not defined.**
  - Notch Effect **Error! Bookmark not defined.**
    - Life-stress **Error! Bookmark not defined.**
    - Strain-Life **Error! Bookmark not defined.**
  - Two-Stage Approach to Fatigue Life Estimation **Error! Bookmark not defined.**
  - Fracture Mechanics **Error! Bookmark not defined.**
    - Stress Intensity Factor **Error! Bookmark not defined.**
    - Region I **Error! Bookmark not defined.**
    - Region II **Error! Bookmark not defined.**
    - Region III **Error! Bookmark not defined.**
    - Fracture Mechanics Approach with Notch Effect
  - Factors Influencing Fatigue Failure **Error! Bookmark not defined.**
    - Size Effect **Error! Bookmark not defined.**
    - Frequency Effect **Error! Bookmark not defined.**
    - Environmental and External Effects
    - Miscellaneous Factors **Error! Bookmark not defined.**
- Wear **Error! Bookmark not defined.**
  - General Form of Wear Equations **Error! Bookmark not defined.**
  - Sliding Wear **Error! Bookmark not defined.**
  - Abrasive Wear **Error! Bookmark not defined.**
  - Impact Wear **Error! Bookmark not defined.**
  - Rolling Wear **Error! Bookmark not defined.**
  - Life Models for Bearings **Error! Bookmark not defined.**
  - Life Models for Seals **Error! Bookmark not defined.**

Wear of Lubricated Contacts **Error! Bookmark not defined.**  
Lubricated Wear And Lubricant Life **Error! Bookmark not defined.**  
Creep **Error! Bookmark not defined.**  
Larson-Miller Theory **Error! Bookmark not defined.**  
Manson-Haferd Theory **Error! Bookmark not defined.**  
Creep Under Uniaxial State of Stress **Error! Bookmark not defined.**  
Cumulative Creep Prediction **Error! Bookmark not defined.**  
Corrosion **Error! Bookmark not defined.**  
Models for Prediction of Corrosion Rate and Service Life

## **Types of Accelerated Testing and Modeling Concepts** **Error! Bookmark not defined.**

Introduction **Error! Bookmark not defined.**  
Types of Accelerated Testing – Qualitative and Quantitative  
Qualitative Accelerated Tests **Error! Bookmark not defined.**  
Environmental Stress Testing **Error! Bookmark not defined.**  
Burn-In Testing **Error! Bookmark not defined.**  
Environmental Stress Screening **Error! Bookmark not defined.**  
Highly Accelerated Life Testing  
Summary of HALT Process **Error! Bookmark not defined.**  
Highly Accelerated Stress Screening **Error! Bookmark not defined.**  
Quantitative Accelerated Tests **Error! Bookmark not defined.**  
Modeling Degradation Associated With Various Failure Mechanisms  
Stress-Strength Model **Error! Bookmark not defined.**  
Damage-Endurance Model **Error! Bookmark not defined.**  
Performance-Requirement Model **Error! Bookmark not defined.**  
Forms Of Degradation And Performance Models **Error! Bookmark not defined.**

## **Analysis of Accelerated Life Testing Data and Physics-Based Reliability Model Development** **Error! Bookmark not defined.**

Introduction **Error! Bookmark not defined.**  
Accelerated Life Data Analysis Methods  
Basics of ALT Data Analysis **Error! Bookmark not defined.**  
Types of Collected Accelerated Life Test Data  
Life-stress Models **Error! Bookmark not defined.**  
Probability Plotting Method for ALT Model Estimation **Error! Bookmark not defined.**  
Life-Stress Model By Regression **Error! Bookmark not defined.**  
Summary of Plotting Method for Analyzing ALT Data **Error! Bookmark not defined.**  
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Maximum Likelihood Estimation Approach to ALT Data Analysis  
Confidence Intervals for MLE **Error! Bookmark not defined.**  
MLE Approach to Estimating Parameters of Common Distributions **Error! Bookmark not defined.**  
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Exponential Life Distribution **Error! Bookmark not defined.**  
Weibull Life Distribution **Error! Bookmark not defined.**  
Lognormal Life Distribution **Error! Bookmark not defined.**  
MLE-Based Parameter Estimation for Different Life-stress Models  
The Exponential Life-stress Model **Error! Bookmark not defined.**  
Exponential Life-stress Model With Weibull Life Distribution  
Exponential Life-stress Model With Lognormal Life Distribution  
The Eyring Life-Stress Model **Error! Bookmark not defined.**  
The Eyring-Weibull Model **Error! Bookmark not defined.**  
The Eyring-Lognormal Model **Error! Bookmark not defined.**

Power Life-Stress Model **Error! Bookmark not defined.**  
Power Life-stress With Weibull Life Model  
Power Life-stress With Lognormal Model  
Dual-Stress Exponential Life-stress Model **Error! Bookmark not defined.**  
Dual-Stress Exponential Life-stress Model With Weibull Life Distribution  
Dual-Stress Exponential Life-stress Model With Lognormal Life Distribution  
Power-Exponential Life-stress Model **Error! Bookmark not defined.**  
Power-Exponential Life-stress Model Weibull Life Distribution  
Power-Exponential Life-stress Model Lognormal Life Distribution **Error! Bookmark not defined.**

Proportional Hazards (PH) Model **Error! Bookmark not defined.**  
The Parametric PH Model, with an Example  
Bayesian Estimation Approach to ALT Model Parameter Estimation  
Prior Information For Bayesian Estimation **Error! Bookmark not defined.**  
A Bayesian Estimation ALT Data Analysis Example  
Determining stress dependencies **Error! Bookmark not defined.**  
Confidence Bounds **Error! Bookmark not defined.**  
Summary of the ALT Steps and Common Problems in Practice  
Time Varying Stress Tests **Error! Bookmark not defined.**  
Step-Stress Analysis And Model Development **Error! Bookmark not defined.**  
Plotting Method for Step-Stress Data Analysis **Error! Bookmark not defined.**  
Maximum Likelihood Estimation Method for Step-Stress Data Analysis  
Bayesian Inference Method for Step-Stress Data Analysis **Error! Bookmark not defined.**

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**Analysis of Accelerated Degradation Data and Reliability Model Development** **Error! Bookmark not defined.**

Introduction **Error! Bookmark not defined.**  
Degradation Models **Error! Bookmark not defined.**  
Simple Degradation Model Without Variation **Error! Bookmark not defined.**  
Consideration of the Variation in Degradation Model and Failure Time  
General Degradation Path Model **Error! Bookmark not defined.**  
Approximate Accelerated Life Degradation Analysis **Error! Bookmark not defined.**  
Maximum Likelihood Approach to Estimating Acceleration Degradation Model Parameters **Error! Bookmark not defined.**  
Bayesian Estimation of ADT Model Parameters  
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**Accelerated Test Planning** **Error! Bookmark not defined.**

Introduction **Error! Bookmark not defined.**  
Issues to Consider Prior to Accelerated Testing **Error! Bookmark not defined.**  
Planning for Accelerated Life Tests **Error! Bookmark not defined.**  
Steps for Accelerated Life Tests **Error! Bookmark not defined.**  
Optimal Design of Accelerated Life Test **Error! Bookmark not defined.**  
Planning for Accelerated Degradation Tests **Error! Bookmark not defined.**  
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**Accounting for Uncertainties and Model Validation** **Error! Bookmark not defined.**

Introduction **Error! Bookmark not defined.**  
Uncertainties in Evidence **Error! Bookmark not defined.** *Error! Bookmark not defined.*  
PPoF Model Uncertainties, Errors, and Validation **Error! Bookmark not defined.**

Applications of Model Validation in ADT **Error! Bookmark not defined.**