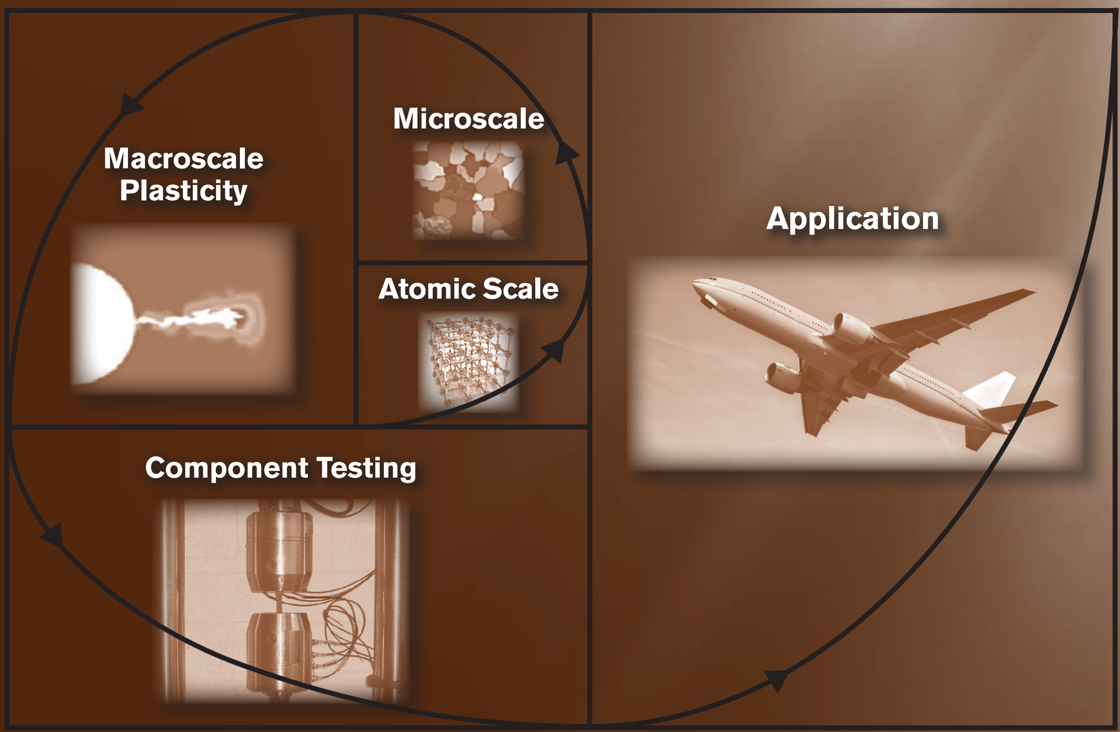
Introduction to Thermodynamics of Mechanical Fatigue



Michael M. Khonsari • Mehdi Amiri

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Dedicated to

Karen, Maxwell,
Milton, Mason Khonsari, and
to the memory of my father (MMK),
and to Hassan Amiri

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Preface

The subject of fatigue degradation and the methodologies for its treatment span multitudes of scientific disciplines, ranging from engineering to materials science and mechanics to mathematics.

Fatigue is probabilistic in nature. For example, fatigue tests performed on the same material subjected to the same operating conditions can yield different results in terms of the number of cycles that the system can withstand before failure occurs. Such uncertainties affect the system design, structural integrity, and operational reliability. Yet the majority of available methods for prediction of fatigue failure—cumulative damage models, cyclic plastic energy hypothesis, crack propagation rate models, and empirically derived relationships based on the curve fitting of limited laboratory data—require many unknown input parameters that must be experimentally determined.

There are other complications. All of the above-mentioned methods concentrate on very specific types of loading and single fatigue modes, that is, bending, torsion, or tension–compression. In practice, however, fatigue involves simultaneous interaction of multimode processes. Further, the variability in the duty cycle in practical applications may render many of these existing methods incapable of reliable prediction. It is, therefore, no surprise that the application of these theories often leads to many uncertainties in the design. Further, their use and execution in practice require one to implement large factors of safety, often leading to gross overdesigns that waste resources and cost more.

In reality, the science base that underlies modeling and analysis of fatigue processes has remained substantially unchanged for decades, leaving a significant gap between the available technology and the science that effectively captures the dynamics of degradation. The premise of this textbook is that fatigue is a dissipative process and must obey the laws of thermodynamics. In general, it can be hypothesized that the degradation of machinery components is a consequence of irreversible thermodynamic processes that disorder a component, and that degradation is a time-dependent phenomenon with increasing disorder. This suggests that entropy—a fundamental parameter in thermodynamics that characterizes disorder—offers a natural measure of component degradation.

Although an entropic approach to problems involving degradation is gaining momentum, its practical applications have not yet become widespread. This concept offers new and exciting research in the field of fatigue fracture analysis for years to come. We hope this introduction to the treatment of fatigue via the principles of thermodynamics serves as a useful contribution to the science of degradation.

Michael M. Khonsari and Mehdi Amiri
Baton Rouge, Louisiana

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About the Authors

Michael M. Khonsari is the holder of the Dow Chemical Endowed Chair and professor of the Mechanical Engineering Department at Louisiana State University, where he directs the Center for Rotating Machinery. Professor Khonsari is a fellow of the American Society of Mechanical Engineers (ASME), the Society of Tribologists and Lubrication Engineers (STLE), and the American Association for the Advancement of Science (AAAS). He holds several patents and has authored two books and over 200 archival journal articles. He is currently the editor of the *ASME Journal of Tribology*.

Mehdi Amiri earned his PhD in mechanical engineering from Louisiana State University, where he is currently a research associate in the Center for Rotating Machinery. His area of research is in the field of fatigue and fracture analysis. He holds one patent and has authored several journal publications. His research interests include thermal/fluid mechanics, thermodynamics, tribology, and failure analysis.

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