ANALYSES FOR DURABILITY AND SYSTEM DESIGN LIFETIME

An important issue in engineering design is a system's design lifetime. Economists study durability choice problems for consumer goods, but seldom address lifetime problem(s) of complex engineering systems. The issues for engineering systems are complex and multidisciplinary and require an understanding of the "technicalities of durability" and the economic implications of the marginal cost of durability and of value maximization. Commonly the design lifetime for infrastructure is set between 30 and 70 years, with limited rationale. Satellite lifetimes are also assigned with limited analysis. This book provides a systemic qualitative and quantitative approach to these problems, addressing first the technicality of durability, second the marginal cost of durability, and third the durability choice problem for complex engineering systems with network externalities (competition and market uncertainty) and obsolescence effects (technology evolution). Because the analyses are system-specific, a satellite example is used to illustrate the essence and provide a quantitative application of these analyses.

Dr. Joseph H. Saleh is an Assistant Professor of Aerospace Engineering at the Georgia Institute of Technology. He received his Ph.D. from the Department of Aeronautics and Astronautics at MIT and served as the Executive Director of the Ford–MIT Alliance. His research focuses on issues of design lifetime and how to embed flexibility in the design of complex engineering systems in general and in aerospace systems in particular. Dr. Saleh is the author or co-author of 50 technical publications and the recipient of numerous awards for his teaching and research contributions. He served as a technical consultant to NASA's Jet Propulsion Laboratory and has collaborated on research projects with various aerospace companies.

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Analyses for Durability and System Design Lifetime

A MULTIDISCIPLINARY APPROACH

Joseph H. Saleh

Georgia Institute of Technology

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To Carl, Mia, Jihad, Abu Ali, Na'ama, and Michal

That they may find fulfillment in a peaceful, diversely rich, and prosperous Middle East

To The Reader

I know that, despite my care, nothing will be easier than to criticize this work if anyone ever thinks of criticizing it. I think those who want to regard it closely will find, in the entire work, a mother thought that so to speak links all its parts. But the diversity of the objects I had to treat is very great, and whoever undertakes to oppose an isolated fact to the sum of facts I cite or a detached idea to the sum of ideas will succeed without difficulty. I should therefore wish that one do me a favor of reading me in the same spirit that presided over my work, and that one judges this work by the general impression it leaves, just as I myself decided, not by such and such a reason, but by the mass of reasons.

Alexis de Tocqueville, *Democracy in America*, 1835

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Preface

Time and the ephemeral nature of human life have been major themes for poets, philosophers, and theologians. Every scripture, philosophical writing, and work of art addresses, explicitly or implicitly, issues of time and the human experience of it.

Engineers have also considered and often grapple with issues of time, except that, instead of the human experience of it, they deal with the relationship of engineering artifacts with time. Less profound than the previous subject but equally thought-provoking is the transiency, not only of human life, but also of human artifacts. Through structural or functional degradation, or loss of economic relevance, the hand of time lies heavy on engineering designs. Several terms are used to describe this particular aspect of a product or a system's relationship with time, namely the duration from fielding a system, that is, when it first enters operation, to its final breakdown or retirement. These terms include *lifespan*, *service life*, *durability*, and *design lifetime*, to name a few. This book discusses these issues in the context of complex engineering systems.

More specifically, this book explores an important issue in engineering design that is becoming increasingly critical for complex engineering systems in general, and aerospace systems in particular, namely the selection and implications of a system's design lifetime. Although economists have grappled with the durability choice problem for simple consumer goods, limited attention has been given to the design lifetime problem(s) of complex engineering systems. The issues at stake in selecting a reduced or an extended design lifetime for an engineering system are complex and multidisciplinary in nature; they require a thorough engineering understanding

of the "technicalities of durability" along with the economic implications of the marginal cost of durability and of the value maximization problem in guiding the durability choice problem.

Systems engineers and program managers recognize the increasing importance of the durability choice problem for engineering systems. For example, design lifetime for infrastructure is typically set at 30–70 years, often with limited rationale, and satellite lifetimes are assigned rather arbitrarily or with limited quantitative analysis (cost-based). This book provides a systemic qualitative and quantitative approach to these problems in the form of a triptych addressing, first, the technicalities of durability; second, the marginal cost of durability, along with the economies of scale (in the time dimension), if any, that result from extended durability; and third, the durability choice problem for complex engineering systems in the face of network externalities (competition and market uncertainty) and obsolescence effects (technology evolution). Because the details of the analyses are system-specific, a satellite example is used in several chapters to illustrate the essence and provide a quantitative application of these analyses.

Also addressed is the increasing tension between the design lifetimes of present-day complex engineering systems and the shortening time scales associated with the obsolescence of their underlying technology base. The book ends with a discussion of the need for and growing interest in the concept of flexibility in system design.

The book is intended for graduate students, researchers, and practitioners. Each chapter is self-contained and can be read independent of the other chapters. The six chapters and Epilogue do, however, tell a coherent story that reaches its climax in Chapters 5 and 6, where traditional engineering wisdom and the "economies of scale" argument in system design are challenged and proved flawed under certain environmental conditions; an alternative framework and solutions are provided in Chapter 6.

Finally, it should be noted that this text is but a small book about a broad topic. It does not pretend to be exhaustive in its treatment of durability related issues. Important topics such as product replacement and recycling, for example, have not been addressed. These topics reflect "downstream" issues that define the end of life, or post-service life, of a system, whereas this book deals with the "upstream" problem of the definition and selection of

the intended design lifetime of the system. More specialized texts would do better justice to these subjects of product replacement and recycling than a summary treatment in the present work.

This book is one "panel" of a triptych that consists of two additional books (forthcoming) on flexibility and uncertainty in engineering design. The close connection among time (durability), uncertainty, and flexibility is elaborated in the Epilogue of the present work.