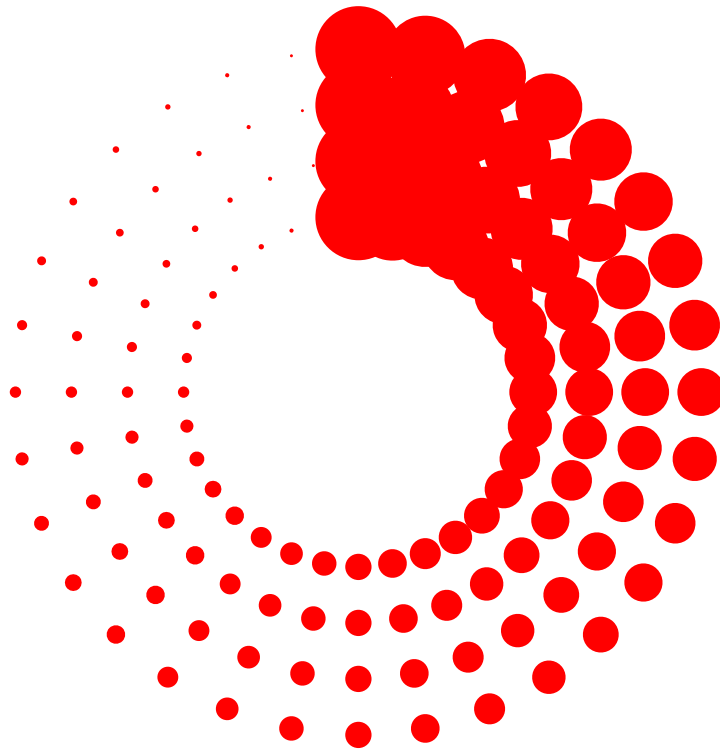

IMPRECISION IN ENGINEERING DESIGN



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Edited by

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Preface

It must be considered that there is nothing more difficult to carry out, nor more dangerous to conduct, nor more doubtful in its success, than an attempt to introduce changes. For the innovator will have for his enemies all those who are well off under the existing order of things, and only lukewarm supporters in those who might be better off under the new.

-- NICCOLÒ MACHIAVELLI
THE PRINCE AND THE DISCOURSES, 1513
CHAPTER 6

*“Scientists investigate
that which already is;
Engineers create that
which has never been.”*

Albert Einstein

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Introduction

Erik Antonsson

This book is a collection of publications produced from research conducted in the Engineering Design Research Laboratory at the California Institute of Technology. The research thread, to which all of these papers are related, is the notion of Imprecision in Engineering Design.

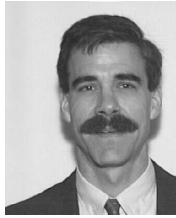
Research over the past 17 years has demonstrated that information with a range of precisions is an essential component of engineering design, and that formal methods can be developed to represent and manipulate this imprecise information. The goal of this volume is to collect into one place a set of relevant publications describing the results of research in this area.

The Chapters

This volume begins with a chapter introducing the notion of imprecision in engineering design, and motivating the research to follow. Chapter 2 introduces strategies for trade-offs among multiple incommensurate attributes of engineering designs. Chapter 3 introduces a method for incorporating uncontrolled variations (noise) into design decision-making. Chapter 4 extends the notion of noise to include *tuning parameters*: those aspects of a design that are adjusted to compensate for uncontrolled variations. Chapter 5 provides an overview of the Method of Imprecision, and a review of and comparison with other methods. Chapter 6 develops the mathematics of aggregation of incommensurate attributes for design decisions. Chapter 7 extends the aggregation methods to negotiation among multiple people or groups involved in an engineering design. Chapter 8 demonstrates the Method of Imprecision on an automobile structure design problem. Chapter 9 shows that methods for economic decision-making or social choice do not necessarily apply to engineering design. Finally, Chapter 10 presents a method for determining how to aggregate multiple incommensurate attributes of an engineering design.

References

- [1] WOOD, K. L., AND ANTONSSON, E. K. Computations with Imprecise Parameters in Engineering Design: Background and Theory. *ASME Journal of Mechanisms, Transmissions, and Automation in Design* 111, 4 (Dec. 1989), 616–625.
- [2] OTTO, K. N., AND ANTONSSON, E. K. Trade-Off Strategies in Engineering Design. *Research in Engineering Design* 3, 2 (1991), 87–104.
- [3] OTTO, K. N., AND ANTONSSON, E. K. Design Parameter Selection in the Presence of Noise. *Research in Engineering Design* 6, 4 (1994), 234–246.
- [4] OTTO, K. N., AND ANTONSSON, E. K. Tuning Parameters in Engineering Design. *ASME Journal of Mechanical Design* 115, 1 (Mar. 1993), 14–19.
- [5] ANTONSSON, E. K., AND OTTO, K. N. Imprecision in Engineering Design. *ASME Journal of Mechanical Design* 117(B) (Special Combined Issue of the Transactions of the ASME commemorating the 50th anniversary of the Design Engineering Division of the ASME.) (June 1995), 25–32. Invited paper.
- [6] SCOTT, M. J., AND ANTONSSON, E. K. Aggregation Functions for Engineering Design Trade-offs. *Fuzzy Sets and Systems* 99, 3 (1998), 253–264.
- [7] SCOTT, M. J., AND ANTONSSON, E. K. Formalisms for Negotiation in Engineering Design. In *8th International Conference on Design Theory and Methodology* (Aug. 1996), ASME.
- [8] SCOTT, M. J., AND ANTONSSON, E. K. Preliminary Vehicle Structure Design: An Industrial Application of Imprecision in Engineering Design. In *10th International Conference on Design Theory and Methodology* (Sept. 1998), ASME.
- [9] SCOTT, M. J., AND ANTONSSON, E. K. Arrow’s Theorem and Engineering Design Decision Making. *Research in Engineering Design* 11, 4 (2000), 218–228.
- [10] SCOTT, M. J., AND ANTONSSON, E. K. Using Indifference Points in Engineering Decisions. In *11th International Conference on Design Theory and Methodology* (Sept. 2000), ASME.



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In 1983 he joined the Mechanical Engineering faculty at the University of Utah, as an Assistant Professor. In 1984 he became the Technical Director of the Pediatric Mobility and Gait Laboratory, and an Assistant in Bioengineering (Orthopaedic Surgery), at the Massachusetts General Hospital. He also simultaneously joined the faculty of the Harvard University Medical School as an Assistant Professor of Orthopaedics (Bioengineering).

He was an NSF Presidential Young Investigator from 1986 to 1992, and won the 1995 Richard P. Feynman Prize for Excellence in Teaching.

Dr. Antonsson is a Fellow of the ASME, and a member of the IEEE, SME, ACM, ASEE, IFSA, and NAFIPS.

He teaches courses in engineering design, computer aided engineering design, machine design, mechanical systems, and kinematics. His research interests include formal methods for engineering design, design synthesis, representing and manipulating imprecision in preliminary engineering design, rapid assessment of early designs (RAED), structured design synthesis of micro-electro-mechanical systems (MEMS), and digital micropropulsion microthrusters.

Dr. Antonsson is currently on the editorial board of the International Journals: *Research in Engineering Design*, and *Fuzzy Sets and Systems*, and from 1989 to 1993 served as an Associate Technical Editor of the ASME Journal of Mechanical Design, (formerly the *Journal of Mechanisms, Transmissions and Automation in Design*), with responsibility for the Design Research and the Design Theory and Methodology area. He serves as a member of the Engineering and Applied Science Division Advisory Group, and as Chairman of the Engineering Computing Facility at Caltech. He was a member of the Caltech Faculty Committee on Patents and Relations with Industry from 1992 to 1999, and since 1990 has been a member of the CALSTART Technical Advisory Committee. He has published over 95 scholarly papers in the engineering design research literature, and holds 4 U.S. Patents. He is a Registered Professional Engineer in California, and serves as an engineering design consultant to industry, research laboratories (including NASA's Jet Propulsion Laboratory and the 10 meter W. M. Keck Telescope), and the Intellectual Property bar.