

SMART STRUCTURES THEORY

The twenty-first century might be called the “Multifunctional Materials Age.” The inspiration for multifunctional materials comes from nature and therefore these are often referred to as “bio-inspired materials.” Bio-inspired materials encompass smart materials and structures, multifunctional materials, and nano-structured materials. This is a dawn of revolutionary materials that may provide a “quantum jump” in performance and multi-capability. This book focuses on smart materials, structures, and systems, which are also referred to as intelligent, adaptive, active, sensory, and metamorphic. The purpose of these materials from the perspective of smart systems is their ability to minimize life-cycle cost and/or expand the performance envelope. The ultimate goal is to develop biologically inspired multifunctional materials with the capability to adapt their structural characteristics (e.g., stiffness, damping, and viscosity) as required, monitor their health condition, perform self-diagnosis and self-repair, morph their shape, and undergo significant controlled motion over a wide range of operating conditions.

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Preface

In 1990, a pilot project was started at the Alfred Gessow Rotorcraft Center (University of Maryland) to build a smart rotor with embedded piezoelectric strips. Soon, it attracted the attention of Dr. Gary Anderson of the Army Research Office (ARO). He encouraged us to put together outlines for a major initiative in the smart structures area, which subsequently resulted in the award of a multi-year (1992–1997) University Research Initiative (URI). This provided us an opportunity to develop an effective team of interdisciplinary faculty from Aerospace, Mechanical, Electrical, and Material Engineering. As a result, there was an enormous growth of smart structures research activities on our campus. Following the success of this URI, we were awarded another multi-year (1996–2001) Multi University Research Initiative (MURI) in smart structures by ARO. For this major program, we collaborated with Penn State and Cornell University. This further nurtured the ongoing smart structures activities at Maryland. We deeply acknowledge the support and friendship of many faculty colleagues at Maryland: Appa Anjannappa, Bala Balachandran, James Baeder, Amr Baz, Roberto Celi, Ramesh Chandra, Abhijit Dasgupta, Allison Flatau, James Hubbard, P. S. Krishnaprasad, Gordon Leishman, V. T. Nagaraj, Darryll Pines, Don Robbins, Jim Sirkis, Fred Tasker, Norman Wereley, and Manfred Wuttig.

While the research frontier in smart structures was expanding at the Alfred Gessow Rotorcraft Center, we also initiated classroom teaching at the graduate level in the smart structures area. This textbook was developed from material covered in early versions of these class notes, and it aims to give a broad overview of smart materials and their applications in smart structures and integrated systems. The focus is on the fundamental physical phenomena observed in active materials and on the mathematical modeling of the coupled behavior of a smart structure with active material actuators and sensors. Simplistic descriptions of the physical mechanisms are given so that the reader can obtain an intuitive grasp of the fundamentals without having to delve deeply into rigorous solid mechanics concepts.

The research activities generated a large cadre of dissertations; many of these were pioneering foundational efforts in smart structures. We fondly acknowledge the contributions of our graduates: Jayasimha Atulsimha (VCU), Ron Barrett (Kansas), Oren Ben-Zeev (NAVAIR), Andy Bernhard (Sikorsky), Mike Bothwell (Bell), Peter Chen (IAI), Peter Copp (UMD), Ron Couch (APL), Anubhav Datta (NASA-Ames), Jeanette Epps (NASA-Astronaut), Farhan Gandhi (RPI),

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During the 1990s, there was tremendous growth of smart structures activities in the United States and abroad. Many new conferences and workshops were initiated during this period, including: ARO Workshop in Smart Structures, SPIE Symposium in Smart Structures and Materials, AIAA Adaptive Structures Forum, ASME Adaptive Structures and Materials Systems (now called SMASIS), and ICAST (International Conference on Adaptive Structures and Technologies). These conferences and workshops not only helped to communicate our activities in smart structures but also provided avenues for meeting many great friends in this discipline. Over the years, we enjoyed the warmth of many friends in the United States and abroad, including V. K. Aatre (IISc), H. Abramovich (Technion), Diann Brei (Michigan), Flavio Campanile (EMPA), Greg Carman (UCLA), Carlos Cesnik (Michigan), Aditi Chattopadhyay (ASU), Eric Cross (Penn State), Marcello Dapino (OSU), Paolo Ermanni (ETH), Mary Frecker (Michigan), Mike Friswell (Swansea), Ephraim Garcia (Cornell), Paolo Gaudenzi (U. Rome), Victor Giurgiutiu (South Carolina), S. Gopalakrishnan (IISc), Z. Gurdal (Delft), Dan Inman (Michigan), Seung Jo Kim (KARI), A. V. Krishnamurthy (IISc), Dimitris Lagoudas (Texas A&M), C. K. Lee (National Taiwan), In Lee (KAIST), Jinsong Leng (Harbin), Don Leo (VPI), George Lesieutre (Penn State), Wei-Hsin Liao (Chinese University of Hong Kong), Chris Lynch (UCLA), John Main (VPI), Dave Martinez (Sandia), Yuji Matsuzaki (Nagoya), Peter Monner (DLR), M. C. Natori (Waseda), Fred Nitzsche (Carleton), Roger Ohayon (CNAM), Zoubeida Ounaies (Penn State), K. C. Park (Colorado), Jinhao Qui (Nanjing), Dimitris Saravanos (U. Patras), Janet Sater (IDA), Jonghwan Suhr (Delaware), J. Tani (Tohoku), Horn-Sen Tzou (Zhejiang), A. R. Upadhya (NAL), Ben Wada (JPL), Kon-Well Wang (Michigan), and Wenbin Yu (Utah).

We also collaborated with rotorcraft and other aerospace industries to transition this technology to full-scale systems. Under the DARPA Smart Rotor Program, Friedrich Straub and Hieu Ngo actively collaborated with the Alfred Gessow Rotorcraft Center and injected enthusiasm among our students. We again fondly acknowledge industrial friends in the United States and abroad, including Eric Anderson (CSA), Dan Clingman (Boeing), L. Porter Davis (Honeywell), Peter Jaenker (EADS), Shiv Joshi (NextGen), and Jay Kudva (NextGen). We would also like to thank the University of Maryland and the University of Texas at Austin, where we worked on material for this textbook.

Finally, we acknowledge our deep appreciation for the support and encouragement that we received from Dr. Gary Anderson, a true gentleman, who spearheaded the growth of smart structures activities in the United States. This book is dedicated to him.

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