Advanced Multifunctional Lightweight Aerostructures

Design, Development, and Implementation

Kamran Behdinan and Rasool Moradi-Dastjerdi

ASME PRESS

WILEY

Table of Contents

List of Tables

List of Illustrations

Chapter 5

Chapter 7

Wiley-ASME Press Series

Advanced Multifunctional Lightweight Aerostructures: Design, Development, and Implementation

Kamran Behdinan and Rasool Moradi-Dastjerdi.

Vibration Assisted Machinery: Theory, Modelling, and Applications

Li-Rong Zheng, Wanqun Chen, and Dehong Huo

Two-Phase Heat Transfer

Mirza Mohammed Shah

Computer Vision for Structural Dynamics and Health Monitoring

Dongming Feng, Maria Q Feng

Theory of Solid-Propellant Nonsteady Combustion

Vasily B. Novozhilov, Boris V. Novozhilov

Introduction to Plastics Engineering

Vijay K. Stokes

Fundamentals of Heat Engines: Reciprocating and Gas Turbine Internal Combustion Engines

Jamil Ghojel

Offshore Compliant Platforms: Analysis, Design, and Experimental Studies

Srinivasan Chandrasekaran, R. Nagavinothini

Computer Aided Design and Manufacturing

Zhuming Bi, Xiaoqin Wang

Pumps and Compressors

Marc Borremans

Corrosion and Materials in Hydrocarbon Production: A Compendium of Operational and Engineering Aspects

Bijan Kermani and Don Harrop

Design and Analysis of Centrifugal Compressors

Rene Van den Braembussche

Case Studies in Fluid Mechanics with Sensitivities to Governing Variables

M. Kemal Atesmen

The Monte Carlo Ray-Trace Method in Radiation Heat Transfer and Applied Optics

J. Robert Mahan

Dynamics of Particles and Rigid Bodies: A Self-Learning Approach

Mohammed F. Daqaq

Primer on Engineering Standards, Expanded Textbook Edition

Maan H. Jawad and Owen R. Greulich

Engineering Optimization: Applications, Methods and Analysis

R. Russell Rhinehart

Compact Heat Exchangers: Analysis, Design and Optimization using FEM and CFD Approach

C. Ranganayakulu and Kankanhalli N. Seetharamu

Robust Adaptive Control for Fractional-Order Systems with Disturbance and Saturation

Mou Chen, Shuyi Shao, and Peng Shi

Robot Manipulator Redundancy Resolution

Yunong Zhang and Long Jin

Stress in ASME Pressure Vessels, Boilers, and Nuclear Components

Maan H. Jawad

Combined Cooling, Heating, and Power Systems: Modeling, Optimization, and Operation

Yang Shi, Mingxi Liu, and Fang Fang

Applications of Mathematical Heat Transfer and Fluid Flow Models in Engineering and Medicine

Abram S. Dorfman

Bioprocessing Piping and Equipment Design: A Companion Guide for the ASME BPE Standard

William M. (Bill) Huitt

Nonlinear Regression Modeling for Engineering Applications: Modeling, Model Validation, and Enabling Design of Experiments

R. Russell Rhinehart

Geothermal Heat Pump and Heat Engine Systems: Theory and Practice

Andrew D. Chiasson

Fundamentals of Mechanical Vibrations

Liang-Wu Cai

Introduction to Dynamics and Control in Mechanical Engineering Systems

Cho W.S. To

Advanced Multifunctional Lightweight Aerostructures

Design, Development, and Implementation

Kamran Behdinan and Rasool Moradi-Dastjerdi
University of Toronto, Toronto, Canada

This Work is a co-publication between John Wiley & Sons Ltd and ASME Press

ASME PRESS
WILEY

This Work is a co-publication between John Wiley & Sons Ltd and ASME Press.

Registered Office
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA

Editorial Office
111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Library of Congress Cataloging-in-Publication Data

Names: Behdinan, Kamran, 1961- editor. | Moradi-Dastjerdi, Rasool, 1984- editor. | John Wiley & Sons, Inc., publisher.

Title: Advanced multifunctional lightweight aerostructures : design, development, and implementation / Kamran Behdinan and Rasool Moradi-

Dastjerdi, University of Toronto.

Other titles: Wiley-ASME Press series.

Description: First edition. | Hoboken, NJ : John Wiley & Sons, Inc., 2021. | Series: Wiley—ASME Press Series | Includes bibliographical references and index.

Identifiers: LCCN 2020033775 (print) | LCCN 2020033776 (ebook) | ISBN 9781119756712 (cloth) | ISBN 9781119756729 (adobe pdf) | ISBN 9781119756736 (epub)

Subjects: LCSH: Airplanes—Design and construction. | Lightweight construction. | Aerospace engineering.

Classification: LCC TL671.2 .A3195 2021 (print) | LCC TL671.2 (ebook) | DDC 629.134/1–dc23

LC record available at https://lccn.loc.gov/2020033775

LC ebook record available at https://lccn.loc.gov/2020033776

Cover Design: Wiley

Cover Image: © guvendemir/Shutterstock

Professor Kamran Behdinan affectionately dedicates this book to his wife, Nasrin, without her love, patience and sacrifices, this and much else would not be possible, and to his dear daughters, Dr. Tina Behdinan and Dr. Asha Behdinan, for their love and unwavering support.

Dr. Rasool Moradi-Dastjerdi warmly dedicates this book to his wife, Arezou, and to his parents for their encouragement, love, and unlimited support.

Preface

In the aerospace industry, innovative designs, which can simultaneously address concerns about safety and fuel efficiency, have created demands for novel materials and structures. These demands have persuaded researchers to propose and investigate advanced structures made of multifunctional lightweight materials. Some notable mentions include porous, composite, nanocomposite, ultra-high temperature ceramic, piezoelectric, and functionally graded materials.

In the design of aerostructures, strength to weight ratio is the key point where the use of lightweight materials results in a considerable reduction in structural weight. However, the decrease of structural strength usually comes with an ordinary reduction in the weight of the utilized materials such as embedding porosity, or use of lighter materials. This reduction in the structural strength can be compensated using multifunctional materials or by improving the design of the structures. These facts were the key drivers in the development of new lightweight technologies where traditional composite materials as lightweight materials have seen greater integration into aerostructure applications over the past two decades. Furthermore, the introduction of nanotechnology into the design of composite materials presents another leap in the increasing effort to reduce weight and tailor the material properties to suit specific aerostructure applications. In this new generation of composites, nanoscale fillers highly affect the overall properties of the resulting nanocomposite materials.

Another class of multifunctional materials which can have specific applications in the aerospace industry are piezoelectric materials. Employing piezoelectric components with the ability to convert electrical charge to mechanical load or vice versa provides self-controlling property with fast response for the whole structure. This converting ability also provides the benefit of harvesting energy, strain measurements, and damage detection in the structures.

Moreover, aerostructures are mainly subjected to either mechanical or thermal loads where ceramic materials can be prospective candidates. Among them, ultra-high temperature ceramics are an advanced class of material that experience superior structural and thermal stability, reaching temperature over 3000 °C without a noticeable sacrifice in strength.

In aerostructures, the use of architected structures along with multifunctional lightweight materials has opened up possibilities for designs previously unimaginable. The analysis of such advanced materials and structures necessitates the application of novel methods which are precise, reliable, and computationally efficient. The necessity of utilizing advanced methods complement complex geometrical shapes, different applied loads, a multi-physics environment, and a wide range of scales from nano up to macro scales.

To cover recent developments about the aforementioned concerns and their most exciting aspects, this book is divided into two parts with 10 chapters overall where the state of the art in the respective fields are comprehensively discussed.

The first part deals with multi-disciplinary modeling and characterization of some advanced materials and structures by developing new methods. This part is composed of four chapters. Specifically, layer arrangement impact on deflections of a proposed five-layer smart sandwich plate subjected to electromechanical loads is investigated in Chapter 1. The layers of the sandwich plates are assumed to be made of three different advanced multifunctional materials including porous, graphene-reinforced nanocomposite, and piezoelectric materials. In Chapter 2, heat transfer analysis of sandwich cylinders consisting of a polymeric core and functionally graded graphene-reinforced faces is studied. Chapter 3 presents the application of a new multiscale approach in the modeling and design of lightweight materials and structures that demonstrate complex phenomena that span multiple spatial and temporal scales. In Chapter 4, chemical kinetics and the multiscale characterization of crystallinity in ultra-high temperature ceramics, polymorphic structures and their composites are described.

In the second part of this book, behaviors of some critical parts of aircraft are discussed as practical benchmark problems. Chapter 5 presents an optimization study on the design of a novel shimmy damper mechanism for aircraft nose landing gears as a practical case in aerostructures. In Chapter 6, a widely used component of helicopters, jet engines and aircraft, a flexible rotor supported by viscoelastic bearings, is modeled to study its nonlinear dynamic behavior. Chapter 7 proposes an innovative analytical–numerical method to efficiently predict the real-time temperature of belt drive systems. Chapter 8 develops an efficient and reliable physics-based approach to predict noise at the far-field of a nose landing gear of an aircraft. Another important part of aircraft is the aeroengine. In the aeroengine, the vibrations and noises can be transferred to the aircraft fuselage and this transmissibility significantly affects the aircraft crew and passenger comfort and safety. In this regard, Chapter 9 develops and implements a reliable analytical transmissibility method to analyze and investigate the vibration energy propagation in an aeroengine structure. This method results in design guidelines which can significantly reduce the development costs as well as the ability of addressing noise and vibration problems in the structure. Chapter 10 also utilizes the developed method in Chapter 9 to perform structural health monitoring to detect and classify the importance of defects and damage in the considered aeroengine using the obtained frequency response functions. Accordingly, this chapter proposes design guidelines which significantly improve the reliability and operational lifetime of the aeroengine at the lowest possible cost.

This book delivers extensive updated investigations and information to address the latest demands for the effective and efficient design and precise characterization of advanced multifunctional lightweight aerostructures. The authors believe that it is a comprehensive and useful reference for graduate students who want to increase their knowledge. This book provides innovative and practical solutions for active engineers, especially in the aerospace industry, who are looking for alternative materials, structures or methodologies to solve their current problems.

All contributions to this book are the result of years of research and development conducted by the research team under the direct supervision of the principal investigator, Professor Kamran Behdinan, in the Advanced Research Laboratory for Multifunctional Lightweight Structures (ARL-MLS) at the University of Toronto. We would like to acknowledge the funding received from the Canadian Foundation for Innovation as well as the Natural Science Engineering Research Council of Canada in support of the ARL-MLS facilities and training of highly qualified personnel. Furthermore, we wish to take this opportunity to sincerely express our appreciation to the ARL-MLS graduate students and postdoctoral fellows for their outstanding research in addressing problems of utmost significance to the aerospace research community/industry in the field of advanced multifunctional lightweight aerostructures. Their informative contributions have allowed our ideas and dreams to become a reality in this book. We are also grateful to Wiley and its team of editors for helping us to finalize this book.

Toronto, June 2020

Kamran Behdinan
Rasool Moradi-Dastjerdi

Biographies

Professor Kamran Behdinan

Professor Behdinan earned his PhD in Mechanical Engineering from the University of Victoria in British Columbia in 1996 and has considerable experience in both academic and industrial settings. He was appointed to the academic staff of Ryerson University in 1998, tenured and promoted to the level of associate professor in 2002 and subsequently to the level of professor in 2007 and served as the director of the aerospace engineering program (2002–2003), and the founding Chair of the newly established Department of Aerospace Engineering (July 2003–July 2011). Professor Behdinan was a founding member and the Executive Director of the Ryerson Institute for Aerospace Design and Innovation (2003–2011). He was also a founding member and the coordinator of the Canadian–European Graduate Student Exchange Program in Aerospace Engineering at Ryerson University. He held the NSERC Design Chair in “Engineering Design and Innovation,” 2010–2012, sponsored by Bombardier Aerospace and Pratt and Whitney Canada. He joined the Department of Mechanical and Industrial Engineering, University of Toronto, as a professor in September 2011. He is the NSERC Design Chair in “Multidisciplinary Design and Innovation – UT IMDI,” sponsored by NSERC, University of Toronto, and 13 companies including Bombardier Aerospace, Pratt and Whitney Canada, United Technology Aerospace Systems, Magna International, Honeywell, SPP Canada Aircraft, Ford, and DRDC Toronto. He is the founding director of the “University of Toronto Institute for Multidisciplinary Design and Innovation,” an