

Dynamics Of Flexible Multibody Systems Rigid Finite Element Method

This volume examines the theoretical and practical needs on the subject of multibody system dynamics with emphasis on flexible systems and engineering applications. It focuses on developing an all purpose algorithm for the dynamic simulation of flexible tree-like systems making use of matrix representation at all levels. The book covers new theories with engineering applications involved in broad fields which include; civil engineering, aerospace and robotics, as well as general and mechanical engineering. The applications include high temperature conditions, time variant contact conditions, biosystem analysis, vibration minimization and control.

This monograph, written from a numerical analysis perspective, aims to provide a comprehensive treatment of both the mathematical framework and the numerical methods for flexible multibody dynamics. Not only is this field permanently and rapidly growing, with various applications in aerospace engineering, biomechanics, robotics, and vehicle analysis, its foundations can also be built on reasonably established mathematical models. Regarding actual computations, great strides have

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been made over the last two decades, as sophisticated software packages are now capable of simulating highly complex structures with rigid and deformable components. The approach used in this book should benefit graduate students and scientists working in computational mechanics and related disciplines as well as those interested in time-dependent partial differential equations and heterogeneous problems with multiple time scales. Additionally, a number of open issues at the frontiers of research are addressed by taking a differential-algebraic approach and extending it to the notion of transient saddle point problems.

Modeling and analysing multibody systems require a comprehensive understanding of the kinematics and dynamics of rigid bodies. In this volume, the relevant fundamental principles are first reviewed in detail and illustrated in conformity with the multibody formalisms that follow. Whatever the kind of system (tree-like structures, closed-loop mechanisms, systems containing flexible beams or involving tire/ground contact, wheel/rail contact, etc), these multibody formalisms have a common feature in the proposed approach, viz, the symbolic generation of most of the ingredients needed to set up the model. The symbolic approach chosen, specially dedicated to multibody systems, affords various advantages: it leads to a simplification of the theoretical formulation of models, a considerable reduction in the size of

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generated equations and hence in resulting computing time, and also enhanced portability of the multibody models towards other specific environments. Moreover, the generation of multibody models as symbolic toolboxes proves to be an excellent pedagogical medium in teaching mechanics.

The papers in this volume present rules for mechanical models in a general systematic way, always in combination with small and large examples, many from industry, illustrating the most important features of modeling. The best way to reach a good solution is discussed. The papers address researchers and engineers from academia and from industry, doctoral students and postdocs, working in the fields of mechanical, civil and electrical engineering as well as in fields like applied physics or applied mathematics.

Modern Flexible Multi-Body Dynamics Modeling Methodology for Flapping Wing Vehicles presents research on the implementation of a flexible multi-body dynamic representation of a flapping wing ornithopter that considers aero-elasticity. This effort brings advances in the understanding of flapping wing flight physics and dynamics that ultimately leads to an improvement in the performance of such flight vehicles, thus reaching their high performance potential. In using this model, it is necessary to reduce body accelerations and forces of an

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ornithopter vehicle, as well as to improve the aerodynamic performance and enhance flight kinematics and forces which are the design optimization objectives. This book is a useful reference for postgraduates in mechanical engineering and related areas, as well as researchers in the field of multibody dynamics. Uses Lagrange equations of motion in terms of a generalized coordinate vector of the rigid and flexible bodies in order to model the flexible multi-body system Provides flight verification data and flight physics of highly flexible ornithoptic vehicles Includes an online companion site with files/codes used in application examples

Thank heavens for Jens Wittenburg, of the University of Karlsruhe in Germany. Anyone who's been laboring for years over equation after equation will want to give him a great big hug. It is common practice to develop equations for each system separately and to consider the labor necessary for deriving all of these as inevitable. Not so, says the author. Here, he takes it upon himself to describe in detail a formalism which substantially simplifies these tasks.

This enhanced fourth edition of Dynamics of Multibody Systems includes an additional chapter that provides explanations of some of the fundamental issues addressed in the book, as well as new detailed derivations of some important

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problems. Many common mechanisms such as automobiles, space structures, robots and micromachines have mechanical and structural systems that consist of interconnected rigid and deformable components. The dynamics of these large-scale multibody systems are highly nonlinear, presenting complex problems that in most cases can only be solved with computer-based techniques. The book begins with a review of the basic ideas of kinematics and the dynamics of rigid and deformable bodies before moving on to more advanced topics and computer implementation. The book's wealth of examples and practical applications will be useful to graduate students, researchers and practising engineers working on a wide variety of flexible multibody systems.

The coupling of models from different physical domains and the efficient and reliable simulation of multidisciplinary problems in engineering applications are important topics for various fields of engineering, in simulation technology and in the development and analysis of numerical solvers. The volume presents advanced modelling and simulation techniques for the dynamical analysis of coupled engineering systems consisting of mechanical, electrical, hydraulic and biological components as well as control devices often based on computer hardware and software. The book starts with some basics in multibody dynamics and in port-based modelling and focuses on the modelling and simulation of heterogeneous systems with special emphasis on robust and efficient numerical solution techniques and on a variety of applied problems including case studies of co-simulation in

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industrial applications, methods and problems of model based controller design and real-time application.

This textbook – a result of the author’s many years of research and teaching – brings together diverse concepts of the versatile tool of multibody dynamics, combining the efforts of many researchers in the field of mechanics.

Robot and Multibody Dynamics: Analysis and Algorithms provides a comprehensive and detailed exposition of a new mathematical approach, referred to as the Spatial Operator Algebra (SOA), for studying the dynamics of articulated multibody systems. The approach is useful in a wide range of applications including robotics, aerospace systems, articulated mechanisms, bio-mechanics and molecular dynamics simulation. The book also: treats algorithms for simulation, including an analysis of complexity of the algorithms, describes one universal, robust, and analytically sound approach to formulating the equations that govern the motion of complex multi-body systems, covers a range of more advanced topics including under-actuated systems, flexible systems, linearization, diagonalized dynamics and space manipulators. Robot and Multibody Dynamics: Analysis and Algorithms will be a valuable resource for researchers and engineers looking for new mathematical approaches to finding engineering solutions in robotics and dynamics.

A practical approach to the computational methods used to solve real-world dynamics problems Computational dynamics has grown rapidly in recent years with the advent of high-speed digital computers and the need to develop simulation and analysis computational capabilities for mechanical and aerospace systems that consist of interconnected bodies.

Computational Dynamics, Second Edition offers a full introduction to the concepts, definitions, and techniques used in multibody dynamics and presents essential topics concerning kinematics and dynamics of motion in two and

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three dimensions. Skillfully organized into eight chapters that mirror the standard learning sequence of computational dynamics courses, this Second Edition begins with a discussion of classical techniques that review some of the fundamental concepts and formulations in the general field of dynamics. Next, it builds on these concepts in order to demonstrate the use of the methods as the foundation for the study of computational dynamics. Finally, the book presents different computational methodologies used in the computer-aided analysis of mechanical and aerospace systems. Each chapter features simple examples that show the main ideas and procedures, as well as straightforward problem sets that facilitate learning and help readers build problem-solving skills. Clearly written and ready to apply, Computational Dynamics, Second Edition is a valuable reference for both aspiring and practicing mechanical and aerospace engineers. The author developed this text over many years, teaching graduate courses in advanced dynamics and flexible multibody dynamics at the Daniel Guggenheim School of Aerospace Engineering of the Georgia Institute of Technology. The book presents a unified treatment of rigid body dynamics, analytical dynamics, constrained dynamics, and flexible multibody dynamics. A comprehensive review of numerical tools used to enforce both holonomic and nonholonomic constraints is presented. Advanced topics such as Maggi's, index-1, null space, and Udwadia and Kalaba's formulations are presented because of their fundamental importance in multibody dynamics. Methodologies for the parameterization of rotation and motion are discussed and contrasted. Geometrically exact beams and shells formulations, which have become the standard in flexible multibody dynamics, are presented and numerical aspects of their finite element implementation detailed. Methodologies for the direct solution of the index-3 differential-algebraic

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equations characteristic of constrained multibody systems are presented. It is shown that with the help of proper scaling procedures, such equations are not more difficult to integrate than ordinary differential equations. This book is illustrated with numerous examples and should prove valuable to both students and researchers in the fields of rigid and flexible multibody dynamics.

This book contains an edited version of lectures presented at the NATO ADVANCED STUDY INSTITUTE on VIRTUAL NONLINEAR MULTIBODY SYSTEMS which was held in Prague, Czech Republic, from 23 June to 3 July 2002. It was organized by the Department of Mechanics, Faculty of Mechanical Engineering, Czech Technical University in Prague, in cooperation with the Institute B of Mechanics, University of Stuttgart, Germany. The ADVANCED STUDY INSTITUTE addressed the state of the art in multibody dynamics placing special emphasis on nonlinear systems, virtual reality, and control design as required in mechatronics and its corresponding applications. Eighty-six participants from twenty-two countries representing academia, industry, government and research institutions attended the meeting. The high qualification of the participants contributed greatly to the success of the ADVANCED STUDY INSTITUTE in that it promoted the exchange of experience between leading scientists and young scholars, and encouraged discussions to generate new ideas and to define directions of research and future developments. The full program of the ADVANCED STUDY INSTITUTE included also contributed presentations made by participants where different topics were explored, among them: Such topics include: nonholonomic systems; flexible multibody systems; contact, impact and collision; numerical methods of differential-algebraical equations; simulation approaches; virtual modelling; mechatronic design; control; biomechanics; space

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structures and vehicle dynamics. These presentations have been reviewed and a selection will be published in this volume, and in special issues of the journals *Multibody System Dynamics* and *Mechanics of Structures and Machines*.

Due to their structural flexibility, spacecraft and space manipulators are multibody systems with complex dynamics and possess a large number of degrees of freedom. Here the spatial operator algebra methodology is used to develop a new dynamics formulation and spatially recursive algorithms for such flexible multibody systems. A key feature of the formulation is that the operator description of the flexible system dynamics is identical in form to the corresponding operator description of the dynamics of rigid multibody systems. A significant advantage of this unifying approach is that it allows ideas and techniques for rigid multibody systems to be easily applied to flexible multibody systems. The algorithms use standard finite-element and assumed modes models for the individual body deformation. A Newton-Euler Operator Factorization of the mass matrix of the multibody system is first developed. It forms the basis for recursive algorithms such as for the inverse dynamics, the computation of the mass matrix, and the composite body forward dynamics for the system. Subsequently, an alternative Innovations Operator Factorization of the mass matrix, each of whose factors is invertible, is developed. It leads to an operator expression for the inverse of the mass matrix, and forms the basis for the recursive articulated body forward dynamics algorithm for the flexible multibody system. For simplicity, most of the development here focuses on serial chain multibody systems. However, extensions of the algorithms to general topology flexible multibody systems are described. While the computational cost of the algorithms depends on factors such as the topology and the amount of

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flexibility in the multibody system, in general, it appears that in contrast to the rigid multibody case, the articulated body forward dynamics algorithm is the more efficient algorithm for flexible multibody systems containing even a small number of flexible bodies. The variety of algorithms described h...

The ECCOMAS Thematic Conference “Multibody Dynamics 2009” was held in Warsaw, representing the fourth edition of a series which began in Lisbon (2003), and was then continued in Madrid (2005) and Milan (2007), held under the auspices of the European Community on Computational Methods in Applied Sciences (ECCOMAS). The conference provided a forum for exchanging ideas and results of several topics related to computational methods and applications in multibody dynamics, through the participation of 219 scientists from 27 countries, mostly from Europe but also from America and Asia. This book contains the revised and extended versions of invited conference papers, reporting on the state-of-the-art in the advances of computational multibody models, from the theoretical developments to practical engineering applications. By providing a helpful overview of the most active areas and the recent efforts of many prominent research groups in the field of multibody dynamics, this book can be highly valuable for both experienced researches who want to keep updated with the latest developments in this field and researches approaching the field for the first time.

This book focuses on structure-preserving numerical methods for flexible multibody dynamics, including nonlinear elastodynamics and geometrically exact models for beams and shells. It also deals with the newly emerging class of variational integrators as well as Lie-group integrators. It discusses two alternative approaches to the discretization in space of nonlinear beams and shells. Firstly, geometrically exact formulations, which are typically used in the finite

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element community and, secondly, the absolute nodal coordinate formulation, which is popular in the multibody dynamics community. Concerning the discretization in time, the energy-momentum method and its energy-decaying variants are discussed. It also addresses a number of issues that have arisen in the wake of the structure-preserving discretization in space. Among them are the parameterization of finite rotations, the incorporation of algebraic constraints and the computer implementation of the various numerical methods. The practical application of structure-preserving methods is illustrated by a number of examples dealing with, among others, nonlinear beams and shells, large deformation problems, long-term simulations and coupled thermo-mechanical multibody systems. In addition it links novel time integration methods to frequently used methods in industrial multibody system simulation.

Mechanical engineering, an engineering discipline born of the needs of the industrial revolution, is once again asked to do its substantial share in the call for industrial renewal. The general call is urgent as we face profound issues of productivity and competitiveness that require engineering solutions, among others. The Mechanical Engineering Series features graduate texts and research monographs intended to address the need for information in contemporary areas of mechanical engineering. The series is conceived as a comprehensive one that will cover a broad range of concentrations important to mechanical engineering graduate education and research. We are fortunate to have a distinguished roster of consulting editors, each an expert in one of the areas of concentration. The names of the consulting editors are listed on the front page of the volume. The areas of concentration are applied mechanics, biomechanics, computational mechanics, dynamic systems and control, energetics, mechanics of material, processing,

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thermal science, and tribology. Professor Leckie, the consulting editor for applied mechanics, and I are pleased to present this volume of the series: Kinematic and Dynamic Simulation of Multibody Systems: The Real-Time Challenge by Professors Garcia de Jal6n and Bayo. The selection of this volume underscores again the interest of the Mechanical Engineering Series to provide our readers with topical monographs as well as graduate texts. Austin Texas Frederick F. Ling v The first author dedicates this book to the memory of Prof F. Tegerizo (t 1988), who introduced him to kinematics.

This volume contains the edited version of selected papers presented at the Nato Advanced Study Institute on "Computer Aided Analysis of Rigid and Flexible Mechanical Systems", held in Portugal, from the 27 June to 9 July, 1994. The present volume can be viewed as a natural extension of the material addressed in the Institute which was published by KLUWER in the NATO ASI Series, Vol. 268, in 1994. The requirements for accurate and efficient analysis tools for design of large and lightweight mechanical systems has driven a strong interest in the challenging problem of multibody dynamics. The development of new analysis and design formulations for multi body systems has been more recently motivated with the need to include general features such as: real-time simulation capabilities, active control of machine flexibilities and advanced numerical methods related to time integration of the dynamic systems equations. In addition to the presentation of some basic formulations and methodologies in dynamics of multibody systems, including computational aspects, major applications of developments to date are presented herein. The scope of applications is extended to vehicle dynamics, aerospace technology, robotics, mechanisms design, intermittent motion and crashworthiness analysis. Several of these applications are

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explored by many contributors with a constant objective to pace development and improve the dynamic performance of mechanical systems avoiding different mechanical limitations and difficult functional requirements, such as, for example, accurate positioning of manipulators.

Dynamics of Multibody Systems, 3rd Edition, first published in 2005, introduces multibody dynamics, with an emphasis on flexible body dynamics. Many common mechanisms such as automobiles, space structures, robots and micromachines have mechanical and structural systems that consist of interconnected rigid and deformable components. The dynamics of these large-scale, multibody systems are highly nonlinear, presenting complex problems that in most cases can only be solved with computer-based techniques. The book begins with a review of the basic ideas of kinematics and the dynamics of rigid and deformable bodies before moving on to more advanced topics and computer implementation. This revised third edition now includes important developments relating to the problem of large deformations and numerical algorithms as applied to flexible multibody systems. The book's wealth of examples and practical applications will be useful to graduate students, researchers, and practising engineers working on a wide variety of flexible multibody systems.

Underactuated multibody systems are intriguing mechatronic systems, as they possess fewer control inputs than degrees of freedom. Some examples are modern light-weight flexible robots and articulated manipulators with passive joints. This book investigates such underactuated multibody systems from an integrated perspective. This includes all major steps from the modeling of rigid and flexible multibody systems, through nonlinear control theory, to optimal system design. The underlying theories and techniques from these different fields are presented using a self-contained and unified

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approach and notation system. Subsequently, the book focuses on applications to large multibody systems with multiple degrees of freedom, which require a combination of symbolical and numerical procedures. Finally, an integrated, optimization-based design procedure is proposed, whereby both structural and control design are considered concurrently. Each chapter is supplemented by illustrated examples.

"This book describes how to build mathematical models of multibody systems with elastic components. Examples of such systems are the human body itself, construction cranes, cars with trailers, helicopters, spacecraft deploying antennas, tethered satellites, and underwater maneuvering vehicles looking for mines while being connected by a cable to a ship"--

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The volume contains 19 contributions by international experts in the field of multibody system dynamics, robotics and control. The book aims to bridge the gap between the modeling of mechanical systems by means of multibody dynamics formulations and robotics. In the classical approach, a multibody dynamics model contains a very high level of detail, however, the application of such models to robotics or control is usually limited. The papers aim to connect the different scientific communities in multibody dynamics, robotics and control. Main topics are flexible multibody systems, humanoid robots, elastic robots, nonlinear control, optimal path planning, and identification.

Multibody Systems Approach to Vehicle Dynamics aims to bridge a gap between the subject of classical vehicle

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dynamics and the general-purpose computer-based discipline known as multibody systems analysis (MBS). The book begins by describing the emergence of MBS and providing an overview of its role in vehicle design and development. This is followed by separate chapters on the modeling, analysis, and post-processing capabilities of a typical simulation software; the modeling and analysis of the suspension system; tire force and moment generating characteristics and subsequent modeling of these in an MBS simulation; and the modeling and assembly of the rest of the vehicle, including the anti-roll bars and steering systems. The final two chapters deal with the simulation output and interpretation of results, and a review of the use of active systems to modify the dynamics in modern passenger cars. This book intended for a wide audience including not only undergraduate, postgraduate and research students working in this area, but also practicing engineers in industry who require a reference text dealing with the major relevant areas within the discipline. * Full of practical examples and applications * Uses industry standard ADAMS software based applications * Accompanied by downloadable ADAMS models and data sets available from the companion website that enable readers to explore the material in the book * Guides readers from modelling suspension movement through to full vehicle models able to perform handling manoeuvres

Multibody systems are the appropriate models for predicting and evaluating performance of a variety of dynamical systems such as spacecraft, vehicles,

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mechanisms, robots or biomechanical systems. This book addresses the general problem of analysing the behaviour of such multibody systems by digital simulation. This implies that pre-computer analytical methods for deriving the system equations must be replaced by systematic computer oriented formalisms, which can be translated conveniently into efficient computer codes for - generating the system equations based on simple user data describing the system model - solving those complex equations yielding results ready for design evaluation. Emphasis is on computer based derivation of the system equations thus freeing the user from the time consuming and error-prone task of developing equations of motion for various problems again and again.

This book presents suitable methodologies for the dynamic analysis of multibody mechanical systems with joints. It contains studies and case studies of real and imperfect joints. The book is intended for researchers, engineers, and graduate students in applied and computational mechanics.

Report presents a recursive formulation for dynamics of flexible multibody systems.

A new approach is presented in this book for modelling multi-body systems, which constitutes a substantial enhancement of the Rigid Finite Element method. The new approach is based on homogeneous transformations and joint coordinates. Apart from its simple physical interpretation and easy computer implementation, the method is also valuable for educational purposes since it impressively illustrates the

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impact of mechanical features on the mathematical model.

This book contains the edited version of the lectures presented at the NATO ADVANCED STUDY INSTITUTE on "COMPUTER AIDED ANALYSIS OF RIGID AND FLEXIBLE MECHANICAL SYSTEMS". held in Troia. Portugal. from the 27 June to 9 July. 1993. and organized by the Instituto de Engenharia Mecanica. Instituto Superior Tecnico. This ASI addressed the state-of-art in the field of multibody dynamics. which is now a well developed subject with a great variety of formalisms. methods and principles. Ninety five participants. from twenty countries. representing academia. industry. government and research institutions attended this Institute. This contributed greatly to the success of the Institute since it encouraged the interchange of experiences between leading scientists and young scholars and promoted discussions that helped to generate new ideas and to define directions of research and future developments. The full program of the Institute included also contributed presentations made by participants where different topics have been explored. Such topics include: formulations and numerical aspects in rigid and flexible mechanical systems; object-oriented paradigms; optimal design and synthesis; robotics; kinematics; path planning; control; impact dynamics; and several application oriented developments in

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weapon systems. vehicles and crash worthiness. These papers have been revised and will be published by Kluwer in a special issue of the Journal of Nonlinear Dynamics and in a forthcoming companion book. This book brings together. in a tutorial and review manner. a comprehensive summary of current work and is therefore suitable for a wide range of interests.

TRANSFER MATRIX METHOD FOR MULTIBODY SYSTEMS: THEORY AND APPLICATIONS Xiaoting Rui, Guoping Wang and Jianshu Zhang - Nanjing University of Science and Technology, China

Featuring a new method of multibody system dynamics, this book introduces the transfer matrix method systematically for the first time. First developed by the lead author and his research team, this method has found numerous engineering and technological applications. Readers are first introduced to fundamental concepts like the body dynamics equation, augmented operator and augmented eigenvector before going in depth into precision analysis and computations of eigenvalue problems as well as dynamic responses. The book also covers a combination of mixed methods and practical applications in multiple rocket launch systems, self-propelled artillery as well as launch dynamics of on-ship weaponry. • Comprehensively introduces a new method of analyzing multibody dynamics for engineers • Provides a logical

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development of the transfer matrix method as applied to the dynamics of multibody systems that consist of interconnected bodies • Features varied applications in weaponry, aeronautics, astronautics, vehicles and robotics Written by an internationally renowned author and research team with many years' experience in multibody systems Transfer Matrix Method of Multibody System and Its Applications is an advanced level text for researchers and engineers in mechanical system dynamics. It is a comprehensive reference for advanced students and researchers in the related fields of aerospace, vehicle, robotics and weaponry engineering.

Flexible Multibody Dynamics comprehensively describes the numerical modelling of flexible multibody dynamics systems in space and aircraft structures, vehicles, and mechanical systems. A rigorous approach is followed to handle finite rotations in 3D, with a thorough discussion of the different alternatives for parametrization. Modelling of flexible bodies is treated following the Finite Element technique, a novel aspect in multibody systems simulation. Moreover, this book provides extensive coverage of the formulation of a general purpose software for flexible multibody dynamics analysis, based on an exhaustive treatment of large rotations and finite element modelling, and incorporating useful reference material. Features

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include different solution techniques such as: * time integration of differential-algebraic equations * non-linear substructuring * continuation methods * nonlinear bifurcation analysis. In essence, this is an ideal text for senior undergraduates, postgraduates and professionals in mechanical and aeronautical engineering, as well as mechanical design engineers and researchers, and engineers working in areas such as kinematics and dynamics of deployable structures, vehicle dynamics and mechanical design.

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