

SYMMETRIES IN THE LINEAR THEORY OF THE DEFORMATION OF THIN SHELLS

YOSHIKI JIKUMARU

ABSTRACT. In this paper, we show that symmetries, which are known in the theory of integrable systems, naturally appeared in the classical linear theory of deformations of thin shells. Our results shows that if the middle surface of a shell becomes ‘integrable’, infinitely many deformations exist that have no shear strains and twisting of the coordinate lines.

1. INTRODUCTION

In the field of architectural surface design, shell structures have the advantage that, with an appropriate geometry, they can be thin and lightweight yet still cover large spaces without supports. In the last two decades, remarkable connections have been discovered between the shell membrane theory and the theory of integrable systems [8, 9, 10, 12]. In this paper, we focus on deformations in the linear theory of thin shells under the hypothesis of Kirchhoff-Love and reveal another relationship with the integrable systems. The strains caused by the deformation must satisfy the St. Venant type compatibility conditions in the theory of elasticity, which is known as Gol’denweizer’s compatibility conditions in the thin shell theory [2, 6]. First, the Gol’denweizer’s compatibility conditions are reformulated as an analogue of the Gauss-Mainardi-Codazzi equations for the middle surface of a shell. It is then shown that Gol’denweizer’s conditions can be regarded as “symmetries” of the Gauss-Mainardi-Codazzi equations under the assumption that no shear strain and twisting of the coordinate lines occurred in the deformation. Finally, some examples of symmetries are given for the case where the Gauss equations become soliton equations, which are important in the field of integrable geometry.

2. PRELIMINARIES

In the linear theory of thin shells, a shell can be analysed using classical differential geometry of surfaces by considering its middle surface as a smooth surface in 3-dimensional Euclidean space and taking parallel surfaces for the thickness. For the basic theory of thin shells, see, for example, [3, 4, 6]. This paper follows the symbols in [6, 8].

Let us consider a surface $\mathbf{r} = \mathbf{r}(\alpha, \beta)$ in the 3-dimensional Euclidean space parametrized by the curvature line coordinates (α, β) , that is, the first and second fundamental forms are diagonalized. We denote the first fundamental form I by

$$(1) \quad I = A_1^2 d\alpha^2 + A_2^2 d\beta^2, \quad A_1^2 = \mathbf{r}_\alpha \cdot \mathbf{r}_\alpha, \quad A_2^2 = \mathbf{r}_\beta \cdot \mathbf{r}_\beta,$$

where the subscripts represent the partial derivatives. Let \mathbf{e}_1 and \mathbf{e}_2 be the unit tangent vectors on the surface defined by the following relations:

$$(2) \quad \mathbf{r}_\alpha = A_1 \mathbf{e}_1, \quad \mathbf{r}_\beta = A_2 \mathbf{e}_2.$$

In the curvature line coordinates, a direct calculation shows that the compatibility condition $(\mathbf{r}_\alpha)_\beta = (\mathbf{r}_\beta)_\alpha$ for the linear system (2) is given by

$$(3) \quad (A_1)_\beta = pA_2, \quad (A_2)_\alpha = qA_1, \quad (\mathbf{e}_1)_\beta = q\mathbf{e}_2, \quad (\mathbf{e}_2)_\alpha = p\mathbf{e}_1,$$

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Theory of Flexible Shells E.L. Axelrad, 2012-12-02 Theory of Flexible Shells **Shell Structures: Theory and Applications** Wojciech Pietraszkiewicz, Jaroslaw Gorski, 2013-09-18 Shells are basic structural elements of modern technology and everyday life Examples are automobile bodies water and oil tanks pipelines aircraft fuselages nanotubes graphene sheets or beer cans Also nature is full of living shells such as leaves of trees blooming flowers seashells cell membranes the double helix of DNA or wings of insect **Localized Dynamics of Thin-Walled Shells** Gennadi I. Mikhasev, Petr E. Tovstik, 2020-04-17 Localized Dynamics of Thin Walled Shells focuses on localized vibrations and waves in thin walled structures with variable geometrical and physical characteristics It emphasizes novel asymptotic methods for solving boundary value problems for dynamic equations in the shell theory in the form of functions which are highly localized near both fixed and moving lines points on the shell surface Features First of its kind work synthesizing knowledge of the localization of vibrations and waves in thin walled shells with a mathematical tool to study them Suitable for researchers working on the dynamics of thin shells and also as supplementary reading for undergraduates studying asymptotic methods Offers detailed analysis of wave processes in shells with varying geometric and physical parameters **Thin Shell Theory** W. Olszak, 2014-05-04 **Applied Mechanics Reviews**, 1973 Vibrations of Hollow Elastic Bodies Magomed F. Mekhtiev, 2018-02-02 This book focuses on the justification and refinement of highly diverse approximate dynamic models for engineering structures arising in modern technology including high tech domains involving nano and meta materials It proposes a classification for vibration spectra over a broad frequency domain and evaluates the range of validity of various existing 2D theories for thin walled shells by comparing them with 3D benchmark solutions The dynamic equations in 3D elasticity are applied to the analysis of harmonic vibrations in hollow bodies with canonical shapes New exact homogeneous and inhomogeneous solutions are derived for cylinders spheres and cones including spherical and conical layers as well as for plates of variable thickness The book includes a wealth of numerical examples as well as refined versions of 2D dynamic formulations Boundary value problems for hollow bodies are also addressed **An Introduction to Nonlinear Finite Element Analysis** Junuthula Narasimha Reddy, 2015 The second edition of An Introduction to Nonlinear Finite Element Analysis has the same objective as the first edition namely to facilitate an easy and thorough understanding of the details that are involved in the theoretical formulation finite element model development and solutions of nonlinear problems The book offers an easy to understand treatment of the subject of nonlinear finite element analysis which includes element development from mathematical models and numerical evaluation of the underlying physics The new edition is extensively reorganized and contains substantial amounts of new material Chapter 1 in the second edition contains a section on applied functional analysis Chapter 2 on nonlinear continuum mechanics is entirely new Chapters 3 through 8 in the new edition correspond to Chapter 2 through 8 of the first edition but with additional explanations examples and exercise problems

Material on time dependent problems from Chapter 8 of the first edition is absorbed into Chapters 4 through 8 of the new edition Chapter 9 is extensively revised and it contains up to date developments in the large deformation analysis of isotropic composite and functionally graded shells Chapter 10 of the first edition on material nonlinearity and coupled problems is reorganized in the second edition by moving the material on solid mechanics to Chapter 12 in the new edition and material on coupled problems to the new chapter Chapter 10 on weak form Galerkin finite element models of viscous incompressible fluids Finally Chapter 11 in the second edition is entirely new and devoted to least squares finite element models of viscous incompressible fluids Chapter 12 of the second edition is enlarged to contain finite element models of viscoelastic beams In general all of the chapters of the second edition contain additional explanations detailed example problems and additional exercise problems Although all of the programming segments are in Fortran the logic used in these Fortran programs is transparent and can be used in Matlab or C versions of the same Thus the new edition more than replaces the first edition and it is hoped that it is acquired by the library of every institution of higher learning as well as serious finite element analysts The book may be used as a textbook for an advanced course after a first course on the finite element method or the first course on nonlinear finite element analysis A solutions manual is available on request from the publisher to instructors who adopt the book as a textbook for a course

Recent Developments in the Theory of Shells Holm Altenbach, Jacek Chróścielewski, Victor A. Eremeyev, Krzysztof Wiśniewski, 2019-09-25 This book commemorates the 80th birthday of Prof W Pietraszkiewicz a prominent specialist in the field of general shell theory Reflecting Prof Pietraszkiewicz's focus the respective papers address a range of current problems in the theory of shells In addition they present other structural mechanics problems involving dimension reduced models Lastly several applications are discussed including material models for such dimension reduced structures *Scientific and Technical Aerospace Reports*, 1992 [Theory of Shells and Plates \(Teoriya Obolochek i Platin\)](#) S. M. Durgar'iñan, S. M. Durgar'ian, 1966

Finite Inelastic Deformations — Theory and Applications Dieter Besdo, Erwin Stein, 2013-03-08 The IUTAM Symposium on Finite Inelastic Deformations Theory and Applications took place from August 19 to 23 1991 at the University of Hannover Germany with 75 participants from 14 countries Scope of the symposium was a fundamental treatment of new developments in plasticity and visco plasticity at finite strains This covered the phenomenological material theory based on continuum mechanics as well as the treatment of microstructural phenomena detected by precise experimental data In a restricted number lectures on new experimental facilities for measuring finite strains were also implemented into the symposium Another important topic of the symposium was the treatment of reliable and effective computational methods for solving engineering problems with finite inelastic strains Within this context it was an essential feature that theory numerical and computational analysis were seen in an integrated way In total 9 sessions with 37 lectures many of them given by well known keynote lecturers and a poster session with 10 contributions met fully our expectations of a high ranking up to date forum for the interaction of four topics namely

the physical and mathematical modelling of finite strain inelastic deformations including localizations and damage as well as the achievements in the numerical analysis and implementation and the solution of complicated engineering systems. Special and important features were reliable material data from macroscopic and microscopic tests as well as test results of complex engineering problems like deep drawing and extrusion.

An Introduction to Nonlinear Finite Element Analysis Second Edition J. N. Reddy, 2014-10-24. The second edition of *An Introduction to Nonlinear Finite Element Analysis* has the same objective as the first edition namely to facilitate an easy and thorough understanding of the details that are involved in the theoretical formulation, finite element model development and solutions of nonlinear problems. The book offers an easy to understand treatment of the subject of nonlinear finite element analysis which includes element development from mathematical models and numerical evaluation of the underlying physics. The new edition is extensively reorganized and contains substantial amounts of new material. Chapter 1 in the second edition contains a section on applied functional analysis. Chapter 2 on nonlinear continuum mechanics is entirely new. Chapters 3 through 8 in the new edition correspond to Chapter 2 through 8 of the first edition but with additional explanations, examples and exercise problems. Material on time dependent problems from Chapter 8 of the first edition is absorbed into Chapters 4 through 8 of the new edition. Chapter 9 is extensively revised and it contains up to date developments in the large deformation analysis of isotropic composite and functionally graded shells. Chapter 10 of the first edition on material nonlinearity and coupled problems is reorganized in the second edition by moving the material on solid mechanics to Chapter 12 in the new edition and material on coupled problems to the new chapter. Chapter 10 on weak form Galerkin finite element models of viscous incompressible fluids. Finally Chapter 11 in the second edition is entirely new and devoted to least squares finite element models of viscous incompressible fluids. Chapter 12 of the second edition is enlarged to contain finite element models of viscoelastic beams. In general all of the chapters of the second edition contain additional explanations, detailed example problems and additional exercise problems. Although all of the segments are in Fortran the logic used in these Fortran programs is transparent and can be used in Matlab or C versions of the same. Thus the new edition more than replaces the first edition and it is hoped that it is acquired by the library of every institution of higher learning as well as serious finite element analysts. The book may be used as a textbook for an advanced course after a first course on the finite element method or the first course on nonlinear finite element analysis. A solutions manual is available on request from the publisher to instructors who adopt the book as a textbook for a course.

Shell Structures: Theory and Applications (Vol. 2) Wojciech Pietraszkiewicz, Ireneusz Kreja, 2009-09-22. *Shell Structures Theory and Applications Volume 2* contains 77 contributions from over 17 countries reflecting a wide spectrum of scientific and engineering problems of shell structures. The papers are divided into six broad groups: 1 General lectures, 2 Theoretical modeling, 3 Stability, 4 Dynamics, 5 Numerical analysis, 6 Engineering.

U.S. Government Research & Development Reports, 1965. *Thin-walled Laminated Structures* Gennadi I. Mikhasev, Holm

Altenbach,2019-04-29 This book presents a theoretical approach that allows the analysis of structures with magnetorheological and electrorheological layers and shows with the help of examples how the mechanical behaviour of thin walled laminated structures can be influenced It consists of six chapters Chapter 1 presents a brief overview of derivation approaches for theories of thin walled structures modelling of composites and modelling of laminated and sandwich structures Chapter 2 describes the equivalent single layer model for thin laminated cylindrical shells including the special cases of plates and beams In addition to the classical mechanical properties it also considers the electrorheological and magnetorheological properties Chapter 3 presents the elastic buckling of laminated beams plates and cylindrical shells discussing various problems such as the influence of the boundary conditions external loading and magnetic fields It also suggests different approximations for asymptotic methods Chapter 4 focuses on the free vibrations of elastic laminated beams plates and cylindrical shells investigating the influence of the boundary conditions and other factors Chapter 5 presents the latest results concerning vibration of laminated structures composed of smart materials and discusses in detail the influence of electric and magnetic fields on smart structures These results provide insights into the optimal design of these structures Lastly Chapter 6 features a short appendix presenting asymptotic estimates and series

Mechanics of Textile and Laminated Composites A. Bogdanovich,Christopher M. Pastore,1996-08-31 Mechanics of Textile and Laminated Composites is in three parts The first part Chapters 1 and 2 covers the fundamental issues of 3 D theory of elasticity and presents the theory of elasticity of an anisotropic body with comprehensive analysis of its specific cases The second part Chapters 3 5 presents the theoretical and experimental characterization of the elastic properties of unidirectional textile and layered composite materials The final part Chapters 6 and 7 addresses the problems of 3 D stress analysis in laminated and textile composite structures Major emphasis is placed on textile composites perhaps the most complex and at the same time most promising group of composite materials One of the most important features of this book is that it provides accurate and efficient 3 D analysis of laminated and textile reinforced structures using novel methods It has become more and more evident in recent years that in many practical design situations such full scale 3 D analyses are required Researchers designers and engineers working with composite materials and structures will find this book an invaluable addition to their libraries

Shell-like Structures Holm Altenbach,Victor A. Eremeyev,2011-07-03 In this volume scientists and researchers from industry discuss the new trends in simulation and computing shell like structures The focus is put on the following problems new theories based on two dimensional field equations but describing non classical effects new constitutive equations for materials like sandwiches foams etc and which can be combined with the two dimensional shell equations complex structures folded branching and or self intersecting shell structures etc and shell like structures on different scales for example nano tubes or very thin structures similar to membranes but having a compression stiffness In addition phase transitions in shells and refined shell thermodynamics are discussed The chapters of this book are

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and Applications held in Wittenberg Germany **Government Reports Announcements** ,1973-09-25 *U.S. Government*
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