

# Nonlinear dynamics of plates and shallow shells interacting with moving fluid

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**Summary.** Self-sustained vibrations of plates at two-sided interaction with moving fluid are considered. Fluid-structure interaction is described by a hyper singular integral equation, which is solved by Galerkin method. The plate performs geometrical nonlinear vibrations, which is described by finite-degree-of-freedom nonlinear dynamical system. Nonlinear modes are developed to analyze the self-sustained vibrations.

## Introduction

Interaction of thin-walled structures with a moving fluid or gas takes place in marine engineering, energetic and aerospace engineering. Therefore, many efforts were made to analyze this problem [1]. Periodic and chaotic self-sustained vibrations, which are generated by airflow moving from one side of the plate, are analyzed in [2-4]. The number of modes for appropriate description of plate self-sustained vibrations in airflow is investigated in [5]. It is shown that six modes are enough for adequate description of vibrations. The Lyapunov values are calculated to analyze qualitative behavior of periodic motions in flutter instability region by Librescu, Chiochia, Marzocca [6]. Incompressible potential flow about two and three-dimension bodies is considered in [7]. The surface-source method, which describes fluid-structure interaction, is treated. This method is reduced to the hyper singular integral equation. 3D potential flow is used to describe pressure acting on vibrating plate by Novichkov [8]. The results are compared with the data obtained by piston theory. Tang, Dowell [9] are analyzed the plate in subsonic potential flow. Vortex lattice method is used to describe fluid-structure interaction. Aeroelastic instability of plates in subsonic flow is analyzed in the paper [10]. 2D incompressible flow is considered: the pressure acting on the plate is described by linear hyper singular integral equation. Liu, Dowell [11] described the vibrations of aerodynamic surface by two-degrees-of-freedom model. The action of incompressible flow on vibrating surface is reduced to lifting force and moments. Dynamics of the system is described by two nonlinear integro- differential equations.

Double-side interaction of a fluid flow with a plate is considered in this paper. Self-sustained vibrations of the plate are analyzed. The surface-source method is used to describe fluid-structure interaction. This method is reduced to hyper singular integral equation, which is solved by Galerkin technique. The vibrations of the plate are described by finite-degrees-of-freedom nonlinear dynamical system. Variant of Shaw-Pierre nonlinear modes is suggested to analyze the self-sustained vibrations. Using this approach, the flutter of the plate is analyzed. The analysis of complex chaotic vibrations is presented too.

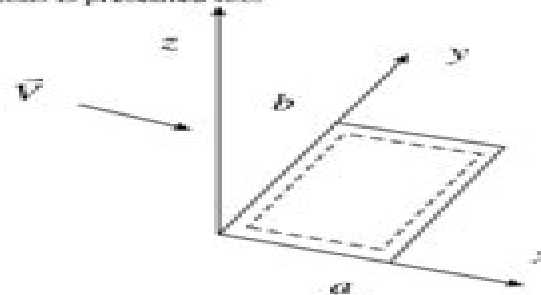


Fig.1. Sketch of the mechanical system

## Problem formulation

Dynamics of simply supported plate in the flow of incompressible potential fluid is considered. The flow at a distance from the plate has constant velocity  $V$  (Fig.1). 3D flow is considered. The fluid dynamics is described by the velocity potential  $\varphi(x, y, z, t)$ . The lateral displacements of the plate is denoted by  $w(x, y, t)$ . It is assumed, that the normal component of the plate velocities is equal to the normal component of the fluid velocities, which is described by the following equations:

$$\left. \frac{\partial \varphi}{\partial z} \right|_{z=w=0} = V \frac{\partial w}{\partial x} + \frac{\partial w}{\partial t}; \quad \left. \frac{\partial \varphi}{\partial z} \right|_{z=-w=0} = V \frac{\partial w}{\partial x} + \frac{\partial w}{\partial t}. \quad (1)$$

The pressure acting on the plate is obtained from the Bernoulli's equation, which has the following form:

# Nonlinear Dynamics Of Shells Plates

**Chen-Shyh Tsay**



## **Nonlinear Dynamics Of Shells Plates:**

**Nonlinear Vibrations and Stability of Shells and Plates** Marco Amabili, 2008-01-14 This unique book explores both theoretical and experimental aspects of nonlinear vibrations and stability of shells and plates It is ideal for researchers professionals students and instructors Expert researchers will find the most recent progresses in nonlinear vibrations and stability of shells and plates including advanced problems of shells with fluid structure interaction Professionals will find many practical concepts diagrams and numerical results useful for the design of shells and plates made of traditional and advanced materials They will be able to understand complex phenomena such as dynamic instability bifurcations and chaos without needing an extensive mathematical background Graduate students will find i a complete text on nonlinear mechanics of shells and plates collecting almost all the available theories in a simple form ii an introduction to nonlinear dynamics and iii the state of art on the nonlinear vibrations and stability of shells and plates including fluid structure interaction problems

**Nonlinear Dynamics of Shells and Plates** M. P. Paidoussis, M. Amabile, Paulo B. Gonçalves, 2000 Thermo-Dynamics of Plates and Shells Jan Awrejcewicz, Vadim Anatolevich Krysko, Anton V. Krysko, 2007-02-15 This monograph is devoted to nonlinear dynamics of thin plates and shells with thermosensitive excitation Because of the variety of sizes and types of mathematical models in current use there is no prospect of solving them analytically However the book emphasizes a rigorous mathematical treatment of the obtained differential equations since it helps efficiently in further developing of various suitable numerical algorithms to solve the stated problems Vibration and Nonlinear Dynamics of Plates and Shells Meilan Liu, Cho W. S. To, 2014-03-25 This e book focuses on the vibrational and nonlinear aspects of plate and shell structure dynamics by applying the finite element model Specifically shell finite elements employed in the computational studies included in this book are the mixed formulation based lower order flat triangular shell finite elements Topics in the book are covered over nine chapters including the theoretical background for the vibration analysis of plates and shells vibration analysis of plate structures shells with single curvature shells with double curvatures and box structures single cell and double cell and the theoretical development for the nonlinear dynamic analysis of plate and shell structures In addition to presenting the steps in the derivations of the consistent element stiffness and mass matrices constitutive relations of elastic materials and elasto plastic materials with isotropic strain hardening yield criterion return mapping configuration and stress updating strategies and numerical algorithms are presented and discussed The book is a suitable reference for advanced undergraduates and post graduate level engineering students research engineers and scientists working in the field of applied physics and engineering **The Nonlinear Dynamics of Plates and Shells** Arnol'd Sergeevich Vol'mir, 1974 The book consists of ten chapters Chapter I contains the fundamental equations of dynamic theory of large deflection plates and shells Chapters II V examine the various types of vibratory motions of plates and shells Specific problems pertaining to natural and forced vibrations are apparently presented here for the first time In the section pertaining to self induced

vibrations principal attention is given to new data on panel flutter Chapters VI IX describe the behavior of thin walled systems under dynamic loading It includes an analysis of deformation of plates and shells under rapid and very rapid impact loads of different types Finally Chapter X presents some problems of shell and plate dynamics requiring a statistical approach

**Numerical Methods for Nonlinear Dynamics of Plates and Shells** Chen-Shyh Tsay,1981 *Nonclassical Thermoelastic Problems in Nonlinear Dynamics of Shells* Jan Awrejcewicz,Vadim Anatol'evich Krysko,2003 From the reviews A unique feature of this book is the nice blend of engineering vividness and mathematical rigour The authors are to be congratulated for their valuable contribution to the literature in the area of theoretical thermoelasticity and vibration of plates Journal of Sound and Vibration Nonlinear Analyses of Laminated Plates and Shells with Damage Yi-Ming Fu,2013 The contents of this book are related to composite mechanics nonlinear plate and shell mechanics damage mechanics elasto plastic mechanics visco elastic mechanics piezoelectric elastic mechanics and nonlinear dynamics which embody the combination and integration among solid mechanics material science and nonlinear science **Nonlinear Dynamics of Shells and Plates Subjected to Pulsatile Flow** Eleonora Tubaldi,2017 Flow induced vibrations due to unsteady flow often occur in many engineering areas A specific type of unsteady flow is represented by oscillatory and pulsatile flows which are prevalent in industrial and biological systems applications include pump and valve operations in pipeline systems as well as blood circulation Associated to pulsatility wave propagation in elastic tubes is recognized as the fundamental principle of the pressure pulse in arteries This propagation phenomenon is due to the fluid structure interaction and not to fluid compressibility The pulse wave velocity is related to the underlying vessel wall stiffness In biomechanics and vascular surgery thin walled shell theory can be applied to model the mechanics of veins arteries pulmonary passages and artificial blood vessels This thesis focuses on the development of a new theoretical framework able to reproduce the nonlinear dynamic response of shells and plates to axial pulsatile flow The flow is set in motion by a pulsatile pressure gradient Coupled fluid structure Lagrange equations of motion for a non material volume subject to pulsatile flow and pressure with and without wave propagation are obtained and presented for the first time in the literature The studied systems are represented by a plate periodically supported and a circular cylindrical shell with flexible boundary conditions The fluid model is based on the potential flow theory Numerical bifurcation analysis and time integration methods are employed to investigate the stability of the systems described using a refined reduced order model The plate is modeled based on the von Krmn nonlinear plate theory and it is assumed to be periodically simply supported in both in plane directions with immovable edges The flow channel is bounded by a rigid wall The effects on the dynamics of the plate of different system parameters such as flow velocity pulsation amplitude pulsation frequency and channel pressurization are fully discussed In vascular surgery artificial blood vessels used for repairing and replacing damaged thoracic aorta in cases of aneurysm dissection or coarctation can be modeled as thin walled shells conveying pulsating flow For this purpose in this study

isotropic and orthotropic circular cylindrical shells with mechanical properties of woven Dacron thoracic prostheses are modeled using the nonlinear Novozhilov shell theory A pulsatile time dependent blood flow model is considered by applying physiological waveforms of velocity and pressure during the heart beating period The fluid is assumed to be Newtonian and the pulsatile flow is formulated using a hybrid model that contains the unsteady effects obtained from the linear potential flow theory and the pulsatile viscous effects obtained from the unsteady time averaged Navier Stokes equations

Geometrically nonlinear vibrations displaying interesting and intricate nonlinear dynamics chaos amplitude modulation and period doubling bifurcation are presented via frequency response curves time histories bifurcation diagrams and Poincaré maps This study provides an efficient fluid structure interaction model that can reveal important aspects on the nonlinear dynamics and stability of systems conveying pulsatile flow It also addresses a crucial but still unexplored issue in cardiovascular surgery related to the dynamics of Dacron vascular grafts subject to physiological pulsatile blood flow An innovative formulation of the three dimensional quasi linear viscoelasticity is presented and applied to fit original experimental data of relaxation in axial and circumferential directions of a woven Dacron aortic graft Experimental dynamic tests have been conducted on a Dacron prosthesis pressurized with a blood analog fluid Modal damping values and natural frequencies have been estimated by experimental modal analysis Numerical simulations and comparisons with experimental results are reported 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 insects In the human body arteries the shell of the eye the diaphragm the skin or the pericardium are all shells as well Shell Structures Theory and Applications Volume 3 contains 137 contributions presented at the 10th Conference Shell Structures Theory and Applications held October 16 18 2013 in Gdansk Poland The papers cover a wide spectrum of scientific and engineering problems which are divided into seven broad groups general lectures theoretical modelling stability dynamics bioshells numerical analyses and engineering design The volume will be of interest to researchers and designers dealing with modelling and analyses of shell structures and thin walled structural elements Anisotropic Doubly-Curved Shells Francesco Tornabene, Michele Baccocchi, 2019-11-01

This book aims to present in depth several Higher order Shear Deformation Theories HSDTs by means of a unified approach for the mechanical analysis of doubly curved shell structures made of anisotropic and composite materials In particular the strong and weak formulations of the corresponding governing equations are discussed and illustrated The approach presented in this volume is completely general and represents a valid tool to investigate the structural behavior of many arbitrarily shaped structures An isogeometric mapping procedure is also illustrated to this aim Special attention is given also to advanced and innovative constituents such as Carbon Nanotubes CNTs Variable Angle Tow

VAT composites and Functionally Graded Materials FGMs In addition several numerical applications are developed to support the theoretical models Accurate efficient and reliable numerical techniques able to approximate both derivatives and integrals are presented which are respectively the Differential Quadrature DQ and Integral Quadrature IQ methods Finally two numerical techniques named Strong Formulation Finite Element Method SFEM and Weak Formulation Finite Element Method WFEM are developed to deal with multi element domains characterized by arbitrary shapes and discontinuities

**Fluid-Structure Interactions, Volume 2** Michael P. Paidoussis,2003-12-15 The text is richly illustrated lightly written and more wide ranging than Volume 1 A comprehensive treatment of fluid structure interactions involving axial flow and slender structures such as piping human veins aircraft nuclear reactor fuel and submarine skins The emphasis is on fundamentals particularly on the physical understanding and underlying mechanisms as well as on applications This book will be invaluable for researchers professional engineers applied scientists and students involved in the design study or operation or systems involving fluid flow internal or external structures wind or ocean currents Emphasizes real world analysis of problems encountered in the field and presents their solutions A practical and thorough literature review of over 1400 references an excellent reference document Bridges the gap between academic researchers and practitioners in industry

**Nonlinear Dynamics of Continuous Elastic Systems** Jan Awrejcewicz,Vadim Anatol'evich Krysko,Alexander F. Vakakis,2004-03-23 This monograph is devoted to recent advances in nonlinear dynamics of continuous elastic systems A major part of the book is dedicated to the analysis of non homogeneous continua e g plates and shells characterized by sudden changes in their thickness possessing holes in their bodies or and edges made from different materials with diverse dynamical characteristics and complicated boundary conditions New theoretical and numerical approaches for analyzing the dynamics of such continua are presented such as the method of added masses and the method of proper orthogonal decomposition The presented hybrid approach leads to results that cannot be obtained by other standard theories in the field The demonstrated methods are illustrated by numerous examples of application Research on Mechanics, Dynamic

Systems and Material Engineering B. Xu,H.Y. Li,2012-12-27 Selected peer reviewed papers from the 2012 International Conference on Mechanics Dynamic Systems and Material Engineering MDSME 2012 November 24 25 2012 Guangzhou

*Nonlinear Mechanics of Shells and Plates in Composite, Soft and Biological Materials* Marco Amabili,2018-11 This book guides the reader into the modelling of shell structures in applications where advanced composite materials or complex biological materials must be described with great accuracy A valuable resource for researchers professionals and graduate students it presents a variety of practical concepts diagrams and numerical results **Applied Mechanics Reviews** ,1992

**The Shock and Vibration Digest** ,1984 **Proceedings of the ASME Dynamic Systems and Control Division--2003** ,2003 **An Energy Decaying Scheme for Nonlinear Dynamics of Shells** Carlo L. Bottasso,2000 A novel integration scheme for nonlinear dynamics of geometrically exact shells is developed based on the inextensible director

assumption The new algorithm is designed so as to imply the strict decay of the system total mechanical energy at each time step and consequently unconditional stability is achieved in the nonlinear regime Furthermore the scheme features tunable high frequency numerical damping and it is therefore stiffly accurate The method is tested for a finite element spatial formulation of shells based on mixed interpolations of strain tensorial components and on a two parameter representation of director rotations The robustness of the scheme is illustrated with the help of numerical examples      *Nonlinear Dynamical Systems: 1983-1995* Jan Awrejcewicz, 2001

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## **Table of Contents Nonlinear Dynamics Of Shells Plates**

1. Understanding the eBook Nonlinear Dynamics Of Shells Plates
  - The Rise of Digital Reading Nonlinear Dynamics Of Shells Plates
  - Advantages of eBooks Over Traditional Books
2. Identifying Nonlinear Dynamics Of Shells Plates
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Nonlinear Dynamics Of Shells Plates
  - User-Friendly Interface
4. Exploring eBook Recommendations from Nonlinear Dynamics Of Shells Plates



- Personalized Recommendations
- Nonlinear Dynamics Of Shells Plates User Reviews and Ratings
- Nonlinear Dynamics Of Shells Plates and Bestseller Lists
- 5. Accessing Nonlinear Dynamics Of Shells Plates Free and Paid eBooks
  - Nonlinear Dynamics Of Shells Plates Public Domain eBooks
  - Nonlinear Dynamics Of Shells Plates eBook Subscription Services
  - Nonlinear Dynamics Of Shells Plates Budget-Friendly Options
- 6. Navigating Nonlinear Dynamics Of Shells Plates eBook Formats
  - ePub, PDF, MOBI, and More
  - Nonlinear Dynamics Of Shells Plates Compatibility with Devices
  - Nonlinear Dynamics Of Shells Plates Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Nonlinear Dynamics Of Shells Plates
  - Highlighting and Note-Taking Nonlinear Dynamics Of Shells Plates
  - Interactive Elements Nonlinear Dynamics Of Shells Plates
- 8. Staying Engaged with Nonlinear Dynamics Of Shells Plates
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Nonlinear Dynamics Of Shells Plates
- 9. Balancing eBooks and Physical Books Nonlinear Dynamics Of Shells Plates
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Nonlinear Dynamics Of Shells Plates
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Nonlinear Dynamics Of Shells Plates
  - Setting Reading Goals Nonlinear Dynamics Of Shells Plates
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Nonlinear Dynamics Of Shells Plates

- Fact-Checking eBook Content of Nonlinear Dynamics Of Shells Plates
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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