



Coupled Fluid-structure Flutter Analysis of a Transonic Fan

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Abstract

A coupled fluid-structure method is developed for flutter analysis of blade vibrations in turbomachinery. The approach is based on the time domain solution of the fluid-structure interaction in which the aerodynamic and structural equations are marched simultaneously in time. The three-dimensional (3D) unsteady Reynolds average Navier-Stokes (RANS) equations are solved with a multiblock finite volume scheme on dynamic deforming grids to evaluate the aerodynamic force. Dual time-stepping technique and an efficient implicit scheme with multigrid are employed to march the solution in time. The blade vibration is modeled with an aeroelasticity model in which blade motion is computed by linear combination of responses of each mode under unsteady loads. The code is validated in prediction of the unsteady flow flutter behavior of an oscillating cascade and is applied to flutter analysis of a transonic fan at the design speed.

Keywords: transonic flow; unsteady flow; flutter; transonic fan; fluid-structure interaction; turbomachinery

1. Introduction

The design trends for modern commercial aircraft engine are towards high thrust/weight ratio, fuel efficiency and safety^[1]. These requirements lead to design fans and compressors with high pressure ratio per stage, thin blades, making the blades more susceptible to fluid induced vibration. Flutter is known as a self-excited vibration of a body in fluid. It poses significant challenge to aero-engine safety. Furthermore, aeroelastic stability causes designers to be conservative in pushing the design of engines to new limits of performance^[2]. Prediction flutter with numerical methods is critical for both the safety and the improvement of the aero-engine performance.

Flutter is a multidisciplinary subject combining unsteady aerodynamics and structural dynamics. The simultaneous integration of the equations of motion

in time for the fluid and structure allows the correct assessment of the energy exchange between fluid and the blade(s). Flutter occurs when the blade absorbs energy from fluid and the blade vibration becomes unstable. When the aero-damping of fluid dissipates the vibrating blade energy, the amplitude of the vibration reduces, and thus the vibration is stable. When a balance between input energy and dissipation occurs, the blade enters auto-oscillation or limit-cycle oscillation mode (LCO)^[3], in which the oscillation amplitude is critical to assess its impact on structure integrity. Flutter is usually associated with fan blades, though other compressor and low-pressure turbine blades may also suffer from such instabilities^[4].

Prediction of blade flutter is proven to be a difficult task due to the perplexing phenomena of fluid-structure interaction in turbomachinery. In addition, people do not fully understand the consequences of many additional features, such as flow distortions due to blade-row interaction, coupling of assembly modes, and loss of spatial periodicity (aerodynamic or structural mistuning), acoustic resonance, etc. Time-linearized (frequency domain) approach has

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Elsalakawy,Ahmed Elshaer,Ayman El Ansary,2025-10-03 This book comprises the proceedings of the Annual Conference of the Canadian Society of Civil Engineering 2024 The contents of this volume focus on specialty conferences in structural engineering This volume will prove a valuable resource for those in academia and industry Mathematical Modeling and Simulation of Systems Volodymyr Kazymyr,Anatoliy Morozov,Alexander Palagin,Serhiy Shkarlet,Nikolai Stoianov,Dmitri Vinnikov,Mark Zheleznyak,2024-09-06 Modern complex multi domain systems require increased efficiency reliability and availability combined with reduced cost This book contains papers on mathematical modeling and simulation of processes in various areas in ecology and the environment production and energy information technology samples of special purpose equipment and cyber physical systems The outcomes presented in the book will be useful to specialists involved in the modeling and simulation of real world system management and decision making models production models and software products Scientists have the opportunity to familiarize themselves with the latest research in a variety of solutions proposed by leading scientists and to determine promising directions for solving complex scientific and practical tasks Chapters of this book contain papers presented at the 18th MODS International Conference November 13 15 2023 Chernihiv Ukraine

Unsteady Computational Fluid Dynamics in Aeronautics P.G. Tucker,2013-08-30 The field of Large Eddy Simulation LES and hybrids is a vibrant research area This book runs through all the potential unsteady modelling fidelity ranges from low order to LES The latter is probably the highest fidelity for practical aerospace systems modelling Cutting edge new frontiers are defined One example of a pressing environmental concern is noise For the accurate prediction of this unsteady modelling is needed Hence computational aeroacoustics is explored It is also emerging that there is a critical need for coupled simulations Hence this area is also considered and the tensions of utilizing such simulations with the already expensive LES This work has relevance to the general field of CFD and LES and to a wide variety of non aerospace aerodynamic systems e g cars submarines ships electronics buildings Topics treated include unsteady flow techniques LES and hybrids general numerical methods computational aeroacoustics computational aeroelasticity coupled simulations and turbulence and its modelling LES RANS transition VLES URANS The volume concludes by pointing forward to future horizons and in particular the industrial use of LES The writing style is accessible and useful to both academics and industrial practitioners From the reviews Tucker s volume provides a very welcome concise discussion of current capabilities for simulating and modelling unsteady aerodynamic flows It covers the various possible numerical techniques in good clear detail and presents a very wide range of practical applications beautifully illustrated in many cases This book thus provides a valuable text for practicing engineers a rich source of background information for students and those new to this area of Research Development and an excellent state of the art review for others A great achievement Mark Savill FHEA FRAeS C Eng

Professor of Computational Aerodynamics Design Head of Power Propulsion Sciences Department of Power Propulsion School of Engineering Cranfield University Bedfordshire U K This is a very useful book with a wide coverage of many aspects in unsteady aerodynamics method development and applications for internal and external flows L He Rolls Royce RAEng Chair of Computational Aerothermal Engineering Oxford University U K This comprehensive book ranges from classical concepts in both numerical methods and turbulence modelling approaches for the beginner to latest state of the art for the advanced practitioner and constitutes an extremely valuable contribution to the specific Computational Fluid Dynamics literature in Aeronautics Student and expert alike will benefit greatly by reading it from cover to cover S bastien Deck Onera Meudon France

Unsteady Aerodynamics, Aeroacoustics and Aeroelasticity of Turbomachines Kenneth C. Hall, Robert E. Kielb, Jeffrey P. Thomas, 2006-05-11 This textbook is a collection of technical papers that were presented at the 10th International Symposium on Unsteady Aerodynamics Aeroacoustics and Aeroelasticity of Turbomachines held September 8 11 2003 at Duke University in Durham North Carolina The papers represent the latest in state of the art research in the areas of aeroacoustics aerothermodynamics computational methods experimental testing related to flow instabilities flutter forced response multistage and rotor stator effects for turbomachinery

Detached-Eddy Simulation Series Methods for Compressor Internal Flow Ruiyu Li, Limin Gao, Lei Zhao, 2024-12-31 This book concentrates on high fidelity numerical methods for predicting internal flows within aeroengines compressors A distinctive features of this work is the establishment of a comprehensive research framework Specifically it starts with engineering application requirements and integrates high performance parallel algorithms to develop detached eddy simulation DES series methods tailored to the needs of compressor design Additionally it encompasses the development of data analysis methods suitable for handling the vast amounts of high fidelity unsteady flow data in compressors and the high spatial resolution experimental results This book takes us from making the intricate details of compressor flow field structures visible to explainable Another noteworthy aspect of this book is its practical orientation seamlessly intergrating theoretical concepts with practical applications Herein it addresses three major engineering problems in detail and elucidates the technical approaches involving advanced numerical methods and data analysis techniques for solving these physical problems The book highlights the challenging issues associated with complex internal flows in compressors the governing equations for DES series methods and the implementation strategies for numerical simulations of internal compressor flows They also delve into data driven analysis methods for unsteady flow field data high fidelity numerical simulations of flow in the blade root region of compressors dynamic flow capture methods in the tip region of compressor blades and simulation and analysis of flow fields in inlet distortion generators This book serves as a valuable reference for researchers and engineering professionals in the aerospace computational fluid dynamics and high performance turbomachinery fields Additionally it can be used as a specialized textbook for doctoral and master s students in disciplines such as aerospace science and technology power

engineering and engineering thermophysics **Proceedings of the ASME Turbo Expo 2002** ,2002 Mechanical Design and Simulation: Exploring Innovations for the Future Duc Truong Pham,Yaguo Lei,Yanshan Lou,2025-01-23 This book is an open access publication This book presents innovative strategies and cutting edge research at the intersection of mechanical engineering and simulation technologies Aimed at addressing the current challenges and limitations in mechanical design this book presents an array of advanced methodologies and tools that promise to revolutionize the field From integrating artificial intelligence and machine learning for design optimization to leveraging the latest in finite element analysis for enhanced stress modelling the proceedings highlight the pivotal role of simulation in pushing the boundaries of what is possible in mechanical design With a strong emphasis on sustainable design practices and the utilization of additive manufacturing this collection not only serves as an indispensable resource for engineers researchers and students but also marks a significant step forward in bridging the gap between traditional mechanical design principles and modern computational innovations *Proceedings of the ASME Turbo Expo ...* ,2004 **Intelligent Structure and Vibration Control** Shaobo Zhong,Yi Min Cheng,Xi Long Qu,2011-02-02 Selected peer reviewed papers from the International Conference on Intelligent Structure and Vibration Control ISVC 2011 January 14 16 2011 Chongqing China 41st AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit 10-13 July 2005, Tucson, Arizona: 05-4000 - 05-4049 ,2005 International Conference on Vibration Measurements by Laser Techniques: Advances and Applications ,2006 **Proceedings of the ASME Pressure Vessels and Piping Conference--2005: Fluid-structure interaction** ,2005 AIAA Aerospace Sciences Meeting and Exhibit, 42nd ,2004 **Integrated Computer Technologies in Mechanical Engineering - 2024** Oleksii Lytvynov,Volodymyr Pavlikov,Dmytro Krytskyi,2025-08-20 This book covers areas such as information technology in engine design and production information technology in the creation of rocket and space systems aerospace engineering transport systems and logistics big data and data science nanomodeling artificial intelligence and intelligent systems networks and communications cyber physical systems and IoE as well as software engineering and IT infrastructure The materials were tested during the International Scientific and Technical Conference Integrated Computer Technologies in Mechanical Engineering Synergetic Engineering ICTM was established by the National Aerospace University Kharkiv Aviation Institute The ICTM 2024 conference was held in Kharkiv Ukraine in December 2024 During this conference technical exchange between the scientific community was carried out in the form of keynote speeches panel discussions and a special session More than 140 papers from different countries were received at ICTM 2024 The book offers us a lot of valuable information and is very useful for the exchange of experience between scientists in the field of modeling and simulation ICTM was created to bring together outstanding researchers and practitioners in the field of information technology in the design and manufacture of engines the creation of rocket and space systems aerospace engineering from all over the world to exchange experiences and expertise *Advances in Mechanical and Power Engineering II* Holm

Altenbach, Xiao-Wei Gao, Stavros Syngellakis, Alexander H.-D. Cheng, Piotr Lampart, Anton Tkachuk, 2025-02-01 This book covers theoretical and experimental findings at the interface between fluid mechanics heat transfer and energy technologies It reports on the development and improvement of numerical methods and intelligent technologies for a wide range of applications in mechanical power and materials engineering It reports on solutions to modern fluid mechanics and heat transfer problems on strategies for studying and improving the dynamics and durability of power equipment discussing important issues relating to energy saving and environmental safety Gathering selected contributions to the XV International Conference on Advanced Mechanical and Power Engineering CAMPE 2023 held online on October 16 19 2023 from Kharkiv Ukraine this book offers a timely update and extensive information for both researchers and professionals in the field of mechanical and power engineering *International Aerospace Abstracts* ,1999 ASME Technical Papers ,2000 *Transport Phenomena in Rotating Machinery: Dynamics II* Agnieszka Muszyńska,1998 Proceedings of the 5th International Symposium on Fluid-Structure Interactions, Aeroelasticity, Flow-Induced Vibration and Noise M. P. Paidoussis,2002 *Proceedings of the 5th International Symposium on Fluid-Structure Interaction, Aeroelasticity, Flow-Induced Vibration and Noise* M. P. Paidoussis,2002

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