



## 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<sup>[1]</sup>. 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<sup>[2]</sup>. 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)<sup>[3]</sup>, 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<sup>[4]</sup>.

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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## **Table of Contents Coupled Fluid Structure Flutter Analysis Of A Transonic Fan**

1. Understanding the eBook Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - The Rise of Digital Reading Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Advantages of eBooks Over Traditional Books
2. Identifying Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - 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 Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - User-Friendly Interface
4. Exploring eBook Recommendations from Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Personalized Recommendations
  - Coupled Fluid Structure Flutter Analysis Of A Transonic Fan User Reviews and Ratings
  - Coupled Fluid Structure Flutter Analysis Of A Transonic Fan and Bestseller Lists
5. Accessing Coupled Fluid Structure Flutter Analysis Of A Transonic Fan Free and Paid eBooks
  - Coupled Fluid Structure Flutter Analysis Of A Transonic Fan Public Domain eBooks
  - Coupled Fluid Structure Flutter Analysis Of A Transonic Fan eBook Subscription Services
  - Coupled Fluid Structure Flutter Analysis Of A Transonic Fan Budget-Friendly Options

6. Navigating Coupled Fluid Structure Flutter Analysis Of A Transonic Fan eBook Formats
  - ePub, PDF, MOBI, and More
  - Coupled Fluid Structure Flutter Analysis Of A Transonic Fan Compatibility with Devices
  - Coupled Fluid Structure Flutter Analysis Of A Transonic Fan Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Highlighting and Note-Taking Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Interactive Elements Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
8. Staying Engaged with Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
9. Balancing eBooks and Physical Books Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Setting Reading Goals Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - Fact-Checking eBook Content of Coupled Fluid Structure Flutter Analysis Of A Transonic Fan
  - 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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