STM JOURNALS

Recent Trends in
Fluid Mechanics

https://journals.stmjournals.com/rtfm

ISSN: 2455-1961
Volume 13, Issue 1, 2026
January–April
DOI (Journal): 10.37591/RTFM

Review RTFM

Recent Trends in Fluid Mechanics with Emphasis on Aeroacoustics and Flow-Induced Noise Control

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Abstract

Fluid mechanics continues to evolve rapidly due to increasing demands in aerospace, automotive, energy, and environmental engineering applications. Recent trends in this field highlight significant advancements in both theoretical understanding and practical implementations, particularly in complex flow phenomena. Among these, aeroacoustics and flow-induced noise control have emerged as critical research areas due to their direct impact on system performance, efficiency, and environmental sustainability. Aeroacoustics deals with the generation, propagation, and control of sound produced by turbulent fluid motion and aerodynamic interactions. Modern research focuses on understanding the mechanisms of noise generation in high-speed and turbulent flows, especially in aircraft, wind turbines, and industrial machinery. Simultaneously, flow-induced noise control techniques have gained attention, aiming to reduce unwanted acoustic emissions through innovative passive and active control strategies. Recent developments include advanced computational fluid dynamics (CFD) simulations, data-driven modeling approaches, and the integration of machine learning techniques to predict and mitigate noise sources more effectively. Experimental methods such as wind tunnel testing and particle image velocimetry also play a crucial role in validating numerical models and improving accuracy. This review paper presents an overview of recent trends in fluid mechanics with a specific emphasis on aeroacoustics and noise reduction strategies. It highlights key technological advancements, identifies current challenges, and discusses future directions for research. The study aims to bridge the gap between fundamental fluid dynamics and practical noise control applications, contributing to the development of quieter and more efficient engineering systems.

Keywords: Fluid mechanics, aeroacoustics, flow-induced noise, turbulence modeling, noise control techniques

INTRODUCTION

Fluid mechanics is a fundamental discipline concerned with the study of fluids in motion and at rest, governed by the conservation laws of mass, momentum, and energy. The theoretical foundation of fluid mechanics is based on the Navier–Stokes equations, which describe the motion of viscous fluid flow. Although these equations are well established, they remain analytically unsolved for most practical engineering problems owing to their nonlinear nature. Consequently, modern research in fluid mechanics increasingly depends on numerical modeling, experimental validation, and data-driven interpretation [1].

In recent years, fluid mechanics has evolved from classical analytical approaches to a highly interdisciplinary field that incorporates computational science, acoustics, materials engineering, and artificial intelligence. This evolution has enabled researchers to analyze

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Received Date: April 29, 2026
Accepted Date: April 30, 2026
Published Date: May 02, 2026

Citation: Deepa A. Sinha, Umang K. Shah, Yagnik Y. Patel, Ankit M. Kela, Tamanna J. Badarshahi, Vrunda D. Joshi. Recent Trends in Fluid Mechanics with Emphasis on Aeroacoustics and Flow-Induced Noise Control. Recent Trends in Fluid Mechanics. 2026; 13(1): 32–38p.

complex flow systems, such as turbulent jets, boundary layers, multiphase flows, and compressible aerodynamic structures. Among these developments, aeroacoustics and flow-induced noise control have emerged as significant areas of focus because of their relevance in high-speed transport systems, industrial machinery, and environmental noise reduction.

Theoretical Foundation of Aeroacoustics

Aeroacoustics is the study of sound generation through fluid motion. It is fundamentally based on the interaction between unsteady fluid flow and pressure fluctuations that generate acoustic waves. The theoretical framework of aeroacoustics was significantly advanced by Lighthill's acoustic analogy, which reformulates the Navier–Stokes equations into a wave equation with source terms representing turbulent stresses. In fluid flow systems, sound is not an independent phenomenon but a by-product of flow instabilities. Turbulence plays a central role in this process. When fluid particles move in an irregular and chaotic manner, they generate fluctuating pressure fields that propagate as sound waves [2]. These waves interact with surrounding boundaries, leading to complex acoustic behavior. Further theoretical developments include extensions such as the Ffowcs Williams–Hawkings (FW-H) equation, which incorporates the effects of moving solid boundaries. These formulations allow the prediction of noise generated by rotating machinery, aircraft wings, and jet exhaust.

Flow-Induced Noise Mechanisms

Flow-induced noise arises when fluid motion interacts with solid surfaces, or when internal flow structures become unstable. The theoretical mechanisms responsible for noise generation include vortex shedding, turbulence–boundary layer interaction, flow separation, and wake formation. From a physical perspective, vortex shedding occurs when alternating low-pressure regions are formed downstream of bluff bodies, thereby producing periodic oscillations. These oscillations generate acoustic waves that propagate through the surrounding environment. Similarly, turbulent boundary layers generate broadband noise owing to random fluctuations in the velocity and pressure fields [3]. The intensity of flow-induced noise depends on several fluid dynamic parameters, including the Reynolds number, Mach number, and surface geometry. At higher Reynolds numbers, turbulence increases, leading to stronger pressure fluctuations and higher acoustic emissions. In compressible flows, the additional coupling between density variations and pressure waves further amplifies the noise generation.

Theoretical Approaches to Noise Control

Noise control in fluid mechanics is based on modifying flow structures or disrupting acoustic source mechanisms. Theoretical strategies can be broadly classified into passive and active control methods. Passive control relies on geometric or material modifications to reduce flow instability. This includes streamlining surfaces, adding vortex generators, or applying acoustic damping materials. The theoretical basis of passive control is the reduction of turbulence intensity and suppression of coherent flow structures that contribute to sound generation [4]. Active control, on the other hand, introduces external energy into the system to manipulate the flow dynamically. This can involve synthetic jets, plasma actuators, or feedback-controlled surfaces. Theoretical models of active control are based on real-time modification of boundary conditions to suppress instability growth in the flow.

Computational and Analytical Developments

Theoretical analysis of fluid mechanics has been significantly enhanced by computational fluid dynamics (CFD). CFD solves the governing equations numerically using discretization techniques, such as the finite volume, finite difference, or finite element methods. In aeroacoustics, CFD is often combined with acoustic analogies to predict the sound generation. Turbulence modeling is a key theoretical challenge in CFD. Models such as Reynolds-averaged Navier–Stokes (RANS), large Eddy simulation (LES), and direct numerical simulation (DNS) provide different levels of accuracy and computational costs [5]. LES is widely used in aeroacoustics studies because it resolves the large-scale turbulent structures responsible for dominant noise generation. Theoretical advancements also include reduced-order modeling techniques, which simplify complex flow systems into lower-dimensional representations while preserving their essential physical behavior. These models are particularly useful for real-time noise prediction and control.

Interdisciplinary Nature of Modern Fluid Mechanics

Modern fluid mechanics is inherently interdisciplinary in nature. It integrates principles from acoustics, thermodynamics, structural mechanics, and computational science. Aeroacoustics represents the coupling of fluid dynamics and wave propagation theory. Structural interactions with fluid flow lead to phenomena such as flow-induced vibrations and acoustic resonance. These interactions require coupled mathematical models that combine fluid and structural dynamic equations. Such Multiphysics modeling is essential for designing aircraft, turbines, and high-speed vehicles [6]. Modern theoretical approaches also incorporate data-driven methods. Machine learning models are increasingly used to approximate complex flow behavior and predict noise characteristics based on simulation and experimental datasets.

Significance and Research Motivation

The theoretical study of fluid mechanics, particularly in the context of aeroacoustics and noise control, is driven by practical engineering requirements. Excessive noise generation is a critical issue in transportation, energy, and industrial environments. They affect human health, structural integrity, and system performance. Understanding the theoretical mechanisms underlying noise generation allows engineers to design more efficient systems with reduced acoustic impact. This includes optimizing aerodynamic shapes, improving turbulence control strategies, and developing smart materials for adaptive noise suppression [7]. Fluid mechanics has become a highly advanced field supported by theoretical, computational, and experimental frameworks. Aeroacoustics and flow-induced noise control are key research directions that bridge fluid dynamics and acoustics. Theoretical models, such as the Navier–Stokes equations, acoustic analogies, and turbulence theories, form the backbone of this study. Continuous advancements in computational modeling and data-driven approaches have further expanded our understanding of complex flow-induced sound generation mechanisms.

LITERATURE SURVEY

Recent research in fluid mechanics has shown a strong shift from classical flow analysis to advanced multiphysics problems involving turbulence, acoustics, and data-driven modeling. The literature indicates that modern fluid mechanics is no longer limited to velocity and pressure field predictions but increasingly focuses on secondary phenomena such as noise generation, energy loss mechanisms, and flow instability control.

A significant body of work has highlighted that aeroacoustics has evolved as an independent yet closely related branch of fluid mechanics. The early theoretical foundations established by Lighthill introduced the concept of aerodynamic sound generation through turbulence-induced quadrupole sources. This framework has been extended in later studies to include moving boundary effects and complex geometries using formulations such as Ffowcs Williams–Hawkings (FW-H). Recent literature emphasizes that these models are essential for predicting noise in high-speed flows, jet engines, and rotating machinery.

Contemporary studies have shown that flow-induced noise is strongly associated with turbulent structures, vortex shedding, and boundary layer separation. Researchers have observed that unsteady flow behavior leads to pressure fluctuations that act as primary acoustic sources. Experimental investigations using wind tunnels and advanced measurement techniques, such as particle image velocimetry (PIV), have confirmed the correlation between turbulence intensity and acoustic emissions.

Computational studies have also become dominant. CFD, particularly LES and DNS, are widely used to resolve the turbulent structures responsible for noise generation. The literature indicates that CFD-based aeroacoustic coupling methods have significantly improved prediction accuracy compared to classical analytical models.

Another important research direction identified in recent studies is the development of flow-induced noise reduction techniques for these vehicles. Passive control strategies, such as surface modification, blade serrations, and acoustic liners, have been widely reported. These methods aim to disrupt the coherent vortex structures and reduce the noise radiation efficiency. However, active control methods involving synthetic jets, plasma actuators, and feedback control systems have been increasingly explored for adaptive noise suppression under dynamic flow conditions.

Recent literature has also highlighted the integration of machine learning and artificial intelligence in fluid mechanics. Data-driven models are being developed to predict turbulent flow behavior and acoustic signatures at reduced computational costs. These approaches are particularly useful in real-time applications and optimization problems, where traditional CFD methods are computationally expensive.

Studies have further indicated that aeroacoustics research is expanding beyond aerospace applications to automotive engineering, wind energy systems, HVAC systems, and biomedical devices. This expansion demonstrates the growing importance of noise control for both industrial performance and environmental sustainability.

Despite these advancements, the literature consistently reports several unresolved challenges. The accurate prediction of turbulent flow-acoustic coupling remains computationally expensive, and hybrid models still require validation for complex geometries. Additionally, balancing aerodynamic efficiency with noise reduction remains a key design constraint in engineering systems.

Overall, the literature clearly shows that fluid mechanics is evolving into a more integrated discipline, where aerodynamics, acoustics, computation, and data science converge. Aeroacoustics and flow-induced noise control are central themes in modern research, driving innovation in both theoretical modeling and practical engineering applications.

DISCUSSION

Functional Objectives in Fluid Mechanics

Recent developments in fluid mechanics indicate a transition in the fundamental objectives of the analysis. Earlier approaches primarily focused on determining flow properties, such as velocity, pressure, and continuity fields. In current research trends, the objective has expanded to understanding how fluid behavior affects system-level performance parameters, such as acoustic emission, structural response, and energy efficiency [8]. This shift reflects a broader theoretical integration of fluid dynamics, acoustics, and system optimization principles.

Theoretical Role of Flow Instabilities in Acoustic Generation

From a theoretical standpoint, flow-induced noise is considered a direct outcome of fluid motion instability. When fluid flow becomes unsteady, it generates fluctuating pressure fields that propagate as acoustic disturbances. These instabilities arise owing to shear layer development, flow separation, and vortex formation. The intensity and frequency of the resulting sound depend on the spatial and temporal coherence of these structures. Thus, noise generation is not treated as an independent phenomenon but as a secondary manifestation of momentum fluctuations in the fluid systems.

Coupling Between Fluid Motion and Acoustic Fields

A key theoretical trend in modern fluid mechanics is the recognition of the strong coupling between hydrodynamic and acoustic fields. In this framework, fluid flow is responsible for generating sound and influencing the propagation of acoustic waves through the medium. This interaction becomes more complex in compressible flows, where density variations contribute to wave amplification and propagation behavior [9]. Consequently, fluid systems are increasingly analyzed as coupled dynamic systems rather than isolated flow fields. Table 1 shows the technical developments in fluid mechanics, focusing on aeroacoustics and noise control.

Table 1. Technical developments in fluid mechanics focusing on aeroacoustics and noise control.

S.N.	Area	Technical focus	Outcome
1	Turbulence modeling	LES and DNS-based flow simulation	Better resolution of complex flow structures
2	Aeroacoustics	CFD–acoustic coupling methods	Improved noise prediction accuracy
3	Flow-induced noise	Vortex shedding and pressure fluctuation analysis	Identification of main noise sources
4	Noise control techniques	Passive and active flow control methods	Reduction of aerodynamic noise
5	Data-driven methods	Machine learning in flow prediction	Faster and efficient flow analysis

Nature of Turbulence in Noise Formation

The theoretical understanding of turbulence has evolved from a statistical description to a structural interpretation. Turbulence is viewed as a system of organized coherent structures embedded within chaotic motion. These structures, such as vortices and shear layers, are primary contributors to acoustic energy generation [10]. Theoretical models suggest that noise intensity is strongly influenced by the interaction, breakdown, and evolution of coherent structures rather than by random velocity fluctuations alone.

Theoretical Basis of Flow-Induced Noise Control

Noise control in fluid systems is fundamentally based on the modification of the mechanisms responsible for flow instability. Theoretical strategies can be categorized into two main approaches.

1. Flow stabilization, where the objective is to reduce the formation of unsteady structures responsible for acoustic generation.
2. Flow modification, where the objective is to alter the flow patterns such that the acoustic energy radiation is minimized.

Both approaches rely on influencing the boundary conditions, velocity gradients, or pressure distributions within the flow domain to achieve a reduced acoustic output.

Passive and Active Control Mechanisms

From a theoretical perspective, noise control strategies are divided into passive and active categories based on their energy interaction with the flow system.

Passive mechanisms operate by structural or geometric modification, leading to a natural reduction in flow instabilities without external energy input [11]. These modifications influence the boundary layer behavior and reduce the formation of strong vortical structures.

Active mechanisms introduce external energy into a fluid system to dynamically alter its flow behavior. This approach theoretically allows for the real-time modification of flow instability patterns, thereby enabling the adaptive control of acoustic emissions under varying operating conditions.

Computational Representation of Fluid–Acoustic Systems

Theoretical advancements in fluid mechanics increasingly rely on the computational representation of governing equations. In this context, fluid flow is modeled using discretized forms of conservation laws, whereas the acoustic behavior is represented through derived wave equations. This dual representation allows for the analysis of both the flow field evolution and sound propagation within a unified framework. A major theoretical development is the concept of multi-domain coupling, in which fluid dynamics and acoustic propagation equations are solved simultaneously or sequentially to capture the interaction effects.

Dimensional and Scaling Considerations in Noise Phenomena

Theoretical analysis of fluid-induced noise also involves a dimensional interpretation of the governing parameters. Key dimensionless numbers, such as the Reynolds number and Mach number, play a critical role in determining whether the flow behavior is laminar, turbulent, compressible, or acoustic dominant. These parameters help define the regime in which noise generation mechanisms become significant and influence the scaling of the acoustic intensity with respect to the flow velocity and geometry.

System-Level Interpretation of Fluid Noise Phenomena

Modern theoretical perspectives treat fluid systems as integrated physical environments in which flow dynamics, structural response, and acoustic radiation are interconnected. This system-level interpretation implies that modifying one component of the system inevitably affects the others. Consequently, fluid mechanics is increasingly analyzed using holistic frameworks that consider the mutual interactions between multiple physical domains. From a theoretical standpoint, recent trends indicate that fluid mechanics is moving toward a unified description of flow and acoustic phenomena. Instead of treating noise as a separate post-processing effect, it is now incorporated into the fundamental analysis of fluid behavior. This integrated view supports the development of predictive models capable of simultaneously describing the flow evolution and acoustic response in complex engineering systems.

CONCLUSION

Recent trends in fluid mechanics, particularly in aeroacoustics and flow-induced noise control, highlight a clear transition from traditional empirical approaches to highly integrated, physics-based, and computationally advanced methodologies. The growing use of high-fidelity simulations such as CFD and computational aeroacoustics (CAA), along with fluid–structure interaction (FSI) models, has significantly improved the ability to predict and analyze complex noise generation mechanisms in turbulent flows. Modern research emphasizes understanding the fundamental sources of noise, including turbulence, vortex interactions, and boundary layer instabilities, while simultaneously developing both passive and active control strategies. Innovations such as bio-inspired designs, optimized geometries, porous materials, and active flow control techniques have shown strong potential in reducing aerodynamic noise across applications like aircraft, wind turbines, and automotive systems. Additionally, emerging fields such as urban air mobility and electric vehicles have intensified the need for quieter systems, pushing researchers toward multidisciplinary solutions that combine acoustics, fluid dynamics, and material science. Despite these advancements, challenges remain in accurately modeling complex coupled phenomena and balancing noise reduction with efficiency and cost. Overall, the field is moving toward more predictive, sustainable, and application-oriented solutions, ensuring that future engineering systems are not only efficient but also environmentally and acoustically optimized.

REFERENCES

1. Adibi T, Razavi SE, Ahmed SF, Fardnia K, Qheydarpoor A, Alotaibi H. Coupled fluid–structure–acoustic analysis of flow-induced noise control using an elastic baffle in a micro channel. Energy Sci Eng. 2026;14:2571–2582. doi:10.1002/ese3.70496.
2. Tamaro S, Zamponi R, Schram C. Development of a didactic demonstrator for flow-induced noise mechanisms and mitigation technologies. J Acoust Soc Am. 2022;151(2):898. doi:10.1121/10.0009366. PMID:35232121.
3. de Jong A, Bijl H. Corner-type plasma actuators for cavity flow-induced noise control. AIAA J. 2014;52(1):33–42. doi:10.2514/1.J051815.
4. Schoder S. Aeroacoustics: theory and methods for analyzing flow-induced sound generation of technical and biological applications [preprint]. 2024. arXiv:2401.11300. doi:10.48550/arXiv.2401.11300.
5. Carpenter PW, Smith C. The aeroacoustics and aerodynamics of high-speed Coanda devices, Part 2: Effects of modifications for flow control and noise reduction. J Sound Vib. 1997;208(5):803–822. doi:10.1006/jsvi.1997.1203.
6. Yuan D, Feng H, Di G, Yang Y, Fan D. Deep reinforcement learning for flow-induced noise control: Multi-objective optimization of acoustic suppression and drag reduction. Phys Fluids. 2026;38(2). doi:10.1063/5.0310175.

7. Siyang ZH, Xun HU. A review of aeroacoustics and flow-induced noise for beginners. Acta Aerodyn Sin. 2018;36(3):363–371.
8. Schulz J, Neise W, Möser M. Active noise control in axial turbomachines by flow induced secondary sources. 8th AIAA/CEAS Aeroacoustics Conference & Exhibit, Breckenridge, CO, USA, 2002 Jun 17–19. doi:10.2514/6.2002-2493.
9. Qin Q, Lu Y, Wu K, Liu Y, Shang D. Numerical and experimental investigation of flow-induced noise control on a hydrofoil using streamwise electromagnetic force. Phys Fluids. 2026;38(1). doi:10.1063/5.0309558.
10. Zhao YH, Ding J, Weng PF, Zhou Q, Dong YH, Yang XQ. Method of aerodynamic noise source identification for cylinder flows. J Fluid Mech. 2025;1012:A13. doi:10.1017/jfm.2025.389.
11. Wu Y, Ji G, Zhang P, Yang X, Ding J. Numerical study of flow and noise control mechanism of shape-optimized series cylinder. J Aerosp Eng. 2024;37(6):04024080. doi:10.1061/JAEEEZ.ASENG-5625.

