
EXPLORING THE PRINCIPLES AND INNOVATIONS IN THEORY OF FLIGHT FROM CLASSICAL AERODYNAMICS TO MODERN APPLICATIONS

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ABSTRACT

This qualitative research study examined how foundational aerodynamic concepts and emerging innovations collectively shape aviation today. The study focused on three key areas: the role of classical aerodynamics, the innovations that address its limitations, and the contributions of modern applications to aviation technology and practice. Findings revealed that classical principles such as Newton's laws of motion, Bernoulli's principle, and early theories of lift and drag provided the scientific groundwork for understanding flight mechanics. These principles remain relevant, serving as a continuous reference for modern computational models and aerodynamic simulations. To overcome the constraints of classical theories, innovations such as Computational Fluid Dynamics (CFD), nonlinear aerodynamics, supersonic and hypersonic models, biomimetic designs, and AI integration have expanded the scope of flight theory, making it more adaptive and precise. Furthermore, modern applications of flight theory were found to play a critical role in enhancing efficiency, safety, and sustainability in aviation. These applications extend to advanced aircraft designs, autonomous flight systems, UAVs, urban air mobility, and next-generation propulsion technologies. Collectively, they demonstrate how aerodynamics evolves by building on classical foundations while embracing technological advancements. The study recommends strengthening the teaching of classical aerodynamics, expanding research in emerging innovations, and integrating modern applications into aviation practice. Finally, it proposes the development of a comprehensive book titled "Flight Theory" to serve as a lasting reference for students, researchers, and practitioners, bridging traditional principles with modern advancements to inspire future innovations in the field of aviation.

Keywords: *Classical aerodynamics, flight theory, computational fluid dynamics (CFD), aviation innovations, modern applications*

INTRODUCTION

The study explored the principles and innovations in the theory of flight, tracing its development from classical aerodynamics to its modern applications. Flight, once regarded as an unattainable dream, became a reality through centuries of experimentation, observation, and scientific discovery. Early theorists laid the groundwork for understanding lift, drag, thrust, and weight, while subsequent breakthroughs in fluid dynamics and structural engineering refined these principles into practical applications. With the rise of modern technology, aerodynamics transcended its classical foundation, allowing for advanced aircraft, space vehicles, and unmanned aerial systems to be developed. This study emphasized the historical evolution of flight theories, the transition of aerodynamic principles across different eras, and the technological innovations that reshaped modern aviation and aerospace engineering.

The research was qualitative in nature, relying on thematic analysis of historical documents, scholarly works, and modern aviation studies. By analyzing the transformation of flight theories, the study provided insights into how traditional concepts merged with contemporary innovations. It further highlighted the continuity of classical aerodynamics as a foundation while exploring how modern computational fluid dynamics, material science, and digital modeling advanced the theory of flight. The exploration was grounded in a scholarly appreciation of both the past and present, underscoring how innovations built upon classical understanding to address current and future aviation challenges.

The scope of the study was limited to the theoretical and conceptual progression of flight principles rather than their technical engineering applications. It covered classical aerodynamics from its early theoretical foundations through to the significant modern developments that defined present-day aviation practices. The research examined innovations such as computational modeling, sustainable aviation technologies, and unmanned aerial systems, but it did not venture into the actual engineering design processes or quantitative performance measurements of aircraft.

The study was delimited to secondary sources such as scholarly articles, historical records, books, and academic publications. Primary experimental testing, simulations, or technical measurements were not conducted, as the intent was to provide a qualitative exploration of theoretical and conceptual frameworks. Furthermore, the study focused on aviation and aerospace contexts, leaving out other aerodynamics-related applications such as automotive engineering, sports science, or marine dynamics. By setting these boundaries, the research maintained a clear focus on the theoretical evolution of flight and its implications for modern aviation.

Statement of the Problem

This study aims to explore the evolving principles and innovations in the theory of flight, tracing its development from classical aerodynamics to modern applications, and to examine how these advancements influence contemporary aviation practices and technologies.

Specifically, it sought to answer the following questions:

1. How have the foundational principles of classical aerodynamics shaped the development of modern flight theory?
2. What key innovations in flight theory have emerged to address the limitations of classical approaches?
3. In what ways do modern applications of flight theory contribute to advancements in aviation technology and practice?

Review of Related Literature

Wu et al. (2023) present a conceptual design and optimization study for a distributed electric-propulsion general-aviation aircraft. The paper models propellers using actuator-disk theory and the lifting surface using a vortex-lattice method, then uses global optimization to select propulsor layout and wing characteristics that maximize effective lift-to-drag performance and range while respecting takeoff/landing constraints. Their CFD validation shows DEP configurations can improve cruise efficiency and change stall and takeoff characteristics —

insights that directly connect classical aerodynamic tradeoffs (lift, drag, stall) to modern electric-propulsion system layout and aircraft-level design.

Santos et al. (2024) report wind-tunnel experiments on a small fixed-wing UAV coated with bio-inspired microfiber films (gecko/shark-skin inspired). They measured static and dynamic-stall behavior and showed substantial drag reductions (up to ~25% in some high-lift conditions) and improved control surface authority in certain regimes. This experimental work links boundary-layer manipulation and passive flow control techniques (classical viscous flow ideas) to practical modern UAV performance improvements and energy-savings strategies.

İnan & Ceylan (2024) use CFD to analyze two-UAV close-formation (swarm) interactions and identify positions that maximize lift-to-drag advantage for the trailing vehicle. Their results quantify classical wake and vortex interaction effects (upwash/downwash) for small fixed-wing UAVs and show possible aerodynamic efficiency gains (~11–12% in optimal positions). This study demonstrates how long-standing aerodynamic principles (wake induction, upwash benefits) are being applied and quantified for modern swarm/formation flight concepts and autonomy-enabled operations.

Shams Taleghani & Torabi's editorial (Frontiers, 2025) surveys recent developments across experimental aerodynamics, CFD, flow control, AI/ML integration, and materials/manufacturing advances. It highlights how classical aerodynamic tools (wind tunnels, PIV, vortex theory) are being augmented by machine learning, advanced sensors, adaptive materials, and new actuation/flow-control strategies — a concise roadmap connecting foundational theory of flight to emergent technologies for efficiency, noise reduction, and new flight modes. This piece is a useful high-level bridge between theory and contemporary innovations.

Barri et al. (2025) introduce additively manufactured rotational bistable elements for chordwise morphing of wings and validate the concept with FEA and wind-tunnel tests. Their multistable rotational mechanisms enable large, reversible camber changes without continuous actuation power, offering an energy-efficient path to the adaptive wing concepts that aerodynamicists have theorized for decades. The work is an excellent example of combining aeroelastic understanding, structural mechanics, and modern manufacturing to realize morphing-wing concepts that map directly back to classical lift/shape relationships but with new, low-energy practical implementations.

Notable events in the history of aerodynamics laid the groundwork for contemporary flight. The first ideas about flight were mostly conjectural and based on speculation rather than hard data. Daniel Bernoulli and Sir Isaac Newton were pivotal figures in this process. Bernoulli's principle, first stated in the 18th century, provided a framework for understanding the possibility of lift by illustrating the link between fluid velocity and pressure. A foundational idea of classical aerodynamics, he postulated that lower pressure would result from faster-moving air above a wing. I am writing in response (To, et al., 2022).

Newton's work offered a new angle, especially his laws of motion. When he pressed down on the air with his wing, he highlighted the reactive forces at work. The ability to explain lift in terms of forces, as opposed to merely pressure differences, relies on this comprehension.

By taking a fresh approach to flying around the turn of the twentieth century, the Wright Brothers were able to put these theoretical concepts into practice. They proved in 1903 that controlled flying was possible by applying the concepts set out by Bernoulli and Newton. In order to bridge the gap between theory and experience, they came up with the idea of wing form and angle of attack to increase lift.

It is critical to investigate the basic ideas of classical aerodynamics to build upon these historical notions. These principles lay the groundwork for future developments in aeronautics and provide light on the current state of flying. It is possible to have a better grasp of this complicated phenomenon by looking at the flaws in the current theories, especially those that attempt to explain lift.

Two forces—lift and drag—are central to classical aerodynamics' guiding principles. Aircraft experience lift, which allows them to rise off the ground, and drag, which is the resistance that an item meets when flying. In order to construct efficient aircraft and improve their performance, it is vital to understand these forces.

These primary ideas laid the groundwork for subsequent developments in the field of aerodynamic theory. Improvements in aviation efficiency and flight capabilities are possible because scientists and engineers are constantly working to better comprehend these forces.

Recent developments in the theory of aerodynamics have revolutionized our comprehension and application of flight design. Computational Fluid Dynamics (CFD) has emerged as a paradigm shifter, allowing for the simulation of airflows around objects with unprecedented power. In contrast to more conventional approaches, computational fluid dynamics (CFD) enables engineers to view and evaluate intricate airflow patterns in real-time, resulting in more effective designs. Using this technique, drones and airplanes can have their forms optimized to improve their performance in different environments.

An additional important tool in this development has been the wind tunnel. These centers allow for the controlled testing of models under a variety of situations and speeds. Wind tunnel experiments assist in boosting lift and decreasing drag by informing design decisions. Wind tunnels are still very useful for checking the theoretical conclusions with real-world conditions, even if computational fluid dynamics (CFD) provides more precise simulations.

Advances in the field of materials science have recently allowed for even greater improvements in aerodynamic capabilities. Reduced weight and improved structural integrity are two benefits of using lightweight, high-strength materials. Thanks to this development, more aerodynamic designs are now possible, which improves performance by reducing drag. By way of illustration, composite materials allow for the fabrication of hitherto unimaginable shapes, thus expanding the capabilities of unmanned aerial vehicles. According to Aljuhaishi et al. (2024).

These advancements laid the groundwork for contemporary aerodynamic applications, which employ classical theory's concepts in complex ways to fulfill the needs of the aviation and drone sectors today.

Commercial aviation, military operations, and space exploration are just a few of the many modern-day fields that have benefited greatly from aerodynamics' use. Modern commercial

airplanes are lighter and more fuel-efficient thanks to developments in aerodynamic design. Airlines may save money on fuel and cut down on carbon emissions thanks to innovations like winglets and sleek fuselage forms, which minimize drag. Not only do these upgrades save the planet, but they also bring down the price of flying for regular people.

Developing cutting-edge fighter jets and UAVs relies heavily on aerodynamics in the military sector. Quickness, agility, and covertness are the focuses here. To build planes that can fly fast and nimble enough to avoid radar, designers use modern aerodynamic principles. This makes it possible to perform military operations more efficiently, which improves the safety of the country.

Aerodynamic principles have also been the basis for some quite astonishing developments in space exploration. Spacecraft landing safely requires exact aerodynamic control as they re-enter Earth's atmosphere, which is fraught with harsh conditions. Missions to the International Space Station and beyond are becoming more reliable as engineers create novel designs and materials that can endure high pressure and temperatures (Kulikov, 2019).

These constant advancements demonstrate the need for ongoing aerodynamics research. In the years to come, aviation and space travel may see significant changes brought about by emerging trends such as hypersonic travel, sustainable aircraft, and the incorporation of AI into flight design. Future generations of aerodynamics researchers will benefit greatly from a better understanding of these impending developments.

Exciting new developments in sustainable aviation, AI, and hypersonic flight are on the horizon as a result of current and future trends in aerodynamic research. Technologies in sustainable aviation aim to lessen the negative effects of flying on the environment. Modern airplanes are more fuel-efficient thanks to developments in biofuels, electric power systems, and lightweight construction materials. Greener practices and reduced carbon emissions are the goals of these innovations in the aviation business.

Aerodynamic design is another area where AI is having a major influence. Aircraft that use less power while still performing well are the result of optimizations made possible by AI algorithms that sift through mountains of data. With this technology, engineers can rapidly simulate multiple designs to find the best solutions for varied flight situations. Using AI streamlines the design process and paves the way for more intelligent planes that can instantly adjust to new conditions.

The study of flying at speeds higher than five times the speed of sound, known as hypersonic flight, is an emerging field in aerodynamics. Flying across the world could be a thing of the past with this new technology. The goal of efficient, fast international travel is getting closer to reality as scientists investigate novel materials and designs that can endure high pressure and temperature.

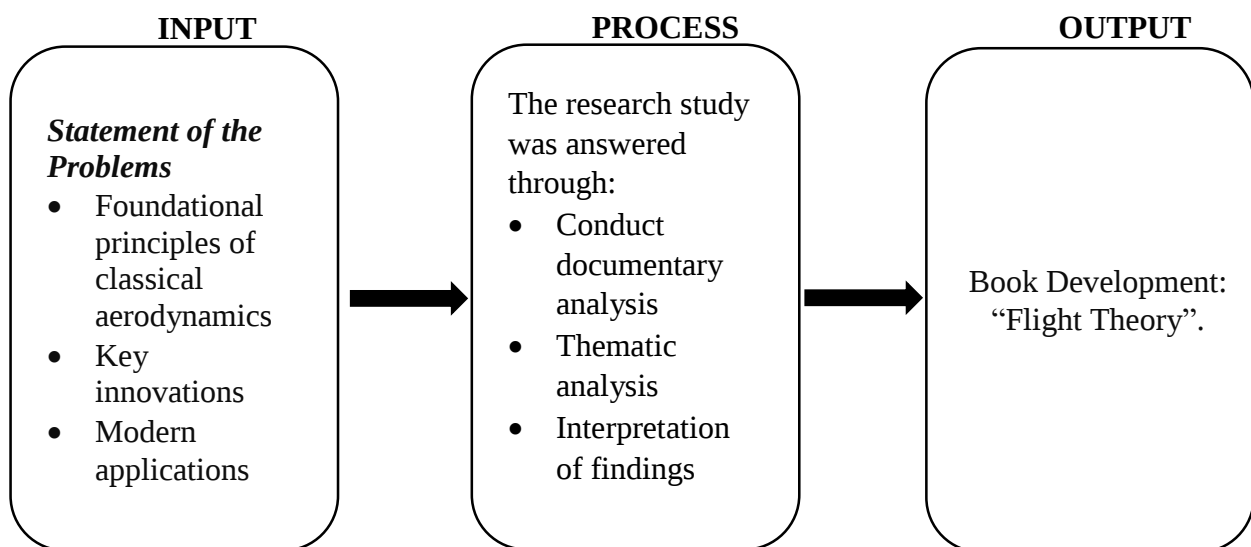
In sum, these tendencies bode well for aerodynamics' future, as they will likely lead to improvements in aviation's performance and sustainability. A more efficient and ecologically friendly age of flight is on the horizon, thanks to researchers who are embracing new technology and novel ideas.

Theoretical Framework

One theoretical framework that guided the study was *Bernoulli's Principle*, proposed by Daniel Bernoulli in 1738. This principle, originally formulated in Hydrodynamica, explained that an increase in the velocity of a fluid resulted in a decrease in pressure. Applied to aerodynamics, it provided an early scientific basis for understanding lift, as the faster airflow over the curved upper surface of an aircraft wing created lower pressure compared to the slower airflow beneath. This pressure difference contributed to the upward force that allowed heavier-than-air machines to rise and sustain flight. The principle served as a cornerstone in classical aerodynamics and shaped the fundamental concepts of flight during its early development.

In the context of the study, Bernoulli's Principle was viewed as a foundation upon which modern innovations in flight theory had been built. While it explained part of the mechanism of lift, subsequent research and applications revealed that a more complex interaction of forces, including Newton's Third Law and circulation theory, further refined the understanding of flight. The framework illustrated how classical theories had been adapted and expanded to align with advancements in technology, such as computational fluid dynamics and modern aircraft design. By examining this progression, the research emphasized the significance of historical principles while acknowledging their evolution into contemporary applications in aeronautics.

Conceptual Framework



In this study, the *Inputs* are the research questions that guide the inquiry: (1) How have the foundational principles of classical aerodynamics shaped the development of modern flight theory? (2) What key innovations in flight theory have emerged to address the limitations of classical approaches? and (3) In what ways do modern applications of flight theory contribute to advancements in aviation technology and practice? These questions serve as the foundation of the investigation, setting the direction for the exploration of both historical and contemporary perspectives in flight theory.

The **Process** involves the qualitative research approach undertaken to address these inputs. This includes a comprehensive review of literature on both classical aerodynamics and modern flight theory, followed by a thematic analysis to identify key principles, patterns, and innovations. Comparative examination is then carried out to highlight the differences and continuities between traditional and modern approaches, after which findings are synthesized to provide a deeper understanding of the evolution of flight theory.

The **Output** of this research is the development of the book titled “*Flight Theory*.” This book serves as the culmination of the study, presenting a coherent and comprehensive discussion that bridges foundational theories with modern innovations, while also illustrating their impact on aviation technology and practice.

METHODOLOGY

The study utilized a qualitative research design through documentary analysis as the sole method for data collection and interpretation. This approach was chosen because it allowed the researcher to examine historical and contemporary sources on the theory of flight, from classical aerodynamics to modern applications. Relevant materials such as textbooks, academic journals, technical reports, historical manuscripts, and credible online publications were gathered and reviewed based on their authenticity, credibility, and relevance to the research topic.

The process of analysis involved identifying, collecting, and screening documents, followed by categorizing them according to major themes, including classical principles, transitional developments, and modern innovations in flight. A qualitative content analysis approach was then applied to uncover recurring patterns, significant concepts, and shifts in the interpretation of aerodynamic principles. Special attention was given to how foundational theories like Bernoulli’s principle and Newtonian mechanics were adapted into modern contexts such as computational fluid dynamics and advanced propulsion technologies.

To ensure trustworthiness, findings were triangulated by cross-referencing information across multiple sources, and scholarly consensus was used to validate interpretations. Reflective notes were also maintained to document analytical decisions. Through this method, the study produced a coherent understanding of how flight theory evolved over time, linking classical foundations with modern innovations in aviation.

RESULTS AND DISCUSSION

Based on the findings, here is how the research questions answered:

SOP 1. How have the foundational principles of classical aerodynamics shaped the development of modern flight theory?

The foundational principles of classical aerodynamics have provided the essential framework upon which modern flight theory has been built. Early concepts such as Newton’s laws of motion, Bernoulli’s principle, and the development of lift and drag theories laid the groundwork for understanding how forces interact with aircraft in motion. These principles clarified the relationship between air pressure, velocity, and wing shape, leading to the scientific explanation of flight that has remained fundamental despite evolving technological

innovations. By establishing the basic laws of airflow, pressure differentials, and stability, classical aerodynamics gave aviation pioneers the tools to conceptualize and design the first successful flying machines.

Moreover, these classical theories have continued to influence and shape advancements in contemporary aeronautics. Modern flight theory, while increasingly supported by computational models and advanced fluid dynamics, still relies on the foundational equations and assumptions derived from classical studies. For instance, the Navier-Stokes equations, which stem from early fluid dynamics research, continue to guide aerodynamic simulations in modern aircraft design. Similarly, the classical understanding of lift-to-drag ratios remains central to optimizing performance, efficiency, and safety in both subsonic and supersonic flight. Without these principles, innovations such as jet propulsion, high-speed aircraft, and even spacecraft aerodynamics would not have had a reliable scientific basis.

In essence, classical aerodynamics has not only provided the conceptual starting point but also a continuing reference for innovation. As engineers and scientists push the boundaries of flight through technologies like unmanned aerial vehicles, computational fluid dynamics, and hypersonic systems, they consistently refine and expand on the same principles that defined early aeronautical science. The persistence of these foundational concepts highlights their enduring relevance, demonstrating that modern flight theory is less a rejection of the past than a sophisticated extension of classical aerodynamic wisdom.

SOP 2. What key innovations in flight theory have emerged to address the limitations of classical approaches?

- ***Computational Fluid Dynamics (CFD)***: Enabled detailed simulations of airflow, turbulence, and aerodynamic behavior beyond what analytical models could handle.
- ***Boundary Layer Theory Extensions***: Improved understanding of laminar-to-turbulent transition, drag reduction, and flow separation control.
- ***Nonlinear Aerodynamics***: Addressed high-angle-of-attack flight, vortex dynamics, and stall recovery beyond the linear assumptions of classical lift and drag.
- ***Supersonic and Hypersonic Aerodynamics***: Developed theories and models for shock waves, compressibility effects, and thermal stresses in high-speed flight.
- ***Advanced Wing Designs (e.g., Winglets, Blended Wing Bodies)***: Innovations that reduce induced drag and improve fuel efficiency, challenging traditional straight-wing concepts.
- ***Unsteady Aerodynamics***: Provided insights into dynamic stall, oscillating airfoils, and rapidly changing flow conditions relevant for modern aircraft and rotorcraft.
- ***Fluid-Structure Interaction (Aeroelasticity)***: Integrated theory to address flutter, vibration, and structural deformation under aerodynamic loads.
- ***Biomimetic Aerodynamics***: Drew inspiration from birds and insects to innovate flapping wings, morphing structures, and efficient lift generation.
- ***Active Flow Control Techniques***: Applied technologies like plasma actuators and synthetic jets to manage airflow and optimize aerodynamic performance.

- **Integration of AI and Machine Learning:** Emerging approaches in flight dynamics modeling, predictive maintenance, and adaptive flight control that overcome analytical limits of classical theory.

SOP 3. In what ways do modern applications of flight theory contribute to advancements in aviation technology and practice?

Modern applications of flight theory significantly contribute to advancements in aviation technology by enabling the development of more efficient, safer, and environmentally sustainable aircraft designs. By integrating classical aerodynamic principles with computational fluid dynamics (CFD), engineers are able to simulate airflow with high precision, reducing the need for extensive wind tunnel testing. This integration not only accelerates the design process but also allows for innovations such as lighter composite materials, optimized wing shapes, and fuel-efficient engines that reduce operational costs and carbon emissions.

Moreover, the application of modern flight theory extends into digital technologies such as artificial intelligence, machine learning, and automation in aviation practice. These innovations are applied in areas like autonomous flight control systems, predictive maintenance, and advanced avionics that enhance both safety and operational efficiency. For instance, flight management systems now rely on refined aerodynamic modeling to optimize routes, minimize turbulence, and improve passenger comfort.

Another important contribution of modern applications is their role in expanding the boundaries of flight beyond traditional aircraft. Unmanned aerial vehicles (UAVs), drones, and emerging concepts in urban air mobility (UAM) rely heavily on updated flight theories to ensure stability, maneuverability, and safety in diverse environments. Similarly, the exploration of supersonic and hypersonic travel has been made possible through the application of advanced theories of aerodynamics and propulsion. These advancements demonstrate how modern flight theory serves as the foundation for innovations that reshape the future of aviation.

In practice, these contributions have transformed aviation from a conventional mode of transportation into a dynamic field that continuously adapts to global challenges and opportunities. By applying modern interpretations of flight theory, the aviation industry achieves higher standards of efficiency, safety, and sustainability while paving the way for future innovations such as electric and hybrid aircraft, space tourism, and next-generation air mobility solutions.

SUMMARY

The findings revealed that the foundational principles of classical aerodynamics have played a crucial role in shaping the development of modern flight theory. Early concepts such as Newton's laws of motion, Bernoulli's principle, and the theories of lift and drag provided the scientific framework for understanding flight. These principles established the relationships between airflow, pressure, and wing shape, enabling aviation pioneers to design the first flying machines. Even today, modern aeronautics continues to rely on these classical foundations, as seen in the enduring relevance of the Navier-Stokes equations and lift-to-drag ratios. Rather

than being discarded, classical aerodynamic theories serve as a continuous reference that modern innovations refine and expand.

To address the limitations of classical approaches, several key innovations in flight theory have emerged. Computational Fluid Dynamics (CFD) has enabled highly detailed airflow simulations, while boundary layer theory extensions and nonlinear aerodynamics have improved understanding of turbulence, stall, and vortex dynamics. Advancements in supersonic and hypersonic aerodynamics addressed the complexities of shock waves and thermal stresses in high-speed flight. New aerodynamic concepts such as winglets, blended wing bodies, and unsteady flow analysis have also transformed aircraft design. Furthermore, modern innovations include aeroelasticity studies, biomimetic inspirations from nature, active flow control techniques, and the integration of artificial intelligence for predictive and adaptive flight modeling. These breakthroughs collectively expanded flight theory beyond the limitations of classical assumptions.

Modern applications of flight theory have significantly advanced aviation technology and practice. By combining classical principles with computational models, engineers are able to design safer, more efficient, and environmentally sustainable aircraft. Innovations such as optimized wing designs, lightweight composites, and fuel-efficient engines have reduced costs and emissions while improving performance. Additionally, the integration of artificial intelligence and automation has enhanced flight management, predictive maintenance, and autonomous operations, contributing to safety and operational reliability. Flight theory applications also extend to UAVs, drones, and urban air mobility systems, supporting stability and maneuverability in diverse environments. Moreover, supersonic and hypersonic travel, as well as the potential for electric and hybrid aircraft, space tourism, and next-generation air mobility, highlight how modern flight theory continues to drive transformative advancements in aviation.

CONCLUSION

- Classical aerodynamics remains the foundation of modern flight, with principles like Newton's laws and Bernoulli's principle still guiding aircraft design and performance. These early theories provided the framework that continues to support innovations in fluid dynamics and aeronautics today.
- Innovations such as CFD, nonlinear aerodynamics, and advanced wing designs have addressed the limits of classical theory. By integrating biomimicry, active flow control, and AI, modern flight theory has become more adaptive, efficient, and capable of handling complex challenges.
- Modern applications merge classical principles with advanced technology to improve safety, efficiency, and sustainability. From UAVs and urban air mobility to hypersonic travel, these applications show how flight theory continues to expand aviation's possibilities.

RECOMMENDATION

Based on the findings and conclusion of the study, the following recommendations are suggested:

1. It is recommended that aviation educators and researchers continue to emphasize the study of classical aerodynamics as a core component of flight training and research. By strengthening the understanding of these foundational principles, future engineers and pilots can better appreciate how modern advancements are rooted in timeless aerodynamic laws.
2. To further advance innovations in flight theory, it is recommended that institutions invest in research on emerging aerodynamic technologies such as CFD, biomimetic designs, and AI-driven flight modeling. Collaborative efforts between academia, industry, and government can accelerate breakthroughs that address complex aerodynamic challenges and enhance practical applications.
3. It is recommended that aviation practitioners integrate modern applications of flight theory into industry practices by adopting sustainable designs, digital technologies, and new air mobility concepts. Emphasizing these applications can lead to safer, more efficient, and environmentally responsible aviation systems.
4. Finally, as a long-term initiative, it is recommended to develop a comprehensive book titled “*Flight Theory*” that bridges classical principles and modern innovations. This resource would serve as a valuable reference for students, researchers, and industry professionals, ensuring that knowledge of aerodynamics continues to evolve while remaining accessible to future generations.

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