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Current study on active flow control and passive flow control

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Abstract. Flow control is a very important research direction in the field of fluid dynamics and one of the important research difficulties in the field of aerospace in the 21st century. This study aims to explore the principles and applications of active flow control and passive flow control, and analyze their practical applications in different fields. By conducting a literature review, this study collected and organized relevant literature and papers related to active flow control and passive flow control, and conducted a comprehensive summary and comparison. The research results indicate that both active flow control and passive flow control are of great significance and can improve efficiency or cost-effectiveness through different methods. The development process of active flow control has undergone evolution, and its basic principle is introduced by classifying different methods and technologies, such as bio-inspired mechanics regulation and jet lag, and illustrating their application principles with examples. Passive control methods require additional mechanical structures, such as ribbing, grooving, etc., in the boundary layer. The active control method requires energy input, and the flow control is achieved by controlling the energy input. By understanding and researching the technologies and methods of active flow control and passive flow control, it can provide reference and reference for researchers and engineers in related fields, and promote the development and application of flow control technology.

Keywords: Active flow control, passive flow control, fluid mechanics, engineering application

1. Introduction

Active flow control and passive flow control are two important directions for studying flow behavior. By controlling and regulating the fluid flow process, efficient and controlled flow in different areas can be achieved [1]. This study aims to explore the principles and applications of active flow control and passive flow control, and analyze their application in practical scenarios.

In active flow control, the fluid flow process is controlled by introducing an external active regulation mechanism. The origin of active flow control can be traced back to a long time, when people began to pay attention to how to influence the flow behavior of fluids through external means. With the advancement of science and technology, researchers have continuously proposed innovative ideas and methods, and developed various active flow control technologies [2]. The basic principle of active flow control is to control the direction, speed and stability of fluid flow by adjusting parameters such as fluid velocity, pressure, and temperature. The purpose of active flow control is to achieve precise control of fluid flow behavior to meet specific needs [3].

In active flow control, classification can be made according to the different control methods and control methods. A common way to control active flow is to use the mechanical properties of fluids to achieve control [4]. For example, controlling the behavior of flow by changing the speed and direction of the fluid. Flow control can also be achieved using the chemistry of the fluid. For example, in the preparation of durable scrubbing materials, the rheological properties of fluids are regulated by adjusting the concentration and pH of the polymer in the fluid [5]. In addition, active flow control can take advantage of the thermal properties of the fluid to control flow behavior. For example, in a cooling system, the speed and direction of flow are controlled by controlling the temperature of the fluid. In active flow control, there are also some special technologies and methods [6]. A common technique is fluid dynamics regulation, which controls fluid flow behavior by changing the flow direction and flow rate of the fluid. One of the important methods is injection technology to change the speed and direction of the fluid by spraying it, thereby achieving control of the flow behavior [7]. For example, in jet thrusters, thrust adjustment of the control body can be achieved by adjusting the speed and direction of the jet fluid [8]. In addition, there are other methods related to hydrodynamic adjustment techniques, such as conformal coating technology.

Passive flow control has different principles and methods than active flow control. Passive flow control refers to the control of fluid flow behavior by designing suitable flow structures or fluid materials [9]. Passive flow control does not require external energy inputs or control mechanisms, but rather directs the flow of fluids by designing properties such as the shape, texture and surface coating of materials. The advantages of passive flow control are simple, reliable, low-cost, and suitable for many practical applications.

In summary, active flow control and passive flow control are two important directions for studying flow behavior [10]. This research aims to explore the principles and applications of active flow control and passive flow control, and analyze their practical application in different fields. By understanding and researching the technologies and methods of active flow control and passive flow control, it can provide reference and reference for researchers and engineers in related fields, and promote the development and application of flow control technology [11].

2. The usage time of flow control

Flow control is a widely used technology that is used in a wide range of fields, from aerospace to the automotive industry to disciplines such as hydraulics and climate simulation. The main purpose of flow control is to change the flow characteristics of the medium by controlling the movement of the fluid to achieve the effect of specific requirements. Active flow control and passive flow control are the two main research directions in flow control.

The concept of active flow control dates back to the 50s of the 20th century, when scientists began exploring ways to alter the movement of fluids through external intervention. This study will introduce the historical evolution, rationale and purpose of active flow control. With active flow control, the movement of the fluid can be altered by applying an external force or intervention. This control method can make the fluid flow more efficient, thereby improving the performance and efficiency of the system. For example, in the design of aircraft, through the control of air flow, the lift of the aircraft can be effectively improved and the drag can be reduced, so as to make the performance of the aircraft more excellent and improve the cost performance of the aircraft [12].

Unlike active flow control, passive flow control changes the movement of a fluid by using special materials or design structures. This study will introduce passive flow control. Compared to active flow control, passive flow control does not require additional energy input, but rather enables fluid control by designing suitable materials or structures [13]. For example, in wind tunnel testing, the flow and separation of fluids on the model surface can be changed by setting special textures or ornaments on the surface of the model, thereby improving aerodynamic performance [14].

In the classification of active flow control, there are many different ways and methods. This study will further refine the classification of active flow control. For example, flow control by applying force or moment to a fluid is called mechanically regulated flow control [15]. Jet flow control is to control the movement of fluids by injecting fluids or gases. These methods have a wide range of applications in aerospace, energy, and environmental engineering. For example, in the lift control of the aircraft, the

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movement of the fluid can be changed by injecting gas to achieve the purpose of improving the control performance [16].

There are also many different methods and techniques for passive flow control. These methods and techniques will be introduced in this study. Passive flow control often uses the natural properties and material properties of the fluid to influence the movement of the fluid through special structural design. For example, the flow and velocity of the fluid is changed by setting the channels and valves through which the fluid passes. This method has a wide range of applications in flow control and automation control of pipeline systems [17].

In practical applications, active flow control and passive flow control are often combined to achieve more efficient and optimized results. For example, in the field of wind power generation, the maximum use of wind energy can be achieved by actively controlling the blade angle and shape of wind turbines and by passively controlling the surface texture of wind turbines. In summary, flow control plays an important role in various fields. Through active flow control and passive flow control, the motion characteristics of the fluid can be changed, improving the performance and efficiency of the system. Active flow control achieves goals through external intervention, while passive flow control achieves goals through material and structural design. Together, they enable more efficient and optimized flow control. In the future, flow control technology will continue to develop and apply, and provide more possibilities and challenges for researchers and engineers in various fields.

3. Active flow control

Active flow control and passive flow control are two important research directions in the field of fluid mechanics. Active flow control regulates the motion state of the flow field through external intervention, which mainly relies on the input of external energy. Passive flow control is to change the characteristics of the flow by modifying the geometry of the flow body or adding a specific flow field structure, which is mainly achieved by using the material, shape and texture of the passive structure.

The research on active flow control dates back to the 30s of the 20th century, mainly due to the focus on fluid mechanical control problems. In the past few decades, with the gradual deepening of people's research on flow behavior and control methods, active flow control has been widely used. The basic principle of active flow control is to change the nature of the flow by applying external excitation, such as the traditional addition of some external force or pressure excitation to the flow field, so as to achieve the purpose of control. This control method is widely used in aerospace, extreme physics, environmental science and engineering [18].

In contrast, the field of application of passive flow control is relatively new, originating in the 80s of the 20th century. The basic principle of passive flow control is to affect the flow by changing the shape and structure of the flow body, so as to achieve the purpose of flow control. There are two main types of passive flow control methods: one is to increase the geometric complexity of the flow body, and use separation and vortex effects to change the flow state; The other type is to change the surface properties of the flow body, using the characteristics of passive structures such as texture and coating to change the properties of the flow. The main purpose of passive flow control is to reduce fluid resistance, improve fluid heat transfer, etc., and is suitable for ships, automobiles, aircraft and pipelines [19].

Both active flow control and passive flow control play an important role in different application areas. In some special environments, active flow control and passive flow control can cooperate with each other to achieve better control effects. For example, in aircraft design, drag can be reduced by using active controls, while passive structures can be used to change the flow field to achieve better fluid control. This combination can improve the performance of aircraft and reduce energy consumption in the aerospace field [20].

In short, active flow control and passive flow control are two important research directions in the field of fluid mechanics. Active flow control regulates the motion state of the flow field through external energy intervention, while passive flow control changes the characteristics of the flow by changing the shape and structure of the flow body. Both control methods are widely used in aerospace, extreme physics, environmental science and engineering. Through the combination of active flow control and

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passive flow control, better fluid control can be achieved, equipment performance and energy consumption can be reduced. In the future, with the deepening of research and continuous improvement of technology, the application prospects of active flow control and passive flow control in various fields will be broader.

4. Examples and principles of active flow control

Active flow control is a method of using external forces or energy to change the behavior of fluid dynamics. In active flow control, there are a variety of ways and methods that can be classified and applied. This chapter will refine the classification of active flow control and illustrate its principles and applications.

An active flow control method is based on body mechanics. This method realizes the control of fluid flow by changing the mechanical properties of the fluid, such as flow rate, flow direction and flow structure. Body mechanics adjustment mainly involves inserting some resistance elements or devices into the fluid to change the flow state of the fluid by changing the position, shape or number of resistance elements. For example, by installing slender obstacles in the pipeline, the speed and direction of the flow field can be controlled, enabling precise control of fluid flow. This method has been widely used in the field of aviation, such as high-lift devices for aircraft wingtips. By adjusting the position and shape of the device, the control of aircraft lift and drag can be achieved [21].

Another way of active flow control is jet flow. In this way, the movement state of the fluid flow is changed by spraying substances such as accelerators or particulates to achieve fluid flow control. Jet flow technology has a wide range of applications in aircraft wake control and traffic flow control. For example, an aircraft will produce a large number of wakes during takeoff and landing, and through the jet wake manipulation system, the speed and direction of the wake can be changed, thereby reducing the impact on subsequent aircraft. In addition, in urban traffic flows, jet flow technology can also be used to reduce congestion and improve traffic efficiency. By setting up a jet device on the road, it is possible to control the flow and speed of the traffic flow, thereby optimizing the traffic flow.

Body mechanics regulation and jet flow are two common methods of active flow control, which control fluid flow by changing the hydrodynamic properties and the motion state of the ejector. These control methods have a wide range of application prospects in aviation, transportation, energy and other fields. With the continuous development of science and technology, active flow control will play an important role in more fields, providing people with more efficient, safer and more sustainable flow control solutions.

5. Passive flow control

Passive flow control refers to a method of regulating the flow of fluids through geometry or material properties, etc., without external energy input. In passive flow control, the design of geometry and material properties plays a crucial role. In this section, we will refine some of the passive flow control, introduce its related methods and technologies, and give examples of its application principles [22].

First of all, one of the most common methods in passive flow control is the design of geometry. By designing special geometries, the flow pattern of the fluid can be changed, so that the flow can be controlled. For example, by designing a surface with an elongated columnar structure, the fluid can be vorticed on its surface and the turbulence in the flow can be reduced or eliminated. This passive flow control method can be applied to aircraft wings, ship rudder surfaces and other fields to improve their hydrodynamic performance.

Another common passive flow control method is design that takes advantage of material properties. By touching the fluid to the surface of a special material, the properties of the flow can be changed and the flow can be controlled. For example, by coating a layer of micron-sized nanowires on the surface of the fluid, the fluid can form a micro-nanostructure similar to lotus leaves on its surface, thereby improving the flow performance of the fluid and reducing the frictional resistance [23]. This passive flow control method can be applied to hydroelectric power generation devices, wind power generation devices and other fields to improve their energy conversion efficiency.

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In addition to the design of geometry and material properties, passive flow control can also be achieved through various phenomena in fluid flow. For example, by using the law of vortex generation and propagation, the flow rate and direction of the fluid can be regulated. Passive flow control methods can also use the particle interaction of the fluid to achieve flow control. For example, the introduction of solid particles into a gas flow can affect the speed and direction of the flow through the collision and friction of the particles. This passive flow control method has a wide range of applications in gas delivery, powder conveying and other fields [24].

In summary, passive flow control is a method of regulating fluid flow through geometry and material properties without external energy input. In this section, we elaborate on the different methods and techniques of passive flow control and illustrate their application principles. The advantage of passive flow control methods is that they are simple, economical, reliable, and can be useful in many areas. In future research, we can further refine and study the passive flow control method in depth, and explore its application potential in more fields.

6. Combination of active flow control and passive flow control.

It is very important to combine the advantages of active and passive and give examples of active and passive flow control. Active flow control and passive flow control each have their own advantages, and their cooperation can improve the effect and performance of flow control.

Active flow control uses external devices or systems to control the flow field by actively intervening in flow behavior. The advantage lies in its flexibility and adjustability, which can be adjusted and optimized at any time according to your needs. A common form of active flow control is the introduction of artificial interference, such as jet air or liquids, into the flow field. This method can change the flow behavior by interfering with the velocity and pressure distribution in the flow field, thus affecting the motion or surface characteristics of the target object. For example, installing a jet device on the wingtip of an aircraft can control the flow near the wingtip through the jet airflow, reducing the drag and aerodynamic noise of the wingtip, and improving the performance and comfort of the aircraft [25].

Another active flow control method is by controlling the surface morphology. For example, installing adjustable deflectors on cars can adjust the angle and shape of the deflectors according to vehicle speed and driving status to improve the aerodynamic performance and stability of the vehicle. Precise control of flow can be achieved by monitoring the flow field and vehicle status in real time, and adjusting the parameters of the deflector according to the preset control strategy [26].

Unlike active flow control, passive flow control does not require external intervention, but rather controls the flow by designing hydrodynamic structures or materials. Passive flow control relies primarily on hydrodynamic effects and material properties, and offers the advantages of simple implementation, no external energy and low maintenance costs. A typical example is the design of distributed microscale particles on the surface of aircraft wings that can separate fluid boundary layers, reducing drag and aerodynamic noise.

In practice, active flow control and passive flow control are often complementary. By combining the two, more efficient flow control can be achieved. For example, on the blades of a wind turbine, both active and passive flow control measures can be applied to improve energy conversion efficiency. Active flow control can monitor and adjust the shape of the blades in real time through the intelligent control system to adapt to the flow characteristics under different wind speed conditions. Passive flow control, on the other hand, can improve blade stability and life by optimizing the blade surface structure and coating material, reducing fluid resistance and chatter.

In addition, the combination of active and passive flow control is also widely used in aerospace, automotive, energy and other fields. Through the research and development of new flow control technologies and materials, the performance and efficiency of fluid systems can be further improved, and more applications can be realized.

In summary, in the study of flow control, the cooperation of active and passive flow control can achieve more efficient flow control effects through innovative technologies and methods. By combining the advantages of the two, the performance and reliability of the flow system can be further improved, and the development and application of flow control technology can be promoted. It is hoped that the results of this research can provide reference and reference for researchers and engineers in the corresponding fields, and promote the further development and application of flow control technology.

7. Realistic use of flow control

Active flow control and passive flow control are two important concepts in the field of fluid mechanics, which are widely used in different fields and provide effective technical means for solving various engineering problems. The following will summarize the scenarios in which active flow control and passive flow control have been used in practice, and analyze their functions and make conjectures and assumptions about possible future applications [27].

Active flow control mainly changes the structure and characteristics of flow through external energy input. A typical example is injection control technology, which changes the speed, direction, and stability of a flow by spraying a fluid or gas into a flow. This technology has a wide range of applications in the aerospace sector, such as nozzle technology used in jet propulsion systems, which can control the attitude and dynamic performance of aircraft through jet airflow. In addition, in automotive engineering, regulating the combustion process of the engine by injecting air or fuel can achieve higher combustion efficiency and lower exhaust emissions. In the future, with the rapid development of aerospace and automotive engineering, active flow control technology will be further applied and promoted, and its power and potential will continue to increase.

Passive flow control mainly relies on the geometry and material properties of the object itself to achieve flow control. A typical example is the application of concave and convex surface structures. By designing an uneven structure on the surface of the object, the separation and winding behavior of the flow can be changed, thereby reducing resistance and noise. This passive flow control technology is widely used in aircraft design, automotive engineering and hydraulics. For example, in the design of aircraft airfoils, by setting a subtle concave and convex structure on the airfoil, the airflow can be better aligned to the airfoil, reducing drag and aerodynamic noise. In the future, with the advancement of materials science and manufacturing technology, passive flow control technology will be more widely used, providing more efficient and sustainable solutions to various engineering problems.

In summary, active flow control and passive flow control have a wide range of application scenarios and important functions in different fields. Active flow control changes the structure and characteristics of flow through energy input, enabling precise flow control and performance optimization. Passive flow control relies on the geometry and material properties of the object itself, and the adaptive and optimized flow can be achieved by designing a reasonable surface structure and material composition. For the future application of conjectures and hypotheses, with the advancement of science and technology and the increasing demand for flow control, active flow control and passive flow control technology will continue to be developed and applied, and bring more innovations and breakthroughs. Especially in the aerospace, automotive engineering, energy and environment fields, active flow control and passive flow control will play an important role in providing reliable technical support for solving practical engineering problems.

8. Conclusion

Active flow control and passive flow control are two important concepts in the field of fluid mechanics, which are widely used in different fields and provide effective technical means for solving various engineering problems. The following will summarize the scenarios in which active flow control and passive flow control have been used in practice, and analyze their functions and make conjectures and assumptions about possible future applications.

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References

[1] Garcia Sainz, M. O.; Delnero, J.; Marañon, J. Turbulence enhancement driven by cavity flow control. 2018 Flow Control Conference 2018.

[2] Durasiewicz, C.; Singh, A.; Little, J. C. A comparative flow physics study of NS-DBD vs AC-dbd plasma actuators for transient separation control on a NACA 0012 airfoil. 2018 AIAA Aerospace Sciences Meeting 2018.

[3] Dunne, P. G. Positive liquidity spillovers from sovereign bond-backed securities. Journal of Risk and Financial Management 2019, 12, 58.

[4] Xu, K.; Zha, G. Investigation of coflow jet active flow control for wind turbine airfoil. AIAA AVIATION 2020 FORUM 2020.

[5] Rubio, L. D.; Potomkin, M.; Baker, R. D.; Sen, A.; Berlyand, L.; Aranson, I. S. Self-propulsion and shear flow align active particles in nozzles and channels. Advanced Intelligent Systems 2020, 3.

[6] Xie; Liang; Han; Niu; Wei; Su; Tang Experimental study on plasma flow control of symmetric flying wing based on two kinds of scaling models. Symmetry 2019, 11, 1261.

[7] Shi, Y.; Su, D.; Xu, G. Numerical investigation of the influence of passive/active flow control on ship/helicopter dynamic interface. Aerospace Science and Technology 2020, 106, 106205.

[8] Nam, N.; Lee, S.; You, S.; Phuc, B. Dynamical analysis and active control for flow instabilities in boiling microchannel. International Journal of Heat and Technology 2019, 37, 203–211.

[9] Andino, M. Y.; Lin, J. C.; Roman, S.; Graff, E. C.; Gharib, M.; Whalen, E. A.; Wygnanski, I. J. Active flow control on vertical tail models. AIAA Journal 2019, 57, 3322–3338.

[10] Zhu, J.; Shi, Z.; Fu, J.; Chen, J. Aerodynamic characteristics of hypersonic airfoils based on Jet Flow Control Technology. AIP Advances 2021, 11.

[11] Klochkova, N.; Obuchova, A.; Protsenko, A. Movement modeling in problems of induction heating. 2019 XXI International Conference Complex Systems: Control and Modeling Problems (CSCMP) 2019.

[12] Yang, Y.; Zha, G. Numerical investigation of entrainment mechanism of jet boat tail passive flow control for base drag reduction. 54th AIAA Aerospace Sciences Meeting 2016.

[13] Huang, J.; Zhang, X.; Ye, Z. A combined load flow method for large shipboard power systems. 2009 Asia-Pacific Power and Energy Engineering Conference 2009.

[14] Zhang; Zhang Microfluidic passive flow regulatory device with an integrated check valve for enhanced flow control. Micromachines 2019, 10, 653.

[15] Analysis of the impact of multiple major shareholders on information transparency: Based on the perspective of controlling shareholders' equity pledge. Financial Engineering and Risk Management 2023, 6.

DOI: 10.54254/2753-8818/26/20241094

[16] NISHIDA, T.; MORINISHI, K.; FUKUI, T. A numerical simulation of the flow near Blade surface on certain grid using virtual flux method. The Proceedings of Conference of Kansai Branch 2018, 2018.93.

[17] Quan, Y.; Zhao, W.; Qiao, H. Improved model for parametric optimization of tuned mass damper-inerter for wind-induced vibration control of high-rise building. Structures 2023, 56, 104862.

[18] Fang, Z.; Gong, C.; Revell, A.; Chen, G.; Harwood, A.; O'Connor, J. Passive separation control of a NACA0012 airfoil via a flexible flap. Physics of Fluids 2019, 31.

[19] Brinissat, M.; Ray, R. P.; Kuti, R. Evaluation of the Szapáry long-span box girder bridge using static and dynamic load tests. Infrastructures 2023, 8, 91.

[20] Visbal, M. R.; Benton, S. I. Exploration of high-frequency control of dynamic stall using large-eddy simulations. AIAA Journal 2018, 56, 2974–2991.

[21] Dolci, D. I.; Carmo, B. S. Sensitivity of the least stable modes to passive control for a flow around an elastically mounted circular cylinder. Physical Review Fluids 2022, 7.

[22] Sarioglu, M. Control of flow around a square cylinder at incidence by using a splitter plate. Flow Measurement and Instrumentation 2017, 53, 221–229.

[23] Guo, W. D.; Peng, W. S.; Wang, L. Study on hydraulic characteristics of flow around rectangular and semicircular cross-section cylinder. Advanced Materials Research 2012, 557–559, 2337–2342.

[24] Yayla, S.; Teksin, S.; Sahin, B. Control of flow structures around a cylinder in deep water employing a passive control element. Fluid Dynamics Research 2019, 51, 055512.

[25] Mimeau, C.; Mortazavi, I.; Cottet, G.-H. Passive flow control around a semi-circular cylinder using porous coatings. International Journal of Flow Control 2014, 6, 43–60.

[26] Hamed, A. M.; Vega, J.; Liu, B.; Chamorro, L. P. Flow around a semicircular cylinder with passive flow control mechanisms. Experiments in Fluids 2017, 58.

[27] Zaresharif, M.; Ravelet, F.; Kinahan, D. J.; Delaure, Y. M. Cavitation control using passive flow control techniques. Physics of Fluids 2021, 33.