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ACTIVE FLOW CONTROL TECHNOLOGY IN AVIATION ENGINEERING

The fast development of the aerospace industry requires continuous integration and search for innovative technologies in aviation engineering to

increase aircraft performance. One of the primary methods to improve aerodynamic performance is flow control, which is divided into passive and active methods. Passive flow control, based on fixed aircraft features, such as vortex generators and wing geometry, enhances aerodynamic performance but has restricted potential for further improvement. Active flow control (AFC) is gaining prominence in modern aircraft design for precise regulation, adaptability across various flight conditions, and enhanced aerodynamic efficiency, using external energy sources and dynamic control mechanisms.

The main topics that will remain of interest in AFC research are:

1. New AFC strategies that consider control of flow instability and separation, mixing and turbulence control, vibration control, and acoustic control;
2. Design and development of new energy-efficient AFC drives, such as sensors and electrohydrodynamic pumps pulsing air high-performance valves, etc;
3. Theoretical, computational, and experimental research of AFC;
4. AFC with machine learning control and AI integration;
5. New AFC programs.

AFC's key promising research directions are circulation control, co-flow synthetic jets, plasma synthetic jets, innovative materials, machine learning, and AI integration.

Circulation control increases lift by blowing a high-speed jet over a curved surface, controlling flow separation, and improving the speed gradient in the boundary layer [1]. Co-flow jet technology, a circulation control method, uses vibrating diaphragms or pistons to inject air through slots on the wing's leading edge and suction at the trailing edge [2]. The cyclical operation of these actuators creates vortex structures, forming a synthetic pulsed jet. This significantly enhances lift by controlling flow at low speeds, preventing flow separation, reducing turbulence, and improving maneuverability. Plasma synthetic jets are also promising. They are generated by ionizing air with high voltage. Plasma actuators are known for their fast response, lightweight construction, and absence of moving parts [3].

The creation and use of nanomaterials and innovative materials are becoming more popular due to their ability to dynamically influence flow without needing complicated mechanical systems. They improve aerodynamic characteristics, flow control, reliability, and real-time radar visibility. These materials include piezoelectric, shape-memory, electroactive polymers, and magnetorheological and electrorheological materials.

It is noteworthy that modern AFC technologies depend on machine learning and AI integration, which are used increasingly in innovative projects [4; 5]. AI supports theoretical calculations, test results processing, and real-time

data optimization, enabling self-adjusting AFC systems that adapt to various flying conditions.

AFC technologies offer efficiency, reduced emissions, improved aerodynamics, enhanced maneuverability, and potential for passenger supersonic aircraft. They remove traditional control surfaces, allowing seamless surfaces and reducing radar detection. Plasma actuators and advanced materials enhance stealth capabilities. However, the technologies face challenges like energy consumption and integration into existing aircraft structures. To reduce energy consumption, research prioritizes energy-efficient actuators. Controlling AFC systems is complicated, necessitating precise and reliable mechanisms. Therefore, integrating machine learning and AI is crucial for advancement.

As a result, verifying AFC strategies has become especially important to guarantee the safety of flights. A conceptual project for the X-65 aircraft is being implemented by the U.S. Department of Defense's Advanced Research Projects Agency and Boeing subsidiary Aurora Flight Sciences under the "Control of Revolutionary Aircraft with Novel Effectors" program. The X-65 experimental aircraft is designed to replace traditional flaps and rudders with AFC effectors, which use jets of compressed air to control the aircraft's flight. The X-65 has a wingspan of 30 feet and weighs 7,000 pounds. At first, it will use both traditional control surfaces and AFC actuators to gradually change the AFC during testing. The modular design of aircraft allows for experimentation with different wing configurations and AFC systems. Demonstration and start of testing are planned for 2025 [6–8].

In conclusion, although challenges remain, the future of active flow control in the aerospace industry is auspicious. It can significantly improve aircraft performance, reduce environmental impact, and open up new possibilities for aviation engineering.

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