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Research and Development Trends of Noise Control Technology for Civil Aviation Aircraft

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Abstract. The environmental impact of civil aircraft noise has increased, adversely affecting airport operations and the health of nearby residents, and representing a major barrier to the aviation industry's green development. This paper aims to systematically explore the main noise sources and their variation characteristics of civil aircraft during different flight stages such as takeoff, cruise and landing, and to clarify the evolution mechanism of typical sound sources. By reviewing recent research, this paper explores three mainstream noise reduction methods, including airframe noise reduction with passive damping and multi-layer sound absorption, engine noise control via bypass ratio optimization and acoustic liners, and active control systems for cabin and external areas. The results show that, despite success in some frequency ranges, current technologies still face issues with cost, structural integration, and operational energy use. As such, it further explores future development paths like additive manufacturing, intelligent control systems and alternative fuels, and points out that civil aviation noise control will tend towards the integrated evolution direction of multi-system coordination and structural intelligence integration, providing technical references for the design of low-noise green aircraft.

Keywords: Aircraft Noise Control, Aerodynamic Noise Reduction, Turbofan Engine Noise, Noise Reduction Technologies

1. Introduction

With global air transportation demand rising, aircraft noise has become an increasingly prominent environmental concern, impacting airport operations, urban planning, and public health. In response, the International Civil Aviation Organization (ICAO) has continuously tightened noise regulations and encouraged manufacturers to enhance aircraft acoustic performance. However, the sources of aircraft noise are diverse and its physical mechanisms complex, encompassing various aspects such as internal engine flow dynamics, aerodynamic structure interference, and variations in propagation conditions. These factors vary with flight conditions, posing key difficulties for the development and integration of noise reduction technologies. At present, aviation noise control technology is gradually shifting from traditional passive sound insulation to structural optimization, active control systems, and integrated approaches. Mainstream strategies for engine noise reduction include higher bypass ratios, optimized fan blade designs, and acoustic liner integration. For airframe structures, multi-layered sound absorption materials and vibration isolation techniques are widely applied,

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while active noise control systems work effectively at low frequencies. Despite these performance improvements, practical limitations remain, including high manufacturing costs, substantial energy consumption, and integration challenges. Through a detailed review of recent literature, this paper examines the main sources of aircraft noise and current control technologies, and analyzes their developmental bottlenecks. Besides, it explores future trends toward integrated and intelligent noise reduction solutions, guiding aircraft noise mitigation strategies.

2. Main sources of civil aviation noise

2.1. Noise during takeoff and climb

The takeoff and climb phases are characterized by the highest levels of aircraft noise, with a broad impact range. During this period, the engines operate at maximum thrust output, resulting in high airflow velocities and significantly increased sound source intensity [1,2]. The primary sources of noise include internal engine noise, jet mixing noise, and aerodynamic noise from the aircraft's surfaces. Engine noise originates from multiple components, with the fan and compressor classified as high-speed rotating systems. The rotation of the fan and turbulence at its trailing edge generate low-frequency noise, while the compressor produces high-frequency disturbances due to unsteady airflow acting on blade gaps. Pressure fluctuations within the combustion chamber and instability in combustion processes further enhance sound radiation through interactions between turbines and high-temperature gas flows. The jet noise from the exhaust system is closely related to the bypass ratio, since low-bypass engines produce higher jet speeds and stronger noise, while high-bypass engines reduce jet noise. In addition, during the mixing process between high-speed hot exhaust jets and still air, strong shear layers form that excite large-scale turbulence, leading to wideband mixing noises that typically dominate this phase with sound pressure levels exceeding 140 dB. Meanwhile, aerodynamic noise cannot be overlooked during near-ground flight operations. At larger angles of attack, airflow around structures such as wings, landing gear, and flaps can lead to flow separation and vortex shedding which induces mid- to high-frequency noises. Due to their exposed structures causing more severe disturbances, landing gear and high-lift devices are significant non-propulsive sources of noise.

2.2. Noise during cruise flight

The noise level during the cruise phase is significantly lower than that during takeoff and landing, largely affected by the dual effects of high-altitude propagation attenuation and changes in engine operating conditions [3]. The flight altitude, usually between 9,000 and 12,000 meters, positions the sound sources away from ground receiving locations. As sound waves propagate, they undergo geometric spreading and frequency-dependent absorption, with high-frequency components rapidly attenuating under thin atmospheric and low-temperature conditions, leading to a marked reduction in perceived noise [3,4]. Simultaneously, engine thrust is maintained at 70% to 80% of maximum thrust, with fan speed decreasing by 15% to 20% compared to takeoff. This reduces overall shock waves, turbulence, and vibration intensity, consequently decreasing the acoustic power output [5]. As flight speed stabilizes around Mach 0.8, aerodynamic conditions also tend toward stability. In addition, the orderly development of boundary layers, combined with greatly reduced turbulence turbulence and flow separation, further suppresses unsteady aerodynamic noise [6]. During this phase, the engine remains the primary source of noise; however, its dominant mechanism shifts from jet noise to fan noise. High bypass ratio designs reduce exhaust velocity and weaken turbulent

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structures within the jet shear layer; thus broad-band jet noise energy diminishes accordingly [5,7]. However, a larger fan diameter amplifies airflow interactions, allowing disturbances at the leading and trailing edges to emit strong mid-to-low frequency noise even at lower rotational speeds. Prior studies have shown that fan noise can account for approximately 75% to 85% of total engine sound power, significantly higher than that produced by jet or core machine noises [5,7,8]. Moreover, airframe aerodynamic noise remains important during cruise, as interactions between turbulent boundary layers and structural surfaces can produce microscale disturbances at wing-nacelle and fuselage junctions. Though each contributes relatively little acoustic energy individually, their cumulative effect can manifest as background noise in far-field measurements, providing a stable contribution to the overall aircraft sound spectrum profile [9].

2.3. Noise during approach and landing

The core reason for the increased noise exposure during the landing phase is the combined effect of enhanced aerodynamic structure noise and weakened near-ground propagation attenuation [10]. The aircraft rapidly reduces its altitude to hundreds of meters during approach, and although the engine thrust drops to 30%-40% of the maximum thrust, the sound wave propagation distance shortens and the attenuation of low-frequency sound energy significantly weakens, causing the perceived noise level of residents around the airport to increase instead [5]. At this stage, unsteady aerodynamic disturbances from exposed airframe components become the dominant source of sound, overtaking engine noise. The landing gear represents the strongest aerodynamic noise source during landing, as its open structure induces circumferential interference and generates high-intensity wideband noise. In the state or deceleration and increased Angle of attack, the first three landing gears form wake coupling with the tail of the aircraft after unfolding, further enhancing the radiated sound pressure [10]. Measured data show that the landing gear can independently contribute more than 30% of the total acoustic energy, and there are obvious narrowband peaks in some frequency bands, which pose a strong interference and health risk to the human ear [2]. During the approach phase, lift devices also produce significant noise, primarily due to the large extension of flaps and slats. To maintain lift and flight stability, aircraft often operate high-lift surfaces at high angles of attack, which can cause edge separation and vortex shedding, producing mid- to high-frequency broadband noise [10]. Without considering the impact of the landing gear, the lift surface can dominate the noise output of the entire aircraft, and its proportion of acoustic energy can be as high as 40% in some models. In addition, even with wingtips designed to weaken vortices, modern wings may experience vortex core rupture at low altitudes and high speeds, leading to increased local far-field noise [1].

3. Noise reduction systems and key applications in civil aircraft

3.1. Airframe noise control techniques

To mitigate aircraft noise, efforts target acoustic radiation from airflow interference and structural vibrations, using passive damping, layered sound absorbers, and integrated structural designs [11]. While improving noise reduction, maintaining structural lightweighting poses a significant challenge. Passive damping materials are commonly employed in fuselage, siding, and load-bearing structures to weaken vibrations and radiated sound. Typical viscoelastic materials provide excellent energy dissipation, suppress structural resonance, and enhance sound damping, especially in mid- and low-frequency bands [12]. In enclosed or semi-enclosed areas such as floors and bulkwalls, viscoelastic layers act as sound insulators, thus limiting noise transmission into the cabin [13]. For

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example, the Boeing 787 uses sandwich structures and damping films to work together for noise reduction in the rear cabin section of the cockpit, achieving remarkable in-cabin quietness. The multi-layer sound-absorbing structure further integrates micro-perforated panels, cavity layers and high-loss substrates to build a wideband sound-absorbing interface. These systems are commonly used in areas like engine compartment walls and cabin partitions, significantly reducing mid- and high-frequency reflected noise and boosting comfort. For example, the layered micro-perforated sound-absorbing structure at the wing root of the Airbus A350 effectively suppresses turbulent boundary layer excitation without compromising aerodynamic performance. Integrated structural design has become a crucial trend in noise reduction, achieving close integration of lightweight structures and acoustic functions via collaborative modeling of porous materials, honeycomb cores, and composite panels. And such designs use numerical simulation to optimize low-frequency sound absorption and transmission loss. Embedding honeycomb sound-absorbing interlayers into interior panels enhances sound energy absorption without notably increasing mass. In the COMAC C919 and new-generation American and European airliners, these structures are gradually replacing traditional acoustic components, enabling simultaneous noise reduction and weight savings.

3.2. Engine noise reduction techniques

Given that engines are the main contributors to civil aircraft noise, their control technologies are key to the aircraft's overall acoustic performance. The main strategies involve optimizing bypass ratio, enhancing sound lining systems, and refining fan blade geometry, collectively transforming engines from high-noise sources into low-noise, efficient systems, with bypass ratio increase as the primary means to mitigate jet noise. By raising air mass flow through the duct and lowering core jet velocity, the wideband turbulence associated with the shear layer is strongly diminished. At present, the bypass ratio of mainstream civil aviation engines typically exceeds 9, with exhaust velocities maintained below 400 m/s. Compared with the traditional low bypass ratio design, the far-field acoustic radiation energy can be reduced by more than 30%, effectively alleviating low-altitude environmental noise pollution during takeoff. The sound lining system is the main technology for reducing fan and its harmonic noise and has been widely deployed in the inner wall structures of the engine intake and exhaust areas. Typical sound linings comprise perforated panels and honeycomb cores, enabling the construction of multi-degree-of-freedom Helmholtz resonators with adjustable frequencies and high structural integration. For example, in new-generation engines like the CFM LEAP and PW1000G, full-surface acoustic lining can reduce mid-frequency noise by 4 to 6 dB and achieve over 90% sound absorption efficiency without compromising aerodynamic performance [14]. Future efforts will center on optimizing acoustic liners and integrating thermal and vibration control to enhance overall performance. The geometric optimization of fan blades is mainly aimed at the suppression of high-frequency rotating noise. By introducing swept or swept-back blade tips, the formation of shock waves can be effectively delayed and the interaction sound with the stator blades can be weakened. The UltraFan engine has applied this strategy, reducing the overall noise level by about 6 dB during cruise while maintaining high propulsion efficiency [15]. This kind of design also further suppresses turbulent wake interference through three-dimensional aerodynamic shaping of the blades, thereby improving the noise-thrust ratio performance.

3.3. Proactive noise management techniques

In modern aviation noise reduction, proactive control systems are increasingly taking the place of traditional passive methods by introducing interference signals to suppress noise or vibration. They

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are mainly divided into two types of paths: in-cabin sound field control and external aerodynamic noise control [16]. In-cabin sound field control, typified by active noise cancellation (ANC), works well for diminishing low-frequency noise in confined areas such as passenger compartments and flight decks. The system uses microphones to pick up the original sound waves, which are then processed by a controller to generate opposing signals that drive the speakers, achieving localized sound pressure nullification. The typical control frequency band is 50 to 500 Hz. In aircraft like the Boeing 787, the ANC system has achieved a sound pressure reduction of about 6 dBA. However, this depends to some extent on the deployment location, control delay and power supply system. Active vibration control (AVC) directly intervenes in the path of structural vibration propagation through real - time coordination of accelerometers and actuators. The system is often deployed in bulkhead, floor and seat support structures, effectively reducing structural resonance responses in the mid- and low-frequency bands, boosting passenger comfort. Compared with ANC, the response of AVC is more localized, which is suitable for complex structural areas but more sensitive to installation location and modal characteristics. Facing external aerodynamic noise sources, active flow control (AFC) adjusts the boundary layer or turbulence structure through means like microjets, plasma excitation, or piezoelectric actuation, thereby weakening the turbulent shedding caused by high-lift devices or landing gear. This method is currently mainly in the prototype validation stage. Experimental results show that it can reduce aerodynamic noise by 3-6 dB in local areas. However, there are still significant challenges in actuation efficiency, system energy consumption, and aircraft integration [17].

4. Existing challenges and future trends

At present, aviation noise control technologies face significant challenges in balancing performance enhancement with engineering application, due to cost constraints, manufacturing complexity, and insufficient system integration. In terms of cost and integrability, existing noise reduction solutions still struggle to balance engineering feasibility with technological advancement. While full-surface honeycomb liners are extensively used in high-bypass engines to improve noise reduction, they are characterized by complex structures and high manufacturing costs. Prior studies have indicated that while such liners offer clear acoustic advantages, they also increase manufacturing difficulty, raise maintenance costs, and shorten maintenance cycles, posing a major conflict between performance and cost-effectiveness in engineering applications [18]. Despite the effectiveness of active control systems in reducing low-frequency noise, the weight and energy demands of their actuator arrays remain significant. For example, the piezoelectric structures deployed in the Boeing 787 add about 80 kg of load and increase life-cycle costs by over 1.5 million US dollars [19]. The development of aviation noise-reduction technologies is moving toward a coordinated approach combining weight reduction, intelligent control, and green propulsion. Furthermore, the use of additive manufacturing in honeycomb liners has simplified structural complexity and increased manufacturing flexibility, offering a novel means to balance noise reduction and weight control. Consequently, intelligent control systems, through multi-sensor fusion and edge computing, can achieve real-time adjustment of complex aerodynamic acoustic fields and have shown engineering potential to improve the cabin acoustic environment in the next-generation passenger aircraft. At the same time, the combination of power system optimization and sustainable aviation fuels not only helps to enhance combustion stability but suppresses noise generation in the core engine section, accelerating the achievement of coordinated noise-reduction and emission-reduction goals [20].

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5. Conclusion

The control of civil aviation noise is a complex, interdisciplinary task, fundamentally centered on achieving synergistic noise reduction across propulsion, structural, and control systems. This paper reviews the main noise characteristics at each stage of flight and clarifies the dominance of jet noise, fan noise and aerodynamic noise under different operating conditions. As such, it summarizes the current mainstream noise reduction technology paths, including passive control methods based on structure and materials, engine acoustic design represented by sound lining and blade optimization, and active control systems for low-frequency noise. Though the current technologies have achieved phased results, they still face bottlenecks such as complex manufacturing, high integration costs, and low energy efficiency in practical engineering applications. The future development of noise reduction technology should focus on multi-system integration and intelligent control, such as using additive manufacturing to boost the integration and economy of acoustic structures, using artificial intelligence to achieve real-time identification and adaptive control of complex sound fields, and exploring the potential of synergistic noise reduction of propulsion systems and green fuels.

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