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APPLICATION STATUS OF COMPOSITE ACOUSTIC LINER IN AERO-ENGINE

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Summary: *The aero-engine noise sources and the classification of aero-engine noise reduction technology were described in this paper. In addition, the application status of composite acoustic liner was summarized. Based on the current research and applied technology around the world, the development trend of composite acoustic liner was prospected.*

1 INTRODUCTION

With the development of aero-engine aerodynamic design technology , structural design technology and composite materials technology , application of composite materials in high bypass ratio turbofan engine has drawn more and more attention from the world's major engine manufacturers and research institutes. The application of composite parts, can further enhance thrust to weight ratio and fuel efficiency of the aircraft, and improve the life and safety and reliability of the engine greatly, while reduce noise and harmful emissions, increase comfort, economy and environmental adaptability, meet airworthiness Claim. The usage of advanced composite materials is an efficient way to achieve weight loss and achieve higher bypass ratio at the same time, which expand and offer the greatest opportunity of the composite application in aero engine.

During aircraft take-off, landing and flight, various types of noise were produced, which is difficult to fully control and even eliminated due to various noise sources and wide frequency range. The aircraft noise is composed of contributions from various source mechanisms and fan noise is one of the dominant components at take-off and landing for aircraft with modern high bypass ratio turbofan engines [1]. With the applications of high bypass ratio engine, replaced by the fan noise, jet engine noise is no longer the most important aviation noise source. Fan tone noise is highly dependent on the engine power, or fan speed [2]. Generation of fan noise depends on many factors [3].Various methods have been developed to reduce the generation and propagation of turbofan noise. The most common and effective method used to the reduction of turbofan noise is the application of acoustic liner [4,5] which is based on the mechanism of Helmholtz resonator. Liners are applied on the internal walls of the engine nacelle, both in the intake and by-pass ducts.

Airworthiness noise level is not only one of the key factors that affect the ability of large passenger aircraft to obtain airworthiness, but also determines the performance parameters of the engine as well as one of the major aircraft noise fatigue strength. Furthermore, US Federal Aviation Regulations (FAR) Part 36 and ICAO Annex 16 have higher noise airworthiness requirements for all types of civil transport aircraft airworthiness compare to stage 3 and stage 4 noise limits [6]. Airworthiness management department in China has similar regulations on noise which makes noise control and reduction become a critical issue of the development of China's aviation engine.

2 AERO-ENGINE NOISE SOURCE AND CLASSIFICATION OF NOISE REDUCTION TECHNOLOGY

Turbofan aero-engine noises are mainly from fans, compressor, turbine, combustion chamber, nozzles and other components. Broadband noise at different frequencies and "buzz-saw" noise were generated by the fan; high-frequency broadband noises were generated by the compressor and turbine; combustion chambers and nozzles produce low-frequency broadband noise, as shown in Figure 1. With the development and application of high bypass ratio engine, the noise source distribution of modern aviation engine has also undergone a corresponding change and very significant progress in reducing jet noise was achieved by the introduction of high bypass ratio engines as shown in Figure 2. The noise of aero-engine in 1960s was mainly in the rear of the engine, the maximum noise source was from the jet stream; with the development of aerodynamic design and aero-engine technology, noise caused by the fan has a substantial increase in the proportion of engine noise, and the noise generated by the compressor and the jet stream is significantly reduced.

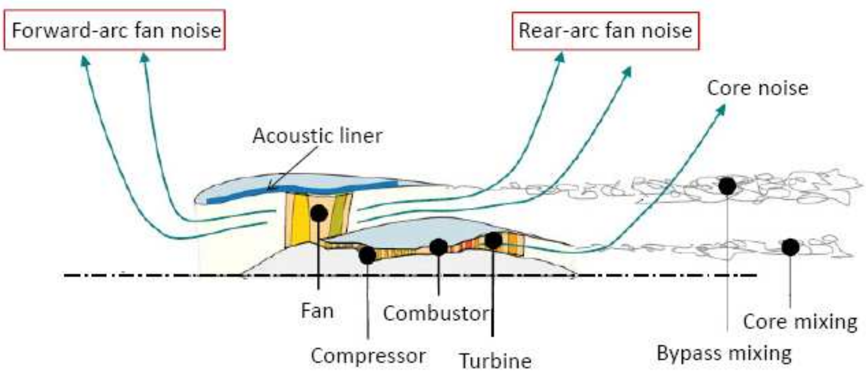

Figure 1: Main noise source of a modern turbofan engine [7].

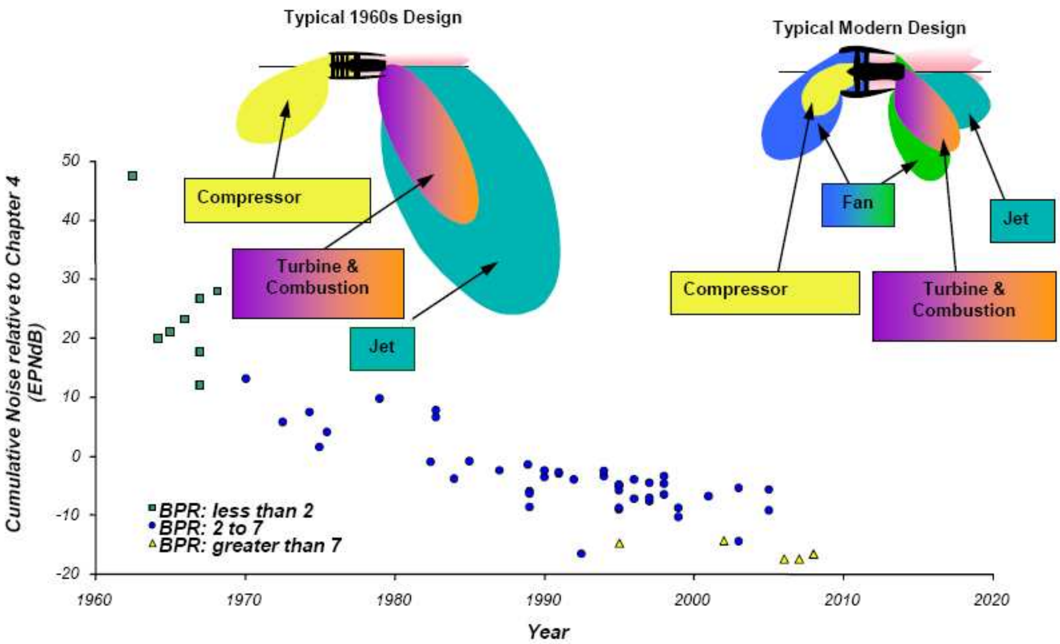

Figure 2: Significant progress in reducing aircraft noise by the introduction of high bypass ratio engines [5].

Among various technologies developed to reduce the generation and propagation of turbofan noise, engine noise reduction technology can be divided into two categories according to the noise reduction methods: source control and process control technology or active control and passive control technology. Compared with source control or active control noise reduction technology such as high bypass ratio, scarf inlets, active noise control, forward swept fans, swept and leaned stators and fan trailing edge blowing, the acoustic liner is process control technology or passive noise reduction technology.

Compared to other noise reduction technology, the process control or passive noise reduction technology is more practical. Source control technology or active noise reduction technology will optimize and improve the acoustic structure of the engine directly and will achieve immediate noise reduction effect. However, the source control technology or active noise reduction technology involves changing the structure of the engine which will lead to problems related to the security and economy and other aspects. On the other hand, without changes related to the engine structure, acoustic liners as process control technology or passive noise reduction technology are mainly arranged in the engine nacelle which can be improved and modified more convenient according to the noise properties of engine. For example, acoustic liners arranged in intake nacelle, thrust reversers and bypass duct can effectively reduce the noise of the engine.

3 THE STRUCTURE OF THE COMPOSITE ACOUSTIC LINER

Acoustic liners are used to absorb sound for many engineering applications ranging from concert halls to aircraft engines. They are mainly installed in the engine inlet, bypass duct and nozzle. Due to the operating temperature of the nozzle is much higher than the tolerant temperature of resin-based composites, so that the resin matrix composite acoustic liners are mainly used in the cold side of the engine. For resin matrix composite acoustic liners, the acoustic liners of current generation of high- bypass ratio turbofan engines (such as GE's CFM56-5-7 turbofan engines) are made of advanced composite materials. Compared with traditional metal materials, fiber reinforced resin matrix composite materials can be designed and have more excellent noise damping properties than metal materials.

The most common acoustic liner consists of a single layer honeycomb and perforate facing sheet, as shown in Figure 3. The facing sheet with a lot of porous are typically formed with aramid fiber fabrics or glass fiber fabrics reinforced resin matrix composite materials (the parameters of porous sheet are corresponding to the frequency and noise of turbofan engine). This facing sheet are often called as impedance layer, which has many characteristics such as high ratio strength and specific stiffness, low thermal conductivity, anti noise vibration, anti-corrosion , anti-aging. The core layer is a porous separator material (e.g., honeycomb core). Outer sheet is a rigid and solid composite back sheet. Some special acoustic liners contain multilayer structure which combine porous composite sheet with the thermoplastic material located in resonant cavity. The structures of resonant cavities are designed based on the noise frequency, noise reduction coefficient of engine requirements, which make it possible to achieve efficient noise reduction and to ensure a reasonable weight increasing. During the propagation of noise through the porous facing sheet into the resonant cavity, acoustic energy of noise is absorbed by 'lining' material and converted into heat. The design of the liners themselves, the selection of target impedances and the placement of lined segments within the duct can be used to scatter and attenuate the modes present at the fan in such a way that the far field sound pressure level is greatly reduced [8]. This acoustic liner can withstand high sound pressure levels and air flow rates (up to withstand approximately 240m/s air velocity).

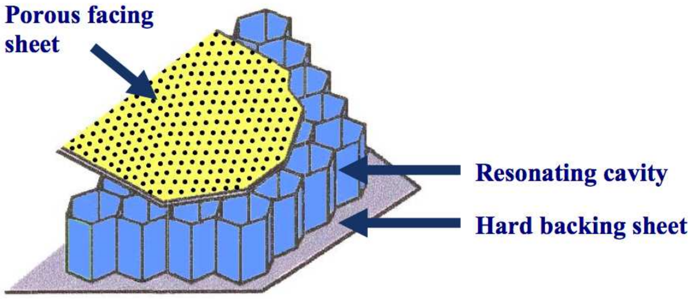

Figure 3: Single layer acoustic liner.

The single layer liners usually have a high value of noise attenuation over about one octave frequency bandwidth. In order to achieve higher efficiency of noise reduction, double layer or multi layers liners were introduced by researchers as shown in Figure 4. Although the insertion loss maximum of the single layer liner response maybe somewhat higher than that of the double layer one, in terms of effective perceived noise level (EPNdB) used for aircraft certification, the double layer liners are more acoustic effective than the single layer one because of their more uniform performance over 1.0-6.3 kHz frequency range [10].

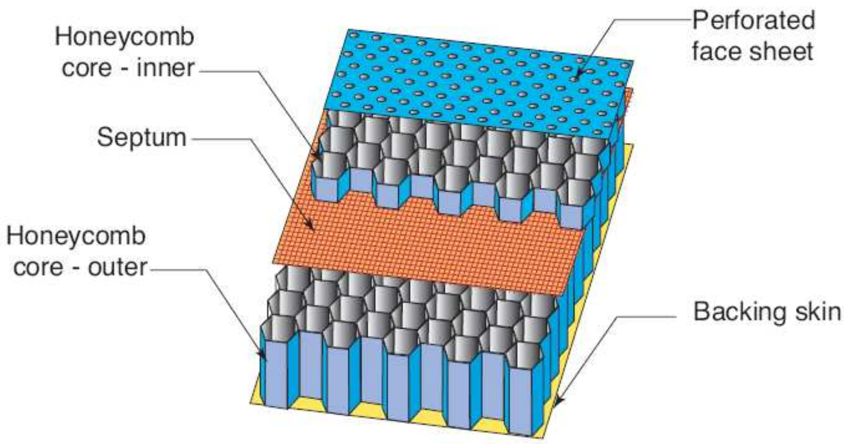

Figure 4: Double layer acoustic liner [9].

4 APPLICATION STATUS AND DEVELOPMENT TREND OF COMPOSITE ACOUSTIC LINER

After years of research and validation, the world's leading designer and manufacturer of aero-engine has been successfully developed and validated composite acoustic liner technology which has been applied in CFM56 series, GE90, PW4084, TRENT800 and other high bypass ratio turbofan engines. The acoustic liners were installed in turbofan engine fan case, the intermediary casing, nacelles, thrust reversers and the combustion chamber outer wall, which can effectively absorb noise of fan blades rotating and combustion noise.

The Boeing 707 is a four-engine jet airliner developed by Boeing in the early 1950s which is the first practical American jet airliner and the world's first successful commercial jet airliner. Pratt & Whitney JT3D-3 turbofan engine was employed in Boeing 707-320B which was a improved model from the Boeing 707-320 type. Because of low bypass ratio, the noise level of JT3D engine was relative high. In order to reduce engine noise to meet Federal Aviation Administration regulations for takeoff, landing process noise requirements and keep the original JT3D-3 turbofan engine structure, acoustic liners were installed in the inner wall of the nacelle inlet for noise reduction. As shown in Figure 5, a is the acoustic liner. The structure of the acoustic liners included 0.5mm thick aluminum perforated facing sheet, rigid back plate which was glass fiber reinforced epoxy composite materials and core materials which were Nomex honeycomb core. The pore size and the panel perforation rate of the facing sheet were 1.6mm and 32% respectively. They are cured together at 170 ℃ with the use of adhesive among the facing sheet, back plate and the core materials.

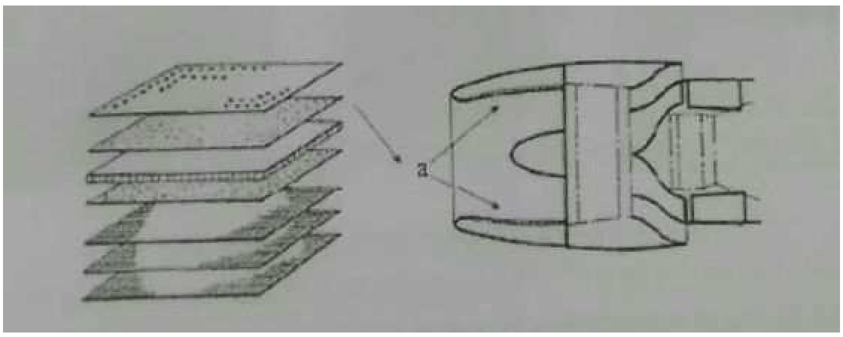

Figure 5: Acoustic liner in nacelle inlet.

The acoustic liners of CFM56-3 engine (the product of CFM International) are manufactured by Kevlar-49 aramid fiber reinforced epoxy composite laminates. The inner surface of the acoustic liners is a kind of thermoplastic elastomer backplane. They are assembled and embedded in the forward fan case as shown in Figure 6.

Figure 6: Installation of hard wall forward acoustic-panels (HWFAP) of CFM56 engine.

The composite acoustic inlet of V2500 engine (the product of Pratt & Whitney) consists of carbon panels attached with wire mesh and honeycomb core which is a double-layer honeycomb core with septum.

The acoustic liner of GEnx engines is a single-piece liner comprises glass fibre /epoxy skins sandwiching a Nomex aramid honeycomb core. This one-piece acoustic inlet liner will be one piece from the lip to the fan blades and will provide more fan noise suppression than the current GE90 segmented acoustic inlet liner. The application of GEnx engine, allows 85dB of noise generated by the Boeing 787 not exceed the airport boundary and more than 60% lower noise impact area of the Boeing 787 aircraft than the noise raised from the same size aircraft.

Hexcel Corporation uses broadband noise-reducing honeycomb for aircraft engines which makes the engine obtained more excellent noise performance without structural weight penalty. The noise-reducing honeycomb consists of permeable cap material embedded into a honeycomb core to create an acoustic septum. Relative technique is used by GE and Rolls-Royce to save weight and reduce engine noise by up to 30%. In addition, Hexcel Corporation developed an aluminum version honeycomb which provided comparable broadband noise reducing performance. This material can withstand temperatures of up to 350°F/175°C during fabrication of the nacelle core blanket and is processable using industry-standard techniques for forming, joining, cutting and machining.

The current largest commercial aircraft Airbus A380 is "unusually quiet" during the process of taking off and landing. Although it is equipped with four Trent 900 engines produced by Rolls-Royce, the noise level of A380 can reach to QC1 level, which is attributed to the noise reduction technology, especially the Zero-Splice engine nacelle liner technology. Through improved manufacturing techniques, Airbus has achieved zero-splice intake liner from the A320 's three 3 ×15cm splice , the A340-600 of two 2 × 7.5cm splice , and ultimately to zero splice of A380, As shown in Figure. In December 2006, Airbus was presented with the prestigious “Décibel d’Or” environmental award for its Zero-Splice technology by the French Minister for Ecology and Sustainable Development.

Figure 7: Improved manufacturing techniques fulfills the zero-splice intake liner [5].

In recent years, Aerospace Research Institute of Materials & Processing Technology has carried out research on the manufacturing of acoustic liner and has achieved good result including the manufacturing technology of high performance fiber reinforced resin matrix composite acoustic liner, precision processing technology, manufacturing technology for micro-perforated composite panel and testing technology.

Besides the research on the simulation of noise reduction and experimental verification of the mechanism and effects of acoustic liner, the development of composite acoustic liner would be concentrated on novel acoustic structure and novel absorber materials. Currently, ceramic foams are used extensively in industrial applications such as composite panels and acoustical liners in aircraft mufflers [11]. Some other porous material like “metal rubber” [12]would be applied as facing sheet materials of honeycomb liners in noise reduction for aviation engine. In addition, use broadband or adaptive liners to better match the liner impedance to the ideal impedance over more frequencies and/or operating conditions is a promising technology for future acoustic liner. Examples would be linear liners, triple layer liners, parallel element liners, or bias flow liners [13].

5 CONCLUSIONS

Acoustic liner is a critical component in noise pollution reduction for aero-engine. The application of composite materials in acoustic liner has provided the greatest opportunity for the noise reduction without structural weight penalty. The acoustic liner should not only be effective over a wide range of engine operating conditions and frequencies, but also be with properties such as meet environmental adaptability, good processing performance, low cost and easy to maintain overall performance. Therefore, extensive researches in future are needed to carry out for the development of composite acoustic liner.

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