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Using Acoustic Liner for Fan Noise Reduction in Modern Turbofan Engines

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Abstract

With the increase in global air travel, aircraft noise has become a major public issue. In modern aircraft engines, only a small proportion of the air that passes through the whole engine actually goes through the core of the engine, the rest passes around it down the bypass duct. A successful method of reducing noise further, even in ultra-high bypass ratio engines, is to absorb the sound created within the engine. Acoustically absorbent material or acoustic liners have desirable acoustic attenuation properties and thus are commonly used to reduce noise in jet engines. The liners typically are placed upstream and downstream of the rotors (fans) to absorb sound before it propagates out of the inlet and exhaust ducts. Noise attenuation can be dramatically improved by increasing the area over which a noise reducing material is applied and by placing the material closer to the noise source. In this paper we will briefly discuss acoustic liner applications in modern turbofan engines.

Key words: Turbofan Engine, Turbofan Engine Noise, High Bypass Turbofan Engine, Fan Noise Reduction, Acoustic Liner.

1. Introduction

Global air traffic is increasing because of the time efficiency of aircrafts over long distances and because of their route flexibility [1, 2]. The well-known health effects associated with elevated sound levels produced by a commercial aircraft can include stress, annoyance, sleep deprivation and hypertension [3]. In an effort to protect people from exposure to adverse levels of noise, governments all over the world have introduced various forms of regulation to combat the problem.

Major sources of noise radiated from an aircraft fall into these categories [4]:

- Propeller noise: propellers and propfans propulsion systems
- Rotor noise: rotorcrafts such as tilt-rotor aircrafts and helicopters
- Turbomachinary noise: compressors and turbines
- Jet noise: supersonic and subsonic jets
- Airframe-generated noise: high-lift systems and landing gears
- Sonic boom: shocks from supersonic bodies

The first generation of subsonic jetliners was very noisy because of the high exhaust velocity of their engines. Introducing the high bypass ratio turbofan reduced the noise level remarkably, by 20–30 dB [5].

The associated gains in propulsive efficiency led to much lower fuel consumption, making the high-bypass turbofan the only choice for commercial aircrafts developed in the 1980s and afterwards. [this sentence was mentioned previously]. In recent decades, aircraft noise mitigation has been investigated by many researchers [6-8]. The sound that propagates in an aircraft turbofan inlet duct is almost entirely due to the fan. Fan tone noise is highly dependent on the

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engine power, or fan speed. Generation of fan noise depends on many factors. The dominant source of fan tone noise is usually the rotor/stator interaction while that of broadband noise is e turbulence [9, 10].

Various technologies have been developed to reduce the generation and propagation of turbofan noise [11]. Example of these technologies include scarf inlets, active noise control, forward swept fans, swept and leaned stators, fan trailing edge blowing, and acoustic treatment placed over the fan.

In this paper, we use a bibliographical approach to discusst the effect of an acoustic liner on fan noise reduction in ultra high turbofan engines.

2. Fan Noise

Turbofan engines are currently the most feasible propulsion method for commercial aircrafts because of their high power and low fuel consumption. However, with the vast array of noise regulations imposed upon aircrafts, manufacturers must now consider exterior flight noise a major design consideration. The sound that propagates in an aircraft turbofan inlet duct is almost entirely due to the fan. Fan tone noise is highly dependent on the engine power, or fan speed. Generation of fan noise depends on many factors [12]. The dominant source of fan tone noise is usually the rotor/stator interaction while that of broadband noise is turbulence [13]. The passage of air over an aircraft structure causes fluctuating pressure disturbances that propagate to an observer and are perceived as noise. These pressure disturbances are created by airflow discontinuities in the engines, where power generation demands significant changes in pressure and temperature, and on the airframe: high-lift devices and landing gears, as well as the significant wetted area associated with commercial aircrafts, create considerable turbulence [14]. The trend in aircraft engine noise has been the growing dominance of turbofan noise in the radiated acoustic field. Particularly, during a high thrust operation, such as take off, reported sound levels radiated by turbofans is typically 15-20 dB greater than the levels of broadband noise [15]. Furthermore, with higher bypass ratio engines becoming the norm, the noise levels can only be expected to rise. Various methods have been developed to reduce the generation and propagation of turbofan noise.

3. Acoustic liner

A successful method of further reducing noise , even in ultra-high bypass ratio engines, is to absorb the sound created within the engine. Acoustically absorbent material or acoustic liners can be placed on the interior surfaces of the engines. Probably the most common passive method of noise control is the use of acoustic liners. The liners absorb the radiated acoustic energy, thereby reducing the far-field noise levels.

Liners are usually placed at the inlet and/or outlet of the engine. A single layer acoustic liner, composed of a perforated sheet with a honeycomb core, is shown in Figure.1, with labels on the most crucial elements. This arrangement produces an array of single degree of freedom resonators. The basic mechanism that allows an acoustic liner to reduce outwardly propagating sound from a turbofan engine parallels the workings of a Helmholtz resonator. Some liners have used multiple layers of honeycomb and perforated sheets to produce multiple degree of freedom resonators, with more than one neck and volume cavity [16-18].

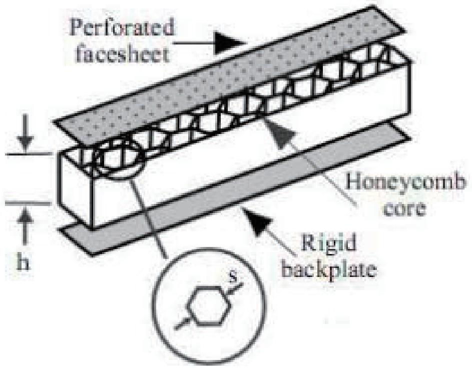

Fig. 1. Schematic of Acoustic Liner[19]

The acoustic liner may cover most of the available surface, both in the inlet and exhaust ducts, based on an optimization procedure involving antagonist factors like the installation of anti-icing systems. Liners are usually manufactured in sections, each of which covers a part of the duct‘s circumference. This facilitates the manufacture and installation of the lining inside the nacelle [20]. The sections are joined together by longitudinal strips or splices. The splices will be acoustically hard, meaning that there will be discontinuities in the acoustic impedance around the circumference of the duct. The typical types of acoustic liners are locally reacting cavity linings. The specific acoustic impedance of these types of liners depends on the properties of the lining, the mean flow and the frequency of the sound [21]. In general, it is more difficult to attenuate the fan tones as the engine power is increased, especially at high supersonic fan speeds. However, the liners increase the engine weight, which is undesirable. Also in the future, the bypass ratio will be increased, and the inlet length will not be scaled with the diameter. These changes will make liners less effective. Their performance is always limited by their confined length, especially for aero engines, which are considerable in number in size and where their multiple dominant tones are related to buzz-saw noise or rotor-stator interaction noise.

Different methods of optimization can focus on the variations in the treatment depth, core-cell dimensions, and number of layers in the lining. Once passive optimization method reached its limit, active methods were studied and developed to further improve upon the success of the passive liner. An active method in this context refers to a method which requires the addition of energy into a system. Dividing the acoustic liner into segments is a method that has been found improved the attenuation of ability of the liner, and an excellent review of the major works that contributed to this knowledge was authored by W. R. Watson [19].

The concept of non-uniform liners has been studied by several authors: Lasing and Zarumski [23] appear to be the first to have published work on the axially segmented liner, using modematching techniques. This type of the axially segmented liner is of interest because it can be used to increase the attenuation of fan tones at high supersonic fan speeds. Unruh [24] first examined how the liner‘s length, as well as its impedance, may be tuned to optimize the attenuation. Also, both Baumeister [25] and Tsai [26] realized that the first segment of the lining acts as a scatterer, which facilitates the attenuation of the sound in the adjacent lined segments. However, Baumeister concluded that an optimized axially segmented liner fails to offer sufficient advantage over a uniform liner to warrant its use except in low-frequency, single-mode applications.

In a circular-section lined duct, with circumferentially varying wall impedance, it is not possible to separate r and y, in order to find the analytic expressions for the modes of the duct. Watson [27], and also Fuller [28, 29], proposed an analytic solution to this type of problem. The wave equation was solved by separating the x-dependence, and then expressing both the mode shapes and wall impedance as Fourier series expansions in y. Then, a solution can be found, in principle, by solving a system of eigen equations.

The fan tones are harmonics of the blade passing frequency (BPF), which is generated by rotor-stator interactions and other similar mechanisms such as interaction of what with mean flow distortion and scattering by liner discontinuities. In aero-engines operating with supersonic fan tip speeds, for example at the engine “cutback” and “sideline” operating conditions (nominally about 80-85 and 90-95 % fan speed, respectively), an acoustic signature containing energy spread over a range of harmonics of the engine shaft rotation frequency will be generated. The name “buzz-saw” noise or multiple pure tones is generally used to describe this component of fan noise. The pressure signature attached to a supersonic ducted fan will be a sawtooth waveform. The non-linear propagation of a high-amplitude irregular sawtooth waveform upstream inside the inlet duct redistributes the energy amongst the buzz-saw tones [30]. “Buzz-saw” noise is radiated from a turbofan inlet duct when the fan tip speed is supersonic. McAlpine et al [30] showed that the principal source of buzz-saw noise is not always the rotor-alone pressure field. Non rotor-alone scattered tones can be a significant source of buzz-saw noise at low supersonic fan speeds. “Buzz-saw” noise is the principal tone noise source radiated from a turbofan inlet duct at supersonic fan speeds. The noise source consists of a set of tones, known as engine orders (EO), that are harmonics of the engine′s shaft rotation frequency. These EO tones are the buzz-saw noise. The levels of the scattered modes can be significantly reduced by the buzz saw noise. The level of the scattered modes can be significantly by having thinner splices.

In another study by Mcalpine, et al [31], the effect of an acoustic liner on buzz-saw noise was examined. However, at the sideline, the rotor-alone field is well cut-on. At this fan speed, the rotor – alone modes are predicted to remain the principal source of fan tones noise. The levels? of the scattered modes at the sideline can be reduced with thinner splices. However, at high fan speeds, thinner splices are not expected to increase the overall sound power transmission loss.

This is because the rotor-alone pressure field is well cut-on, and poorly absorbed by the duct liner. Acoustic liners in current aircraft engines are generally located in the inlet and/or the aft fan duct. If the liner is placed nearer to the fan rotor, or over the rotor, preliminary tests [32] suggested that significant additional noise attenuation could be realized. Sutliff and et.all [33] used a Foam- Metal Liner (FML) installed in close proximity to the fan. In their study, two FML designs were tested and compared to the hardwall baseline. Traditional single degree-of-freedom liner designs were also evaluated to provide a comparison. They showed that the FML designs achieved up to 5 dB Acoustic Power Level (PWL) overall attenuation in the forward quadrant, equivalent to the traditional liner design.

4. Conclusions

The rotating fan within a turbofan engine is a significant source of broadband noise, which spans a large range of the audible frequency spectrum. Although engineers have some degree of control over the noise produced at the exhaust and over the broadband noise produced by the fans, they have less control over the noise produced at the inlet duct, which is also a critical issue. Acoustic liners are an excellent means to reduce noise propagation from a turbofan engine.

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