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Jet noise modelling and control/Modélisation et contrôle du bruit de jet

Large eddy simulation of serration effects on an ultra-high-bypass-ratio engine exhaust jet

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ABSTRACT

Serrated jet nozzles are considered to be an efficient and practical passive control approach for jet noise. However, some fundamental mechanisms of serration effects on jet noise are not fully understood, especially in terms of the sound source. In this paper, a high-fidelity simulation framework using large-eddy simulation (LES) is demonstrated to predict near-field turbulence and far-field acoustics from an ultra-high-bypass-ratio engine with round and serrated nozzles. Far-field sound is predicted using Ffowcs Willams–Hawkings (FWH) integration. The results show that the serrated nozzle increases mixing near the nozzle and hence the turbulence decay rate, reducing the turbulence level downstream. The serrations shift the energy from the low frequencies to the high frequencies and decrease overall sound pressure levels by about 3 dB over the low-frequency range. Sound sources are analysed based on fourth-order space–time correlations. There are six major source components (R_{1111}, R_{2222}, R_{3333}, R_{1313}, R_{1212}, and R_{2323}) inside the jet shear layers. The serrations are able to reduce the amplitude of these source terms, causing them to decay rapidly to a level below the round nozzle jet within $2D$ downstream of the nozzle.

1. Introduction

Aircraft noise has become a major concern to residents neighbouring airports nowadays as the air traffic volume is increasing dramatically. Among aircraft noise sources, jet noise is the dominant component when an aircraft takes off. Research about the jet noise dates back to Lighthill and his celebrated eighth power law [1]. Since then, considerable progress has been made in this field, but the main noise reduction technology still follows the guidance of Lighthill's theory and relies mainly on reducing the exhaust exit velocity by aeroengine bypass ratio increase [2]. Some current research shows that noise reduction can be achieved by altering the flow structures responsible for sound generation without substantially reducing the exhaust velocity [3] and this concept can be accomplished through active and passive control [4]. Therefore, more insight into jet turbulence and its effects on sound sources is needed to explore the potential of noise-control strategies.

Noise control strategies are considered if it is not practical to increase the bypass ratio any further. For example, engines become so large in diameter that there is little room between the engine and the ground or wing. Nozzle serrations are regarded as an effective noise control technology without bypass ratio increase and has been successfully used on several civil aeroengines. Research into the effects of nozzle serrations on jet noise was first focused on isolated jets [5–7]. It shows

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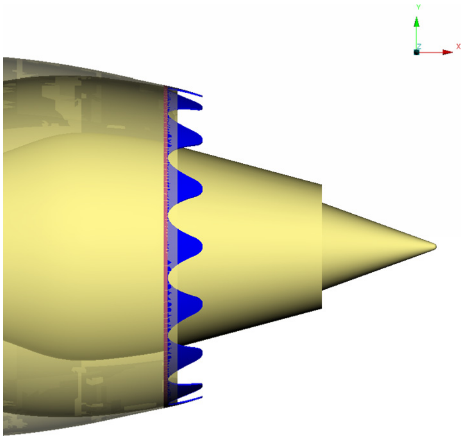

Fig. 1. Overlay of baseline and serrated nozzle geometries.

Table 1
Jet operating conditions.

	p_0/p_a	T_0/T_a	$\dot{m}$ (kg/s)
Bypass	1.342	1.128	6.373
Core	1.222	2.652	0.414

that the serrations can break down large coherent flow structures and reduce the isolated jet noise at low polar angles. Mengle [8,9] tried to design azimuthally varying chevrons (serrations) to reduce the installation noise generated when the jet is mounted to the airframe and test them experimentally. However, due to the lack of detailed unsteady flow data, the serration effects have not been fully understood and the design of serrations mainly relies on empirical experience gained from a range of limited rig tests.

Large-eddy simulation (LES) is a reliable method to capture the flow structures that are responsible for sound generation. Compared to the experiments, it can provide much more insight into the unsteady flow field and reveal the sound source mechanisms. It has proved to be a reliable predictive tool for jet noise [10] and has been successfully used to simulate single-stream round [11,12] and serrated nozzle jets [13] and coaxial dual-stream jets [14,15]. In this paper, an LES framework is demonstrated to simulate an ultra-high bypass-ratio (UHBPR) jet engine with and without serrations. The paper explores the serration effects on the jet flow, acoustics, and its sources using the LES data. It also shows its potential and mechanism to reduce jet noise in the circumstance of UHBPR aeroengines. The article is organized into three parts: first, the simulated cases are introduced. Then the simulation methodology is shown, describing LES methods and a modular hybrid mesh strategy for serrated nozzles. Finally, the LES results are analysed from the perspectives of jet aerodynamics and acoustics.

2. Case description

The simulation is performed for an UHBPR jet. Two cases are numerically simulated in this paper to investigate the serration effects. One is the baseline round nozzle, the other is the serrated nozzle. Fig. 1 shows the overlap of two nozzle geometries. The serrations are shown in blue and the baseline nozzle in pale yellow. Sixteen serrations are designed around the bypass nozzle edge to increase near-nozzle mixing. The serration roots are set slightly backward compared to the baseline nozzle lip; however the tips protrude further downstream. This is to reduce the serration penalties on nozzle performance. The bypass and core mass flow remain unaltered. The two nozzles are operating at the same condition and under an outer flight stream of 90 m/s. The nozzle operating conditions are summarized in Table 1. The corresponding Reynolds and Mach numbers based on bypass velocity and nozzle diameter are 3×10^6 and 0.66. The bypass ratio of the nozzle is around 15, which is representative of UHBPR engines. By comparing these two cases, the serration effects can be quantified.

3. Methodology

To predict this flow, LES is used to simulate large turbulent structures in the jet plume and RANS to model streaks in the attached boundary layers on the nozzle. The methodology, including turbulence modelling, serrated nozzle meshing strategy, and far-field sound prediction, are introduced as follows.

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