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Combustion noise

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Abstract

Combustion noise is becoming increasingly important as a major noise source in aeroengines and ground based gas turbines. This is partially because advances in design have reduced the other noise sources, and partially because next generation combustion modes burn more unsteadily, resulting in increased external noise from the combustion. This review reports recent progress made in understanding combustion noise by theoretical, numerical and experimental investigations. We first discuss the fundamentals of the sound emission from a combustion region. Then the noise of open turbulent flames is summarized. We subsequently address the effects of confinement on combustion noise. In this case not only is the sound generated by the combustion influenced by its transmission through the boundaries of the combustion chamber, there is also the possibility of a significant additional source, the so-called 'indirect' combustion noise. This involves hot spots (entropy fluctuations) or vorticity perturbations produced by temporal variations in combustion, which generate pressure waves (sound) as they accelerate through any restriction at the exit of the combustor. We describe the general characteristics of direct and indirect noise. To gain further insight into the physical phenomena of direct and indirect sound, we investigate a simple configuration consisting of a cylindrical or annular combustor with a low Mach number flow in which a flame zone burns unsteadily. Using a low Mach number approximation, algebraic exact solutions are developed so that the parameters controlling the generation of acoustic, entropic and vortical waves can be investigated. The validity of the low Mach number approximation is then verified by solving the linearized Euler equations numerically for a wide range of inlet Mach numbers, stagnation temperature ratios, frequency and mode number of heat release fluctuations. The effects of these parameters on the magnitude of the waves produced by the unsteady combustion are investigated. In particular the magnitude of the indirect and direct noise generated in a model combustor with a choked outlet is analyzed for a wide range of frequencies, inlet Mach numbers and stagnation temperature ratios. Finally, we summarize some of the unsolved questions that need to be the focus of future research.

Keywords: Combustion noise; Acoustic perturbation; Entropy perturbation; Vorticity perturbation; Choked nozzle

1. Introduction

In the last four decades noise emission has developed into a topic of increasing concern to society. This mainly stems from the adverse physiological impacts on those exposed to noise over

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lengthy periods. As a result, in air, road and rail transport technologies, the control of noise emissions is central to social acceptance and economic competitiveness. Due to its intermittent nature, aircraft noise is deemed to be the most annoying transportation noise, with road noise being the least likely to annoy. Noise has an immediate effect upon observers at the time of emission, causing annoyance and physiological change, and it also impedes the efficiency of observers. Longer term effects of noise are physiological impairment, e.g. hearing damage, speech and sleep interference. Although individual aircraft have become less noisy over the last 30 years, the increase in air traffic means that many citizens are concerned by aircraft noise. According to the International Civil Aviation Organization [1], global air transportation is anticipated to double over the next couple of decades. It is therefore expected that the negative social and environmental impacts of its noise emission will increase.

Aircraft noise is noise pollution produced by any aircraft or its components during various phases of a flight: on the ground such as auxiliary power units, while taxiing, on run-up, during take-off, underneath and lateral to departure and arrival paths, or during landing. The primary source of noise in an aircraft can be contributed to the fan, compressor, combustor, turbine, and jet exhaust [2] (see Fig. 1). On approach the airframe is also a significant source of noise.

During the last few decades, research efforts have enabled a significant reduction of jet, fan and external aerodynamic noise. The reduction of jet noise was mainly achieved by introducing ultra-high-bypass ratio turbofan engines. Fan noise has been reduced through effective acoustic liners and complex designs of fan blade geometry. These efforts on the reduction of jet and fan noise have left combustion noise as an important remaining contributor [2,3]. Figure 2 shows the significance of combustion noise relative to other noise sources for a typical turbojet application.

Combustion noise appears to be the third dominant source in the whole turbojet engine noise after fan and jet noise, especially at approach and cut back conditions. Furthermore, recent studies on low-NOx combustors such as lean premixed prevaporized (LPP) combustion show considerable increase in noise emission [4]. This is because lean premixed and stratified combustion burns more unsteadily [5–7]. As discussed in these references, lean premixed combustors can also be susceptible to an instability arising from the feedback interaction between unsteady combustion and acoustic waves. Such an instability occurs at a discrete tone related to the acoustic resonances of the combustor usually shifted slightly by the flame response. Even when the self-excited instability has been eliminated by a careful combustor design, which reduces the sensitivity of the rate of combustion to acoustic waves, LPP systems generate substantial broad-band noise, which can be heard outside the engine. Furthermore, noise from auxiliary power units (APU) is an important contributor to the overall level of ramp noise (the noise generated by an aircraft while it is on the ground, typically parked at the ramp). A significant component of APU noise is combustion noise [8,9]. It is therefore crucial to investigate this broad-band combustion noise and develop methods to predict and reduce it, in order to enable

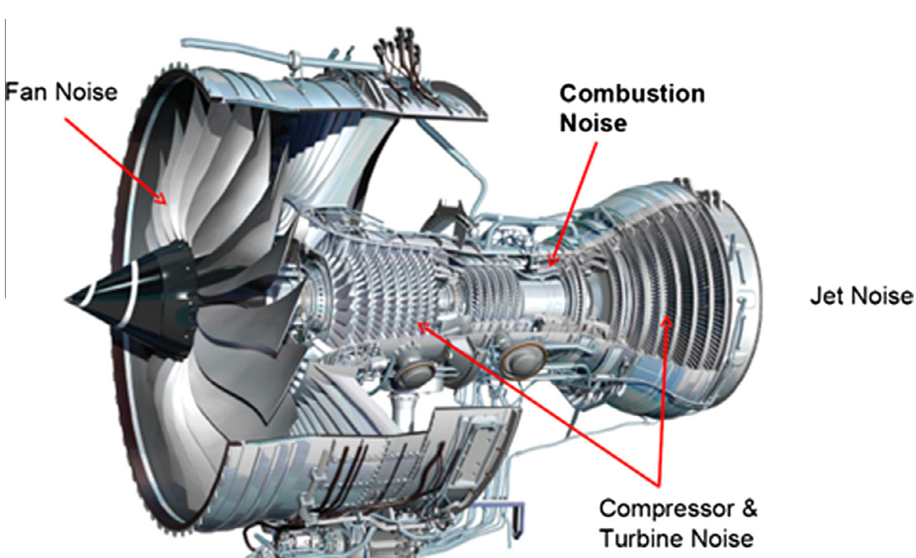

Fig. 1. Summary of engine noise sources (Rolls-Royce Trent 1000, copyright Rolls-Royce, published with permission).

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