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Experimental characterization of velocity and acoustic fields of single-stream subsonic jets

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ABSTRACT

The characterization of velocity and acoustic fields from a single-stream free jet operating at subsonic regimes is essential for aeronautical applications. For instance, the investigation of exhaust gases from single or coaxial nozzles or from bleed valve in turbojets and turbofan engines is crucial for understanding the mechanisms of noise generation and propagation and eventually for finding ways to reduce aircraft noise. This article evaluates the velocity and acoustic fields of an isothermal single jet discharging from a circular 38.1 mm conical nozzle at three different Mach and Reynolds numbers of 0.25 ($Re = 2.5 \times 10^5$), 0.50 ($Re = 4.9 \times 10^5$) and 0.75 ($Re = 6.8 \times 10^5$), respectively. Pitot-tube and hot-wire probes were used to identify the mean velocity profiles in longitudinal and transversal directions in the wake of the jet. The hot-wire anemometry system was also used to evaluate the turbulence intensity distribution over eleven axial lines, from the centerline to the edge of the nozzle. The accuracy of hot-wire anemometers for turbulent intensities lower than 15% at low and high subsonic Mach numbers was evaluated by comparing the experimental measurements with available data from the literature. An acoustic investigation was carried out by analyzing the sound pressure level obtained at six positions in the far field, with viewing angles ranging from 40° to 110°. The results were integrated to a database with sound pressure level as a function of Strouhal number, aiming to provide a benchmark for further RANS-based methods applied to aeroacoustic simulations of single jets.

1. Introduction

Air transportation is one of the safest travel modes nowadays. The number of daily flights is significant, and the number of air passengers has increased at a fast pace. The industry and research centers have focused on reducing aircraft noise, which has been a major concern in the aeronautical field since the introduction of jet-engine-powered aircrafts [1]. Studies have shown noise exposure, which is significantly burdened by traffic noise, has been the most undesirable feature in current urban life [1].

Fig. 1 shows the global trend of noise exposure to aircraft operation [2]. It plots the population in millions exposed to 55, 60 and 65 dB aircraft noise from year 2000 through 2025.

Fig. 2 shows an actual example of such exposure to aircraft noise at Congonhas Airport in Sao Paulo, Brazil, once the airport is surrounded by a very populated area subjected to approximately 600 daily flights.

Aircraft-emitted noise stems from several noise sources. Engines are one of the major noise sources on the ground, while fan and jet exhausts are the major noise contributors at take-off and climb. As a major concern in aeronautical applications, jet noise has been widely investigated. Driven by new noise regulations [4–5], the aeronautical industry and research centers have made efforts to propose new techniques to reduce engine and consequently aircraft noise.

This article reports on an experimental study of free jets with a view to providing a benchmark to aid in the development of computational aeroacoustic methods oriented to jet noise reduction. Experimental research on the mean velocity profiles of free jets has been reported for at least one century, since the pioneer work of Trüpel [6], followed by Abramovich [7], Corrsin and Uberoi [8,9] and Hinze [10], among others.

At first, instrumentation usually relied on Pitot-tube probes, which were largely used to measure mean velocity profiles and some of the turbulence quantities in the free jet flow. Subsequently, hot-wire anemometry was introduced to obtain point-wise measurements of turbulent fluctuations and complete velocity fields [11–13]. Both Pitot-tube probes and hot-wire

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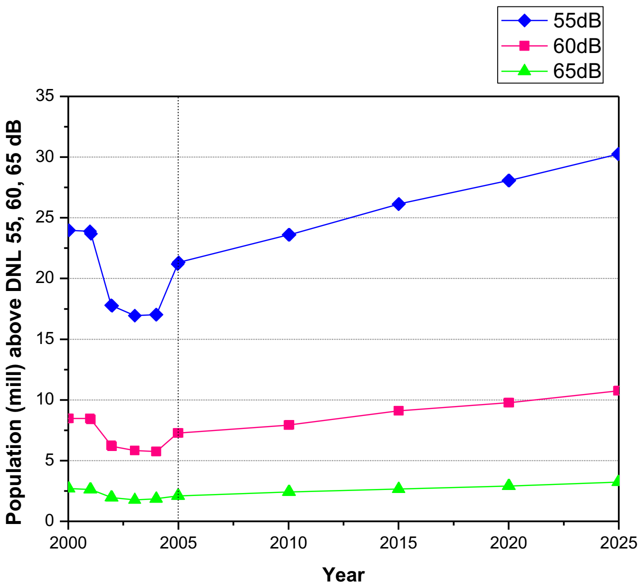

Fig. 1. Trend of exposure to aircraft operation. Source: [2].

anemometers have been used to measure mean velocity fields, turbulent intensity and frequency spectra among other quantities in a jet flow field.

Pairs of hot-wire sensors have been used to define the size and shape of regions with correlated turbulent velocities. Measurements of space correlations at retarded times have been used to define, for instance, a convection velocity and then obtain spectra and time scales in the turbulence-moving frame [14–16]. Laser Doppler Velocimetry (LDV) and hot-wire probes have been used to obtain additional data on single-stream subsonic jets [17]. Hot-wire-only measurements have also been obtained in the work [18]. Further research has shown the effect of nozzle exit conditions on subsonic jet noise [19] and the importance of studying turbulent high-speed, single-stream jets for aeronautical applications.

From an acoustic perspective, jet noise can be obtained directly from using a set of microphones. Accurate instrumentation and facilities for jet noise measurements became available in the second half of 1980, providing a large amount of high-quality narrow-band jet noise data [20]. One of the main applications of acoustic measurements of free jets is building a database to predict jet noise by interpolating and extrapolating data, usually through a semi-empirical model. For example, ESDU 98019 [21] and SAE ARP 876D [22] are databases for single-stream jets obtained in different experiments, each with specific data for Strouhal number, temperature ratio, and observer angles.

Despite the importance of investigating jet noise, the lack of experimental data has been a major problem to research groups since mathematical and numerical models require benchmark for validation. As jet noise is a profit factor in the aeronautical industry, open source databases have not been widely available in the literature. The few available databases have not been adequately provided with their input parameters or else have featured restrictions to retrieve some of their parameters, including velocities and observer angles. Recent cooperation projects between universities and companies have addressed this problem, as is the case of the European Union research framework programs for new engine noise reducing technologies.

This article reports on a study developed within a consortium involving Embraer S.A. and 6 Brazilian universities co-associated with foreign partners. The consortium carried out two research projects from 2012 through 2015 aiming to develop expertise and methods for aeroacoustic predictions of fan noise, airframe noise and jet noise. The main contribution of this work was to use Pitot-tube probe, hot-wire anemometry and far-field acoustic measurements to perform an experimental characterization of velocity and acoustic fields of single-stream subsonic jets operating at Mach 0.25, 0.50 and 0.75. The resulting data provided a better understanding of the flow dynamics and acoustic fields of such jets. The data have been used to validate ongoing numerical approaches to reducing jet noise with accuracy and at relatively low costs, which will eventually allow for the application of such techniques in the aeronautical industry.

2. Experimental arrangement

Measurements were performed at the Doak laboratory, a Rolls Royce University Technologic Center (UTC) facility located in the Institute of Sound and Vibration Research (ISVR) at University of Southampton, United Kingdom. The Doak laboratory is a 15 m × 7 m × 5 m fully anechoic chamber for frequencies down to 400 Hz. Its four walls, ceiling and floor were covered with wedge-type sound absorbing material. A non-forced exhaust system was built with a rectangular collector section allowing air to

Fig. 2. Congonhas Airport – Sao Paulo, Brazil. Source: [3].