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Acoustic measurements of models of military style supersonic nozzle jets

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Abstract Modern military aircraft jet engines are designed with variable-geometry nozzles to provide optimal thrust in different operating conditions, depending on the flight envelope. However, acoustic measurements for such nozzles are scarce, due to the cost involved in making full-scale measurements and the lack of details about the exact geometries of these nozzles. Thus the present effort at Pennsylvania State University (PSU) in partnership with GE Aviation and the NASA Glenn Research Center is aiming to study and characterize the acoustic field produced by supersonic jets issuing from converging-diverging military style nozzles, and to identify and test promising noise reduction techniques. An equally important objective is to develop methodology for using data obtained from small- and moderate-scale experiments to reliably predict the full-scale engine noise. The experimental results presented show reasonable agreement between small-scale and medium-scale jets, as well as between heated jets and heat-simulated ones.

1. Introduction

Military aircraft have engines with noise characteristics much louder than civilian aircraft, due to their very low bypass ratios and high exit temperatures and velocities of the jets. The resulted increased noise poses a health threat to ground crews as well as causing an annoyance to communities in the vicinity of military airbases. This has led to the development of noise suppression mechanisms that involve new nozzle design concepts such as chevrons, corrugations, beveled nozzles, and other non-axisymmetric geometries. One idea behind noise reduction concepts is to increase the mixing rate between the jet potential core and the surrounding air flow to shorten the length of the high turbulence, noise producing region. A possible way to achieve this is to alter the nozzle geometry at the exit plane in a way that it results in an increase in the turbulence within the shear layer surrounding the potential core. Chevrons and corrugations are examples of such designs. However, noise suppression can also be achieved by departing from the traditional axisymmetric geometries. For example, rectangular and elliptic nozzles are known for producing acoustic spectra with amplitude that depends on the azimuthal angle. Both of these nozzle designs produce decreased acoustic levels in the major axis plane compared to a round nozzle with an equivalent exit area, but an increased overall sound

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pressure level (OASPL) in the minor axis plane. Similarly, beveled nozzles produce an orientation of the acoustic field that results in decreased sound at some azimuthal angles.

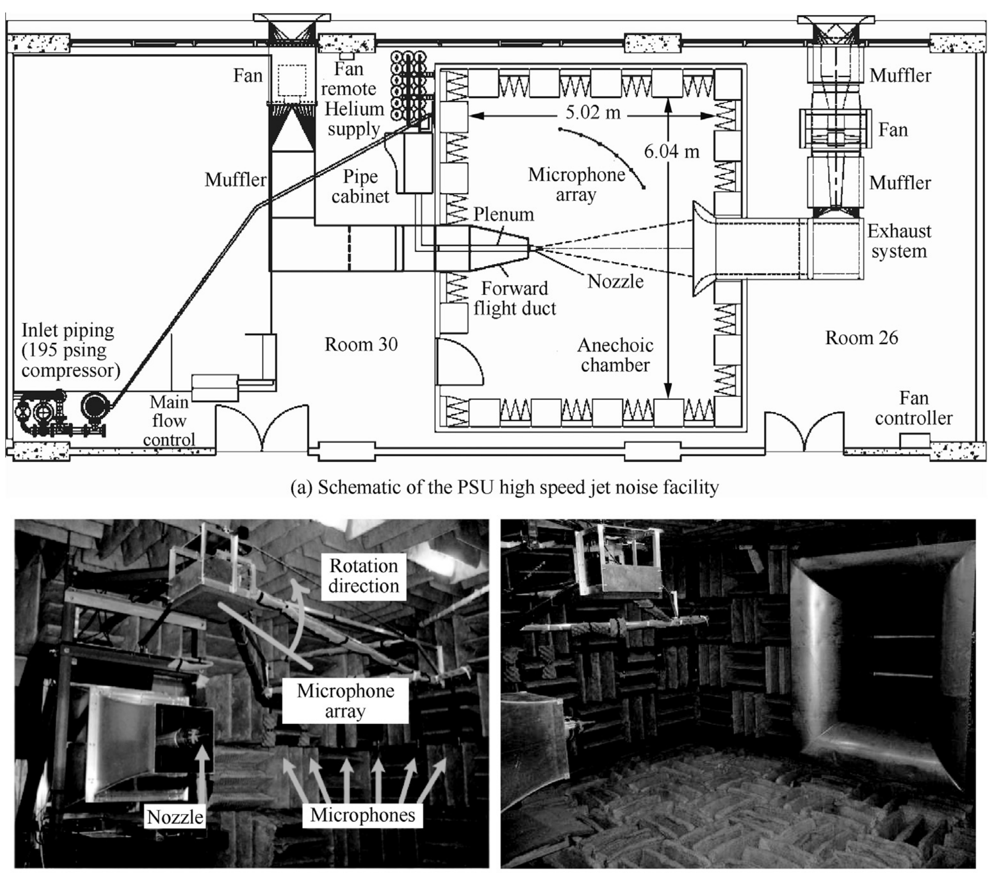
Modern military aircraft jet engines are designed to provide optimal thrust in different operating conditions, depending on the flight envelope. To satisfy this requirement, variable throat areas were deployed in the SR-71 "Blackbird" in order to increase the overall performance. A variable-geometry nozzle was also used in the F-14 "Tomcat", improving the overall engine efficiency. Thrust-vectoring rectangular nozzles were also developed and installed in the F-22 "Raptor". All these novel concepts increase the nozzle complexity and the manufacturing cost while having a non-negligible effect on the radiated sound. The database of acoustic measurements for such nozzles is scarce, due to the cost involved in making full-scale measurements and the lack of details about the exact geometries of these nozzles. A clear assessment of the noise generation of jets issuing from these kinds of nozzles needs to be undertaken in order to accurately predict the impact on ground crews and communities and develop efficient noise reduction techniques.

This study is part of an effort led by Pennsylvania State University (PSU) with partners involving GE Aviation and the NASA Glenn Research Center. The aim of the overall project is to study and characterize the acoustic field produced by supersonic jets issuing from converging-diverging military style nozzles, and to identify and test promising noise reduction techniques. An equally important objective was to develop methodology for using data obtained from testing at small and moderate scales, supported by computations, to reliably predict the full-scale engine noises. Therefore, the first step of this project was to conduct and compare small- and medium-scale experiments with nozzles representative of military jet engine exhaust nozzles. Comparisons across scales with data obtained in different facilities would provide confidence in the quality of the measurements performed, and in the ability of the methodology to extrapolate subscale data to full-size aircraft. The second stage is to conduct similar experiments with the addition of chevrons with various detailed designs onto the jet exhaust. Eventually, comparison with flight data obtained with aircraft such as an F-16XL or an F-18 will be performed. This paper focuses solely on the first step of the study: making extensive comparisons between small-scale measurements performed at PSU and medium-scale measurements gathered at the NASA Glenn Research Center, in order to determine whether small-scale and heat-simulated jets can accurately simulate the acoustics issuing from moderate-scale and hot jets.

2. Technical approach

2.1. Description of the experimental facility and instrumentation

The small-scale experiments presented in this study were conducted in the high speed small-scale jet noise facility at PSU, shown in Fig. 1(a). High-pressure air is drawn from a tank,



(a) Schematic of the PSU high speed jet noise facility

(b) Photograph of the PSU high speed jet noise facility

Fig. 1 Schematic and photographs of the PSU high speed jet noise facility.