JET NOISE PREDICTION MODEL FOR TURBOFAN ENGINES WITH INTERNAL FORCED MIXERS

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1 INTRODUCTION

Many turbofan engine exhaust designs feature internal forced mixers to rapidly mix the hot core flow with the cold bypass flow before the nozzle exit, primarily to enhance mixing and thus improve Specific Fuel Consumption (SFC). The low frequency jet noise is reduced as a result of the lowerrelative mixed jet velocity compared to a confluent nozzle, at the expense of an increase of the high frequency noise attributed to the mixer. Due to the complexity of the flow field downstream of forced mixer, the effect of mixer geometry on noise is difficult to capture analytically or from noise databases. There is no industry standard on predicting noise from such complex jets. The existing empirical models, such as SAE ARP876D [1] or ESDU98019 [2], for far field noise spectra prediction of single stream jets are not adequate, but remain essential for the engineering community. More accurate methods are deemed essential to increase the confidence level of noise control measures.

Various approaches are being used to assess the noise from jet engines. Numerical methods based on CFD / CAA solvers, such as Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES), remain complex and computationally expensive, thus limited to academic researchers. Other simplified methods use CFD results for the near field flow sources region, solving the acoustic far field with the acoustic analogy, e.g RANS solution coupled with Ffowcs-Williams and Hawkings formulation may present a good compromise if properly pursued.

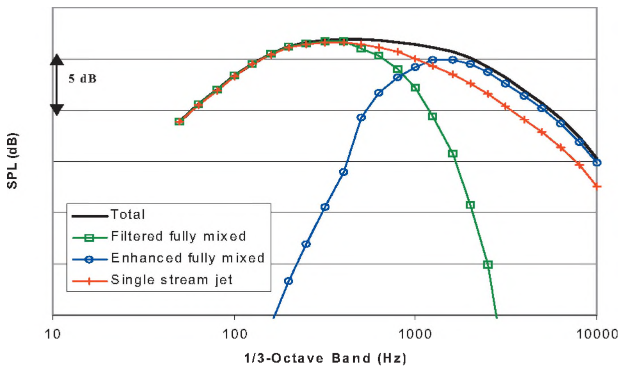

Figure 1: Jet noise prediction using the filtered single stream jets method.

One recent approach developed by Tester et al. [3], and Garrison et al. [4] relies on SAE ARP876D or ESDU98019 far field noise spectra predicted for single stream jets, with appropriate filtering to decompose the spectrum on an enhanced jet spectrum and a fully mixed jet spectrum. In the present study, far field jet noise predictions were performed for seven lobed mixer configurations and compared to full scale engine noise data obtained in an outdoor test facility. The required turbulence scales are deduced from a data fitting exercise of test data and compared with similar quantities obtained from RANS-CFD for two mixer configurations [5].

2 JET NOISE MODEL

The jet noise modeling approach consists of dividing the jet plume into two regions. The upstream region or "Enhanced fully mixed jet", close to the nozzle exit, is modeled using the far field single stream jet spectra in which the low frequency part is filtered out. A hypothetical turbulence factor is added to the equation to account for the enhanced turbulence due to mixing inside the nozzle. The downstream region or "filtered fully mixed jet" is also predicted using the far field single stream jet method with the high frequency filtered and removed. More details of the method can be found in Ref. [3, 4, 5].

The total jet noise of an engine with an internal forced mixer is the sum of two jet sources: the enhanced fully mixed jet given by

$$SPL_{enhj} = SPL_s + 10\,Log_{10}\left(1 - FilterF\right) + 40\,Log_{10}\left(Fm\right)$$

and the fully mixed filtered jet given by

$SPL_{mixj} = SPL_s + 10\,Log_{10}\left(FilterF\right)$, SPL_s is the single stream jet noise spectrum at the fully mixed condition. The characteristic of the filter function is defined as

$FilterF = \exp(-u)\left[1 + u + \frac{1}{2}u^2 + \frac{1}{6}u^3\right]$, where $u = 4f/f_c$, f is the frequency and f_c is the cut off frequency of the filter defined by its Strouhal number $S_t = f_c\, D_m / V_m$ and $f_c = \dfrac{(X/D)_{PC}\; Vm}{LenJ\; Dm}$, V_m is the fully mixed jet velocity. L_{enJ} is defined as the length of the enhanced region, $(X/D)_{PC}$ is the axial location of the end of the potential core, and Fm is the turbulence factor. A sample result that shows the effect of both jet components and the total jet noise is shown in *Figure 1.*

3 DISCUSSION

The accuracy of the predictions depends on the accuracy of the empirical model used to calculate the far field of single stream jets, i.e. SAE ARP876D or ESDU 98019. It was reported that this prediction method can be accurate within +/- 3-5 dB in amplitude, but may also result in a substantial discrepancy in the spectral shape compared to the measured noise data. Although the accuracy may be found acceptable for engineering use, it yields significant errors in the interpretation of the engine sources noise when performing engine sources noise breakdown, for instance.

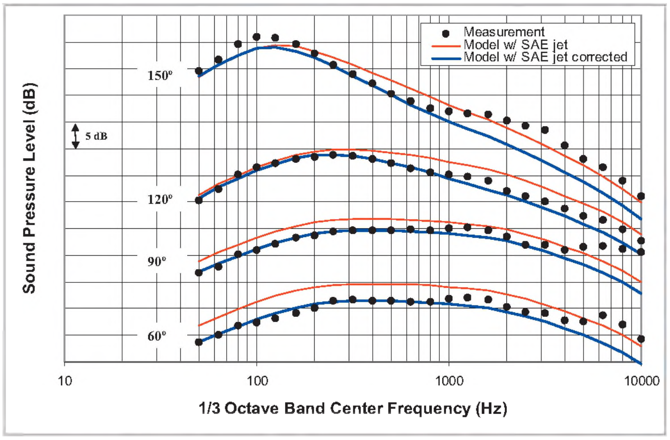

Figure 2: Jet noise prediction vs. measurement for Engine A for high power- Data was offset for clarity.

A study was conducted for seven turbofan engines all featuring an internal exhaust forced mixer, where the predicted noise spectra were compared to the measured far field noise spectra of the corresponding engines. It was found that the two-source method reasonably predicts the noise from jets with internal forced mixers, despite the existence of amplitude and spectral shape discrepancies at given angles and engine power settings. The SAE method was found to over-predict the jet noise at most forward angles relative to the inlet axis, and a large discrepancy exists in the spectral shape for aft angles. Extensive data analyses established a first amplitude correction to the jet noise spectra predicted with the SAE single stream jet noise method. The amplitude correction was then applied to all predicted jet spectra of all engines studied independent of engine power setting and type.

A second correction was then developed to correct for the spectral shape discrepancy. The latter correlation was established using a surface fitting function since the irregularity varies with the frequency and the observation angle. *Figure 2* and *Figure 3* show sample results for Engine A and B at various directivity angles. The figures show a comparison of the measured noise spectra with jet noise spectra predicted using ISVR / Purdue university method using the SAE single stream jet noise model. Also shown is the prediction using the same method but with the improved or corrected SAE jet noise model. It is shown that more accurate results are obtained when including the amplitude and spectral shape corrections. It should be noted that the very high frequencies (above 3 kHz) are not dominated by jet noise sources.

The improved jet noise model was validated with full-scale engine data with mixed exhaust flow temperature ratios between 1.3 and 1.6, Bypass ratios (BPR) between 3 and 5, and Mach numbers between 0.5 and 1.1. This covers a wide range of small to medium size commercial turbofan engine designs and operating conditions.

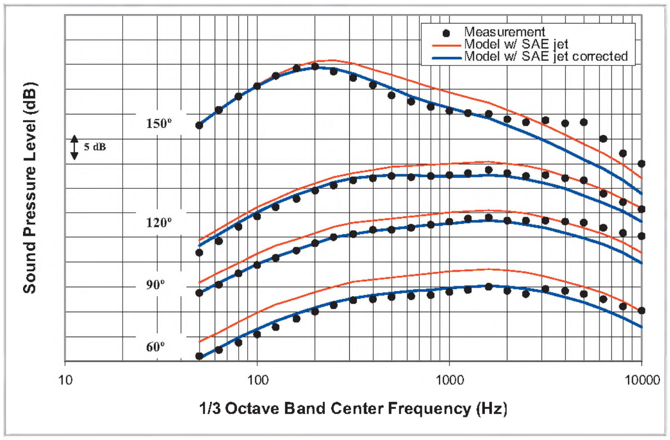

Figure 3: Jet noise prediction vs. measurement for Engine B for high power- Data was offset for clarity.

ACKNOWLEDGMENTS

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