NASA Technical Memorandum 88971

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(NASA-TM-88971) COMBUSTICN NCISE FROM GAS TURBINE AIRCRAFT ENGINES MEASUREMENT OF FAR-FIELD LEVELS (NASA) 8 p CSCL 20A

N87-17480

Unclas

G3/71 43727

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Prepared for the
1987 National Conference on Noise Control Engineering
sponsored by the Institute of Noise Control Engineering
Pennsylvania State University, Pennsylvania, June 8-10, 1987

NASA

COMBUSTION NOISE FROM GAS TURBINE AIRCRAFT ENGINES MEASUREMENT OF FAR-FIELD LEVELS

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INTRODUCTION

One of the sources of gas turbine aircraft engine noise that can be a significant contributor to the total aircraft noise is combustion noise. Measurement of combustion noise is often difficult, especially when jet noise is at a level equal to or greater than that of combustion noise. Since in-flight reduction of jet noise is greater than that of combustion noise, combustion noise can be a major contributor to in-flight noise even if it does not dominate under static conditions. The spectra and directivities of jet and combustion noises are very similar and do not exhibit any unique characteristics that allow for identification of jet and combustion noises based on far-field noise signatures alone.

To overcome this difficulty, several researchers have developed techniques that make it possible to directly measure combustion noise levels even in situations where other noise sources, such as jet noise, dominate. In general these techniques use cross-spectra between far-field measurements or between measurements in the engine core and those in the far-field. These techniques are based on one or both of the following properties of cross-spectra: 1) Signals not common to the two measurements being analyzed are not included in the cross-spectra; and 2) The cross-spectra contains within it, the transfer function between the two signals being analyzed.

In this report several of these techniques are described and far-field combustion noise levels, obtained using these techniques, are presented.

DESCRIPTION OF MEASUREMENT TECHNIQUES

Tester and Fisher, in Ref. 1, present a technique, termed "Automatic Source Breakdown Method" using cross-spectra between pairs of far-field microphones to determine fan inlet, fan exit, jet and combustion noise levels from a turbofan engine. Tester and Fisher assume that fan and core noise can be represented by point sources located at the fan inlet and exit for fan noise, and at the core exit for core noise. Jet noise is modeled as a distributed source with a distribution described by a formula recommended by Glegg in Ref. 2.

$$S_J(y,w) = \frac{A_J(w)\left(\frac{m}{y_J}\right)^m y^{m-1} e^{\frac{-my}{y_J}}}{(m-1)!}$$

where

$S_J(y,w)$ source strength per unit length, Pa^2/M

$A_J(w)$ total strength of jet mixing noise, Pa^2

y axial location, M

y_J axial position of centroid of jet noise distribution, M

w angular frequency, rad/sec

m adjustable parameter ≥ 2 (4 for data presented in this paper).

Using this distribution and the relation for the cross-spectrum generated by n mutually incoherent point sources, the cross-spectrum between two far-field microphones separated by angle α becomes:

$$C(\alpha,w) = \sum_{i=1}^{3} A_i(w) e^{\frac{-jwy_i \sin\alpha}{a_o}} + \frac{A_J(w)}{\left(1 + j\frac{w}{a_o}\frac{y_J}{m}\sin\alpha\right)^m}$$

where

A_i strength of fan inlet, fan exhaust and core noise for $i = 1,2,3$, Pa^2

α angular separation, rad

y_i axial location of fan inlet, fan exhaust, and core noise for $i = 1,2,3$, M

a_o = ambient speed of sound, M/sec

Although Eq. (2) could be solved for the source amplitude by using measured cross-spectra corresponding to four angular separations, Tester and Fisher recommend using additional measurements to determine the source amplitudes in terms of a least squares fit to the more extensive set of cross-spectral data.

Parthasarathy, et al., Ref. 3, also used cross-spectra between far-field microphones to separate jet and combustion noise. Their approach is based on the hypothesis that jet noise, originating from moving sources, would have a different frequency, due to doppler shift, at each measurement angle and thus jet noise at one measurement angle would not correlate with that at another angle. Core noise, however, being emitted from a stationary source, would correlate at all angular differences. The hypothesis regarding jet noise is in conflict with the model of Tester and Fisher. Data reported by Fisher, et al., Ref. 4, support the model of Tester and Fisher. The data shows, and the model predicts, that jet noise at one measurement angle does correlate with that at another angle, but the correlation decreases with increasing angular separation. The data indicates that for angular separations of greater than 30°, the cross-correlation of jet noise is approximately zero for Strouhal numbers greater than 0.1. Thus the approach of Parthasarathy, although apparently based on an incorrect hypothesis, should be successful if the angular separation is large. Fortunately, Parthasarathy et al., used a large angular separation (> 60°) for their experiment.

Krejsa, Ref. 5, and Shevashankara, Ref. 6, used cross-spectra between internal microphone signals and far-field microphone signals to determine combustion noise levels. Their approach is an extension of the "coherent output power" concept, Refs. 7 and 8, but overcomes the limitation that all of the signal at the internal microphone be correlated with the far-field microphone. As will be shown later, "coherent output power," which uses only one internal measurement, underestimates the far-field combustion noise levels. The approach used by Krejsa and Shevashankara, which was first derived by Chung, Ref. 9, uses two internal microphones and eliminates the bias error due to noncorrelating signals at the internal microphone. This approach is referred to by Krejsa as "Three-Signal Coherence." The equation for the far-field combustion noise level, in the form derived by Krejsa is:

$$\left|P_{FF_c}(w)\right|^2 = \frac{\left|G_{P_1P_F}(w)\right| \times \left|G_{P_2\ P_c}(w)\right|}{\left|G_{P_1P_2}(w)\right|}$$

where

$\left|P_{FF_c}(w)\right|$ is the spectrum of the far-field combustion noise, Pa^2

$\left|G_{P_1P_F}(w)\right|$ is the magnitude of the cross-spectrum between the first internal microphone signal and the far-field, Pa^2

$\left|G_{P_2P_F}(w)\right|$ is the magnitude of the cross-spectrum between the second internal microphone signal and the far-field, Pa^2

and

$\left|G_{P_1P_2}(w)\right|$ is the magnitude of the cross-spectrum between the two internal microphone signals, Pa^2

The requirements for the location of the internal microphones are: 1) one microphone should be located near the core exit to detect all combustion noise generated, and 2) the two internal microphones must be separated sufficiently so that there is no correlation between the portions of their signals that do not correlate with the far-field.

RESULTS

Typical results using the "Automatic Source Breakdown Method" are shown in Fig. 1 (from Fig. 9 of Ref. 1). The results are shown for a Viper 601 at 90 percent engine speed with an acoustic liner installed in the engine tailpipe. As can be seen, the attenuated core noise levels were measured even though these levels are from 10 to 15 dB below the total noise.

Results using the "Three-Signal Coherence," Ref. 5, are shown in Fig. 2 for a YF102 turbofan engine at 95 percent engine speed. Shown are total noise, core noise determined using the three-signal coherence" method and predicted jet and fan noise. At this engine speed, jet noise dominates; however the three signal coherence technique enables the core noise to be measured even though it is up to 10 dB below the total noise. In Fig. 3, core noise determined using the "three-signal coherence" technique is compared with that determined using the "coherent output power" method. The levels determined using the "coherent output power" method are 3 to 10 dB below those determined using the "three signal coherence" technique. This is due to the presence of pressure fluctuations at the internal engine microphone that do not correlate with the far-field. The "three-signal coherence" technique eliminates this problem.

SUMMARY

Several methods for measuring the far-field combustion noise levels of aircraft engines were presented. These methods make it possible to measure combustion noise levels even in situations where other noise sources, such as jet noise, dominate. Sample results are also presented.

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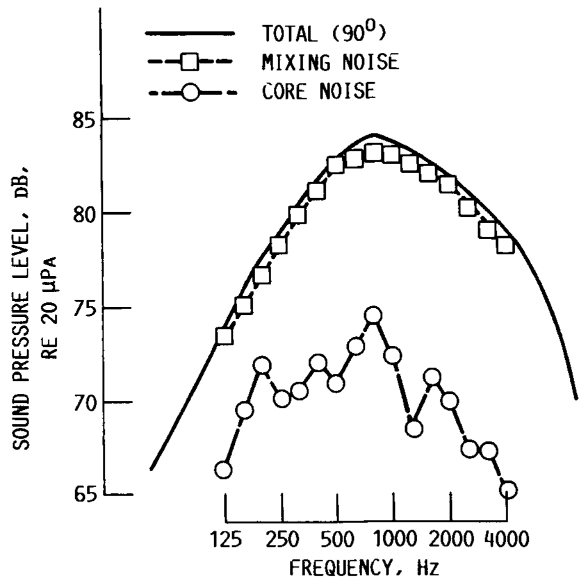

FIGURE 1. - (FROM REF. 1) JET (MIXING) AND CORE NOISE LEVELS DETERMINED USING "AUTOMATIC SOURCE BREAKDOWN METHOD". VIPER 601, 90% N_L, WITH TAILPIPE LINER.

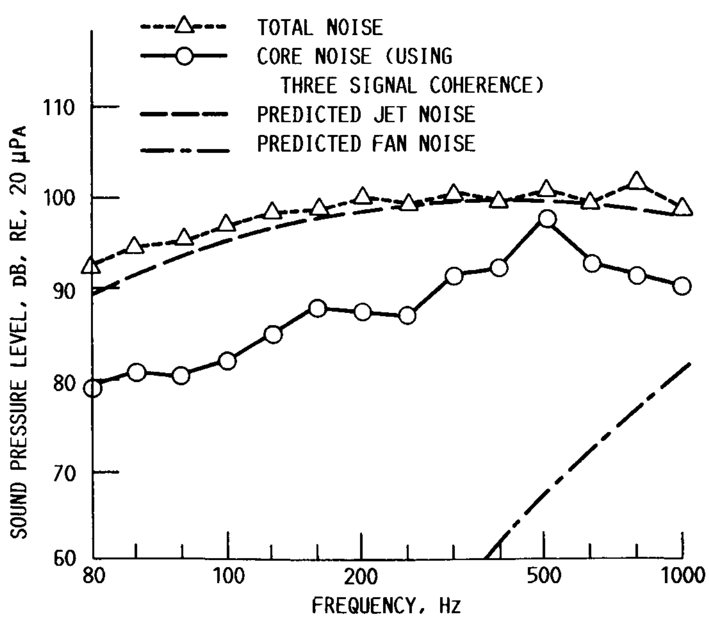

FIGURE 2. - COMPARISON OF CORE, JET, AND FAN NOISE LEVELS TO TOTAL NOISE AT 120° FROM THE ENGINE INLET. YF102 ENGINE AT 95% ENGINE SPEED.

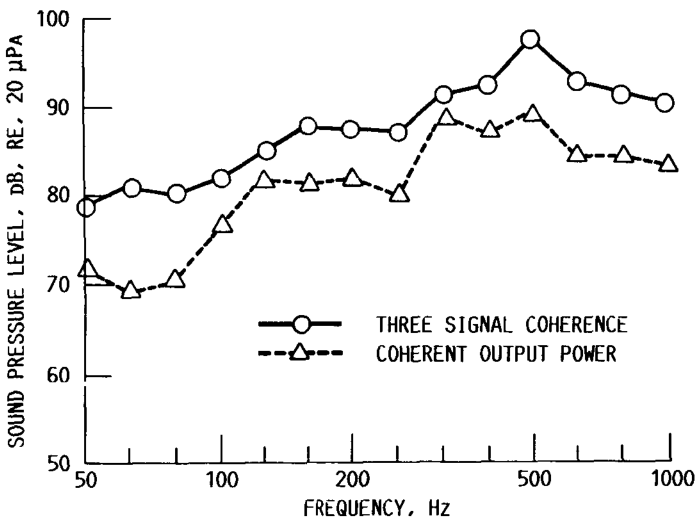

FIGURE 3. - COMPARISON OF CORE NOISE LEVELS DETERMINED USING THREE SIGNAL COHERENCE TECHNIQUE WITH CORE NOISE LEVELS DETERMINED USING COHERENT OUTPUT POWER METHOD, 120° FROM ENGINE INLET. YF102 ENGINE AT 95% ENGINE SPEED.

1. Report No.
NASA TM-88971

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle

Combustion Noise from Gas Turbine Aircraft Engines Measurement of Far-Field Levels

5. Report Date

6. Performing Organization Code
535-03-01

7. Author(s)
Eugene A. Krejsa

8. Performing Organization Report No.
E-3407

10. Work Unit No.

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared for the 1987 National Conference on Noise Control Engineering, sponsored by the Institute of Noise Control Engineering, Pennsylvania State University, June 8-10, 1987.

16. Abstract

One of the sources of gas turbine aircraft engine noise that can be a significant contributor to the total aircraft nose is combustion noise. Measurement of combustion noise is made difficult by the fact that both jet noise and combustion noise exhibit broadband spectra and peak in the same frequency range. Since in-flight reduction of jet noise is greater than that of combustion noise, combustion noise can be a major contributor to the in-flight noise of an aircraft but will be less evident, and more difficult to measure, under static conditions. Several methods for measuring the far-field combustion noise of aircraft engines are discussed in this paper. These methods make it possible to measure combustion noise levels even in situations where other noise sources, such as jet noise, dominate. measured far-field combustion noise levels fro several turbofan engines are presented. These levels were obtained using a method referred to as "Three-signal coherence." This method requires that fluctuating pressures be measured at two locations within the engine core in addition to the far-field noise measurement. Cross-spectra are used to separate the far-field combustion noise from far-field noise due to other sources. Spectra and directivities are presented. Comparisons with existing combustion noise predictions are made.

17. Key Words (Suggested by Author(s))
Acoustics
Combustion noise
Noise

18. Distribution Statement
Unclassified - unlimited
STAR Category 71

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22161