Gas Turbine Core Noise Source Isolation by Internal-to-Far-Field Correlations

Belur N. Shivashankara*
Boeing Commercial Airplane Company, Seattle, Wash.

An auxiliary power unit (APU) was tested for exhaust noise in an anechoic chamber. Six internal and numerous near- and far-field microphones were employed. Extensive cross-correlation and coherence function analysis were performed. The combustor was found to be one of the dominant sources of exhaust noise in the far field below 400 Hz. Additional noise generation around 375 and 600 Hz was apparent between the combustor exit and the turbine exit, which may be entropy noise or flow noise generated in the turbine inlet torus. The mixing process between the cooling air and the exhaust flow (which takes place a short distance upstream of the nozzle exit) was also identified as an important source of low-frequency noise.

I. Introduction

THE core noise of a gas turbine engine includes contribution from various internal noise sources. The nature of these sources and their relative importance varies from one engine to another. It also varies with the power setting. Generally, the noise radiating from an engine tailpipe has significant energy in the 0-1000 Hz range, in addition to turbomachinery noise that occurs at higher frequencies. The isolation of sources contributing to core noise in the 0-1000 Hz range is the subject of this paper.

Correlation analysis has been used by various investigators in an attempt to identify the sources of core noise. Mathews and Peracchio[1] reported cross-correlation functions between various internal and far-field microphones in a test of a Pratt & Whitney Aircraft JT3D engine. The time delay at which these correlations maximized appeared to indicate the combustor as the dominant source of core noise at low engine power settings.

By testing a Lycoming YF-102 turbofan engine instrumented with internal microphones, Karchmer and Reshotko[2] performed cross-correlation and coherence function analyses between internal and far-field microphones. The coherence functions showed that the combustor pressure fluctuations were coherent with the far-field acoustic pressure fluctuations in the 0-250 Hz frquency range. Similar results were obtained between the tailpipe and far-field microphones. However, the combustor exit to far-field cross-correlation function maximized at a time delay somewhat greater than that required for an acoustic wave to traverse the distance between the measurement stations. The authors examined the transfer function and phase relationships and concluded that the combustor behaves as a source region for far-field sound at frequencies below 250 Hz. Somewhere between the combustor and the upstream tailpipe probe position, the pressure disturbances became a source of acoustic energy that propagates through the tailpipe and out to the far field. For the engine used in Ref. 2, Reshotko et al.,[3] showed that below 60% of maximum fan speed, the low-frequency core noise contributes significantly to the far-field noise.

Results of internal to far-field cross-correlation and coherence functions obtained by testing an APU are presented in this paper. The unit is used in airplanes, when parked on the ramp, to 1) provide compressed air for starting main engines, 2) supply compressed air for air-conditioning the passenger cabin, and 3) run the electrical generator. The APU tested utilized an AiResearch GTCP 85 series gas turbine engine.

The object of the study discussed was to isolate sources of far-field noise in the 0-1000 Hz range. To achieve this, the APU was instrumented with six internal dynamic pressure probes. The exhaust noise was measured by arrays of near- and far-field microphones.

II. Test Installation

The APU was mounted inside a soundproof box to eliminate contamination of exhaust noise by inlet and case-radiated noise. The exhaust was located with its axis horizontal in the Boeing anechoic chamber. This anechoic chamber has a working space of $65 \times 75 \times 30$ ft and is lined with foam wedges.

A cut-away view of the AiResearch GTCP 85 gas turbine engine used is shown in Fig. 1a. In this figure, four of the six internal microphone locations are identified. In the APU application, the gas turbine is enclosed within a cooling shroud. The engine tailpipe ends within a secondary duct, as shown in Fig. 1b. This secondary duct is a part of the engine cooling shroud. The cooling air is sucked into the shroud by ejector action as the gas turbine engine exhausts within the secondary duct.

A schematic showing of internal and external acoustic instrumentation is presented in Fig. 2.

The internal probes in I1 through I4 were of the infinite tube type (Fig. 2c). The I5 and I6 probes were flush wall-mounted, water-cooled transducers. The locations for each of these internal probes are named in Fig. 2a. All of the internal probes were found to have linear frequency response (within ± 1 dB) in the frequency range of interest that was 0-1000 Hz.

The APU was tested at two typical operating conditions: 1) ON without bleed/electrical power and 2) ON with full bleed and full electrical power output. The results discussed in this paper were obtained at the second test condition.

III. Results

Internal-to-Far-Field Coherence Functions

On the upper portion of Fig. 3, narrow band spectra at the combustor exit and 120 deg far field (FF) are presented.† Visual examination shows no similarities in the spectra, except for the occurrence of humps in the 50-100 Hz and 200-400 Hz regions. When the coherence spectrum is obtained

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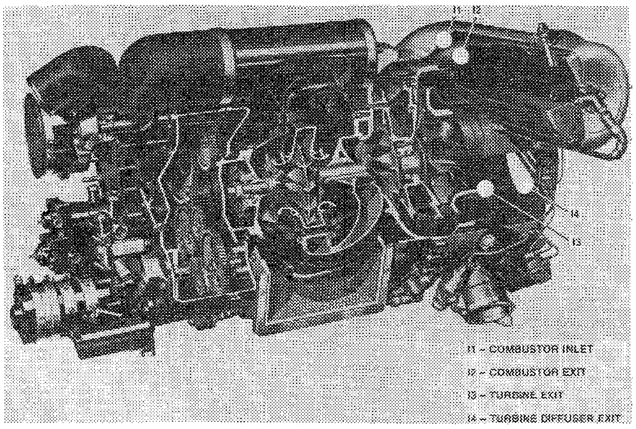
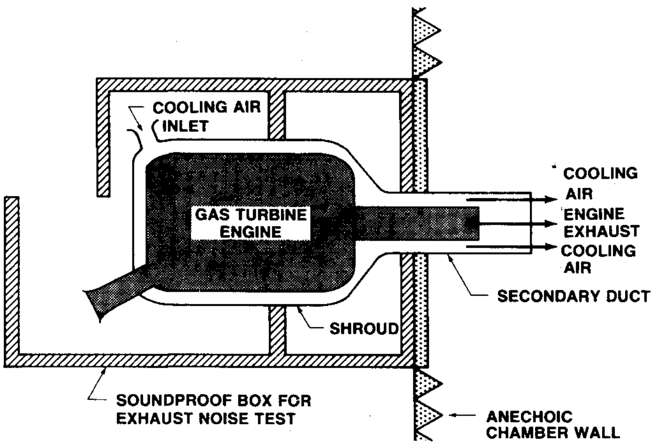
*Specialist Engineer, Noise Research Unit.

†The 400-Hz spike in the combustor exit spectra is due to electronic noise originating at the APU's 400-Hz electrical power generator.

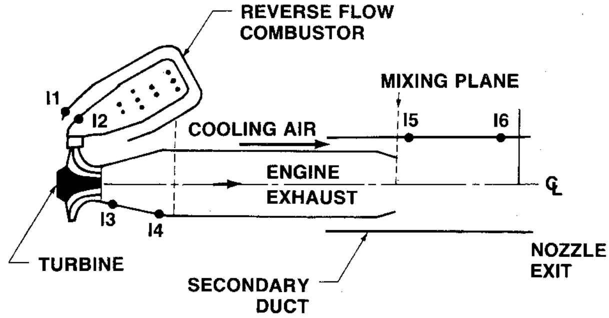


a) Auxiliary power unit gas turbine engine



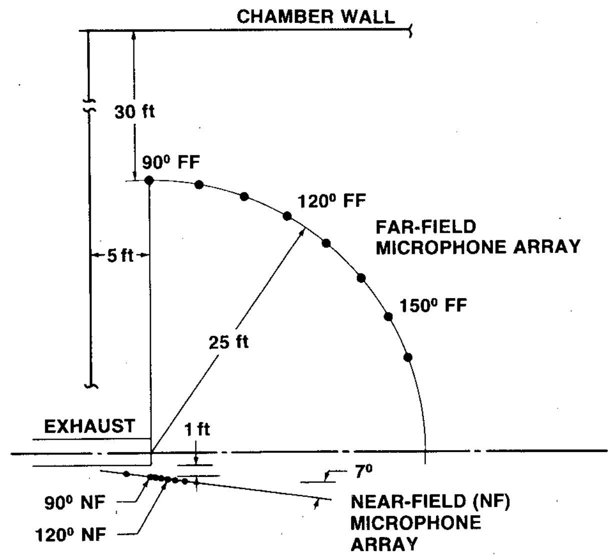
b) Test setup

Fig. 1 Test installation.

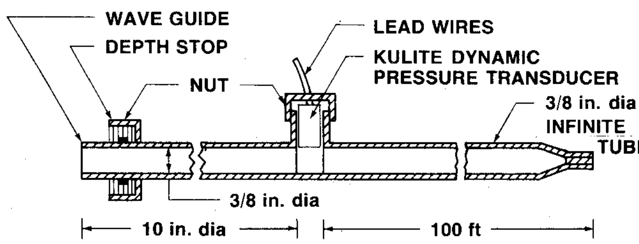


I1 COMBUSTOR INLET
I2 COMBUSTOR EXIT
I3 TURBINE EXIT
I4 TURBINE DIFFUSER EXIT
I5 MIXING PLANE
I6 NOZZLE EXIT

a) Internal microphones



b) External microphones



c) Infinite tube wave guide assembly – probes I1-I4

Fig. 2 Acoustic instrumentation.

(lower portion of Fig. 3), it is possible to distinctly see two regions that have strong coherence. One of the regions is between 0-100 Hz, while the other is between 200-400 Hz. Further, somewhat smaller coherence is observed in the region around 600 Hz. Therefore, at these frequencies, the combustor appears to be a dominant source of far-field APU noise.

Now the coherence function using the 120 deg FF microphone as the reference with various internal locations will be examined. In Fig. 4, the coherence function between the combustor exit and 120 deg FF microphone (Fig. 3) is reproduced. In addition the coherence function between the turbine diffuser exit and 120 deg FF and that between the mixing plane and 120 deg FF are included. It can be seen that there is a much greater coherence between the turbine diffuser exit and the far field, compared to that between the combustor exit and the far field. The coherences observed in the frequencies 0-100 Hz and 200-400 Hz still exist. In addition to this, stronger coherences in the frequency ranges 300-400 Hz, 500-650 Hz, and 700-1000 Hz are observed. This clearly indicates that noise generation occurs in the region between the combustor exit and the turbine diffuser exit. The coherence function analyses, however, cannot identify the noise-generating mechanism. The possibilities are: 1) the flow noise generated in the turbine inlet torus (Fig. 1a) and the 2) entropy noise. It is equally likely that both mechanisms are contributing to the far-field noise.

Referring back to Fig. 4, the mixing plane to 120 deg FF coherence is now examined. In addition to the coherence observed between the turbine diffuser exit and 120 deg FF locations, a considerably improved coherence is obtained at all frequencies between 150 and 1000 Hz. The reason for the improved coherence was judged to be additional noise generation at the mixing plane. This shows that the process of mixing between the engine exhaust and the cooling air within the secondary duct generates a significant amount of noise.

The coherence function between the nozzle exit and 120 deg FF locations is presented in Fig. 5. The coherence levels are much lower than those observed between the mixing plane and 120 deg FF locations, although it was expected that they would be very nearly the same. The reason for this is not clear at this time.

The coherence function between the combustor inlet probe (I1) and 120 deg FF is shown in Fig. 6. Strong coherence in the 0-100 Hz range, accompanied by a smaller coherence in the 350-400 Hz region, is observed. It is impossible to determine from the coherence analysis whether the noise generation occurred upstream or downstream of the combustor inlet

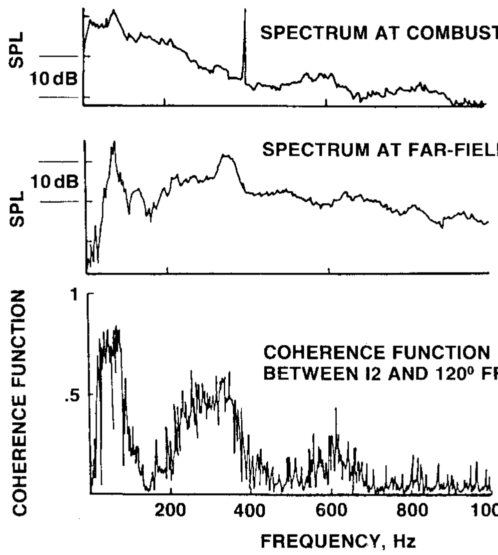


Fig. 3 Combustor exit and far-field correlation.

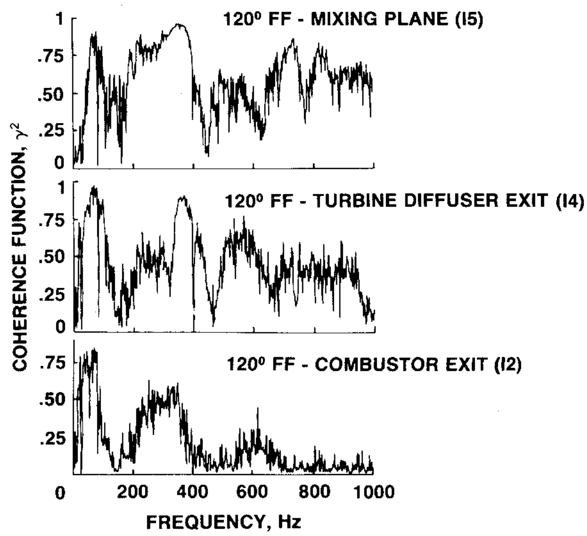


Fig. 4 Coherence between far-field and internal microphones.

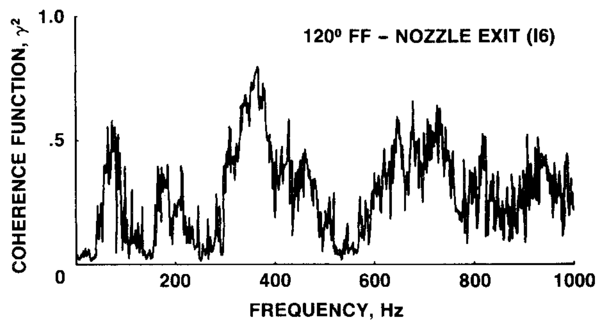


Fig. 5 Coherence between far-field and nozzle exit.

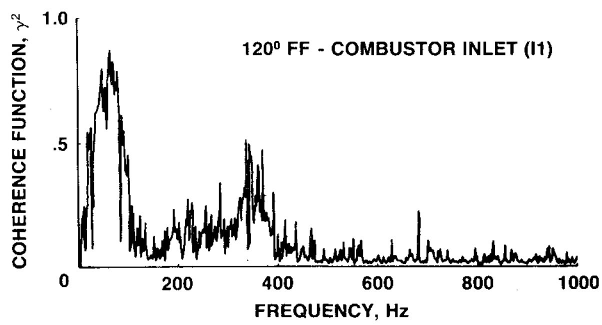


Fig. 6 Coherence between far-field and combustor inlet.

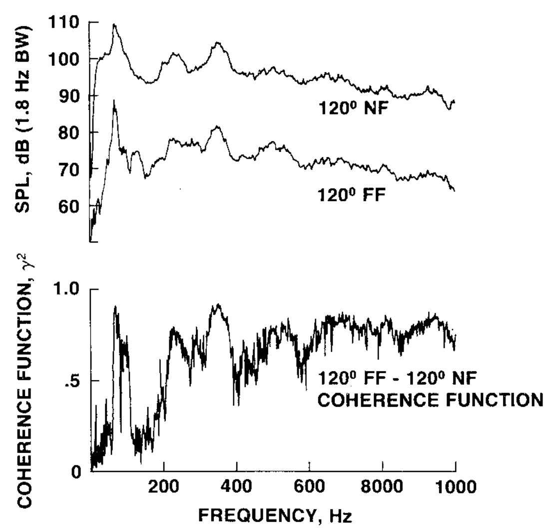


Fig. 7 Near-field to far-field comparison.

probe location. A cross-correlation function analysis can help in this respect. The results of cross-correlation function obtained using a frequency range of 0-1000 Hz between (I1) and 120 deg FF was compared to that between (I2) and 120 deg FF for this purpose. However, no clear conclusion could be drawn from this analysis regarding the source location for noise measured at (I1). If cross-correlations were obtained using a narrower frequency window, it may have been possible to improve the situation. Unfortunately, this has not yet been done.

Comparison Between Near-Field and Far-Field Spectra

The 120 deg NF and 120 deg FF spectra are compared in Fig. 7. The spectra are almost identical in shape and are about 23 dB apart. Assuming the nozzle exit as the origin, the 120 deg NF microphone was at 1.7 ft, whereas the 120 deg FF microphone was 25.0 ft. Spherical divergence gives 23.3 dB noise difference between the two locations. Thus, from the comparison between the near- and far-field spectra, the apparent sourc3 for far-field noise appears to be at the nozzle exit in the frequency range between 0 and 1000 Hz.

The coherence function between the near- and far-field acoustic signals is also presented in Fig. 7. The signals are found to be strongly coherent at most frequencies in the 0-1000 Hz range.

Internal-to-Far-Field Cross-Correlation Functions

Cross-correlation functions between the 120 deg FF microphone with itself and 120 deg NF microphone, together with those between 120 deg FF and five internal microphones, are presented in Fig. 8. These correlations were obtained using signals up to 1000 Hz.

The 120 deg FF to 120 deg FF autocorrelation has a normalized maximum value of 1.0 and the maximum occurs at zero time delay. The near- to far-field correlation maximizes at 21 ms and has a maximum value of 0.7 The lowering of the correlation coefficient may be due to the presence of exhaust jet noise. However, its high value indicates that both near- and fair-field microphones are measuring essentially the same noise signal, since 21 ms corresponds to the time required for a signal originating from the nozzle exit to travel the distance between 120 deg NF and 120 deg FF microphones.

Reasonably well-defined maxima are observed for the 120 deg FF to nozzle exit (I6) and 120 deg FF to mixing plane (I5) cases in Fig. 8. The time delays are consistent with the time

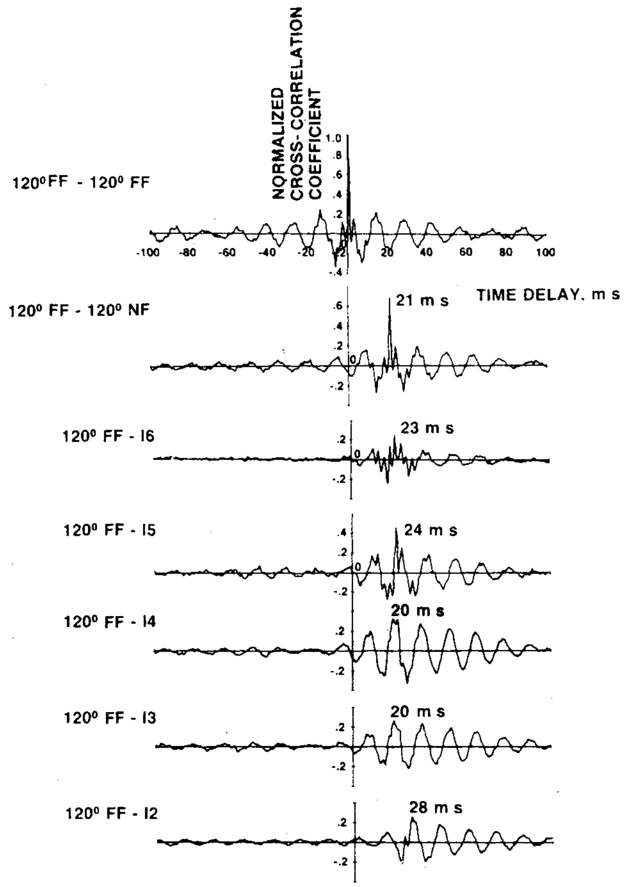


Fig. 8 Cross-correlation functions.

required for acoustic waves to travel the distance between the measurement stations. The maximum value of the cross-correlation function are much lower than 1.0. One of the reasons for this is that the correlation are obtained using 0-1000 Hz frequency range. However, as can be seen in Figs. 4 and 5, the signals are poorly coherent at certain frequencies e.g., at 180 Hz. These poorly coherent portions of the signals tend to lower the value of the overall cross-correlation coefficient.

Referring back to Fig. 8, it can be seen that correlation between 120 deg FF and turbine diffuser exit (I4) maximizes at 20 ms, compared to 24 ms for 120 deg FF-I5 correlation. This indicates that there is a source between the I4 location and the far field which is dominating the correlation. This source is nothing but the mixing noise within the secondary duct discussed earlier. The 120 deg FF to turbine exit (I3) correlation maximizes at about the same time delay as the 120 deg FF to I4 case since the I3 and I4 locations are within 6 inches of each other.

The 120 deg FF combustor exit (I2) correlation is found to maximize at 28 ms in Fig. 8. This time corresponds closely to the time an acoustic signal would require to travel the estimated distance between the I2 and 120 deg FF locations. Therefore, based on the cross-correlation function (Fig. 8) and coherence function (Fig. 5) analysis, it can be concluded that direct combustion noise contributes to the far-field noise a frequency below 400 Hz for the APU tested. This result is different from that of Ref. 2. In Ref. 2, it was reported that combustor to far-field correlation maximized at a time delay greater than acoustic propagation time and that it had a negative peak. The authors of Ref. 2 concluded that combustor to far-field correlation was not one of pure propagation. The results presented for the APU in this paper do show pure propagation from the combustor to the far field.

IV. Concluding Remarks

The results and discussions presented in this paper lead to the following conclusions:

1) Cross-correlation and coherence function analysis is an efficient method for core noise source isolation in gas turbine engines.

2) Direct combustion noise contributes to the APU far-field noise in the frequency range below 400 Hz.

3) Additional noise generation occurs between the combustor exit and the turbine exit, the source of which could be flow noise in the turbine inlet torus or entropy noise.

4) The noise due to mixing of the engine exhaust with the cooling air within the secondary duct contributes significantly to the far-field APU noise.

Acknowledgments

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References

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