NASA TECHNICAL MEMORANDUM

NASA TM X-73556

NASA TM X-73556

(NASA-TM-X-73556) MACROSCOPIC STUDY OF TIME UNSTEADY NOISE OF AN AIRCRAFT ENGINE DURING STATIC TESTS (NASA) 14 p HC A02/MF A01 CSCL 20A
N77-11052
Unclas
G3/07 54532

MACROSCOPIC STUDY OF TIME UNSTEADY NOISE OF AN AIRCRAFT ENGINE DURING STATIC TESTS

by B. J. Clark, M. F. Heidmann, and W. J. Kreim
Lewis Research Center
Cleveland, Ohio 44135

TECHNICAL PAPER to be presented at the
Ninety-second Meeting of the
Acoustical Society of America
San Diego, California, November 16-19, 1976

E-8995

MACROSCOPIC STUDY OF TIME UNSTEADY NOISE OF AN AIRCRAFT ENGINE DURING STATIC TESTS

by B. J. Clark, M. F. Heidmann, and W. J. Kreim

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

Static tests of aircraft engines can exhibit greater than 10 dB random unsteadiness of tone noise levels because flow disturbances that prevail near test site facilities are ingested. Presumably such changes are related to installation and test site features. This paper presents some properties of unsteady noise observed at a NASA-Lewis facility during tests of a Lycoming YF-102 turbofan engine. Time and spatial variations in tone noise obtained from closely spaced far-field and inlet duct microphones are displayed. Long (0.5 sec) to extremely short (0.001 sec) intermittent tone bursts are observed. Unsteadiness of the tone, its harmonics, and the broadband noise show little similarity. In the far-field, identity of tone bursts is retained over a directivity angle of less than 10^{o}. In the inlet duct, tone bursts appear to propagate axially but exhibit little circumferential similarity. They show only slight relationship to tone bursts observed in the far field. The results imply an intermittent generation of random mixtures of propagating duct modes.

INTRODUCTION

An important current problem in the calculation of the noise levels for an aircraft in flight is the amount and kind of correction to be allowed for the effect of the "clean-up" in inlet flow on fan noise generation. Acoustic tests of turbofan engines for aircraft are typically performed on a static test stand at various engine conditions. Appropriate corrections must then be made when attempting to use this data to predict engine noise levels at various flight conditions.

Fan-generated tones, especially at the blade passing frequency (BPF), arise from interaction of the rotor with inlet turbulence and vortices resulting in pressure disturbances on the rotor blade surfaces (refs. 1 and 2), and from "rotor-stator interaction" as the rotating wakes from the rotor blades impinge on the stator blade surfaces (ref. 3). During static testing, the noise levels due to inflow disturbances can be very high, depending on the local air turbulence and induced vortices caused by the particular test site and installation (refs. 4 to 6). In testing quiet fans designed to minimize rotor-stator interaction noise (ref. 7), inflow distortion noise becomes the dominant noise source. The noise ad-

STAR category 01

vantages of designing for "cut-off" of certain tones cannot be evaluated solely by static testing unless inlet flow disturbances can be eliminated or minimized (ref. 8). In some cases of static testing (ref. 9), fine screens have been installed across the flow approaching the bellmouth inlet in an attempt to attenuate local turbulence and vortices.

In the NASA Refan Program, acoustic measurements in the inlet duct of the JT8D-109 engine demonstrated a high degree of variability in the BPF tone level in static testing (ref. 5). However, during flight the BPF tone level was relatively steady. Other evidence pointing to the time-unsteadiness in these tones comes from experience in spectral analysis of engine noise data. Some experimentors use averaging times as long as 30 seconds in an attempt to obtain stationary averages for tone levels. Averaging times of a few seconds may show as much as 5 decibels variation in BPF tone levels during a constant-speed run.

During acoustic and aerodynamic performance evaluation of a high bypass turbofan engine on a static test stand at Lewis Research Center (Fig. 1), observations made by ear while walking around the engine indicated that there might be narrow lobes of intense sound which could be missed by microphones placed at 10 degree intervals. However, it was impossible to distinguish between spatial fluctuations and time fluctuations in the tones. Accordingly, for the results in this paper, the intense region of the inlet noise field was monitored by microphones spaced at 2 degree intervals. The tape-recorded signals from these microphones and from microphones in the engine inlet duct were then time-expanded to reveal the nature of the time fluctuations at each point.

The purpose of this paper is to display these time and spatial fluctuations in some detail in the hope it will lead to better understanding of those processes which cause elevated tone levels in static acoustic testing of fans.

TEST DESCRIPTION

Turbofan engine. - The acoustic data were obtained during a Lewis Research Center test program to evaluate the acoustic and aerodynamic characteristics of the AVCO-Lycoming YF102 engine. Four of these engines will be used in the Quiet Short-Haul Research Aircraft being built for Ames Research Center. The engine (fig. 1) consists of a modified T-55 core driving a 6:1 bypass-ratio fan exhausting through a separate flow nozzle. The fan stage has 40 rotor blades and 85 stator vanes. The fundamental blade passing tone due to rotor-stator interaction is cut-off below about 6650 rpm, while that due to rotor-alone is cut-off below 5740 rpm (fig. 2). For the results shown in this paper, fan speeds were limited to approximately 3800 rpm. Relative Mach number of the flow at the blade tips is subsonic below about 6400 rpm. After the fan the core flow goes through a supercharger stage with 90 rotor blades.

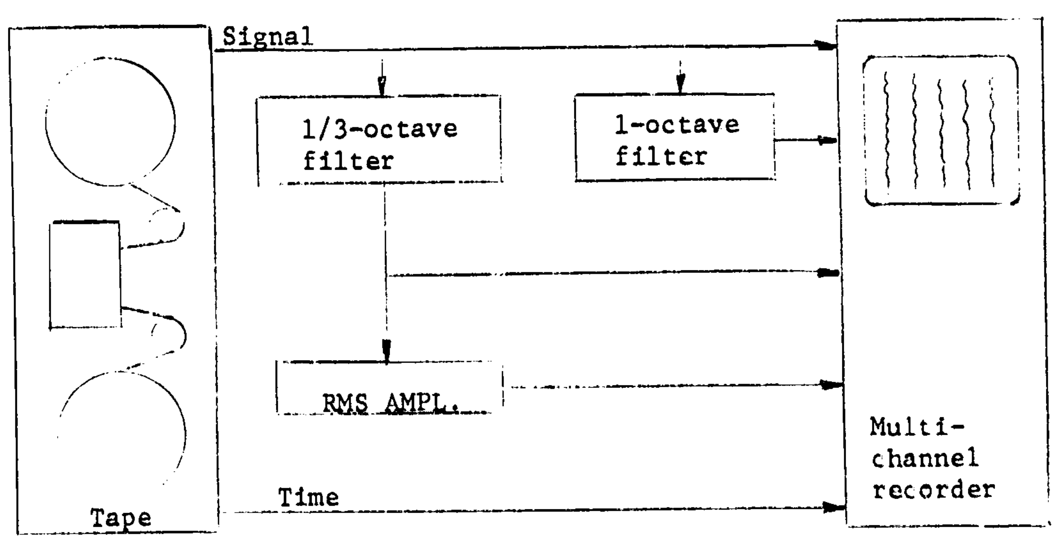
For static testing the engine inlet was cylindrical, terminating with a bellmouth. Within the cylindrical inlet duct, three 1/4-inch microphones were flush-mounted at a two-inch spacing alined circumferentially and axially (fig. 3).

Acoustic arena. - In addition to the duct microphones, far-field microphones were distributed on a 100-foot arc as shown in figure 3. Microphones were placed on the ground to avoid ground reflection interference. Between 30° and 50° from the inlet axis microphones were spaced at 2 degree intervals in order to detect any narrow lobes of sound in this region.

All far-field microphones were 1/2-inch diameter condenser type with a frequency response flat (±2 dB) to 20 kilohertz.

The outputs of the microphone amplifiers were FM-recorded simultaneously on two 14-channel tapes. Standard IRIG time code was also recorded on both machines so that good time correlation could be maintained.

Acoustic analysis. - To obtain detail of the fluctuating tone levels, the acoustic data tapes were played back at slower speeds to give time expansion factors of up to 32. Tape outputs were filtered through a standard Bruel and Kjaer 1/3-octave and/or one-octave filter. For com-



parison of the slower fluctuation characteristics, the output from the 1/3-octave filter was converted to a slowly varying d.c. signal by a Bruel and Kjaer RMS amplifier output. The frequency response was limited by the RMS circuit to about 20 Hz. Signals were recorded at various paper speeds on a Brush multi-channel recorder. The one-kilohertz carrier of the IRIG time code was recorded simultaneously with each data sample. The sample time traces shown in the figures of this paper are representative and are selected from the same time interval during the run.

The time-averaged spectra were taken from the FM tape recording using standard analyzers. The sound pressure levels (SPL) for the 1/3-octave spectrum were derived from 12-second averages of the signals. The narrow band (60 Hz bandwidth) spectrum was obtained from a 500-line analyzer using 128 ensemble averages.

RESULTS AND DISCUSSION

Time-averaged data. - At intermediate speeds or power settings, the YF102 engine generates noise typical of a high bypass-ratio turbofan engine. The fan tip speed is subsonic and jet velocity is moderate, hence the spectrum consists of broadband fan and internal noises with fan and turbine tones superimposed (figs. 4 and 5). The most prominent far-field tone at these speeds is the blade passing tone, as shown by both 1/3-octave and narrow-band spectra for the microphone at 40 degrees from the engine inlet. The narrow-band spectrum shows that tones from the fan and supercharger are the main contribution to the high frequency region of the spectrum. (Note that a one-octave filter bracketing the BPF tone will not pass the higher harmonics.) The higher fall-off in the high frequency region of the far-field spectrum relative to the in-duct spectrum is mainly due to atmospheric attenuation, for which no correction is made in these examples.

The closely spaced microphones used for these experiments are able to distinguish some finer variation in directionality (fig. 6) than would be shown by microphones at the usual 10 degree spacing intervals. The 1/3-octave BPF tone level has a similar directionality pattern to the overall noise level. Although the data show variations with angle of several decibels, no clear lobe pattern is evident in these time-averaged values. The prominence of the noise in the region of 20 to 40 degrees is obvious.

Time fluctuations. - In figure 7 samples of the time fluctuations in the 1/3-octave and one-octave filtered BPF tones are shown for the 40 degree microphone. Pressure traces of the filtered microphone output are displayed at several time expansions, with brackets to indicate the period of time common to all expansions. The average 1/3-octave SPL at 40 degrees for this condition is 92 dB Note that the period of the fluctuations ranges from on the order of one second to about a millisecond. In fact, the traces from the one-octave filter even show appreciable differences between adjacent peaks Both slow and fast fluctuations are of very high amplitude (doubling the amplitude corresponds to a 6 dB increase in level). There are many instances of rapid change, where the level changes at a rate of 10 dB or more per millisecond. The bursts appear random in both the long term and short term. In some instances cancellations may be occurring giving briefly a local amplitude of zero.

Time fluctuations in the 40 degree microphone and in the near-field signals obtained by microphones in the inlet duct wall are compared at high and low time expansions in figures 8(a) and (b). The individual curves do not have matching grids because they were recorded separately and assembled by means of the recorded time code signal. The fluctuation phenomena look similar in these duct and far-field signals, in that the amplitude of the fluctuations and their period or scale are of the same order. However, detailed comparisons of the phasing and character of individual bursts show that they are mostly unrelated (transit time from the near field to far field is approximately 0.1 sec). Whereas the axially alined microphones (#2 and #3) are similar in fluctuations, the circumferentially alined pair (#1 and #2) show little similarity, particularly when viewed at the greater time expansion. It should be noted that when averaged over several seconds, the three duct microphone outputs are essentially the same.

The surprising lack of similarity in acoustic signals from two microphones spaced circumferentially only two inches apart can be rationalized in two ways. In terms of distributed random sources across the fan face, the sources propagate primarily axially with random interference (constructive or destructive) at various points around the circumference. Hence, the observed tone bursts at two circumferential stations are unrelated. In terms of acoustic modes present in the duct, the modal propagation is mainly axial rather than spiral. At least parts of the modal content must be random in phase and/or amplitude, so that two distinct but proximate points see unrelated patterns of interference between modal mixtures.

Figure 8(c) demonstrates a time trace of the RMS level of the BPF-tone 1/3-octave band from these same 40-degree and duct microphones. Because of the reduced tape playback speed, the RMS converter circuit is able to faithfully follow fluctuations in pressure amplitude up to rates somewhat above 100 hertz. The correspondence between the RMS output and the filtered pressure trace appears very good at low frequencies.

The next question is whether or not the fluctuations in the near field (inlet duct) appear to have any relationship to fluctuations somewhere in the far field. Comparisons at low frequencies (larger scale disturbances) are facilitated by using the RMS of the tones. In figure 9 the RMS levels of a duct microphone and all the far field microphones are displayed for comparison. For the limited number of locations in the inlet and in the plane of the ground microphones, there is very little recognizable commonality. Among the far-field microphones, major "events" causing large perturbations in one microphone can be recognized only in adjacent microphones within about ±6 degrees. Even in adjacent microphones (with a 2 degree, or approximately $3\frac{1}{2}$-foot separation on a 100-

foot radius), there is considerable difference in the character and amplitude of the fluctuations. Thus, although no strong lobes were apparent in the time-averaged acoustic data, the random tone bursts seem to be concentrated in narrow lobes randomly distributed in the inlet region of the acoustic far field.

Fluctuations in the BPF third harmonic and in the BPF tone are shown in figure 10 along with the unfiltered pressure signal. At the third harmonic the filter bandwidth is three times as wide as at the fundamental, allowing more rapid fluctuations to pass than in the BPF filter. Amplitude of the harmonic fluctuations is much lower than of the BPF, and there seems to be no similarity to the BPF fluctuations. It may be that at this fan speed the third harmonic fluctuations are somewhat masked by the sum tone of the supercharger and fan stage fundamentals, which falls within the same 1/3-octave band (fig. 5).

The relationship between the broadband noise level and the BPF tone level is shown in figure 11. The broadband level chosen for illustration is the 1/3-octave filter output at 0.64 BPF (two 1/3-octave bands below BPF). The narrower bandwidth limits the rate of fluctuation in the filter output. Comparison of the broadband and tone fluctuations indicates that the perturbations generating tone bursts are not related to the broadband noise level.

CONCLUDING REMARKS

Several observations should be made about these data:

1. The signals shown are highly variable in both time and space. The duration of a tone burst is often less than the propagation time as an acoustic wave to the upstream end of the inlet. Some large fluctuations persist for only a few cycles of blade passing tone. Adjacent closely spaced microphones in the far field frequently show large differences in their time histories. Therefore, whatever acoustic modes exist in the inlet duct must have correspondingly large temporal and spatial variability in their strengths. Some of this may be due to random constructive and destructive interference between modes.

2. In view of the observed high degree of variability, time-averaged tone levels in the far-field may not correspond to any specific modes in the inlet at any time. Rather, far-field patterns represent the effect of averaging the instantaneous sum of the far-field pressures produced by various short-lived modes in the inlet duct.

3. The same kind of fluctuations occur in all the signals, so that comparisons made between time-averages are meaningful.

4. The effects are probably unique to static testing at or near the ground; scales and amplitude may vary with features of the test site.

5. The results presented herein are intended to stimulate more investigation and to caution analysts on the use of averaged data obtained in static tests.

REFERENCES

1. C. E. Feiler and J. E. Merriman, "Effects of Forward Velocity and Acoustic Treatment on Inlet Fan Noise," Paper No. 74-946 (AIAA, New York, 1974).

2. D. B. Hanson, "Spectrum of Rotor Noise Caused by Atmospheric Turbulence," J. Acoust. Soc. Am. 55, S3-S4 (1974).

3. J. D. Kester and G. F. Pickett, "Application of Theoretical Acoustics to the Reduction of Jet Engine Noise," J. Physics D: Appl. Phys. 5, 12-27 (1972).

4. J. E. Merriman and R. C. Good, "Effect of Forward Motion on Fan Noise," Paper No. 75-464 (AIAA, New York, 1975).

5. J. E. Merriman, et al., "Forward Motion and Installation Effects on Engine Noise," Paper No. 76-584 (AIAA, New York, 1976).

6. N. A. Cumpsty and B. W. Lowrie, "The Cause of Tone Generation by Aero-Engine Fans at High Subsonic Tip Speeds and the Effect of Forward Speed," Paper No. 73-WA/GT-4 (ASME, New York, 1973).

7. M. F. Heidmann, "An Observation on Tone Cut-off in Static Test Data from Jet Engine Fans," NASA TM X-3296 (1975).

8. B. W. Lowrie, "Simulation of Flight Effects on Aero Engine Fan Noise," Paper No. 75-463 (AIAA, New York, 1975).

9. J. P. Roundhill and L. A. Schaut, "Model and Full Scale Test Results Relating to Fan Noise In-Flight Effects," Paper No. 75-465 (AIAA, New York, 1975).

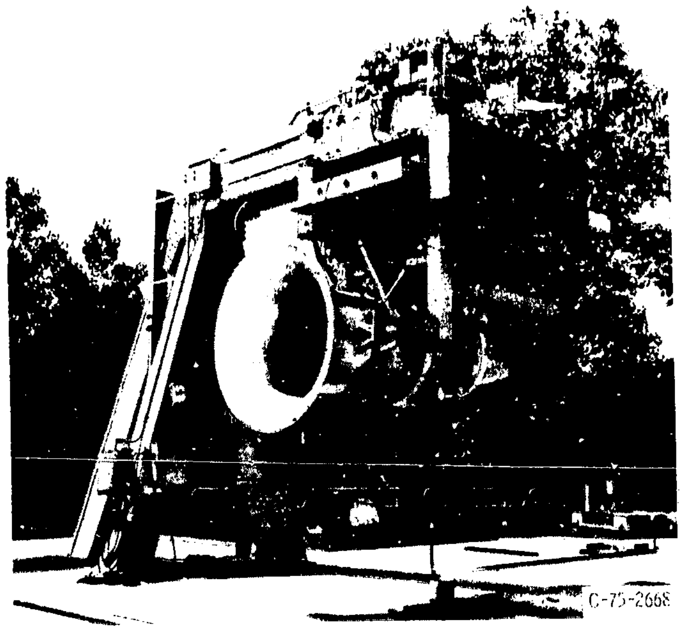


Figure 1. - Turbofan engine in test stand at Lewis Research Center.

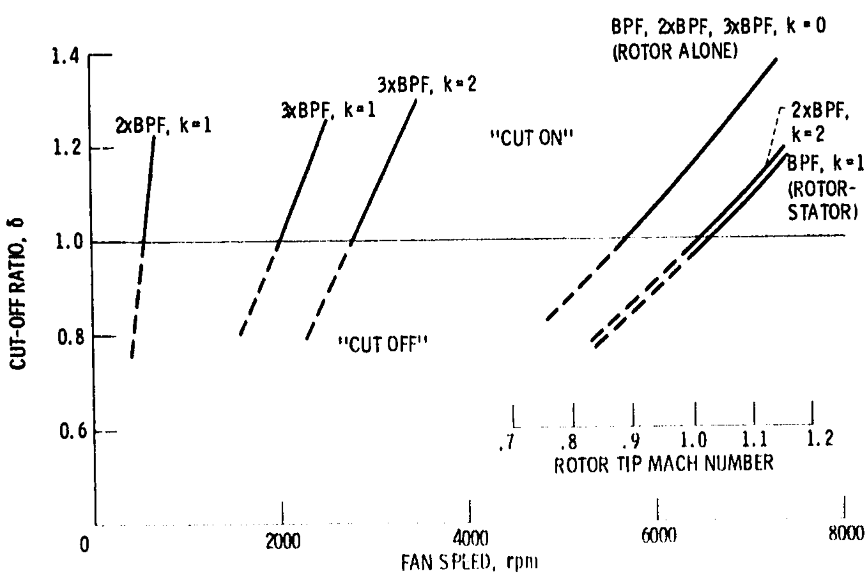
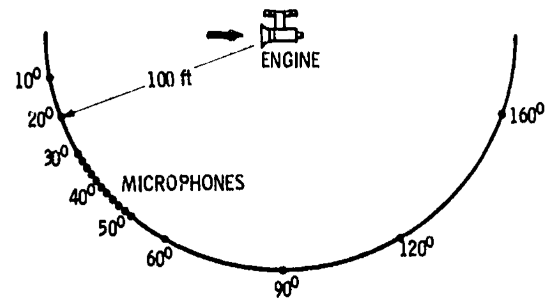
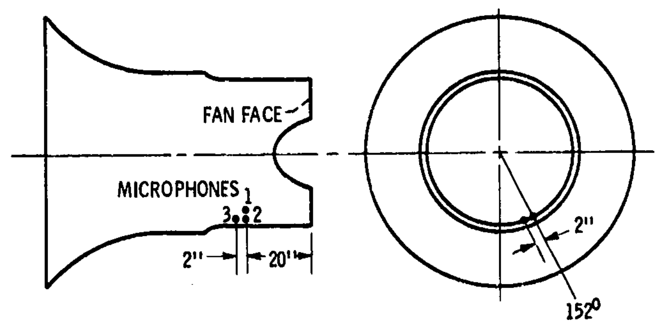


Figure 2. - Cut-off ratios for fan tone and harmonics of YF 102 turbofan engine. Lines shown are for those modes with lowest order radial component. Cut-off ratios $\delta = \frac{nM_T B}{nB - kV}\left(\frac{1}{M\sqrt{1 - M_x^2}}\right)$.



(a) FAR-FIELD ACOUSTIC ARENA.



(b) NEAR-FIELD MICROPHONE LOCATIONS IN ENGINE INLET.

Figure 3. - Locations of near-field and far-field microphones.

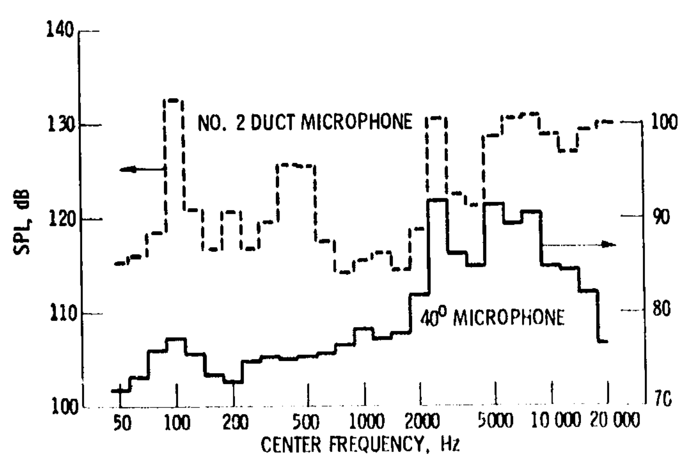


Figure 4. - Time-averaged 1/3-octave sound pressure levels (SPL) spectra of near-field inlet duct microphone no. 2 and far-field microphone at 40°, uncorrected for atmospheric attenuation. Engine at 3800 fan rpm.

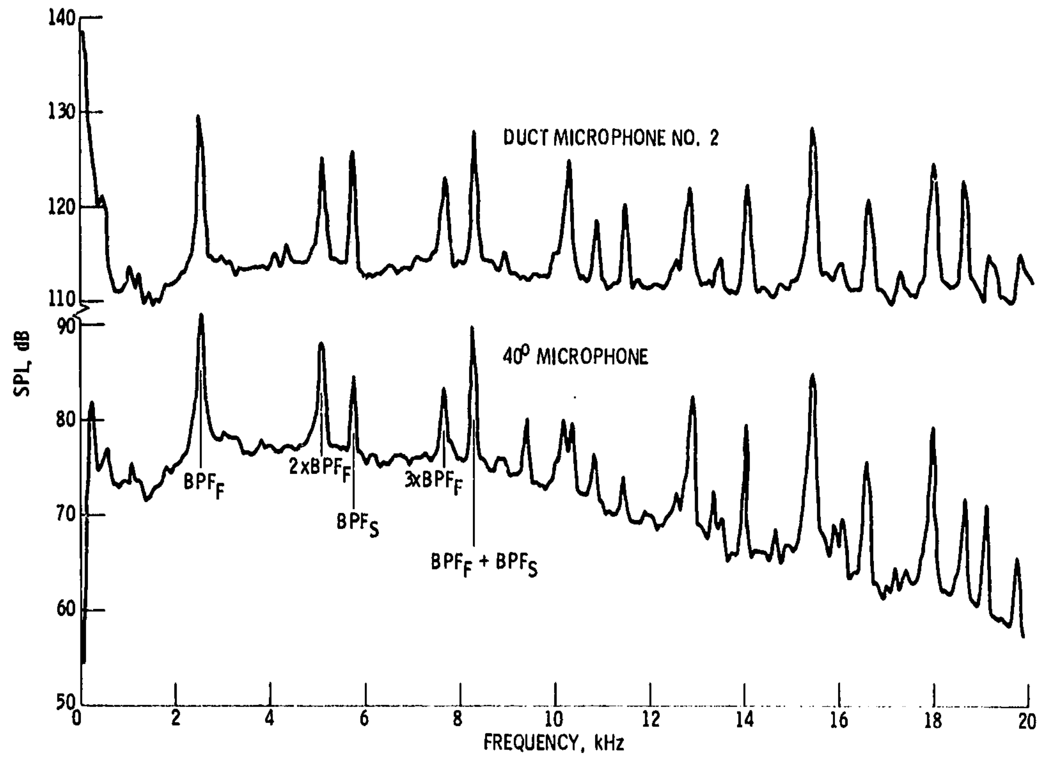


Figure 5. - Narrow-band spectra of near-field and far-field microphones. Engine at 3800 fan rpm. Filter bandwidth is 60 Hz. Subscripts F and S refer to fan and supercharger, respectively.

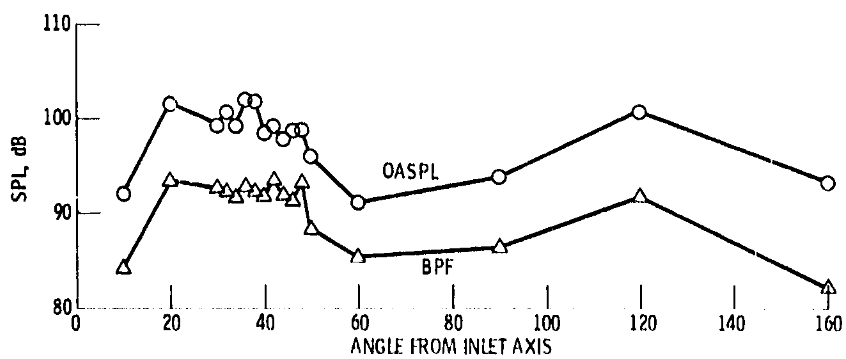
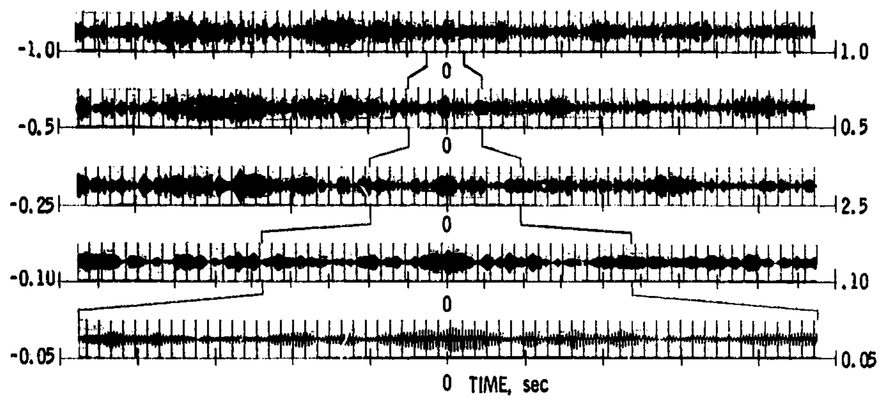
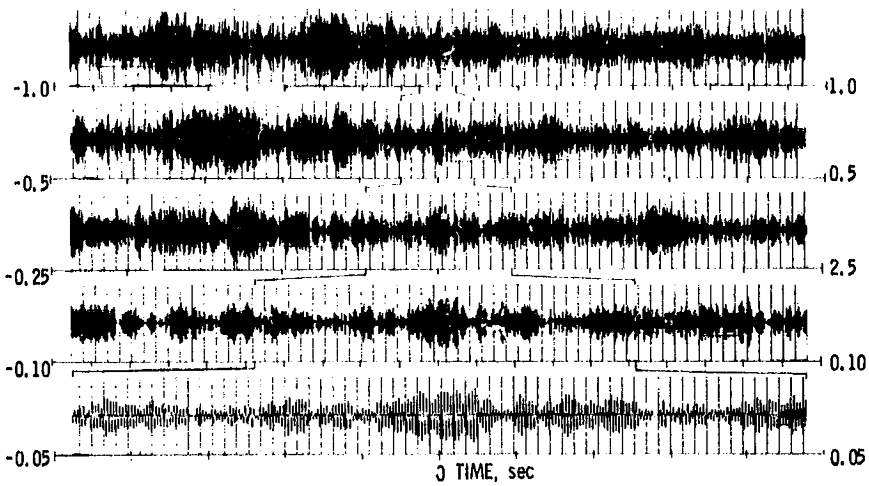


Figure 6. - Directionality of OASPL and 1/3-octave SPL of blade passing tone (BPF) on 100-foot radius, 3800 fan rpm.



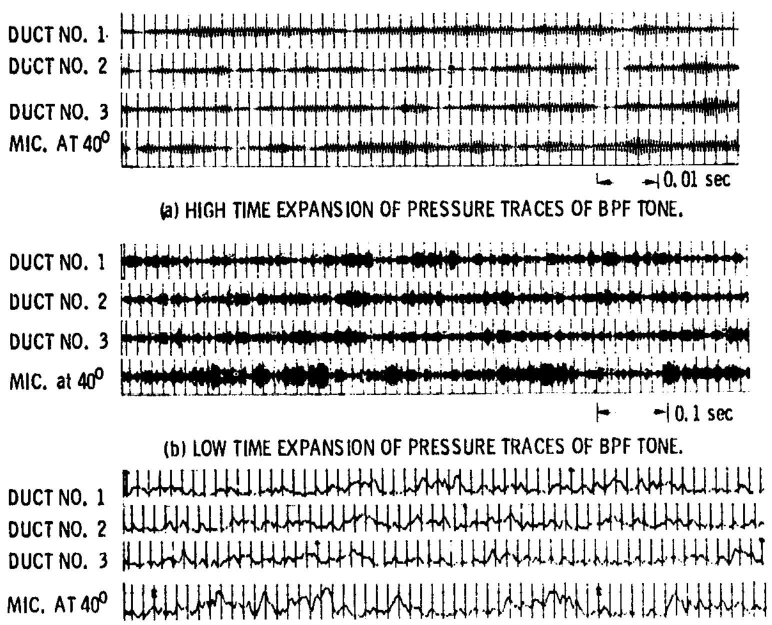
(a) ONE-THIRD OCTAVE FILTER OUTPUT.

Figure 7. - Various time expansions of BPF-filtered signals from 40° microphone; fan speed is 3800 rpm.



(b) ONE-OCTAVE FILTER OUTPUT.

Figure 7. - Concluded.



(a) HIGH TIME EXPANSION OF PRESSURE TRACES OF BPF TONE.

(b) LOW TIME EXPANSION OF PRESSURE TRACES OF BPF TONE.

(c) RMS OF BPF TONE AT LOW TIME EXPANSION.

Figure 8. - Comparisons at high and low time expansion of duct and 40° microphone pressure traces from 1/3-octave filter, and corresponding RMS amplitude fluctuations.

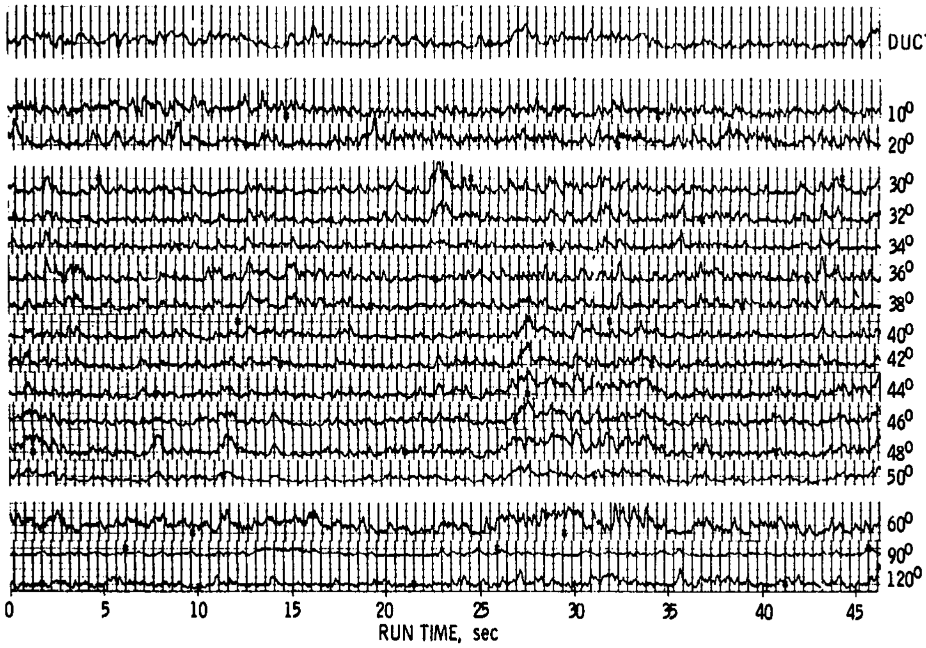


Figure 9. - Comparisons of RMS of BPF tones in near-field and far-field microphones.

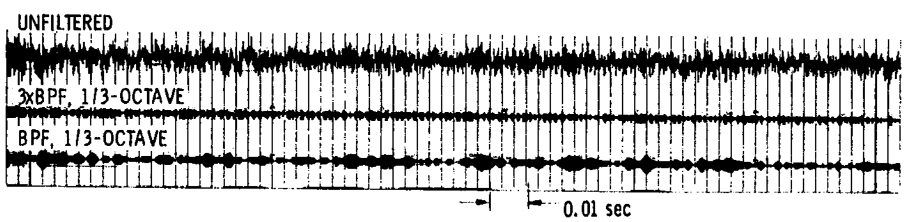


Figure 10. - Comparison of fluctuations in BPF tone level with those of its third harmonic (3xBPF); microphone is at 40°, and fan is at 3800 rpm.

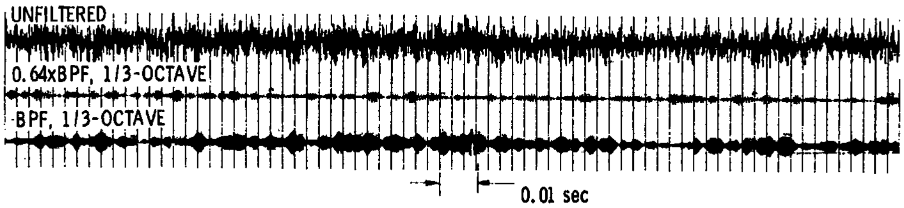


Figure 11. - One-third octave comparison of fluctuations in broadband noise level at 0.64xBPF (two 1/3-octave bands below BPF) with tone level fluctuations at BPF. Signals are from 40° microphone; fan speed is 3800 rpm.

F-6395