GL-TR-90-0225

Infrasonic Emissions From the Otis AFB Hush House

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10 September 1990

Scientific Report No. 6

GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731-5000

"This technical report has been reviewed and is approved for publication"

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	10 September 1990	Scientific Report No.6

4. TITLE AND SUBTITLE
Infrasonic Emissions from the Otis AFB Hush House

5. FUNDING NUMBERS
PE 61101F
PR 7600
TA 09
WUAG
Contract F19628-86-C-0055

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Geophysics Laboratory/Earth Science Division/LWH
Hanscom AFB
Bedford, MA 01731-5000

Contract Manager: James C. Battis/LWH

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
GL-TR-90-0225

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
approved for public release;
distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Hush House infrasonics produced by F-100 engine runs at Otis AFB appear to be generated by a single point source located in the vicinity of the exhaust deflector. The results of this study suggest that a non-vertical jet plume might be an appropriate source model for the Hush House infrasonics. When tested at military power, engines installed on a test stand produce slightly stronger infrasonic emissions than engines installed in an aircraft. The most significant factor in the overall level of infrasonic emissions, however, is whether the engines are run at military power or in afterburner. The azimuthal radiation pattern of infrasonics generated by the Otis Hush House is, in a general sense, comparable to that reported for the Hush House at Luke AFB. The peak sound level observed behind the Hush House at audible frequencies is not generally observed for infrasonic pressure vibrations. In fact, at frequencies lower than about 10 Hz, pressure vibrations are generally greater along the side of the Hush House than behind the facility.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Jet engine noise, infrasonic emissions acoustic vibrations, noise suppression.	42
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassfied	Unclassified

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1. INTRODUCTION

The T-10 jet engine noise suppressor (Hush House) at Otis AFB is part of an Air Force wide effort to upgrade engine test operations with a standard test cell. Figure 1 shows a plan view of a model T-10 Hush House. The Hush House at Otis AFB was built in 1985. Acceptance tests were concluded in October of that year with a J75 engine on a test stand and installed in an F-106A aircraft. For acceptance, "A-weighted" pressure levels (Beranek, 1971) were measured at 20 points over a pair of arcs centered 250 feet from each end of the Hush House augmenter tube (Figure 2). Sound levels recorded for those acceptance tests are shown in Figure 3. The sound level around the Hush House is not uniform. The peak sound level radiated by the Hush House generally occurred behind the facility (in the direction of the exhaust deflector) when the engine was operated in afterburner installed on a test stand.

Acceptance and impact estimates for siting Hush Houses are based on spherically propagated A-weighted pressure levels. These criteria, however, do not fully account for vibroacoustic emissions from Hush Houses because the noise suppression characteristics of a Hush House are achieved, at least in part, by the transfer of energy from the audible (>20 Hz) to the infrasonic (<20 Hz) band. The ability to forecast Hush House generated vibrations, therefore, requires estimating pressure emissions at infrasonic frequencies, well below the audible (A-weighted) band.

This study of the Otis AFB Hush House is a step towards constructing a data base to define the Hush House as an infrasonic source. The resulting data base can be used to test concepts for forecasting and controlling unwanted vibrations excited by current and future engine "sound suppression" cells. The overall objective of this type of study is to develop an infrasonic source model for Hush Houses and to test the extent to which that model is independent of a particular location. In this report, we present the results of a study of infrasonics emitted by the Otis AFB Hush House, and we compare the results from the Otis Hush House with previous results obtained from a study of Hush House emissions at Luke AFB.

2. FINDINGS

Hush House infrasonics produced by F-100 engine runs at Otis AFB can be accurately modelled by a single point source, located in the vicinity of the exhaust deflector. This type of single point source model was also hypothesized for the Hush

House at Luke AFB (Beaupre and Crowley, 1987). The results of this study indicate that there is no evidence of a second low-frequency source associated with the air intakes at the front of the Hush House.

Although it was previously concluded by Beaupre and Crowley (1987) that the Hush House infrasonics could be modelled as a vertical annular jet, the results of this study suggest that a non-vertical jet plume might be an appropriate source model.

When tested at military power, engines installed on a test stand produce slightly stronger infrasonic emissions than engines installed in an aircraft. The most significant factor in the overall level of infrasonic emissions, however, is whether the engines are run at military power or in afterburner.

The azimuthal radiation pattern of infrasonics generated by the Otis Hush House is, in a general sense, comparable to that reported by Beaupre and Crowley (1987) for the Hush House at Luke AFB. The peak sound level, observed at audible frequencies, behind the Hush House (in the direction of the exhaust deflector) is not generally observed for pressure vibrations in the infrasonic frequency range. In fact, at frequencies lower than about 10 Hz, pressure vibrations are generally greater along the side of the Hush House than behind the facility.

3. THE OTIS AFB HUSH HOUSE

The Hush House at Otis AFB is currently used for Air National Guard verification tests with F-100 engines mounted either on a test stand or installed in F-15 aircraft. Otis AFB is located on a glacial moraine, consisting largely of unconsolidated sand and gravel. The ground structure underlying the Hush House facility is revealed by nearby drilling logs, and is found to be uniform. The depth to the water table is about 70 m, and the depth to bedrock is about 150 m.

A plan view of the facilities in the area surrounding the Otis Hush House is shown in Figure 2. The area south and west of the Otis Hush House is flat and clear of structures. To the east, a large aircraft hanger strongly reflects pressure loads emitted from sources near the Hush House. Pressure levels east of the Hush House are likely to be significantly altered by reflections from this hanger. In contrast, pressures to the west of the Hush House are probably only weakly modified.

Based on the results of the acceptance tests, the Otis AFB control tower and Fire House lie in a strong acoustic lobe (i.e. behind the Hush House). Occupants have reported that strong, disruptive vibrations are excited in the Fire House (the closer of the two facilities) when the test cell is in use.

4. THE MEASUREMENT SYSTEM AND RECORDED DATA

The Air Force Geophysical Data Acquisition System (GDAS) was used to measure the Hush House emissions. The system records and stores seismic and pressure measurements taken from up to 16 sensors. These measurements are recorded at 100 scans/sec for later retrieval, display and analysis. The system is calibrated with its sensors in place. A typical response for the GDAS pressure channels is shown in Figure 4. The measurement band for this study was chosen to cover low mode resonances of "large" class structures with a modest frequency overlap into the A-weighted acoustic regime.

In this study, pressure sensors were placed on the ground under a permeable, low silhouette (molded "horse hair") wind shield that stagnates airflow in the immediate vicinity of the transducer. The GDAS sensors were installed at the following locations (Figure 2 and Table 1):

Location 1. A seven element array was centered at a distance of 110 m and an azimuth of 115° from the center of the Hush House exhuast deflector. This array was centered at appoximately the same azimuth and distance from the Hush House as one of the measurent sites at Luke AFB in Arizona.

Location 2. Three recording sites (sites 1, 2, and 3) were installed in the vicinity of the acceptance point located at an azimuth of 53°. Site 3 is located in the same position as that acceptance point.

Location 3. Three recording sites (sites 5, 6 and 7) were installed in the vicinity of the acceptance point located at an azimuth of 110°. Site 7 is located at the same position as that acceptance point.

For each engine run, 30 sec of pressure signal was recorded at each site. Each 30 sec trace was processed to produce an average power spectral density plot by averaging spectra calculated from a series of 2.56 sec overlapping time windows. These measurements extend the acoustic (A-weighted) measurements into the infrasonic band, and they provide data to test the hypothesis that the single point source model should be extended to include additional point sources.

5. AMBIENT PRESSURE

Hush House emissions, albeit intense, are only one of a number of disturbances that affect the infrasonic environment at Otis AFB. Hence, measurements were collected to establish ambient pressure levels close to the flight line free of Hush House generated disturbances. An example of the ambient pressure spectra is given in Figure 5. The ambient pressure spectra exhibit the characteristic frequency "roll-off" and spatial coherency associated with wind driven turbulence (Beranek, 1971). The overall strength of these pressure fluctuations is controlled by topography, surface "roughness", and wind speed.

GDAS hardware noise is a trivial contributor compared to the ambient pressure levels. The signal-to-noise ratio was estimated from the ratio of pressure spectra at recording site 2 (102 m from the Hush House) with the test cell active and dormant. The results from that site show that, when the engines were running at military power, the Hush House disturbance ranges from about 10 times greater than ambient at 5 Hz to about 50 times greater than ambient at 20 Hz. Signal-to-noise ratios were significantly greater when the engines were running in afterburner. At the times that these measurements were made, the Hush House could be considered to be the dominant infrasonic "noise" source at Otis AFB, even for points quite close to the flight line.

6. INFRASONIC EMISSION LEVEL

Observed spectra are shown in Figures 6 through 15 for pressures measured at sites 3 and 7 with the Hush House operating F-100 engines at two different power settings (and engines in and out of the aircraft). Of the 10 Hush House operations investigated in this study, three runs involved engines running on a test stand and seven involved engines installed in an F-15 aircraft (Table 2). Seven of the runs were at military power, and three were with the engine settings in afterburner.

For the acoustic regime, A-weighted pressure levels are greater for an engine installed on a test stand than for an engine installed in an aircraft (Figure 3). A comparison of the spectra measured at a common point indicates that engine runs on a test stand produce slightly stronger infrasonic emissions than an engine installed in an aircraft when the engines are tested at military power (Figure 16). For the three afterburner runs analyzed in this study, there was no systematic relationship between the level of infrasonic emissions and the installation of the engines in an aircraft versus on a test stand. In general, the most significant factor in the overall pressure level at infrasonic frequencies is whether the engines are run at military power or in afterburner.

The spectra obtained in this study generally exhibit two peaks, one at about 5 Hz, and another (broader) peak located between about 10 and 20 Hz. Although the pressure level observed at frequencies higher than about 8 Hz is generally greater at site 7 than at site 3, the pressure level for vibrations at frequencies lower than about 8 Hz are generally greater at site 3 than at site 7. The details of this difference in radiation pattern at high versus low frequency are discussed below in Section 8 after we first discuss the location of the source of the infrasonic vibrations in the next section.

7. SOURCE LOCATION

After preliminary Hush House studies at Luke AFB and Fort Smith, Arkansas, it was hypothesized by Battis (1987) that the Hush House infrasonic source could be modelled as a tripole source. The dominant source in this model was assumed to be a jet-like source located over the exhaust deflector at the end of the augmenter tube with weaker "negative" jets in proximity with the air intakes along both sides of the main structure. This hypothesis was developed on consideration of the spectral structure of the infrasonics recorded during the two Hush House studies. This study at Otis AFB provided an opportunity to test this hypothesis using array processing techniques.

Acoustic measurements made during the Otis study were examined by J.C. Battis (personal communication) using frequency-wavenumber (FK) analysis. The procedure estimates the relative power in the signals at a given frequency that can be fit to a plane wave front crossing the array from various azimuths and at various apparent velocities. A result of this plane wave assumption is that the sensors used in the analysis must be tightly clustered relative to the source-receiver distance. For this reason, only a subset of the available recording sites were used in this analysis (sites 5, 6, 7 and 10 through 15). The configuration of the array used is shown in Figure 17, where the y-axis (defined as 0° azimuth) is parallel to the axis of symmetry of the Hush House.

During the Otis study, a series of small explosions were detonated approximately 4.1 m behind the exhaust deflector and essentially at the ground surface. As a preliminary check on our analytical techniques and bearing angles from the array, FK analysis was performed on the signals from these shots. Figure 18 shows the signals recorded from the second shot of this sequence. Figure 19 is a plot of the FK analysis results for these signals for a bandpass centered at 25 Hz, the approximate spectral peak of the detonations. First, note that the wavenumber used in these plots is linear wavenumber (i.e. 1/wavelength). The analysis shows a maximum occurring at an azimuth of 287.6° with an apparent velocity of 0.338 km/sec. The remaining contours result from spatial and temporal aliasing. As should be expected, the apparent velocity is reasonable for the speed of sound in air. The results from all the shots agreed with this bearing angle and apparent velocity within ±0.5° and ±2 m/sec, indicating that the shot azimuth from the array is well determined through FK analysis.

Figure 18 shows a distinct echo arriving at approximately 0.6 sec after the direct acoustics. Figure 20 shows the FK analysis for that echo. Again the apparent velocity (0.342 km/sec) is close to that of the speed of sound in air, but the azimuth is now found to be 10° behind the augmenter tube at 277°. From Figure 2, it can be seen that this azimuth is appropriate for an echo from building 858, the large hanger to the east of the Hush House. Although the configuration of the sites is not ideal for azimuth determination at high frequencies due to spatial and temporal aliasing, the separation of the direct and echo azimuths demonstartes sufficient resolution for the separation of the hypothesized Hush House sources.

Using bandpass filters of 3.0 Hz bandwidth and centered at 5° intervals from 5° to 25°, an FK analysis was conducted on all Hush House runs. Figure 21 shows typical data, in this case collected during Hush House operations with the engine in the aircraft and operating in afterburner. The pressure spikes seen in Figure 21 (at about 5 and 7 sec) have not been previously observed, and their cause is uncertain. It is not known if they are a result of a Hush House property or an engine condition. During the observing period, some of the engines had mechanical problems that might be responsible for these impulses.

Figure 22 shows the mean spectrum derived from the array outputs in nominal units of spectral density. As an example of the FK analysis, Figure 23 shows the results of FK analysis for this run at a frequency of 10 Hz. In this case maximum power is found for an arrival with an apparent velocity of 0.344 km/sec coming from 290.5°. The lesser local maxima seen in the plot are the result of temporal and spatial aliasing of the data. All analyses produced essentially the same results as this particular run and the variations observed over the runs are within the expected errors of the procedure. It is of particular note that azimuth to the infrasonic source appears to be insensitive to the power setting of the engine. Table 3 lists the azimuth and apparent velocity determined from each run in the five frequency bands.

The apparent source of the Hush House infrasonics at all frequencies lies within a narrow arc from the array between approximately 286° and 292°. Assuming that the source lies along the center line of the Hush House, this would place it somewhat behind the deflector plate, suggesting a non-vertical jet plume source. There is no indication from this analysis of a second, hypothesized low-frequency source thought to have been associated with the air intakes at the front of the Hush House. That hypothesis must now be abandoned, and it appears that a monopole source, located in the vicinity of the exhaust deflector, must be assumed.

It was previously concluded by Beaupre and Crowley (1987) that the Hush House infrasonics could not be modelled as a vertical annular jet. Observation of the exhaust plume and the results on source location as given above, however, suggest that a non-vertical jet plume over the augmenter tube might be a good replacement hypothesis.

8. RADIATION PATTERN OF INFRASONIC EMISSIONS

A-weighted pressure levels at site 7 are substantially larger than levels encountered at site 3 during the acceptance tests for a common engine installation and power setting. The results of the acceptance tests show that, in the audible frequency band, the level of pressure vibrations around the Hush House is not uniform. The peak sound level radiated by the Hush House generally occurred behind the facility (in the direction of the exhaust deflector). In this section, we discuss the azimuthal radiation pattern of the Hush House at infrasonic frequencies.

Figure 24 shows average spectral values corrected for amplitude to a constant distance of 76 m (assuming an attenuation of 1/r) for the infrasonic data obtained during this study. Results are shown for center frequencies of 5, 10 and 20 Hz in Figures 24(a), (b) and (c) respectively. For each of the points shown in Figure 24, the spectral values were averaged over 5 frequencies in the vicinity of the center frequencies, and the resulting average values were again averaged over all runs at military power and in afterburner. At frequencies of 10 and 20 Hz, the pressure levels are greater at azimuths near that of site 7 than at azimuths near that of site 3. At 5 Hz, however, the pressure levels are lower in the direction of site 7 than in the direction of site 3.

This observation of lower levels of infrasound in the direction of site 7 cannot be explained by invoking a different source location for the 5 Hz spectral peak. The results of the FK analysis indicate that the source is located in essentially the same place for all frequencies investigated. Thus, the difference in radiation pattern for low versus high frequency must be caused by some other phenomenon.

9. COMPARISON OF OTIS HUSH HOUSE WITH HUSH HOUSE AT LUKE AFB

Figure 25 shows a comparison of the radiation pattern observed at Otis with that reported by Beaupre and Crowley (1987) for the Hush House at Luke AFB. The data shown for Otis are average spectral values corrected for amplitude to a constant distance of 76 m. Results are shown for center frequencies of 6.250, 10.937 and 29.687 Hz, which are the frequencies that were reported in the Beaupre and Crowley study. For the Otis recording sites, the spectral values were averaged over 5 frequencies in the vicinity of the center frequencies, and the resulting average values were again averaged over all runs with engine settings at military power and in afterburner. The data were then normalized by dividing by the values observed at site 15 for each specific frequency and site. This provided a direct comparison between the Otis and Luke studies, since Beaupre and Crowley normalized their data to observed spectral values at a site that was at approximately the same azimuth and distance as site 15. Since there were only 3 runs in afterburner, only the averages of the seven runs at military power are shown. The results for the afterburner runs are similar to those shown for military power, although the afterburner data exhibit somewhat more scatter.

The azimuthal radiation pattern of infrasonics observed for the Otis Hush House is, in a general sense, comparable to that reported by Beaupre and Crowley (1987) for the Hush House at Luke AFB. Because the azimuths covered by the experimental setups of the two different studies only overlap across a fairly narrow arc, it is difficult to compare the details of the differences in radiation patterns. Also, the experimental design at Luke AFB included a string of sensors located along a line almost parallel to the axis of symmetry of the Hush House. Thus, the experimental setup at Luke was more appropriate for investigating the source radiation pattern than the experimental setup at Otis. Nonetheless, several points of comparison between the two sites are quite clear from the data shown in Figure 25.

The pronounced peak in the A-weighted sound level behind the Hush House (i.e. at azimuths greater than 100°) is also observed at both sites for frequencies between 20 and 30 Hz (i.e. at the lower end of the audible frequency band). At frequencies lower than 20 Hz, this peak becomes less pronounced, and at frequencies lower than about 10 Hz, pressure vibrations are generally greater along the side of the Hush House than behind the facility [Figures 24(a) and 25(a)].

10. DISCUSSION AND CONCLUSIONS

The results of this study indicate that Hush House infrasonics produced by F-100 engine runs at Otis AFB can be accurately modelled by a single point source, located in the vicinity of the exhaust deflector. This type of single point source model was also hypothesized for the Hush House at Luke AFB (Beaupre and Crowley, 1987). There is no evidence of a second low-frequency source associated with th air intakes at the front of the Hush House. Although it was previously concluded by Beaupre and Crowley (1987) that Hush House infrasonics could be modelled as a vertical annular jet, based on this study a non-vertical jet plume appears to be a more appropriate source model.

For audible frequencies, A-weighted pressure levels are greater for an engine installed on a test stand than for an engine installed in an aircraft. In the case of this study of the Otis Hush House, there is some evidence that "bare" engine runs (at military power) produce slightly stronger infrasonic emissions than an engine installed in an aircraft. The most significant factor in the overall pressure level at infrasonic frequencies, however, is whether the engines are run at military power or in afterburner.

The azimuthal radiation pattern of infrasonics observed for the Otis Hush House is, in a general sense, comparable to that reported by Beaupre and Crowley (1987) for the Hush House at Luke AFB. The peak audible pressure observed at sites behind the Hush House is not generally observed for pressure vibrations in the infrasonic frequency range. In fact, at frequencies lower than about 10 Hz, peak pressures are generally greater along the side of the Hush House than behind the facility.

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Beaupre, J. T., and Crowley, F.A., Hush House Infrasonic and Seismic Emissions Produced by F-100 Engine Tests at Luke AFB, Arizona, Weston Observatory Scientific Report, 30 April 1987.

Beranek, L.L., Noise Vibration and Control, McGraw-Hill Book Company, New York, NY, 1971.

Table 1.

Sensor Locations for Otis AFB Hush House Study

Site #	Range (meters)	Azimuth (degrees)
1	93.3	60.7
2	102.1	58.3
3	89.5	53.2
5	72.5	98.7
6	67.8	108.4
7	76.3	110.1
9	100.9	114.7
10	105.8	110.4
11	114.9	110.8
12	119.2	114.7
13	114.9	118.7
14	105.8	119.0
15	110.1	114.7

Table 2.

Hush House Operations Investigated at Otis AFB

Run #	Engine Installation	Engine Setting
1	In Aircraft	Military Power
3	In Aircraft	Afterburner
4	In Aircraft	Military Power
5	In Aircraft	Military Power
6	In Aircraft	Afterburner
7	Test Stand	Military Power
8	Test Stand	Military Power
9	Test Stand	Afterburner
11	In Aircraft	Military Power
12	In Aircraft	Military Power

Table 3.

Results of FK Analysis

	5 Hz		10 Hz		15 Hz		20 Hz		25 Hz		RUN MEAN	
RUN	AZ (deg)	C (m/sec)	AZ	C	AZ	C	AZ	C	AZ	C	AZ	C
1-ML	288.5	332	290.0	349	287.8	344	289.2	350	289.1	344	288.9	342
3-AB	291.3	359	292.2	336	288.4	346	288.9	348	289.0	344	290.0	347
4-ML	293.4	353	289.5	339	289.3	343	289.7	341	288.1	343	290.0	344
5-ML	297.6	350	290.7	350	286.5	348	290.5	348	287.8	343	290.6	348
6-AB	292.3	354	290.5	344	287.9	341	285.7	337	288.7	337	289.0	343
7-ML	290.4	355	288.0	339	291.8	357	290.0	351	289.7	350	290.0	356
8-ML	289.7	348	287.3	353	289.2	347	290.3	347	288.2	347	288.9	346
9-AB	280.9	337	291.3	349	288.5	350	289.2	352	289.3	348	287.8	348
MEAN	290.5	347	289.9	347	288.7	347	289.2	347	288.7	346	289.4	347

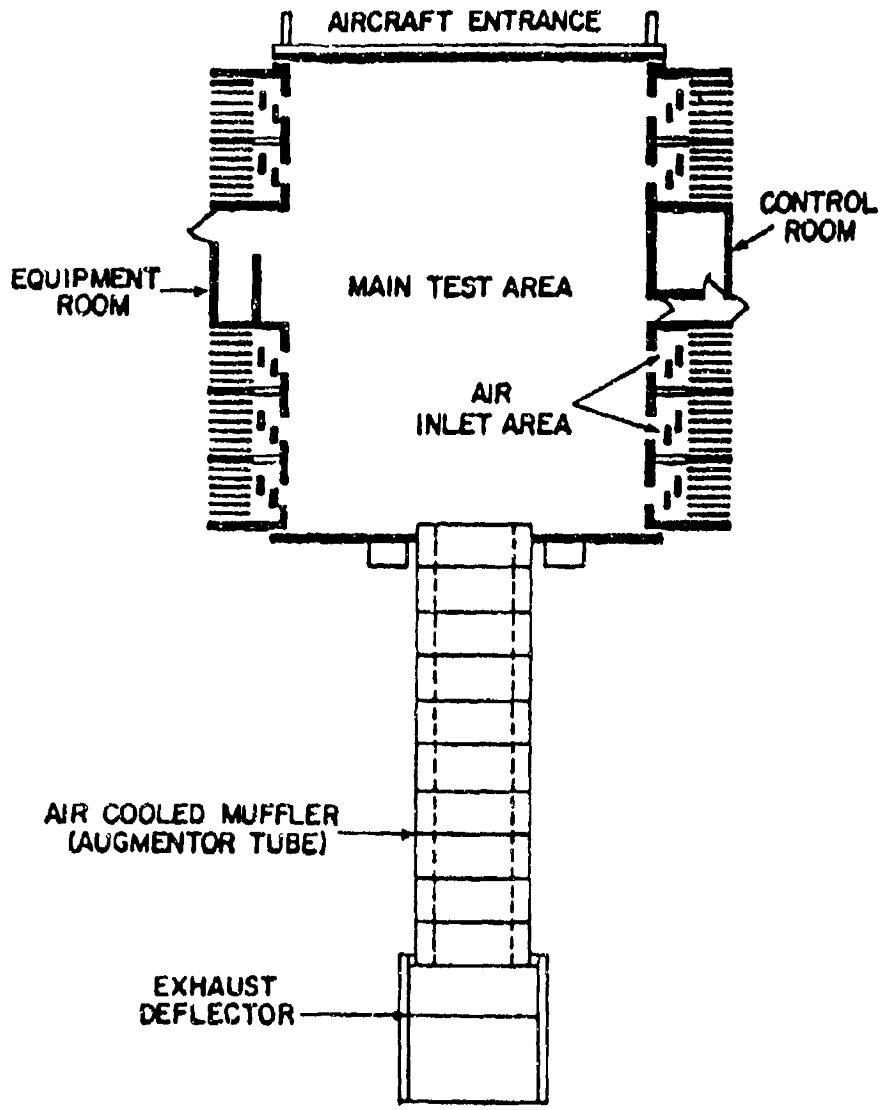


Figure 1: Plan view of a model T-10 "Hush House" jet engine noise supressor.

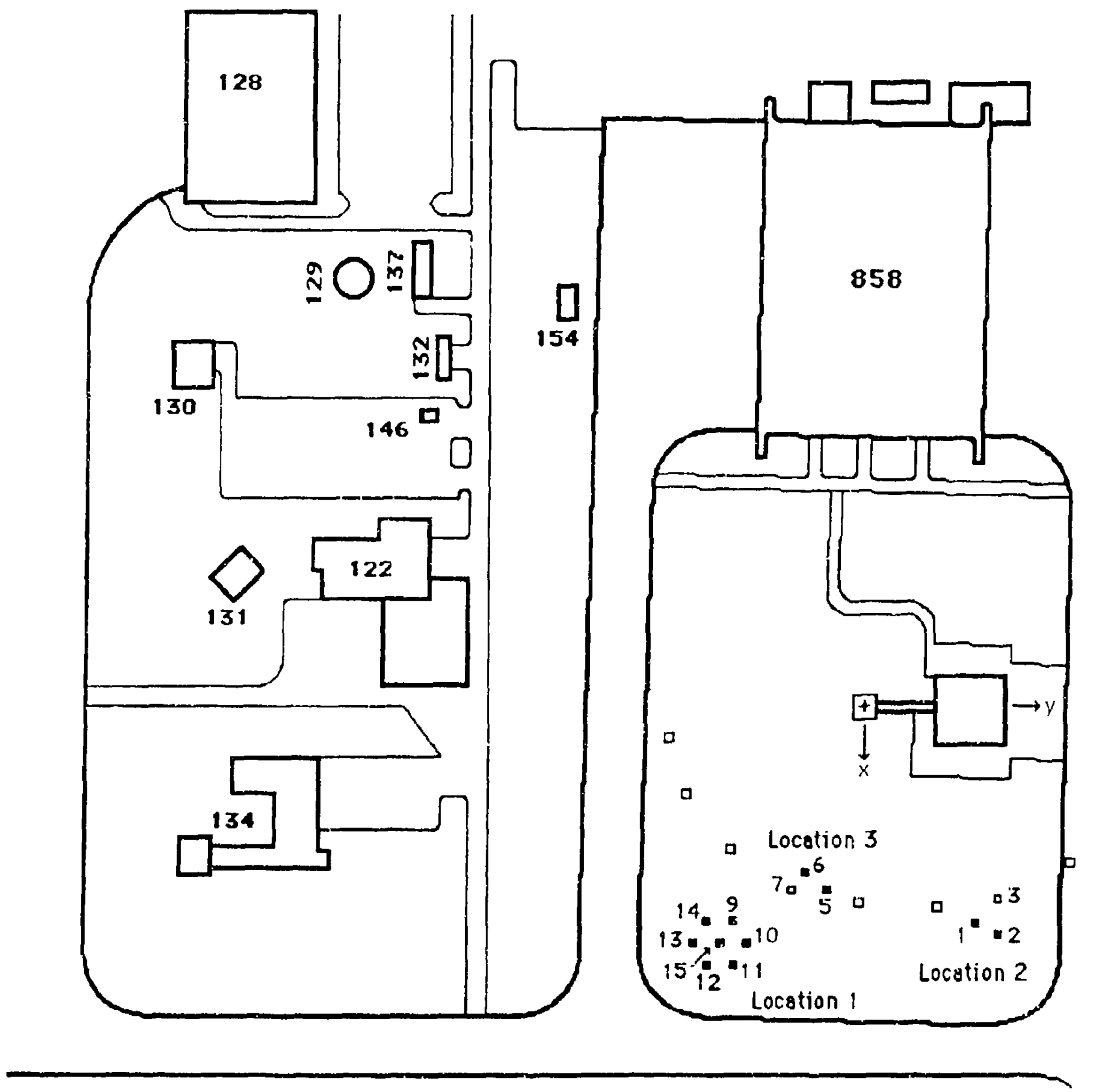


Figure 2: Facilities in the area surrounding the Hush House at Otis AFB, and sensor locations for Otis AFB Hush House study. The y-axis (defined as 0° azimuth) is parallel to the axis of symmetry of the Hush House. Open squares indicate locations of acceptance points, and small open squares indicate recording sites for this study that coincide with acceptance points. Clc.ed squares indicate locations of other recording sites for this study.

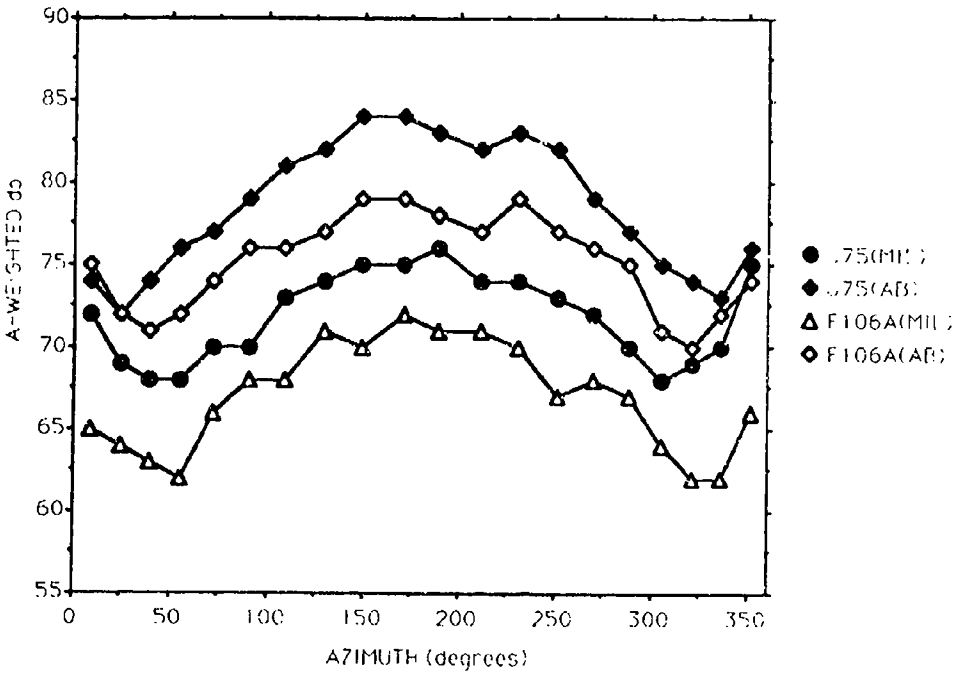


Figure 3: Sound pressure levels recorded for the Hush House acceptance tests at Otis AFB.

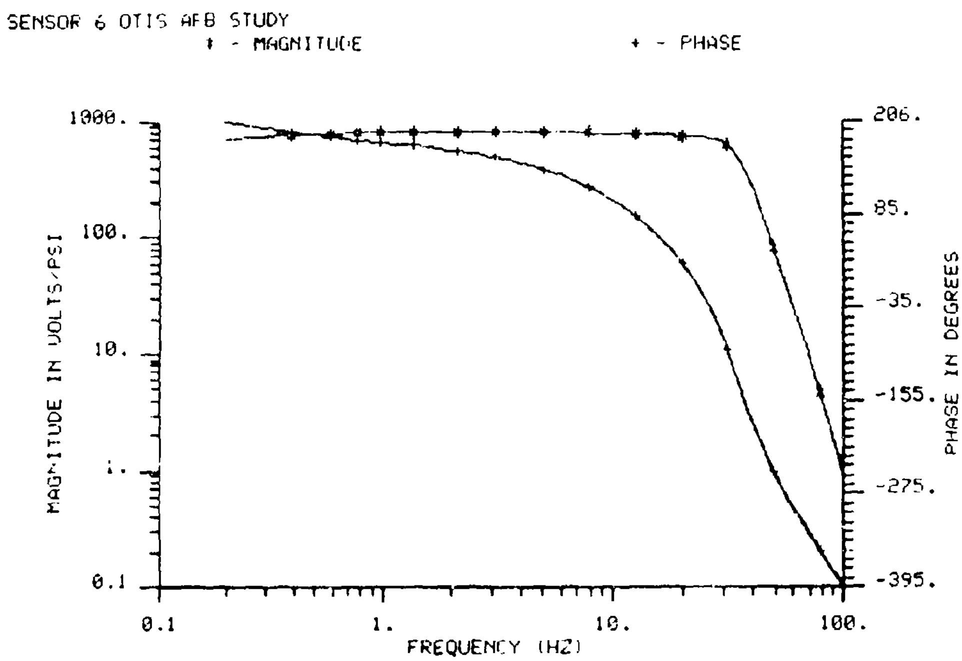


Figure 4: Pressure response of the GDAS system.

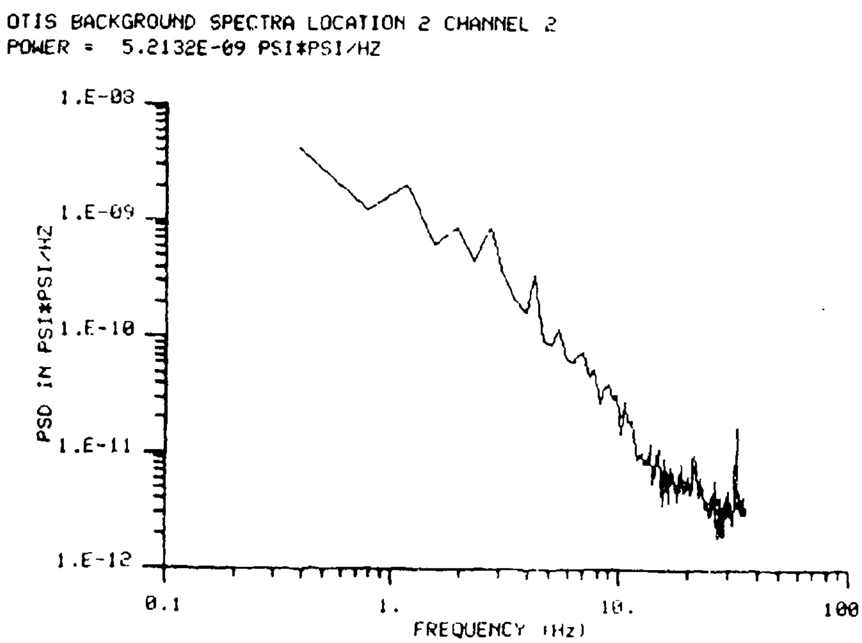
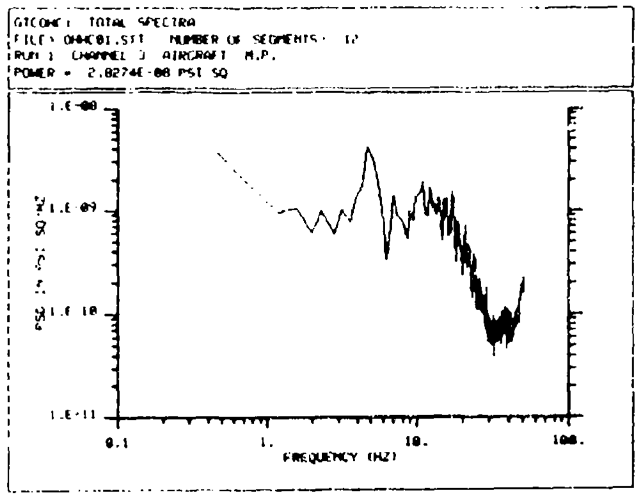
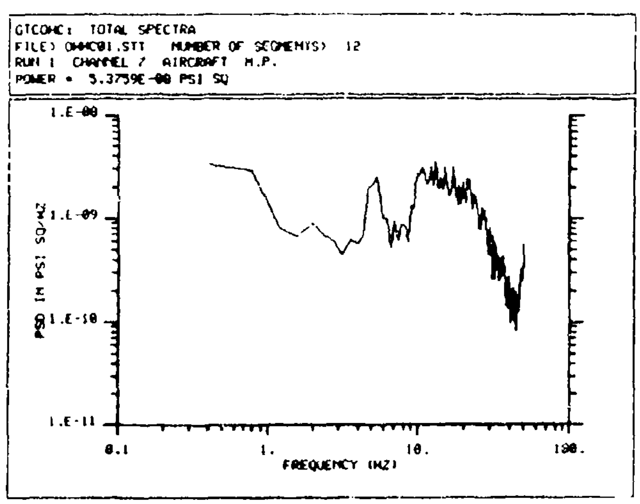


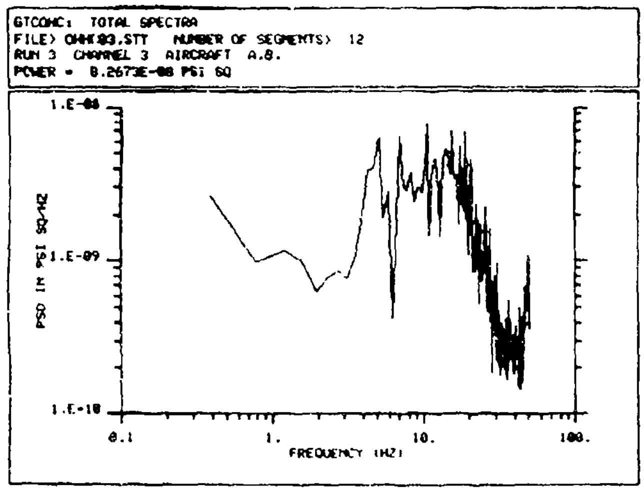
Figure 5: Example of ambient pressure spectra recorded in the vicinity of the Otis Hush House.

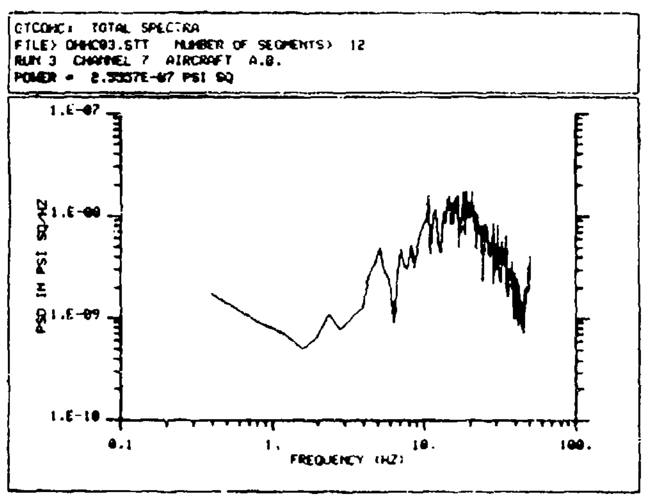




Run #1 (In Aircraft)

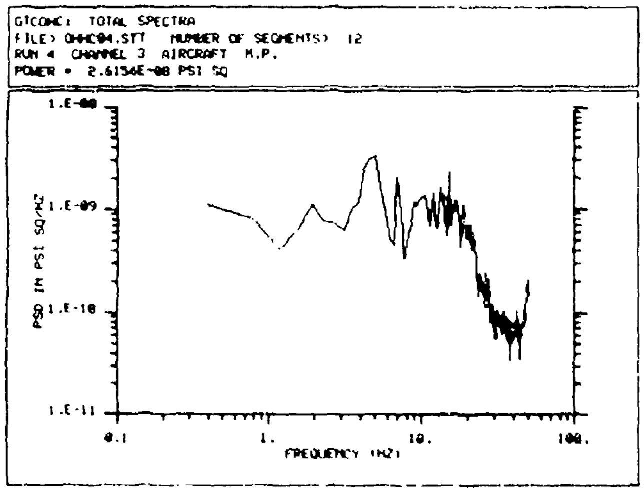
Figure 6: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #1 with the Hush House operating an F-100 engine at military power (with the engines in the aircraft).

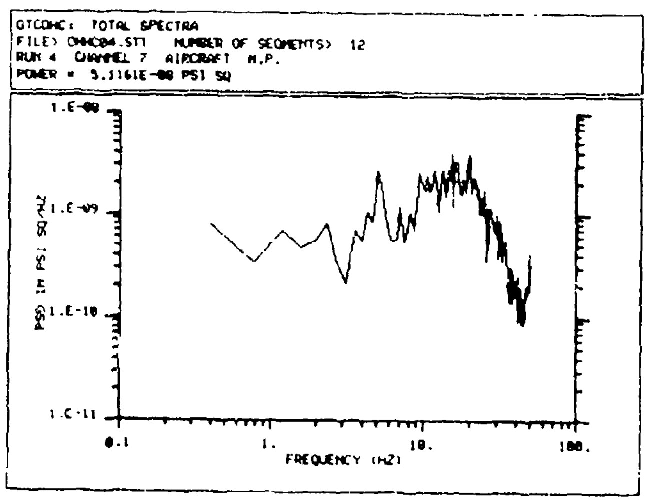




Run #3 (In Aircraft)

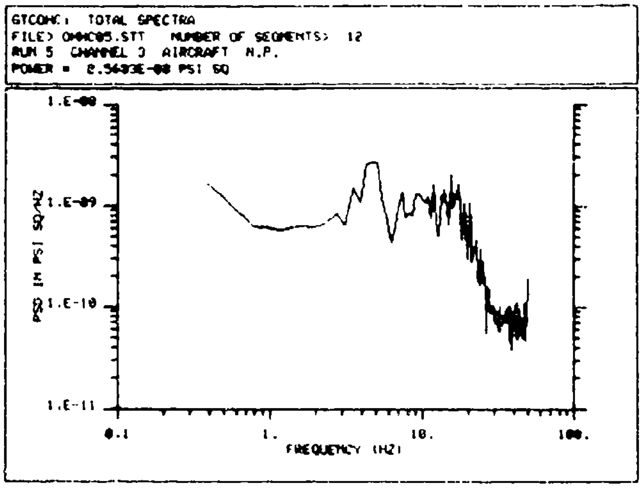
Figure 7: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #3 with the Hush House operating an F-100 engine in afterburner (with the engines in the aircraft).

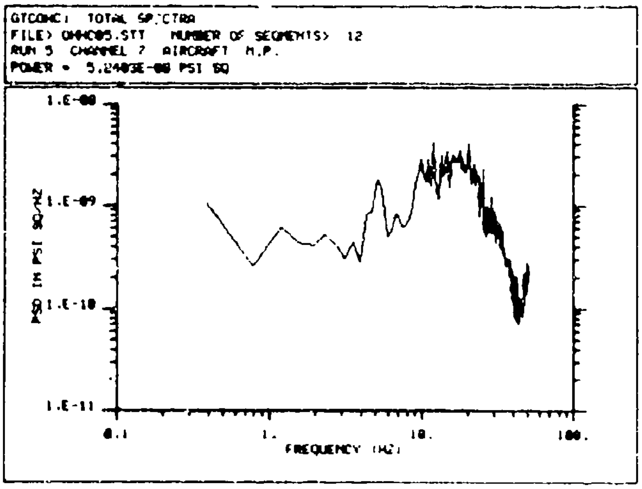




Run #4 (In Aircraft)

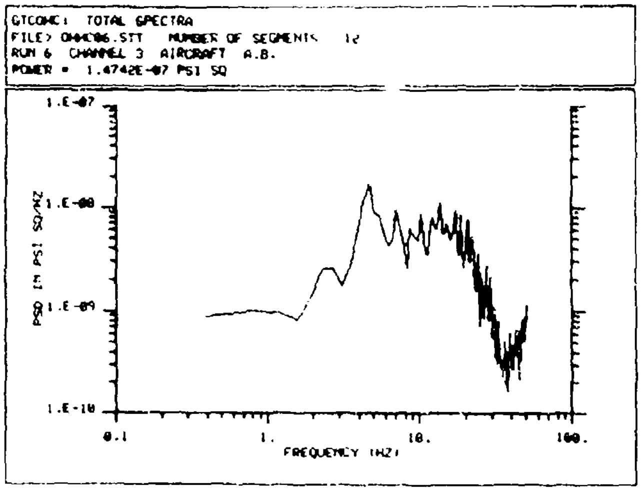
Figure 8: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #4 with the Hush House operating an F-100 engine at military power (with the engines in the aircraft).

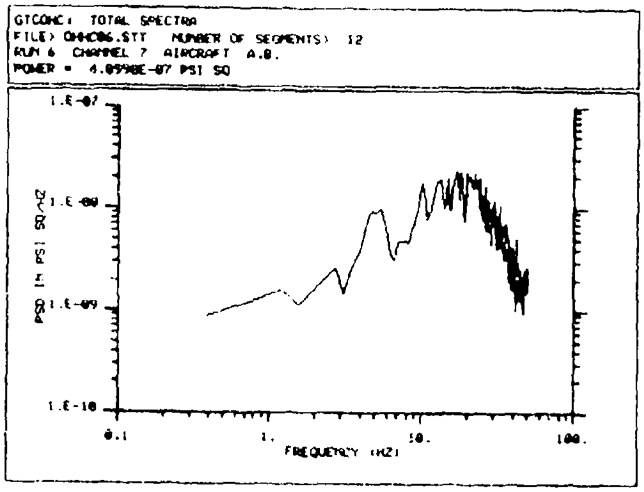




Run #5 (In Aircraft)

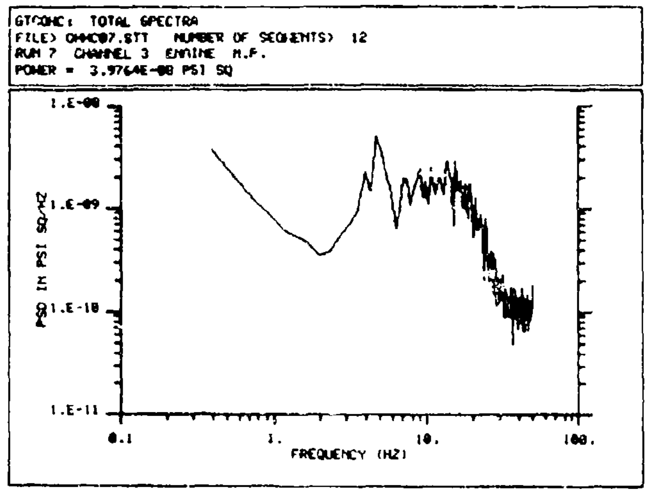
Figure 9: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #5 with the Hush House operating an F-100 engine at military power (with the engines in the aircraft).

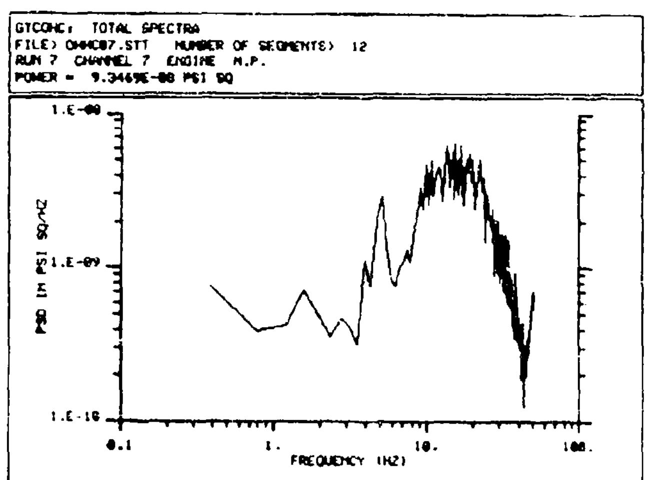




Run #6 (In Aircraft)

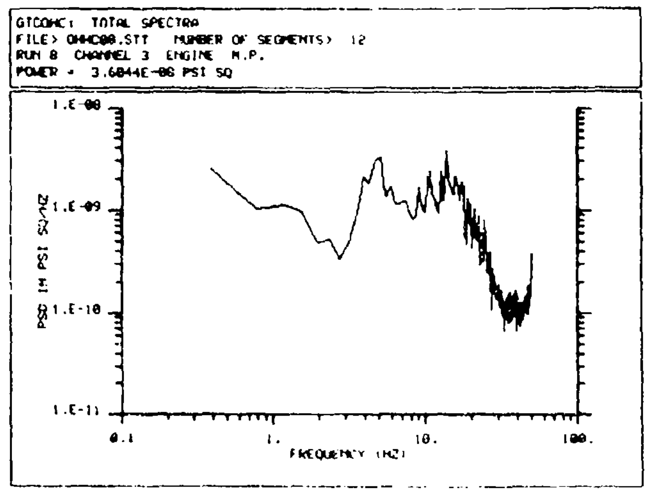
Figure 10: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #6 with the Hush House operating an F-100 engine in afterburner (with the engines in the aircraft).

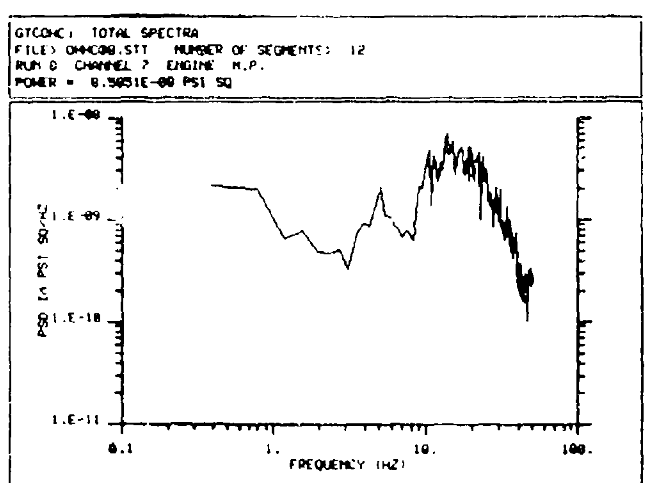




Run #7 (Test Stand)

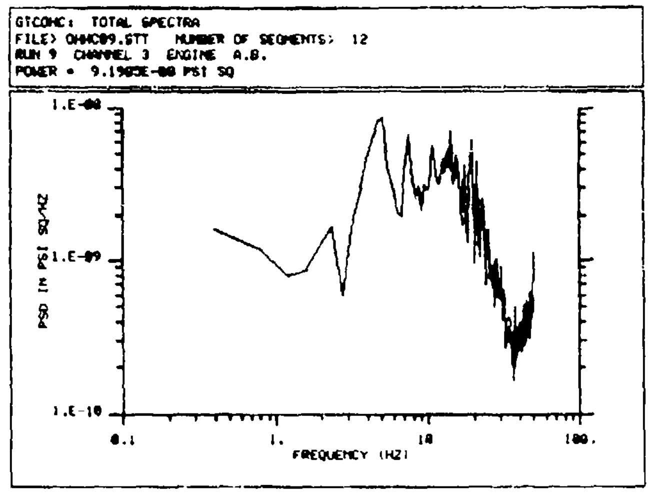
Figure 11: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #7 with the Hush House operating an F-100 engine at military power (with the engines installed on a test stand).

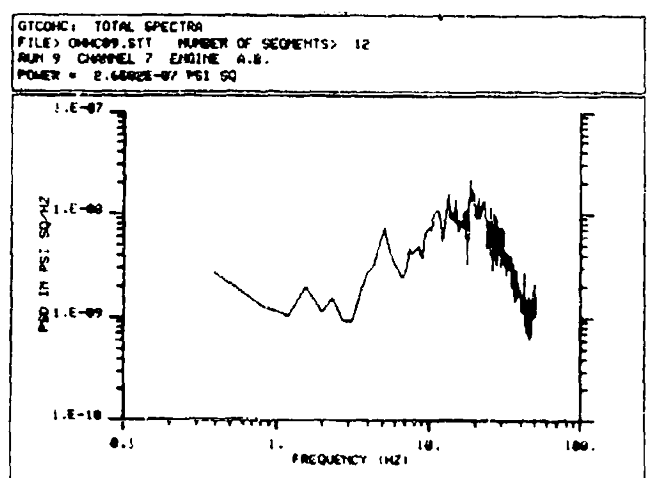




Run #8 (Test Stand)

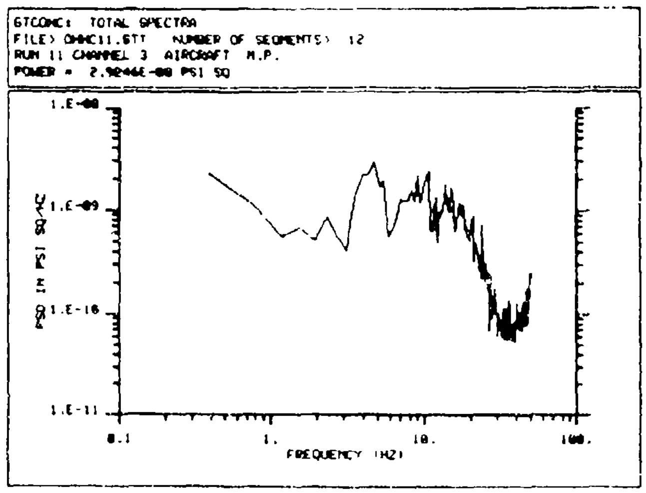
Figure 12: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #8 with the Hush House operating an F-100 engine at military power (with the engines installed on a test stand).

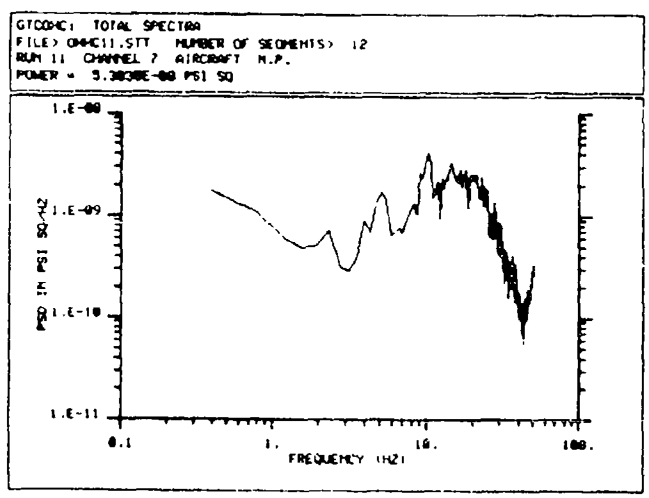




Run #9 (Test Stand)

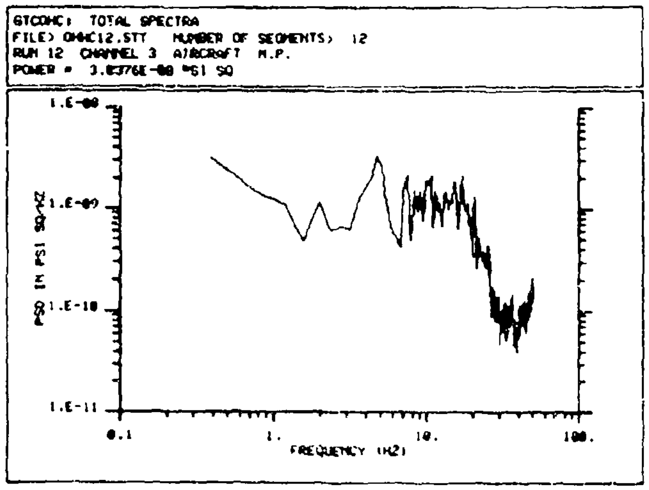
Figure 13: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #9 with the Hush House operating an F-100 engine in afterburner (with the engines installed on a test stand).

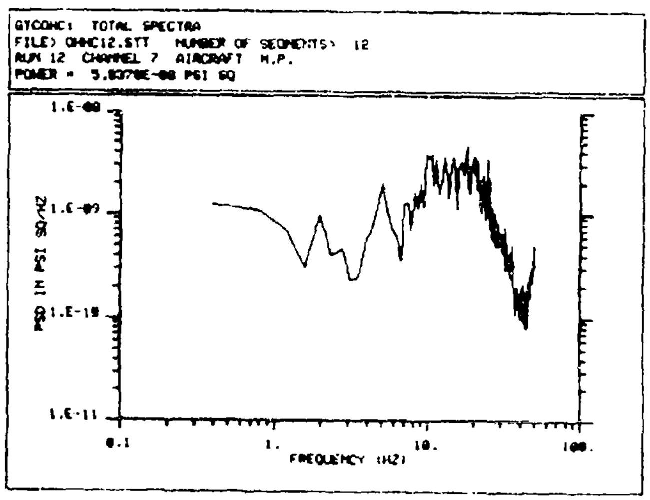




Run #11 (In Aircraft)

Figure 14: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #11 with the Hush House operating an F-100 engine at military power (with the engines in the aircraft).





Run #12 (In Aircraft)

Figure 15: Infrasonic spectra for pressures measured at sites 3 and 7 during Run #12 with the Hush House operating an F-100 engine at military power (with the engines in the aircraft).

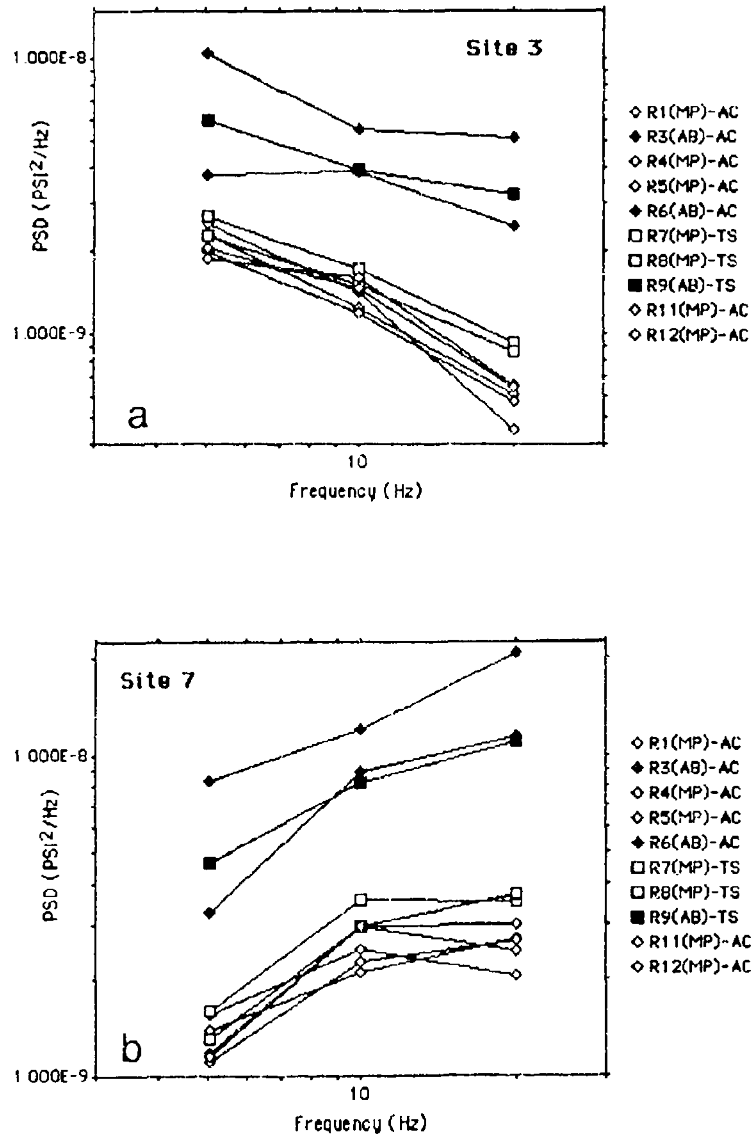


Figure 16: Comparison of 5, 10, and 20 Hz spectral values measured at (a) site 3 and (b) site 7 for engines operating at military power and in afterburner (in aircraft and installed on a test stand). Vertical axis is power spectral density in PSI^2/Hz, and horizontal axis is frequency in Hz. Open symbols indicate engine runs at military power (MP), and closed symbols indicate engine runs in afterburner (AB). Diamonds indicate engines tested in aircraft (AC), and squares indicate engines installed on a test stand (TS).

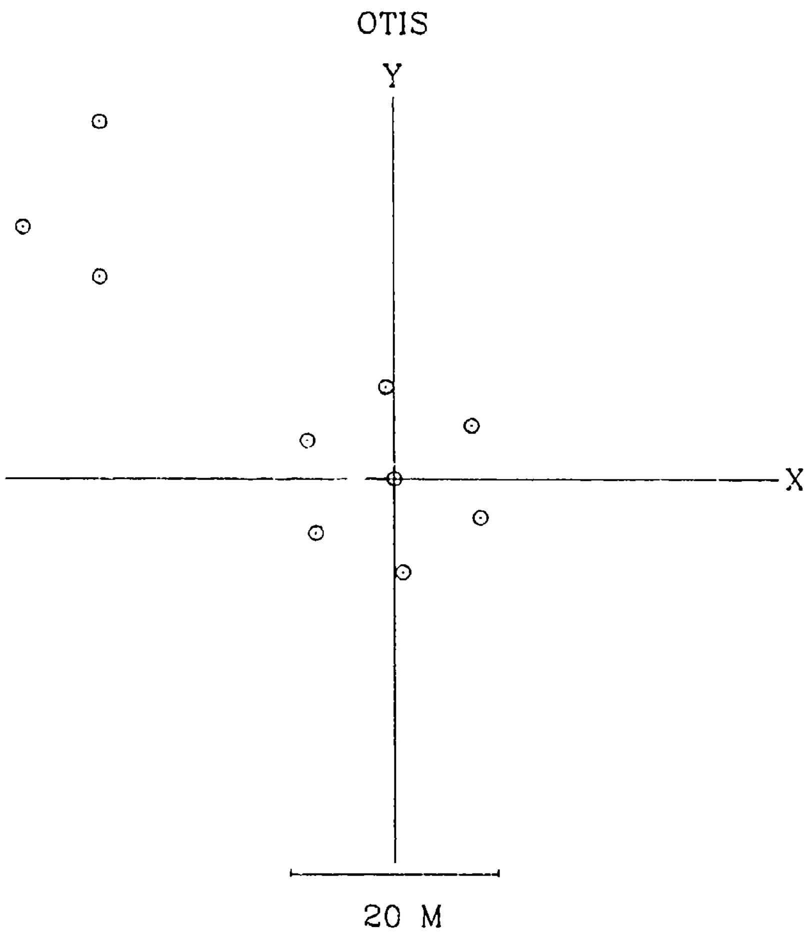


Figure 17: Configuration of array used for FK analysis. The y-axis (defined as 0° azimuth) is parallel to the axis of symmetry of the Hush House.

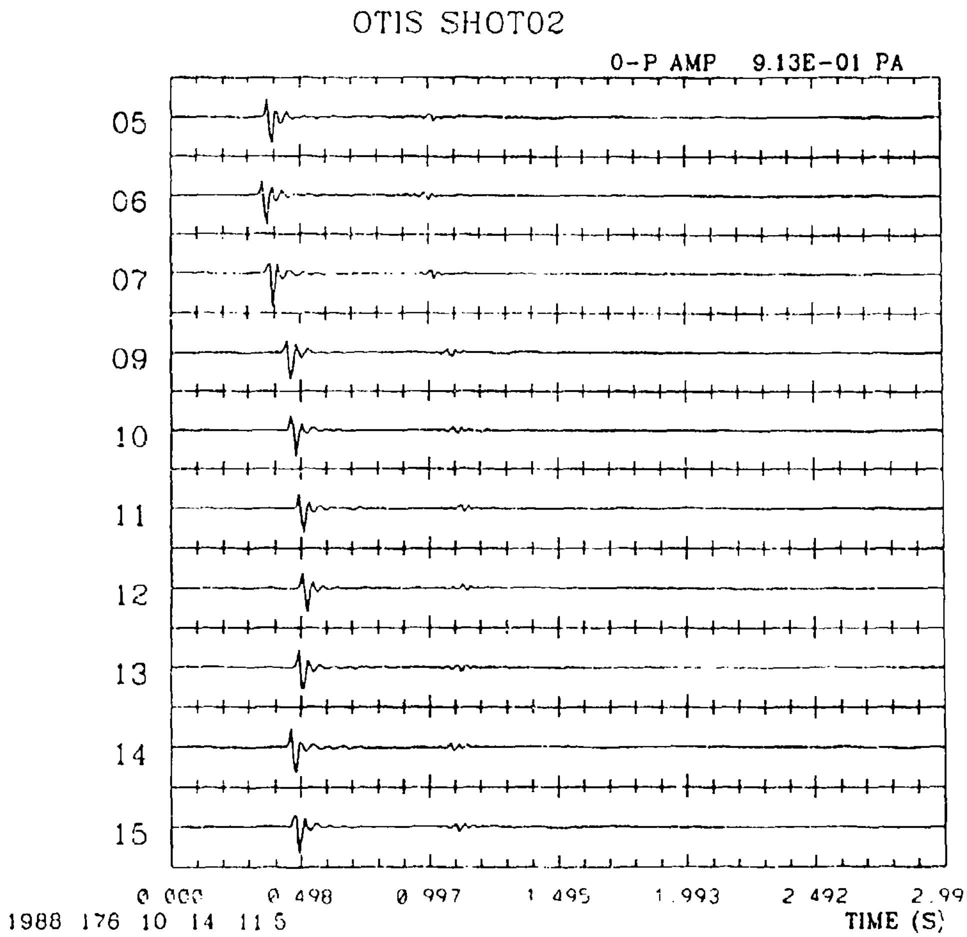


Figure 18: Signals recorded from a small explosion detonated approximately 4.1 m behind the exhaust deflector and essentially at the ground surface.

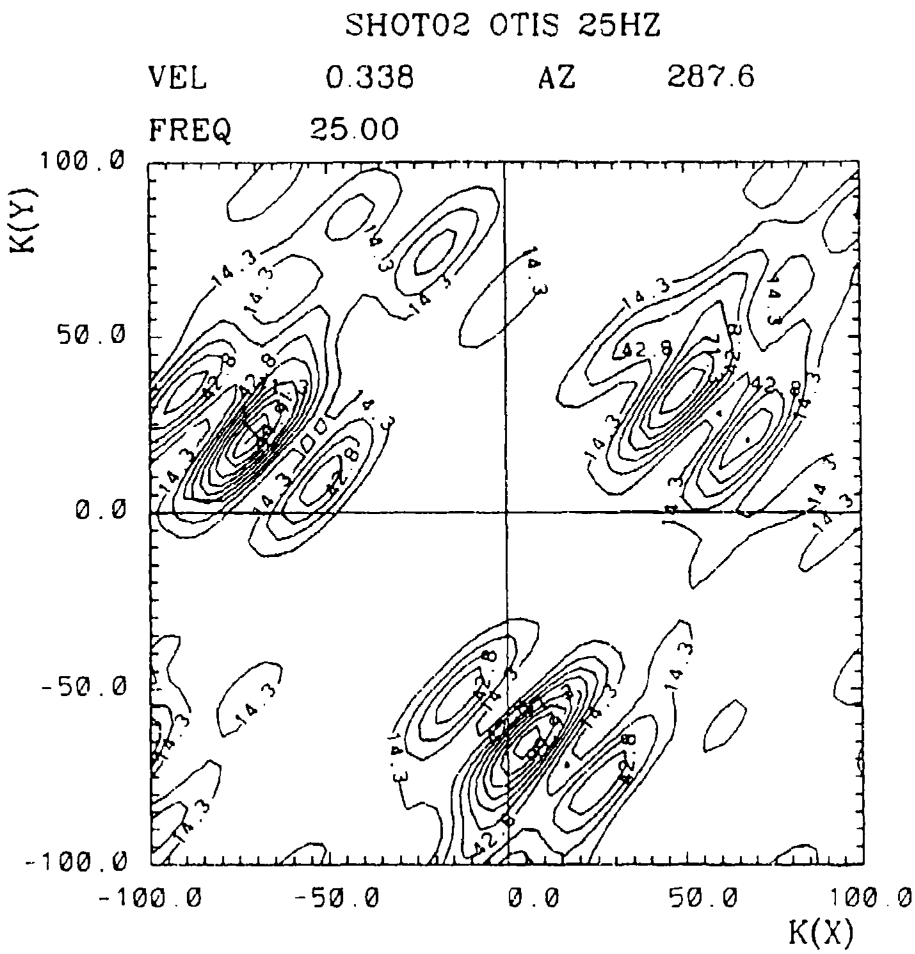


Figure 19: FK analysis results for the signals shown in Figure 18 for a bandpass centered at 25 Hz, the approximate spectral peak of the detonations.

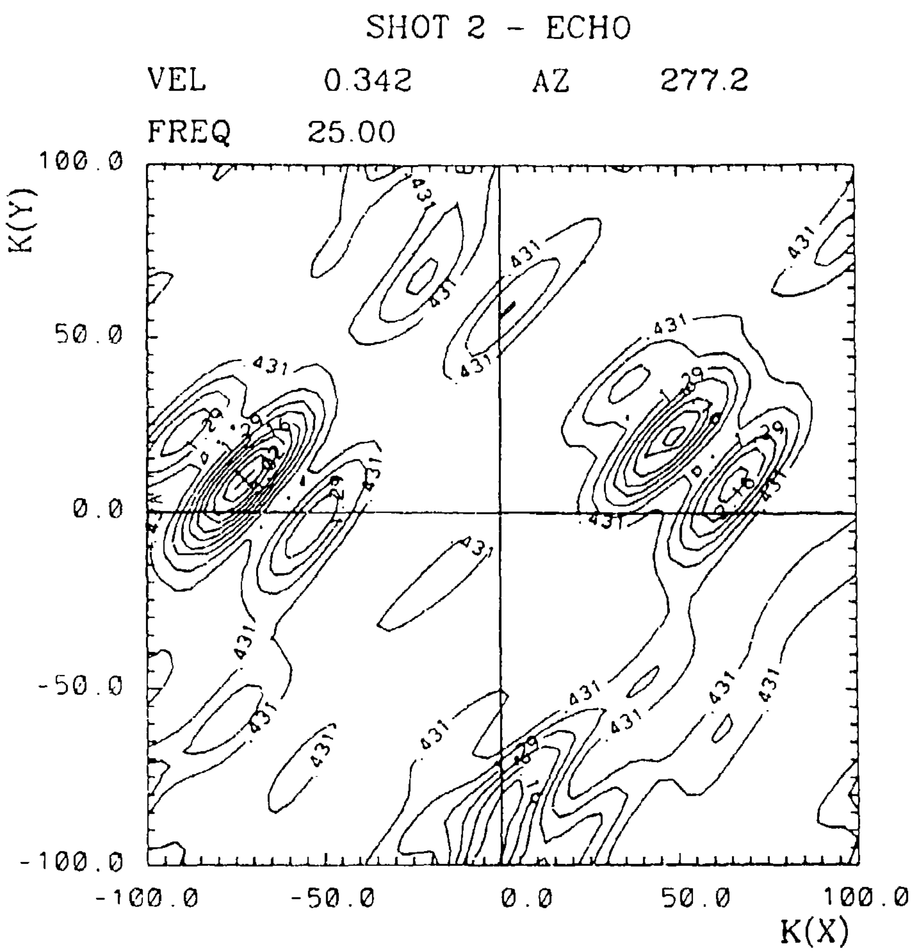


Figure 20: FK analysis for a distinct echo observed in the signals shown in Figure 18. The echo arrives approximately 0.6 sec after the direct acoustics.

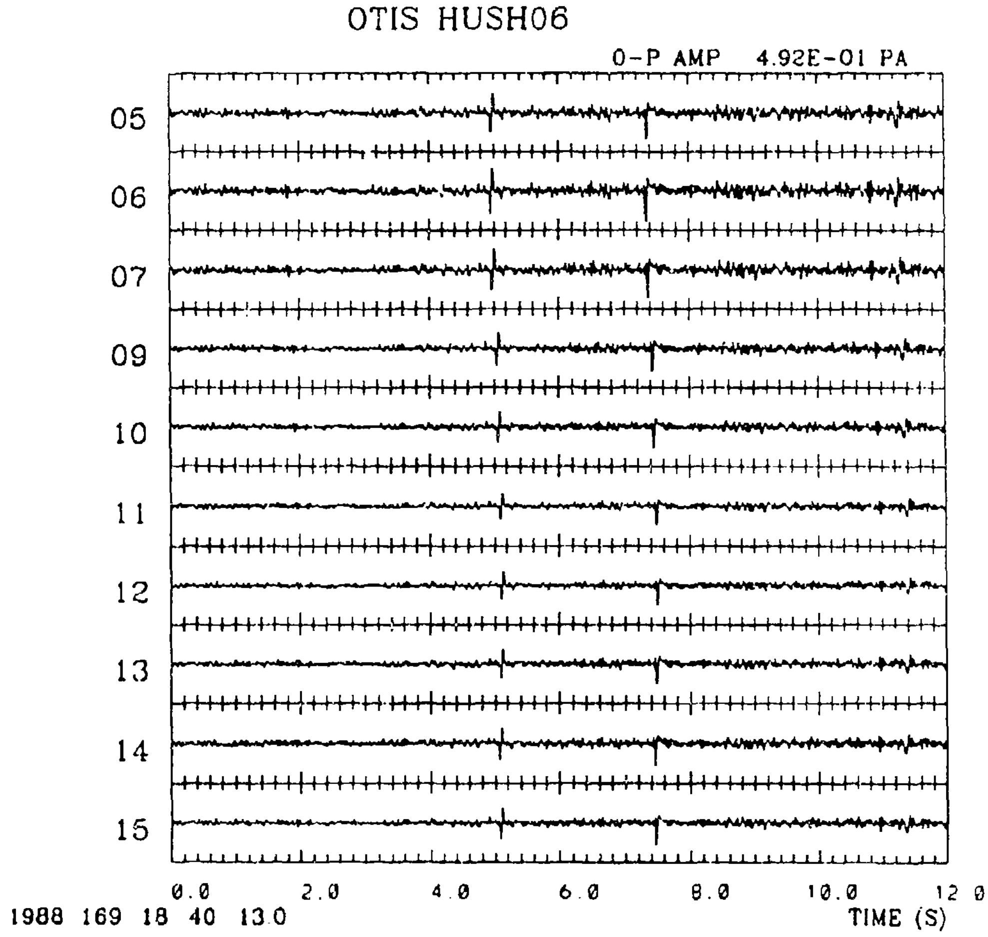


Figure 21: Typical data collected during Hush House operations with the engine in aircraft and in afterburner.

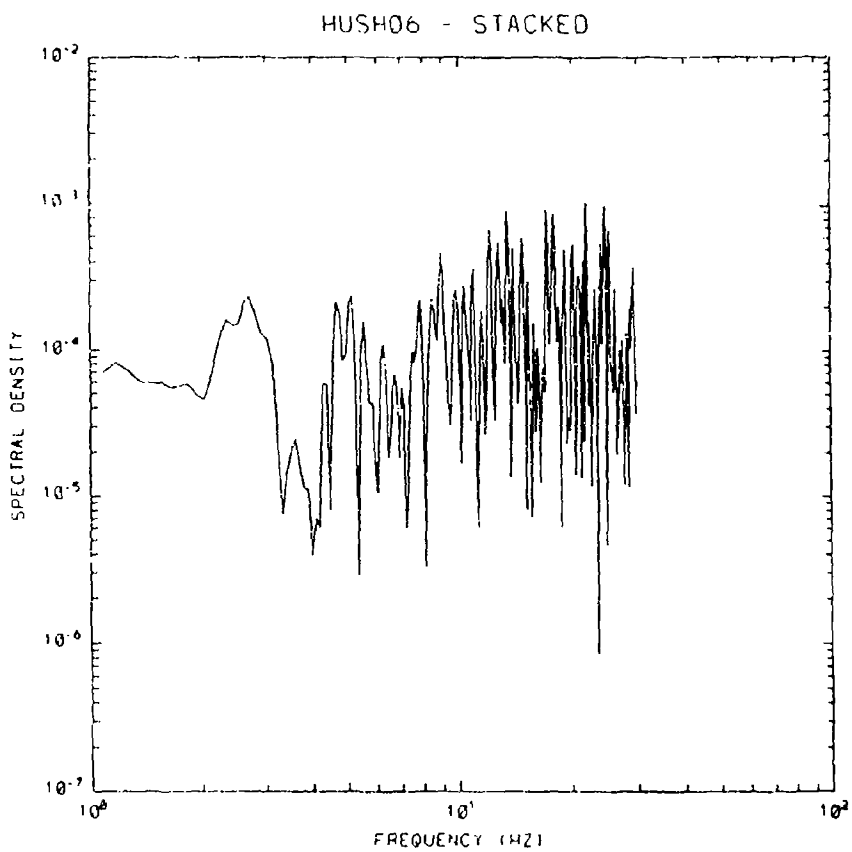


Figure 22: Mean spectrum derived from the data shown in Figure 21.

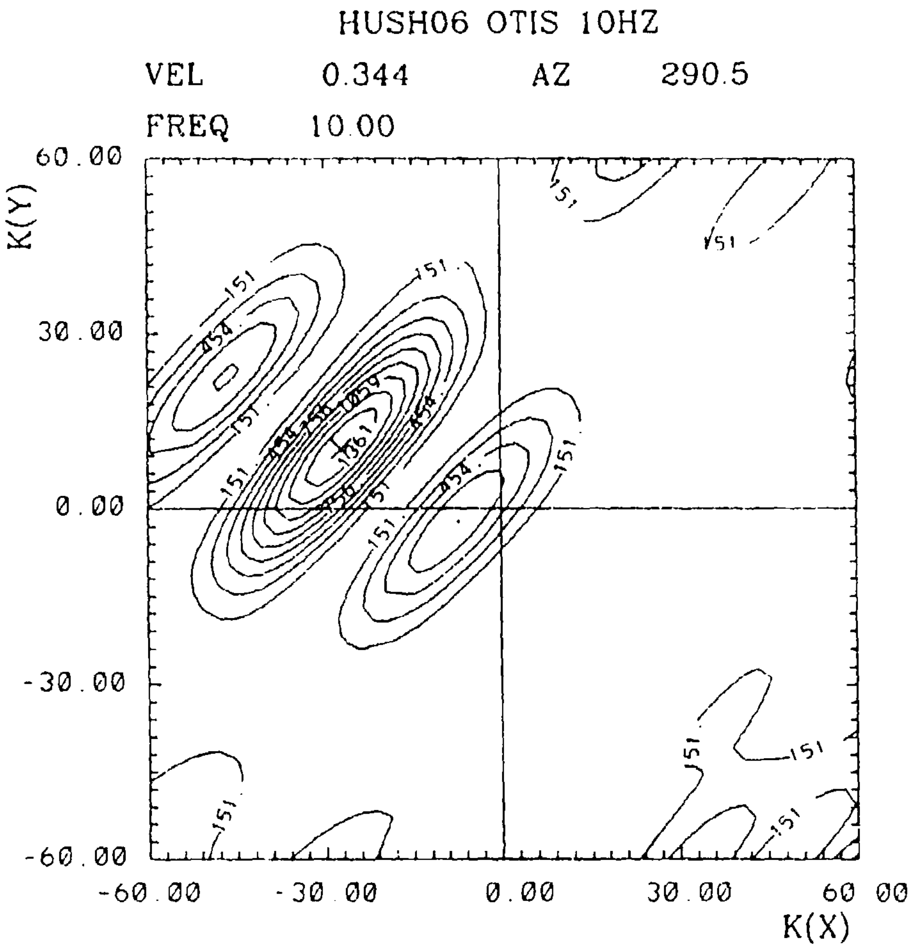


Figure 23: The results of FK analysis for the data shown in Figure 21 (at a frequency of 10 Hz).

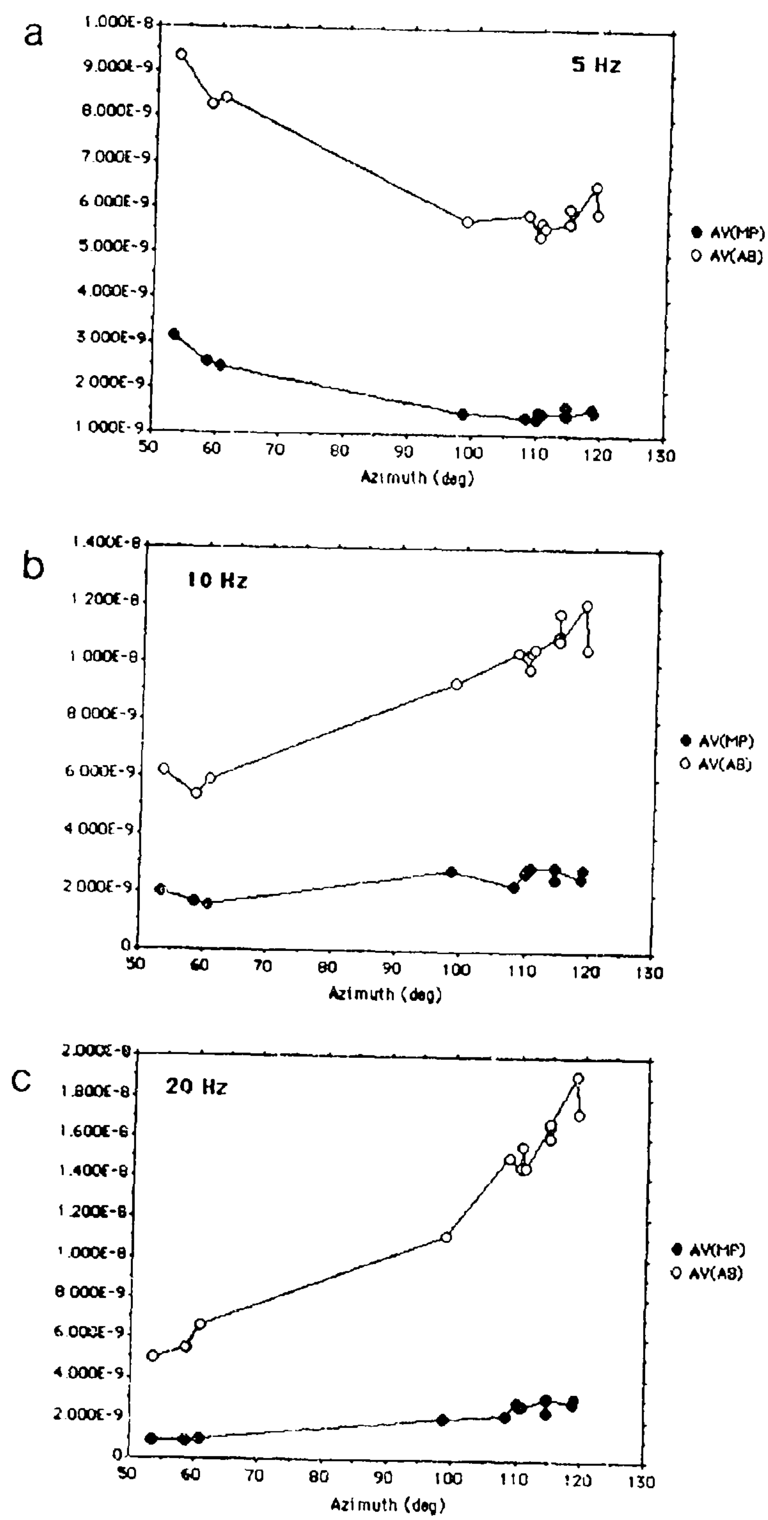


Figure 24: Radiation pattern of the Otis Hush House at frequencies near (a) 5 Hz, (b) 10 Hz, and (c) 20 Hz. Vertical axis is power spectral density in PSI^2/Hz, and horizontal axis is azimuth in degrees. Closed circles indicate engine runs at military power, and open circles indicate engine runs in afterburner.

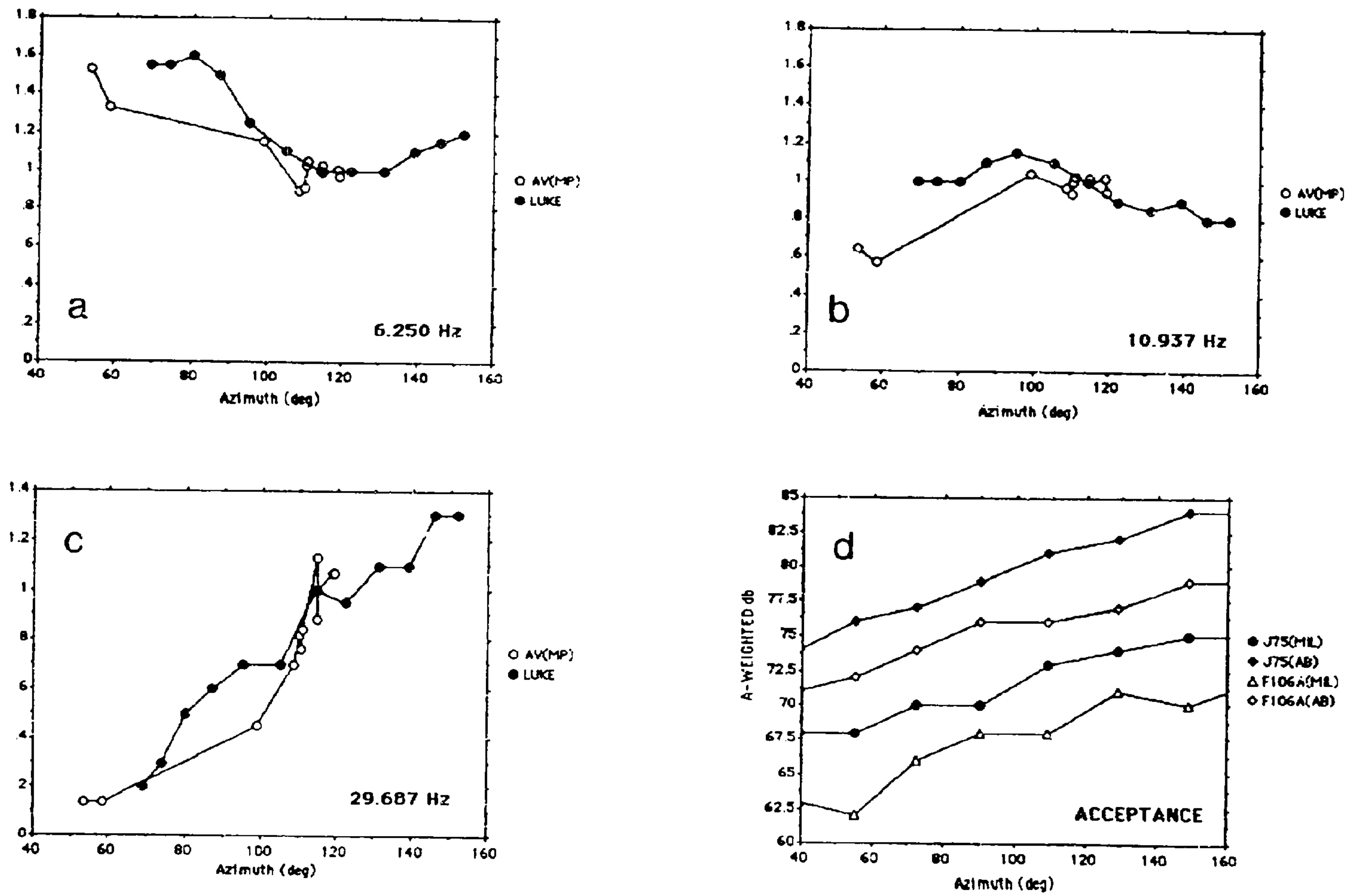


Figure 25: Comparison of the radiation patterns of the Otis and Luke Hush Houses at frequencies near (a) 6 Hz, (b) 11 Hz, and (c) 30 Hz. In (a), (b), and (c) the vertical axis is relative amplitude, and the horizontal axis is azimuth in degrees. Closed circles indicate results from Beaupre and Crowley (1987) for Luke AFB, and open circles indicate results of this study. (d) Radiation pattern of acoustic "A-weighted" pressure levels measured during Otis AFB acceptance tests.