Ground Plane Microphone for Measurement of Aircraft Flyover Noise

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Ground interference distortion is present in aircraft flyover noise spectra acquired using microphones mounted on poles, such as the 1.2-m height required for noise certification. This spectral distortion is undesirable and can be avoided by using microphones that are mounted flush with the surface of a large, flat, acoustically hard surface. However, flush mounting is usually not possible. As a practical implementation of a flush installation, Boeing has developed the flush-dish microphone that consists of a dish placed on the ground with its convex side up. The microphone is flush mounted at the center of the dish. Two designs of this concept, circular and exponential flush-dish microphones, are described in this paper. The first design, the circular flush dish, was found to be free from ground interference effects for all incidence angles except for angles within about 15 deg of the overhead position. In this region, it exhibited periodic spectral modulation due to the interaction between direct and edge-diffracted waves. To diminish the edge effect, a new design, the exponential flush dish, was conceived. The edge was shaped to gradually match the impedance between the dish and the ground and to avoid the in-phase addition of edge-diffracted waves. The experimental results showed the exponential dish to be free from edge diffraction and ground interference effects. Furthermore, the response was insensitive to whether the flush dish was mounted on an acoustically hard surface or a typical natural terrain.

Introduction

HIGH-QUALITY aircraft flyover noise measurements are required for research leading to the accurate prediction and effective reduction of community noise. This paper addresses one of the important aspects of the noise measurement, namely, a microphone installation that avoids ground interference effects in the noise spectra. On numerous flyover tests, including certification tests, microphones placed on stands (typically 1.2 m high) have been used. For research tests, the use of such microphones causes a problem in the measured noise data because of ground reflection effects. The microphone receives both the direct signal and the signal reflected from the ground, which has a phase shift relative to the direct signal (Fig. 1). This causes reinforcements and cancellations of the total signal measured at the microphone as a function of both frequency and the relative position of the microphone to the airplane.

The theoretical ground interference of a 1.2-m-high microphone mounted over an acoustically hard surface is illustrated in Fig. 2. Both pure tone and one-third-octave broadband cases are included in this figure. For the pure tone case, the sound pressure levels (SPLs) will increase by 6 dB for reinforcements and will be negative infinity for the cancellations. For the one-third-octave broadband case, the bandwidth increases with frequency, allowing several cancellations and reinforcements to occur in each band. The integrated effect will be to increase the SPL by 3 dB at the higher-frequency one-third-octave bands. Ground effects are clearly seen in the lower-frequency region.

Some arguments have been put forth recommending the use of 10-m-high microphones to avoid the ground effects. However, the ground interference plot in Fig. 3 shows that the measurement is not free from the ground interference effects in the lower part of the audible range. For pure tones, the interference pattern repeats with smaller spacing on the frequency scale than in the 1.2-m microphone case. For the one-third-octave band analysis, the major interference effects shift to a lower-frequency range, and the resulting spectra will be smoother over the 50–10,000-Hz range.

The actual ground interference pattern depends on the ground impedance when the microphone is located on a natural terrain surface that is not acoustically hard. Furthermore, the cancellation and reinforcement frequencies are constantly changing as the airplane flies over the microphone. The ground effect therefore distorts the noise spectra as a function of the airplane position and ground properties. This distortion is undesirable when the objective is the accurate measurement and component decomposition of aircraft noise. The ground interference can be removed approximately by the analytical method if sufficient details are available. However, it is preferable to avoid the distortions by using microphone installations that avoid ground interference effects, generally referred to as ground plane microphones.

In this paper, ground plane microphone concepts are briefly described, followed by a description of two configurations developed at Boeing. In addition, test results to verify the acceptable frequency response of these microphones are included. An empirically derived ground interference curve for a 1.2-m-high microphone mounted over natural terrain will also be presented.

Ground Microphones

Four types of ground microphone installations are shown in Fig. 4. The true flush arrangement of Fig. 4a is the ideal case where the microphone is mounted with its diaphragm flush with a large, flat, acoustically hard surface. Such a microphone will measure a sound pressure level 6 dB higher than free field at all frequencies and incidence angles. However, the installation of a true flush microphone is impractical most of the time since it requires a hole in the test surface for accommodating the microphone itself. For many tests the test surface is a runway, which precludes making holes in it. Further-

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more, even if holes were allowed, the true flush arrangement would leave very little flexibility, should the repositioning of the microphone become necessary. The three other microphone setups in Figs. 4b, 4c, and 4d are attempts to achieve approximations to the true flush microphone in a practical way.

The grazing incidence microphone[1] shown in Fig. 4b is placed with its axis perpendicular to the airplane flight path on a large, flat, acoustically hard surface. This is done to maintain the same sound incidence angle at the microphone as the airplane flies over. Since the microphone diaphragm is very close to the ground, the direct and reflected waves are almost in phase at low and middle frequencies. A pressure doubling effect similar to the true flush arrangement is obtained at these frequencies. Although the first cancellation occurs at a very high-frequency band, the gradual rolloff from pressure doubling starts several one-third-octave bands earlier. This deviation from the true flush microphone is undesirable. However, since there is usually only one ground cancellation in the 50–10,000-Hz frequency range, it may be possible to analytically remove this from the measured spectrum with a reasonable degree of accuracy.

The inverted microphone shown in Fig. 4c is widely used for static tests[1] and has also been suggested for flyover tests. This arrangement will have varying microphone sound incidence angles as the airplane flies over. Its response is similar to that of the lying microphone for diaphragm-to-ground spacings of the order of the microphone diameter or larger. For microphones placed closer to the ground, SPL's more than 6 dB above free field are obtained at the high-frequency end of the spectrum. The main attraction of the lying and inverted microphone arrangements is the relative ease of installation, provided that a large, acoustically hard surface is available at the test site. The experimentally determined responses of inverted and lying microphones are reported in Ref. 2.

A ground plane microphone design called the flush-dish microphone shown in Fig. 4d has been developed by Boeing and used for acquiring ground-reflection-free noise data for research flyover tests. A similar microphone is described in Ref. 1. The following sections describe two designs of the flush-dish microphone along with the results of a controlled laboratory experiment to determine their characteristics. Of special interest was the effect of placing these dishes on natural terrain instead of a large, hard surface. This aspect was also evaluated during laboratory and field experiments.

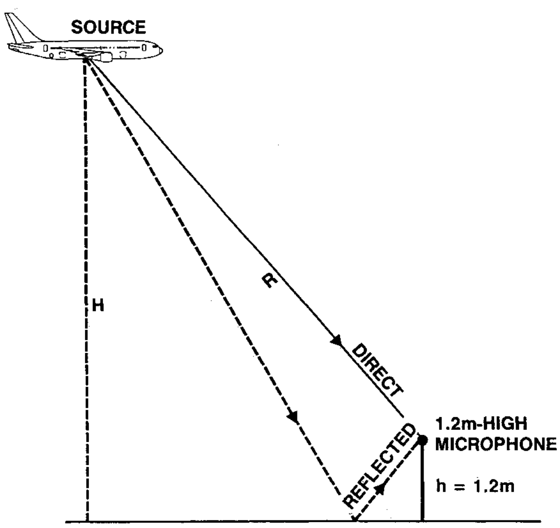

Fig. 1 Acoustic waves received by a 1.2-m-high microphone.

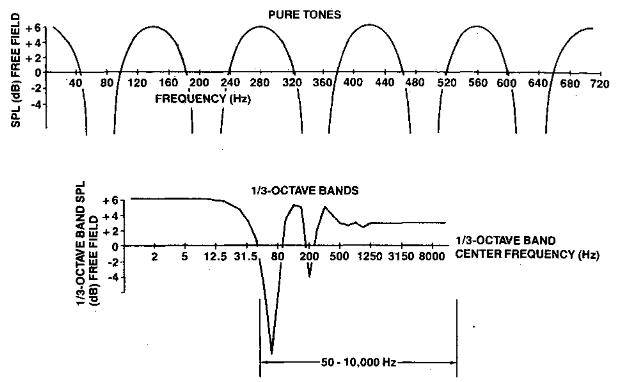

Fig. 2 Typical theoretical ground interference for a 1.2-m-high microphone over an acoustically hard surface.

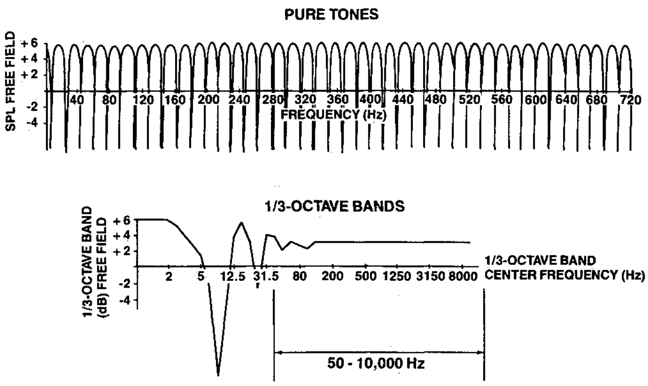

Fig. 3 Typical theoretical ground interference for a 10-m-high microphone over an acoustically hard surface.

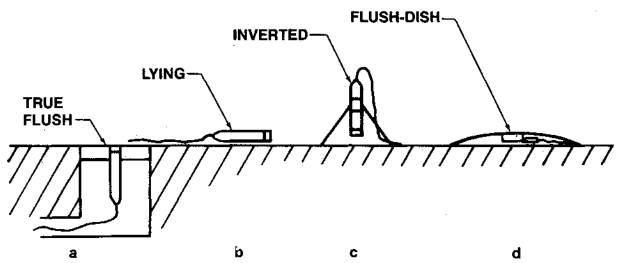

Fig. 4 Ground plane microphones.

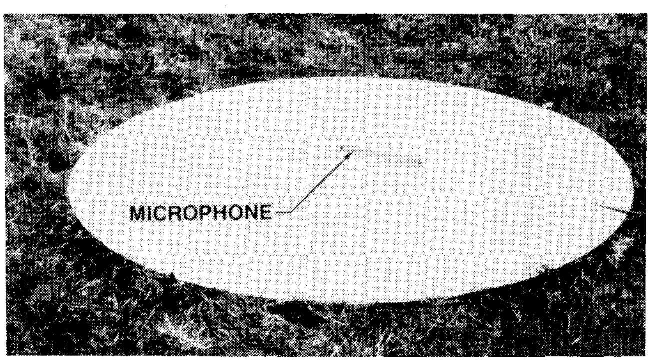

Fig. 5 Circular flush-dish microphone arrangement.

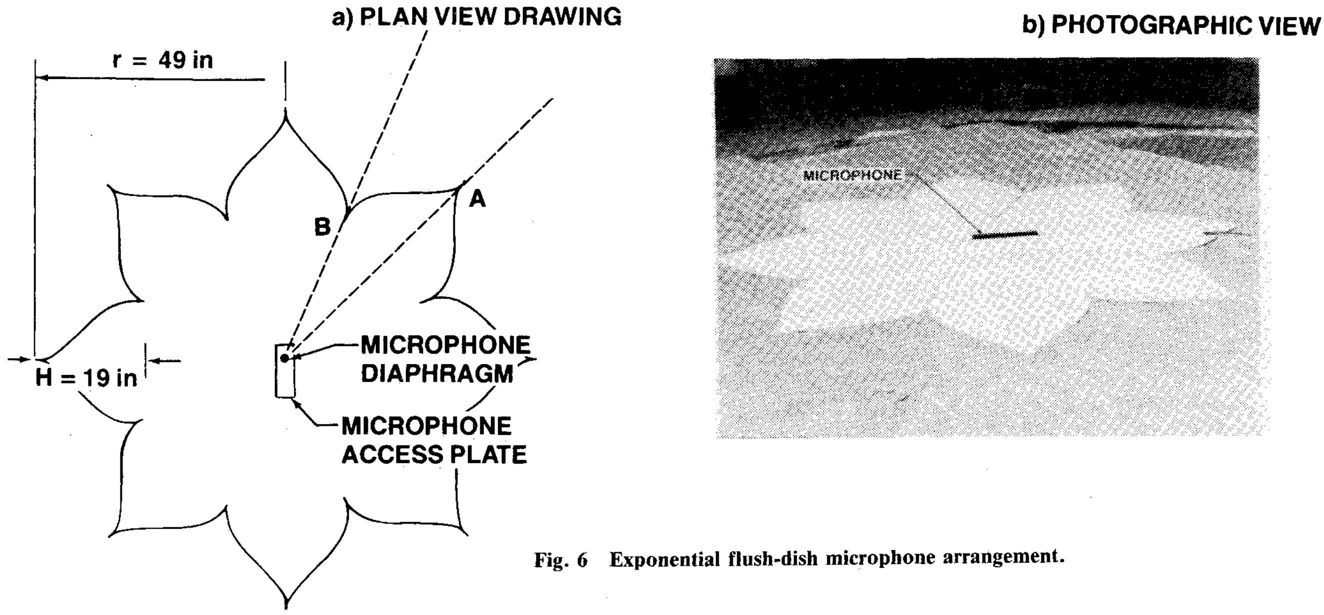

Fig. 6 Exponential flush-dish microphone arrangement.

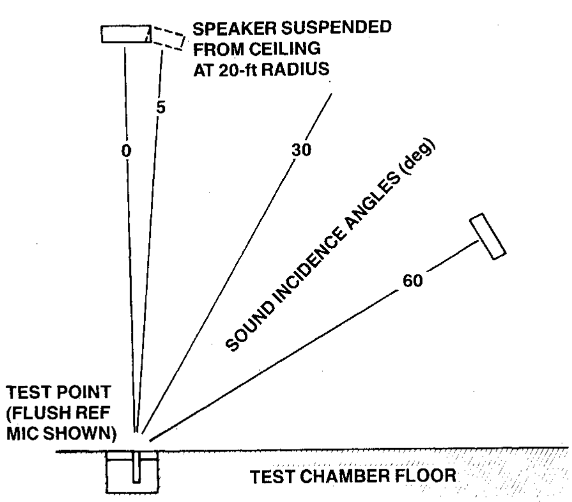

Fig. 7 Anechoic chamber test setup for flush-dish evaluation.

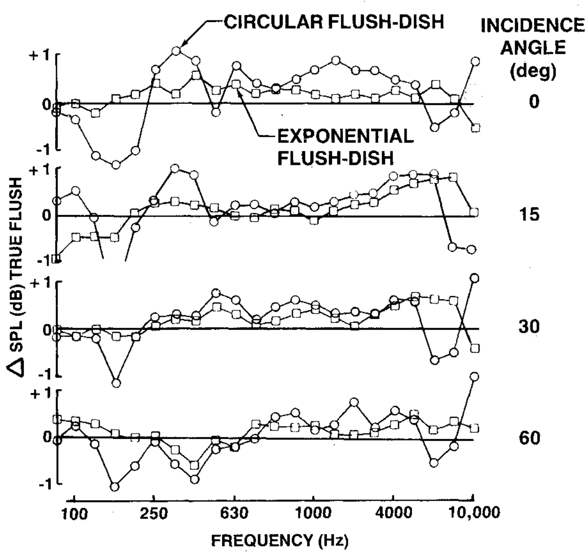

Fig. 8 One-third-octave band response of flush-dish microphones over bare floor.

Description of Flush-Dish Microphones

Circular Flush-Dish Microphone

This design has been in use within the Boeing Company for a few years. It started out as a 4-ft-diam convex plaster of paris dish formed in situ as a close approximation to the true flush installation. The thickness of the plaster dish was kept small by the use of a 90-deg adapter between the microphone cartridge and the preamplifier. The current design is constructed of fiberglass and is shown in Fig. 5. It is a 1.5-m-diam convex dish with a maximum thickness of 4.4 cm at the center. The microphone diaphragm is situated flush with the dish surface at the center of the circular planform. The underside of the dish is filled with viscoelastic damping material to help prevent dish vibration due to relatively high-intensity aircraft noise.

The circular flush-dish microphone has been utilized for the acquisition of flyover noise spectra on both acoustically hard and natural terrain surfaces. No obvious anomalies could be noticed in the flyover noise spectra (both narrow-band and one-third-octave band), and the spectral "hash" was of the order of magnitude expected for random error due to finite sampling effects. However, an earlier laboratory test of the circular dish microphone showed potential for significant edge diffraction effects in the measurement when the sound source was directly overhead of the microphone. This indicated a need for improving the flush-dish microphone to remove the edge effects. Mounting the microphone off-center was eliminated as an option since it was felt that it would only smear the effect, not eliminate it. Furthermore, the work of Smith[3] reported results from a microphone mounted at one-fourth radius from the center of a 2.44-m-diam dish where "board edge effects" were noticed in the measurements.

Exponential Flush-Dish Microphone

The solution devised for the edge diffraction problem was to shape it as shown in Fig. 6. The basic idea is to assure that the transition from the dish to the ground surface occurs very gradually in the radial direction both when going from the dish center to the ground and coming from the ground to the dish. The curve line AB in Fig. 6a defines the shape of the dish edge and is tangential to the local radial lines at both points A and B. This assures that the dish edge area in the planform smoothly reduces to zero when going from the dish to the ground or vice versa. The size of the edge shapes was chosen

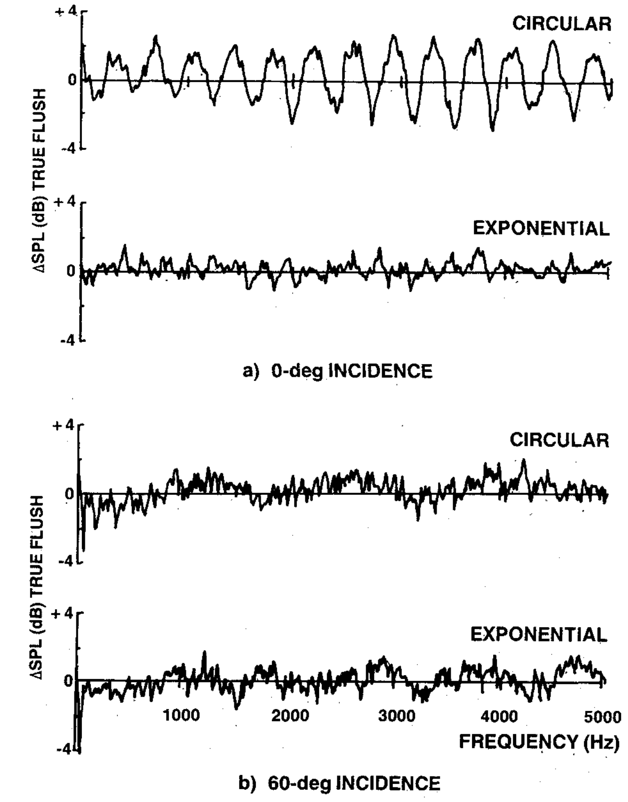

Fig. 9 Narrow-band response of flush-dish microphones over bare floor.

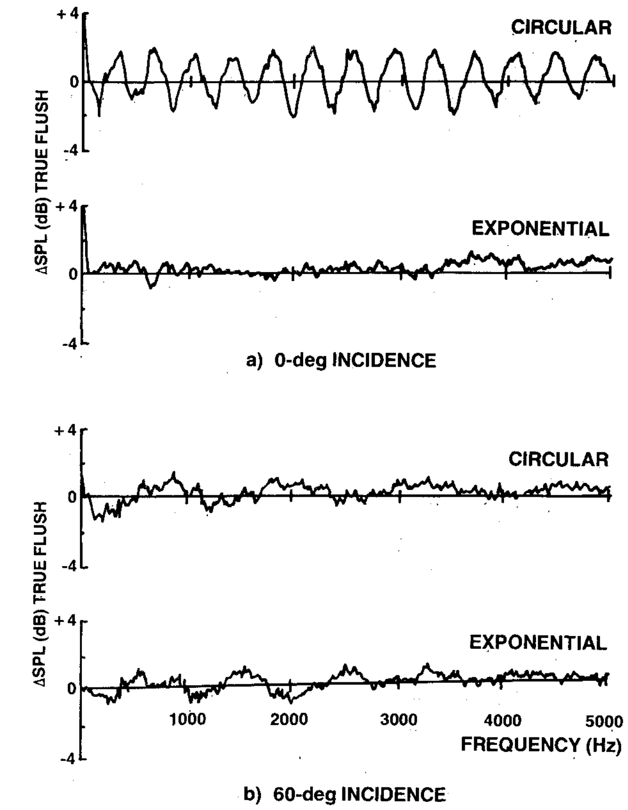

Fig. 10 Narrow-band response of flush-dish microphones with simulated natural terrain.

so that the dimension H in Fig. 6a would correspond to one-fourth wavelength at about 150 Hz. This also gave the maximum radius r that corresponded to a one-fourth wavelength at about 65 Hz. This was considered to be a good compromise between an acceptable dish size and an acceptable lower frequency limit. The new flush-dish design with specially shaped edges is referred to hereinafter as the "exponential flush-dish" to distinguish it from the circular dish microphone.

Laboratory Evaluation of Flush-Dish Microphones

The experiments were conducted in the Boeing anechoic chamber, which has interior dimensions of 20 m × 23 m × 9 m. For this test, the acoustic wedges over the concrete floor of the chamber were removed in one quadrant to accommodate the placement of the test microphone. The noise source was a loudspeaker suspended from the ceiling of the anechoic chamber at a radius of 5.5-m from the test microphone as shown in Fig. 7. By means of tension ropes, the speaker could be positioned at several sound incidence angles. The input to the speaker was a pink noise that was filtered using a one-third-octave band shaper to provide a nearly flat one-third-octave band spectrum at the true flush microphone position.

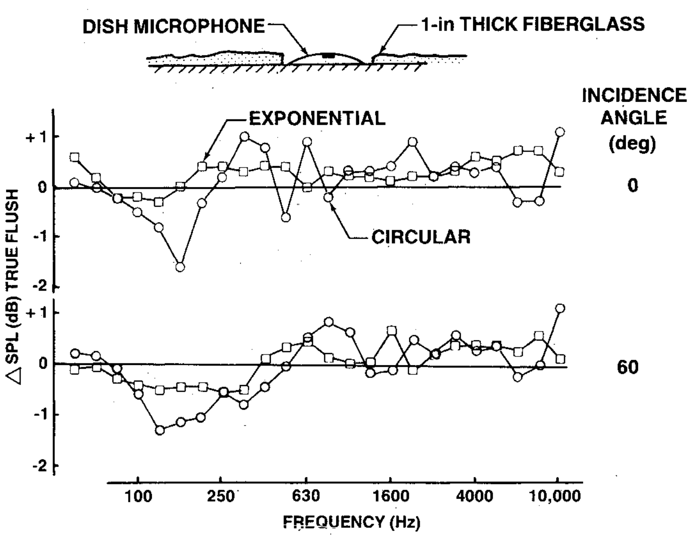

Fig. 11 One-third-octave band response of flush-dish microphones with simulated natural terrain.

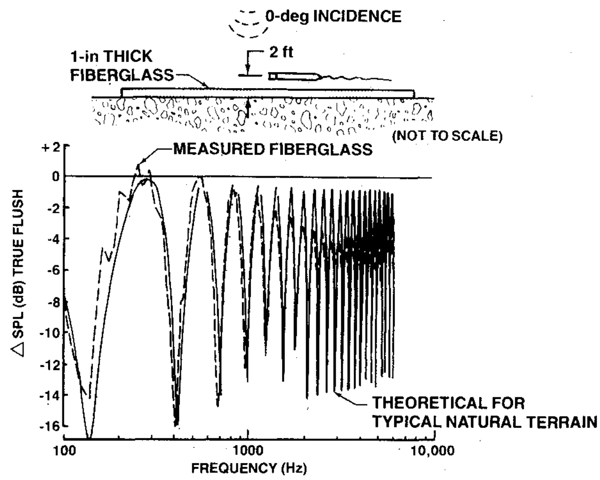

Fig. 12 Results of test to determine how closely the 1-in.-thick fiberglass simulated the natural terrain.

Reference Microphone

The flush-dish microphones were evaluated against a true flush microphone as a reference. The reference microphone was mounted in a thick metal plate covering a cavity in the floor. Care was taken to assure that the cover plate fit snugly over the opening with no visible gap. Furthermore, the floor around the microphone at a 3-m radius was treated with an acoustically hard material to make it uniformly flat, since the concrete floor of the chamber was slightly uneven. The surface around the microphone was sealed with a clear epoxy paint as an extra precaution to assure that it was indeed acoustically hard in the frequency range of interest (50–10,000 Hz).

Test Procedure

The loudspeaker was positioned for the desired incidence angle and was turned on. Its one-third-octave band spectrum was obtained on-line using the true flush reference microphone. Then, the input to the loudspeaker was shaped and a new on-line spectrum was generated. This process was repeated until a nearly flat one-third-octave band spectrum was obtained at most of the frequencies in the 50–10,000-Hz range. Once this was done, the loudspeaker input was left undisturbed and noise data were recorded for the reference true flush microphone and the test flush-dish microphone by placing them at the test point one at a time. During the test, both the one-third-octave band and narrow-band spectra were generated on-line. Also, the signals were recorded on analog magnetic tape for off-line analysis.

Results

For the two dish microphones, the difference in SPL, ΔSPL, at each frequency is calculated as follows:

$$\Delta SPL, dB = SPL_{dish} - SPL_{true\ flush\ reference}$$

Both one-third-octave band and narrow-band ΔSPL's were calculated. The ΔSPL is referred to as the response of the dish microphone. A ΔSPL equal to zero corresponds to a response of free field + 6 dB or pressure doubling.

Bare Floor Response

The one-third-octave band responses of both the circular and exponential flush-dish microphones are compared in Fig. 8 at four incidence angles. The dishes were placed on a bare floor for these measurements. The corresponding narrow-band responses at 0 and 60 deg are shown in Fig. 9.

For 0-deg incidence, i.e., when the speaker is directly above the microphone, the circular flush-dish one-third-octave band response deviates from the true flush reference by about + 1 to − 1.5 dB. The minima at 160 and 315 Hz are the most prominent features of this response. The narrow-band response, Fig. 9a, shows that the low-frequency features of the one-third-octave band response are due to a regular interference pattern with 375-Hz periodicity. The 375-Hz periodicity corresponds to the acoustic path length difference between a direct wave and waves diffracted from the dish edge. For the circular dish at 0-deg incidence, the path length difference for the entire dish edge circumference is the same. Thus, the sound waves diffracted from each elemental section at the dish edge will arrive in phase at the dish center where the microphone is located. Even if the strength of the diffracted wave at each elemental section of the edge is weak when it arrives in phase at the dish center, the combined amplitude can be comparable to that of the direct wave. This is probably the reason for the observed strong interference pattern.

Examination of the narrow-band response of the exponential dish at 0-deg incidence in Fig. 9 shows that the interference pattern has been successfully eliminated by the use of the exponential edge shapes. As shown in Fig. 8, the corresponding one-third-octave band response is smooth with less than ±0.5 dB deviation from true flush at most frequencies.

Returning to Fig. 8, the one-third-octave band response of the circular dish microphone still shows the interference effects at 15 deg. At 36 and 60 deg, the effects are diminished. The one-third-octave band response of the exponential dish is free from edge interference effects at all angles.

Simulated Natural Terrain Response

In many instances, there is no suitable large, acoustically hard surface available at the flyover test site for placing the flush-dish microphones. For example, the research flyover noise data are often acquired along with a noise certification test for which the acoustic test site is chosen at a distance of several thousand feet from the end of the runway. Thus it becomes necessary to place the flush-dish microphones on natural terrain surfaces to acquire ground reflection interference-free flyover noise data.

The response of the two dish microphones with 2.5-cm-thick fiberglass surrounding the dishes was measured in order to simulate the effect of a natural surface that is not acoustically hard. Measurements made with the dishes resting on top of a 2.5-cm-thick mat gave misleading results (a strong interference pattern in the low-frequency region). This installation is equivalent to the dish being suspended above the reflecting surface, a situation for which strong edge effects are expected. Therefore, the natural terrain simulation was achieved by cutting the fiberglass mats to fit snugly against the dish edge. The dish itself rested on the bare floor.

The natural terrain simulation responses at 0- and 60-deg incidence angles are presented in Fig. 10 for the narrow-band SPL's. The responses of both the circular and exponential dishes are nearly the same as those obtained for bare floor measurements (Fig. 9). The circular dish has interference effects at 0-deg incidence whereas the exponential dish does not have any recognizable effect.

At 60-deg incidence, both dishes are free from the interference effect. Again, no recognizable impact due to the surrounding fiberglass is noticed, comparing results from Figs. 9b and 10b.

The corresponding one-third-octave band responses for natural terrain simulation are shown in Fig. 11. Once again the results are similar to those for the bare floor case.

To determine whether the fiberglass closely simulated natural terrain simulation are shown in Fig. 11. Once again, the using a microphone mounted at grazing incidence 2 ft above the floor. Acoustic data were acquired with and without fiberglass mats. Data were also acquired for the true flush reference.

The ground interference ΔSPL obtained for the test fiberglass is shown in Fig. 12. Also shown in this figure is the ground interference curve for a 61-cm-high microphone using

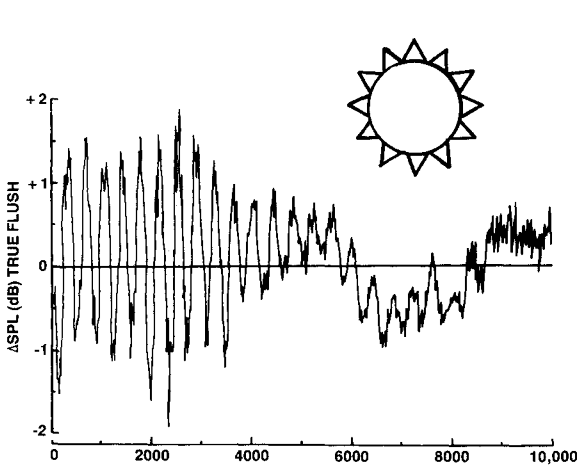

Fig. 13 Effect of star-shaped edge on narrow-band response of circular dish on bare floor at 0-deg incidence.

ground impedance values typical of natural terrain. How this ground impedance was derived will be explained later in this paper. It can be seen in Fig. 12 that the two interference curves are reasonably close, thus indicating that the fiberglass mats did in fact closely simulate a typical natural terrain situation.

Dish Mounting and Edge Treatment Effects

Several additional bare floor experiments were conducted using the circular flush-dish microphone with the speaker in the overhead position. The purpose of these tests was to determine whether the edge diffraction interference effects, observed for the circular dish microphone in Fig. 9, could be eliminated by a simple edge treatment or by a change in the mounting method.

The following treatments had no noticeable effect on the circular flush-dish response: 1) sealing the edge with modeling clay, 2) sealing the edge with aluminum tape, 3) multiple balls of clay distributed at several points under the dish, and 4) edge seal plus multiple point support. The edge treatments that showed improvements were the following: 1) the attachment of approximately 18-cm × 18-cm aluminum tape squares so as to form a star-shaped outline, and 2) the application of four 61-cm × 61-cm squares of 0.8-mm-thick aluminum plate. The narrow-band responses for these configurations are shown in Figs. 13 and 14. The star-shaped dish shows improvement beyond 5 KHz. The configuration with the 61-cm square plates showed improvement beyond about 1 KHz. On a one-third-octave band basis, the improvement was not obvious (Fig. 15).

Field Evaluation of Circular Dish Microphone

The laboratory test results discussed earlier showed that both circular and exponential flush-dish microphones are satisfactory for obtaining one-third-octave band spectra that are within about +1 to −1.5 dB of free field + 6 dB at all frequencies and angles. For narrow-band analysis, the exponential dish was found to be satisfacory at all angles. The circular flush dish was acceptable at all angles except in a region covering ±15 deg around the direct overhead position.

Also, the two dishes showed negligible change in behavior between bare floor mounting and with surrounding fiberglass to simulate the natural terrain. This result is qualitatively in line with the physics of the problem. This is because at low frequencies, most test site surfaces are acoustically hard. Thus, for low-frequency sound waves, there will be very small acoustic impedance change at the dish-ground interface. The installation, therefore, should be acoustically close to a flush-dish mounted on a large, hard surface. At high frequencies, the ground is quite absorptive; however, the wavelengths are small and the 1.5-m-diameter dish surface, by comparison, is relatively large. Thus the sound pressure measured by the microphone should be insensitive to the ground impedance at the high frequencies.

To validate the physical reasoning and the laboratory result, data taken during an earlier full-scale airplane flyover test will be presented here. This test was conducted at an airport in Seattle using circular flush-dish microphones. Noise from an airplane takeoff was simultaneously recorded, both by a flush-dish microphone on a large, hard runway surface and by another on a natural grassy surface (Fig. 16). It was found that there was no significant measurement difference between the two microphones, as shown in Fig. 17, where the PNLT vs time plots are compared. Similar comparisons were obtained for one-third-octave band SPL's, although the SPL time histories showed more randomness, as should be expected (Fig. 18). This microphone evaluation test also indicates that the use of flush-dish microphones on natural surfaces will provide satisfactory results.

On Ground Interference of 1.2-m Microphones

Background

Most static engine noise data are obtained using ground plane microphones from which free-field levels are derived. On the other hand, 1.2-m microphones over natural terrain must be used for aircraft noise certification measurements.[4] As previously explained, the direct and reflected signal received by the 1.2-m microphones cause the spectrum to be modulated by reinforcements and cancellations. This is termed the ground interference effect.

Sometimes it becomes necessary to project the static engine data to flight and compare it with the flyover data measured

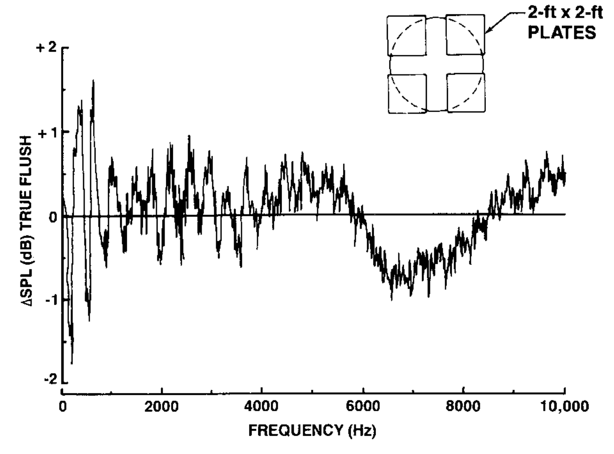

Fig. 14 Effect of attachment 61-cm-square plates on the narrow-band response of circular dish on bare floor at 0-deg incidence.

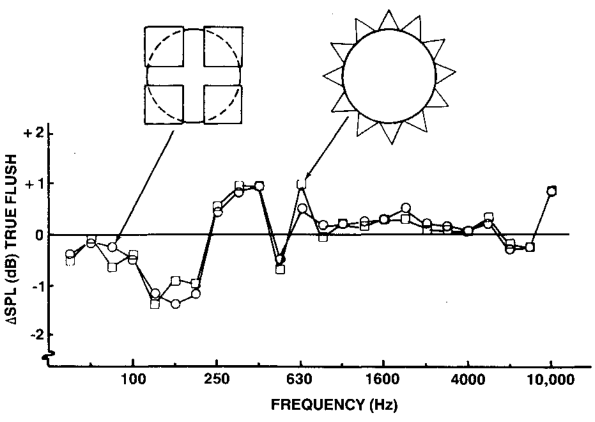

Fig. 15 Effect of edge treatments on one-third-octave band response of circular dish at 0-deg incidence on bare floor.

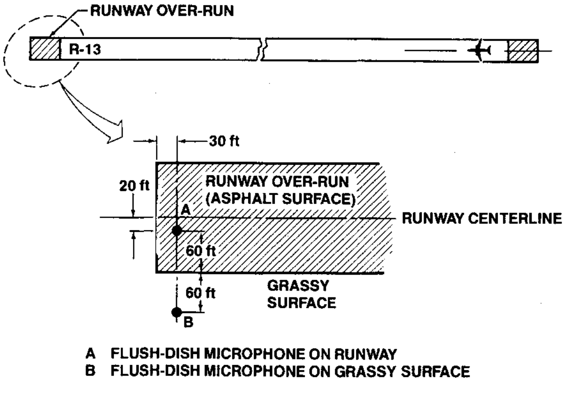

Fig. 16 Test setup to validate the use of flush-dish microphone over natural terrain.

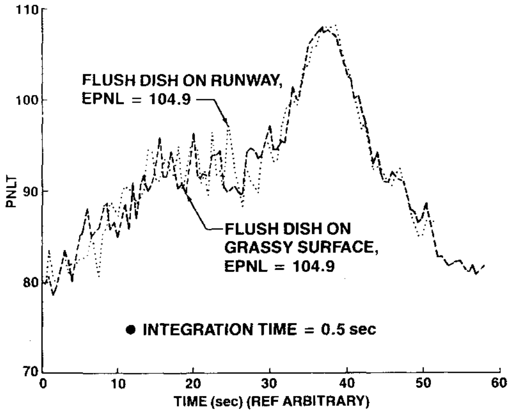

Fig. 17 Comparison of PNLT between flush-dish microphones on large, hard surface and a flush-dish microphone on natural surface.

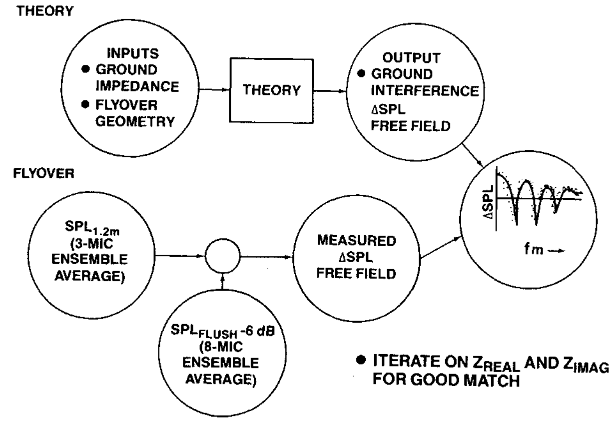

Fig. 20 Outline of analysis used in derivation of ground interference model for 1.2-m-high microphone.

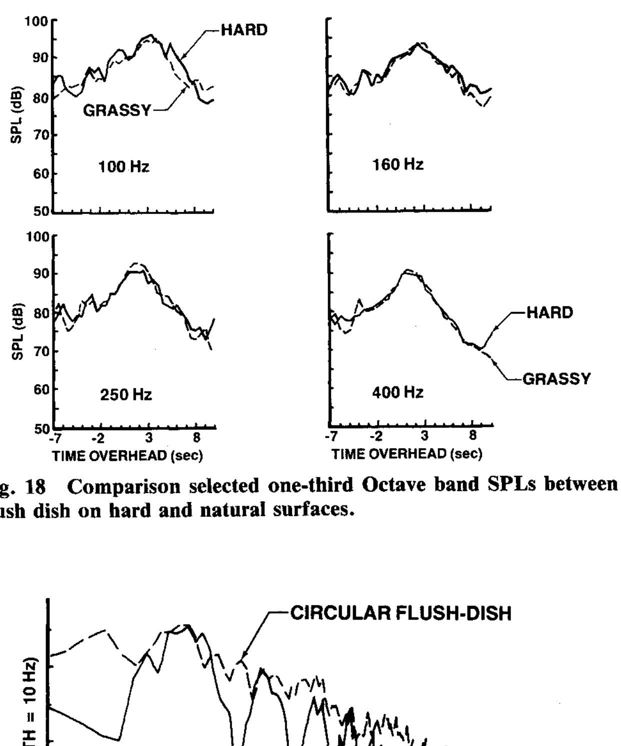

Fig. 18 Comparison selected one-third Octave band SPLs between flush dish on hard and natural surfaces.

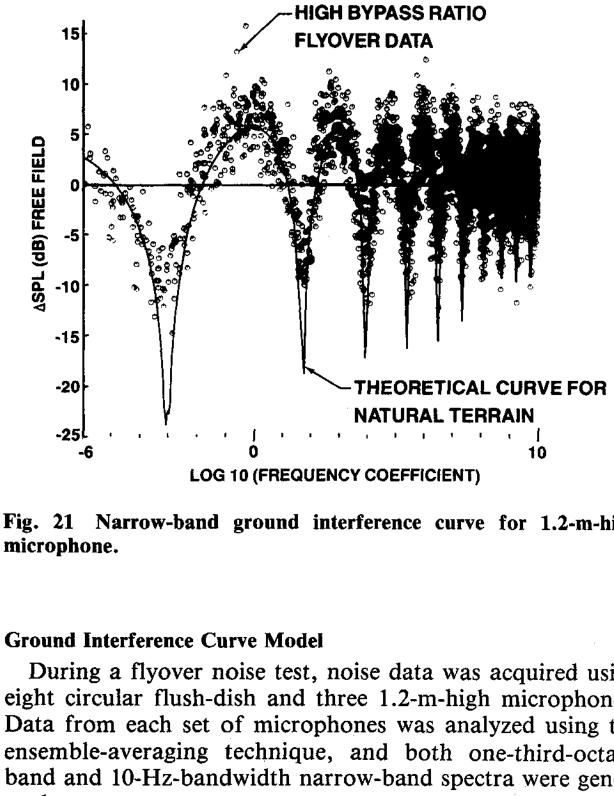

Fig. 21 Narrow-band ground interference curve for 1.2-m-high microphone.

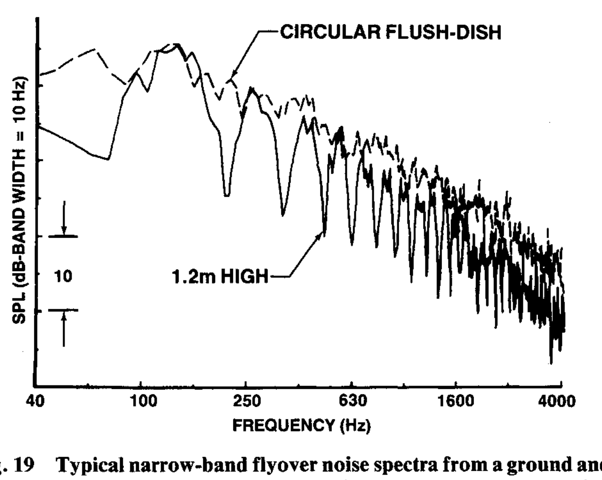

Fig. 19 Typical narrow-band flyover noise spectra from a ground and 1.2-m-high microphones obtained using the ensemble-averaging technqiue.

using 1.2-m-high microphones. To be able to compare the two sets of data properly, the static data projection process should include a method to convert the free-field levels to that representative of the 1.2-m-high microphones. This can be done by analytic means provided that ground impedance values are known. Since accurate ground impedance values are usually unavailable, it was decided to derive the ground interference model by experiment.

Ground Interference Curve Model

During a flyover noise test, noise data was acquired using eight circular flush-dish and three 1.2-m-high microphones. Data from each set of microphones was analyzed using the ensemble-averaging technique, and both one-third-octave band and 10-Hz-bandwidth narrow-band spectra were generated.

Typical ensemble-averaged narrow-band spectra for the flush-dish microphone and the 1.2-m-high microphone are shown in Fig. 19. The flush microphone spectrum is relatively smooth, whereas the 1.2-m microphone spectrum exhibits several interference dips. Further in the low-frequency end, the SPL's at the reinforcements of the 1.2-m microphone spectra are nearly equal to the flush microphone SPL's, which is indicative of pressure doubling.

The analysis method will now be briefly explained. The same method was used for both one-third-octave band and narrow-band data and is shown as a block diagram in Fig. 20. For each emission angle, the 1.2-m microphone interference effect was calculated by the expression

$$\Delta SPL(f) = SPL_{1.2\,m}(f) - [SPL_{flush}(f) - 6]$$

Since the path length difference varies with the emission angle, the cancellation frequencies will also differ with the emission angle. However, by defining a frequency coefficient, a Strouhal number based on path length difference, as

$$f_m = f(\Delta R)/c$$

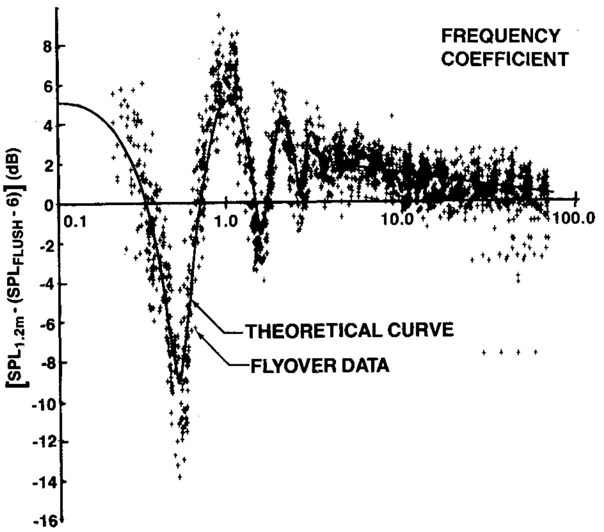

Fig. 22 One-third-octave band ground interference curve for 1.2-m-high microphone over natural terrain.

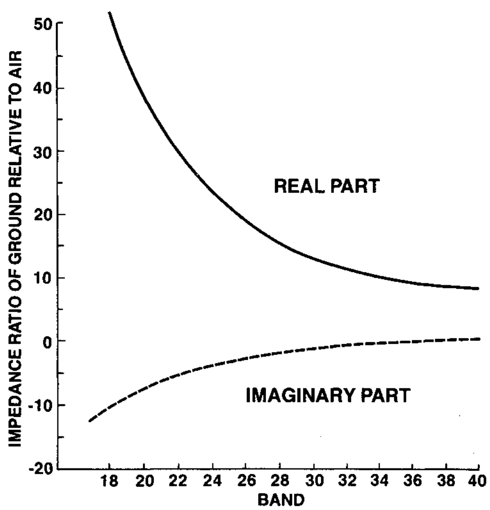

Fig. 23 Iteratively derived ground impedance values for natural terrain.

where f_m is the frequency coefficient, f the frequency in Hz, ΔR the path length of reflected wave minus the path length of direct wave in m, and c the speed of sound in m/s; it is possible to make the cancellation occur at the same frequency coefficients for all emission angles. This has been done in Fig. 21, where circular symbols represent narrow-band SPL's from various emission angles calculated by using the flyover data.

The theoretical curve that fits the measured data is also shown in Fig. 21. The theory needs ground impedance as an input. Since the complex ground impedance was not available for the test site, the analysis was done with a set of impedances generally expected for natural terrain. These values were iterated to obtain a good match between the measurement and theory. The same result obtained using one-third-octave band SPL's is shown in Fig. 22. The final values of ground impedance obtained by iteration are presented in Fig. 23.

It should be pointed out that the ground impedance, iteratively derived to match the ground interference in the present flyover data, was very close to that derived in another Boeing study for a different airplane case at a different test site. This leads us to believe that when detailed ground impedance information is not available, the impedances shown in Fig. 23 may be used. Furthermore, in most instances, the SPL vs f_m theoretical curve shown in Figs. 21 and 22 can be used as a general correction curve for a typical, natural-terrain 1.2-m-high microphone installation similar to that used in deriving the curve (1-in. Bruel and Kjaer normal incidence microphone with wind screen).

Concluding Remarks

In this paper, two flush-dish microphone designs were described for the measurement of ground reflection interference-free aircraft flyover noise. The responses of both flush-dish microphones were nearly the same whether they were mounted on a large, hard surface or on natural terrain. The circular flush-dish design was found to be satisfactory in the 50–10,000 Hz range for all incidence angles except for angles that were within about 15 deg of the overhead position. At the overhead position, the circular dish microphone response showed spectral modulation with a spacing of about 375 Hz. This frequency spacing corresponded to the path length difference between direct and edge-diffracted waves. To diminish the edge diffraction effect, a new design called the exponential flush-dish was conceived where the edges were shaped to gradually match the impedance between the dish and the ground. Also, the edge shape was intended to avoid the in-phase addition of diffracted waves at the dish center.

The experimental results showed that the design objective was achieved, and the exponential flush-dish microphone was free from edge diffraction effects at all incidence angles, including the overhead position.

The exponential flush-dish microphone is, therefore, the preferred configuration. Recent Boeing tests have shown that by attaching sheet metal "petals" that simulate the shape of the exponential dish to the circular dish, equivalent results can be obtained.

The test experience has shown that during the microphone installation it is advisable to ensure that the following requirements are satisfied: 1) for hard surface mounting, seal the edge of the dish with putty, and 2) for natural terrain mounting, mount the dish on the soil surface formed by completely removing all vegetation under the dish. Furthermore, the ground in the vicinity of the dish up to about a 7–8-m radius should be cleared and compacted as much as possible. No air gap should be present between the dish and the ground.

Also, the paper presents the ground interference curve derived experimentally for a typical noise certification-type 1.2-m-high microphone mounted over natural terrain.

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