MICROPHONE ORIENTATION IN THE SOUND FIELD

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Many excellent papers have been published on the fundamentals of practical acoustical measurements, None dwell on the very important matter of microphone selection. It is erroneous to believe that all sound level meters are identical or even equivalent on the basis that all are manufactured to a stated standard; their microphones differ. The selection of a microphone and its orientation in the sound field is an important consideration.

TWO CLASSES OF INSTRUMENTATION MICROPHONES are available, the pressure microphone and the free-field microphone. The nature of the sound field, the measurement condition and the purpose of the measurement determine which class of microphone will give the best data. We will discuss five measurement conditions which can exist within the sound field depending upon reflection conditions. They are ranked with the most common condition first and the unique condition last:

- ☐ Perpendicular-incidence measurement
- ☐ Omnidirectional measurement
- ☐ Pressure measurement
- ☐ Grazing-incidence measurement
- ☐ Random-incidence measurement

These are shown pictorially in Figure 1. Each represents a distinct microphone application. The fundamentals of the sound field must be reviewed and the microphones must be discussed before the selection of a microphone for each condition can be considered.

The Sound Field

The response of a microphone to a sound field depends upon the location of the microphone with respect to the sound source and upon the environment that surrounds the microphone and the sound source. Figure 2 shows the variation of sound level as a function of separation between the sound source and the microphone. In the shaded areas the sound pressures vary widely and rapidly and small shifts in microphone position cause level fluctuations within the limits shown. The near and far-field conditions relate to the source radiation behavior as a function of its distance from the sound source and the free- and reverberant-field conditions have to do with the external environment.

Consider an air conditioner. If a microphone is moved around in close proximity to it, the sound level and spectrum will change. This near-field variability (shown in Figure 2) is caused by several things. The microphone responds to the nearest generating source, such as the compressor, the fan, or the motor. Indeed, a probe microphone is an excellent tool for locating the source of noise. Furthermore, phase additions and cancellations from nearby radiating objects can give widely varying results.

Occasionally probe microphones are used in the near field to isolate sources of noise. However, most serious sound measurements are made in the far field. Why? Because we are interested in the total sound *radiated* from the noise source. If the microphone is far enough away, a uniform measurement can be obtained at any point along the path of propagation. This is known as the far field. Because the sound energy is distributed over a larger space as it propagates from a source, the energy decreases. It decreases inversly with the square of the distance. Since sound energy is proportional to the pressure squared, the level in decibels drops 6 dB as the pressure is halved or the energy goes to one-quarter its earlier value. Conversly, the pressure increases by 6 dB for every halving of the distance to the source until the near field is reached.

It is important to know when you are in the far field. A good rule of thumb is that the microphone distance should be at least 3 to 4 diameters of the

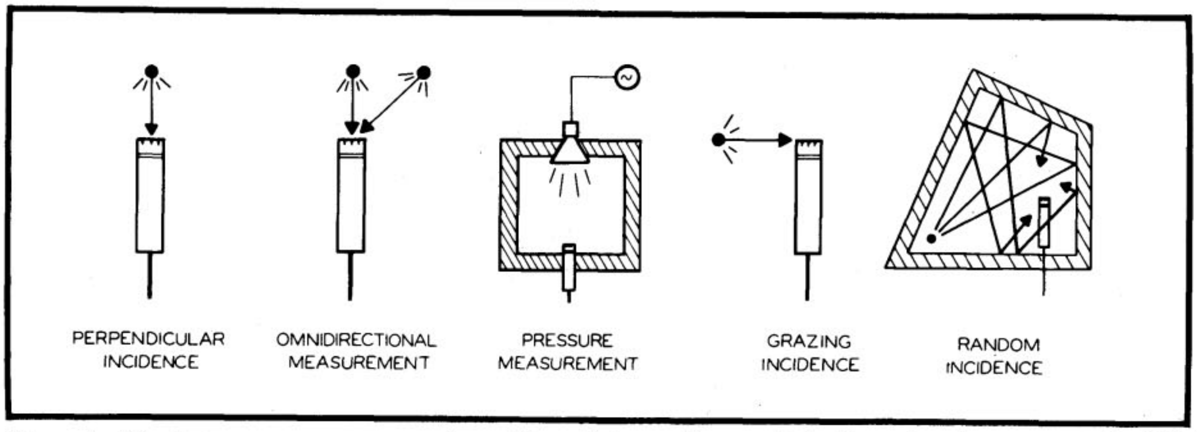

Figure 1—The five common measurement conditions that may be expected when microphones are used within a free field, small closed cavity, or a diffuse field.

largest dimension of the radiating source. A simple test is to double the distance of the microphone and see if the pressure level decreases by 6 dB. In the far field, the external environment becomes important. If there are no reflections of sound waves from the ground, the walls of a room, or any other reflective surface, the microphone sees only the directly propagated sound from the source and a free field is said to exist. But reflections usually exist (even outdoors), so the field is partly reverberant. The microphone will see reflected sounds as separate sources so reflections may affect the data. The proper microphone must be selected and oriented in the sound field to minimize these effects. Figure 2 shows a shaded area in the reverberant field. The area covers the limits of level fluctuations observed with small shifts in microphone position. This apparent variability is entirely caused by reflections. Because of these difficulties, extremely critical measurements are often made in anechoic rooms. A reverberant room is often used to determine total sound power. The room's rotating vanes and nonparallel, hard-surface walls reflect sound from all directions. In such a room the energy density and sound level is evenly distributed and is readily related to the power radiated from a sound source.

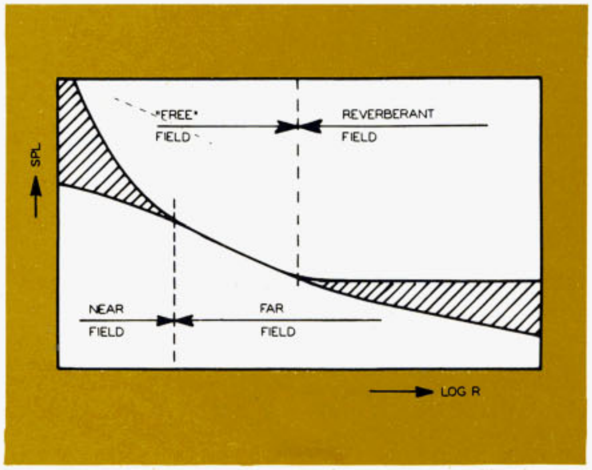

Figure 2—The variation in sound pressure level, L_p, as a function of distance, R, between a noise source and microphone. The shaded areas indicate positions where the levels may vary when the microphone is shifted to another nearby point at the same distance from the source. The near field/far field border usually occurs at about three times the sound source diameter. The free field/reverberant field border will occur when the reduction in sound pressure with distance becomes nonlinear. In the reverberant field, reflected sound energy predominates over the direct sound energy from the source.

The Condenser and Piezoelectric Microphone

Only two types of sensors are generally considered for sound measurements—the condenser microphone and the piezolectric microphone. Within these two types, two classes are available; the pressure microphone and the free-field microphone. The condenser microphone is far superior for most applications. It is an accepted standard and the ANSI Type L model is acceptable for NBS calibration. It is less sensitive to vibration and, for comparable size, has much higher frequency response and about 25 dB greater acoustic sensitivity than piezoelectric microphones. More environmental data is published for the condenser microphone and more accessories are available. The condenser microphone depends only on the diaphragm for its frequency response. The piezoelectric microphone uses its diaphragm to couple motion to the ceramic or crystal element. The element's resonant frequency

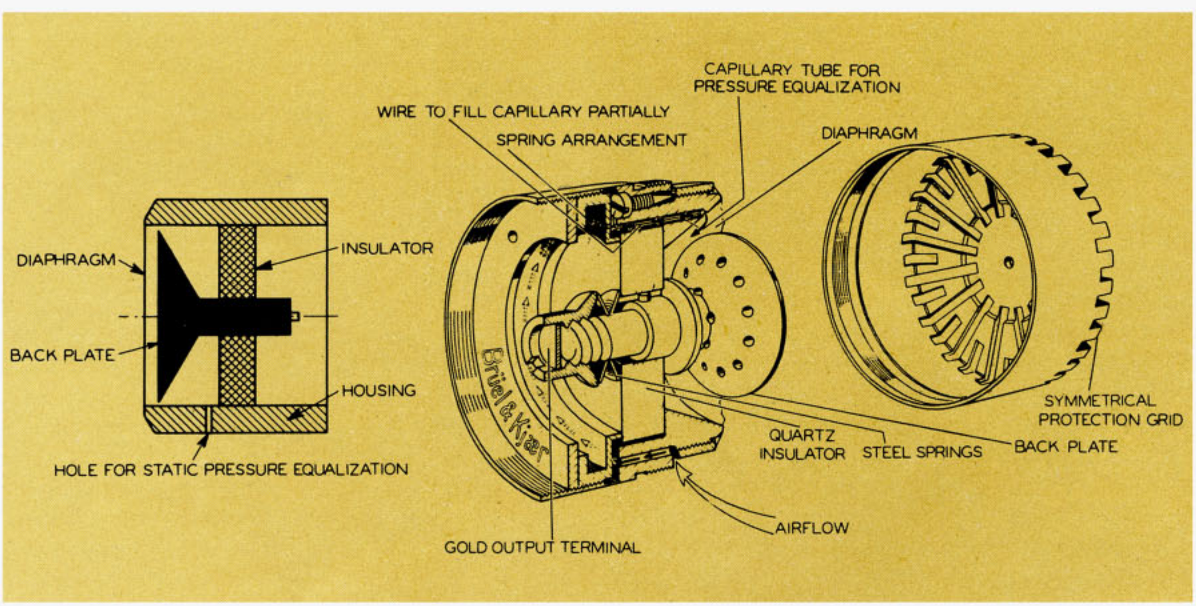

Figure 3—Schematic and cutaway views of a typical B&K condenser microphone.

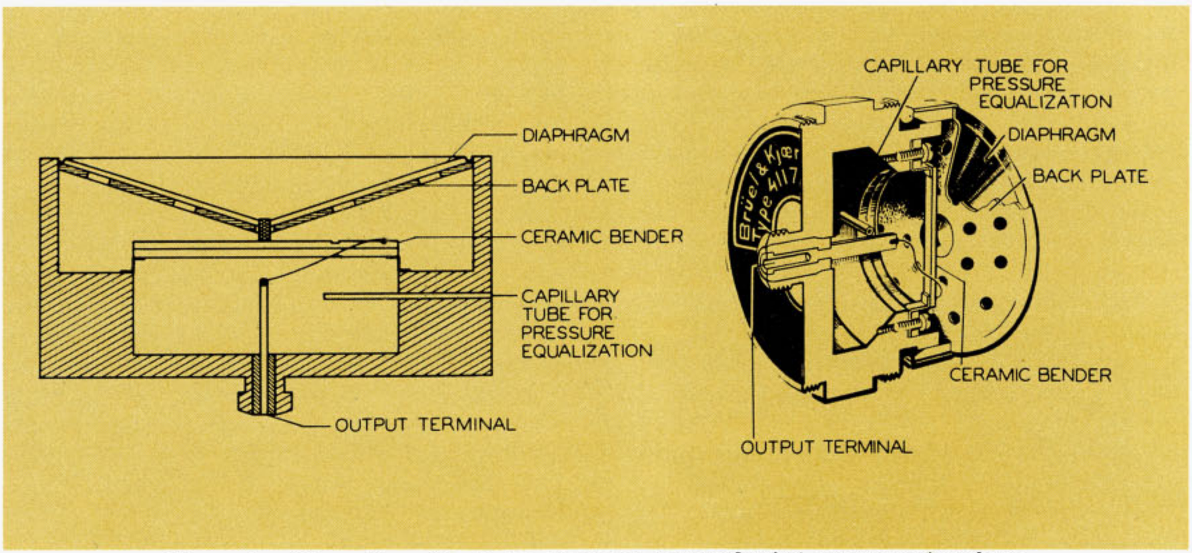

Figure 4 — Schematic and cutaway views of a typical B&K ceramic microphone.

is lower than that of the diaphragm of the condenser microphone. Therefore, the piezoelectric sensor has a limited high frequency response.

A condenser microphone cartridge is shown schematically on the left in Figure 3. A thin metallic diaphragm is located in close proximity to a rigid backplate and electrically insulated from it so that together they form a capacitor. A hole through the sidewall permits equalization for ambient pressure variations. The diaphragm is critically damped or over damped under sea level pressure conditions. These are gage pressure devices; they measure dynamic variations from atmospheric pressure.

The B & K Free Field Ceramic Microphone is shown in Figure 4. The metal diaphragm transfers motion to the ceramic bender element. Its response is flat to 10 kHz for normal incidence in a free field.

The Pressure Microphone. The history of instrumentation condenser microphones began with the ANSI Type L standard. The original intent was to standardize the microphone and coupler used for calibrating earphones and audiometers. B & K built their first modern condenser microphone in 1958 to this standard. It was the Model 4132; It has recently been superseded by the Model 4144. Next, B & K built ½ in., ¼ in. and ⅛ in. sensors to meet other measurement needs. The ANSI Type L sensor is a pressure microphone, so named because its high frequency response is best under close-coupled or constant pressure measuring conditions such as inside an artificial ear or in the near field of a sound source. Its frequency response is flat to 7 kHz under these conditions. Figure 5 shows the frequency responses of the 1 in. through ⅛ in. pressure microphones for measurements within a close-coupled pressure field, a reverberant field, and free field conditions.

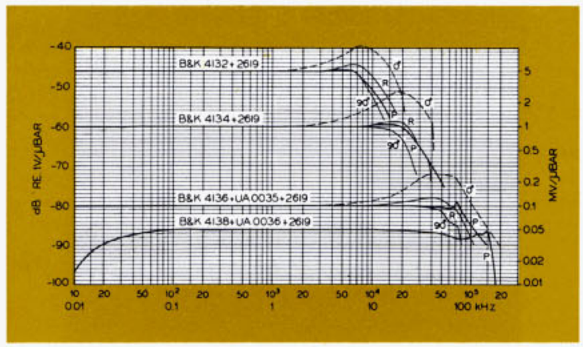

Figure 5 — Composite frequency response curves for typical B&K pressure microphones. The sensitivities in dB re 1V/microbar as a function of various measurement conditions are shown. Curve P (pressure) is the frequency response of the microphone when used within a closely coupled constant pressure field such as a small closed cavity. Curve R (random incidence) is the frequency response when the microphone is used within a diffuse or reverberant field. Curve 0° and 90° show the responses under free field conditions when the microphone is used at perpendicular incidence and at grazing or parallel incidence, respectively.

When a microphone is placed in a free field or semireverberant field, it may affect the field. Below 1500 Hz, a 1 in. microphone will not disturb the sound field, and is therefore omnidirectional. But above about 1500 Hz, an increasing amount of diffraction and reflection occurs to the sound waves incident upon the face of the microphone. The sound pressure measured at the effective surface of the diaphragm is no longer the same as that in the undisturbed sound field. The difference between the effective and free field pressure depends upon the angle of incidence and the ratio of wavelength to the diameter of the microphone. When the wavelength equals the diameter (about 14 kHz for a

1 in. microphone) the effective pressure is about 11 dB higher than the free field pressure for a 1 in. microphone equipped with a protective grid. The family of free field *corrections* to the *pressure response* of 1 in. microphones is shown in Figure 6.

When pressure microphones are used in a free field, they must be oriented for grazing (90°) incidence to produce the flattest frequency response. For example, Figure 5 shows that the pressure response of the 1 in. microphone is flat to 7 kHz. Figure 6 shows that the grazing-incidence correction is negligible over that range. When a direct or reflected sound wave is incident on the diaphram of a pressure microphone at some angle less than 90°, the microphone's basic frequency response is unpredictable. The random incidence response is also shown in Figure 6. It is derived from the composite response for all angles of incidence.

The Free Field Microphone. Today, most measurements are made under free field or semireverberant conditions. The 1 in. pressure microphone in a free field does not cover the entire audio range, however. Also, an inexperienced user might point it at the sound source and obtain an excessive reading in the frequency region above 1 kHz without realizing his error. An alternate cartridge was designed by B & K for free-field applications (normal incidence to the diaphragm). The diaphragm was overdamped so that the pressure response roll-off compensated for the 0° nonlinearity. The result is the 4145 (formerly 4131) which is flat to 18 kHz. It covers the audio range and can be pointed directly at the sound source. For the ½ in. and ¼ in. series, the same scheme was used to produce flat frequency responses to 40 kHz and 100 kHz respectively. This family of response curves for free field condenser microphones is shown in Figure 7. Note that the smaller sensors provide the high frequency response necessary for model tests. The 4117 Ceramic Microphone is also a free-field sensor. It is flat within 2 dB to 11 kHz.

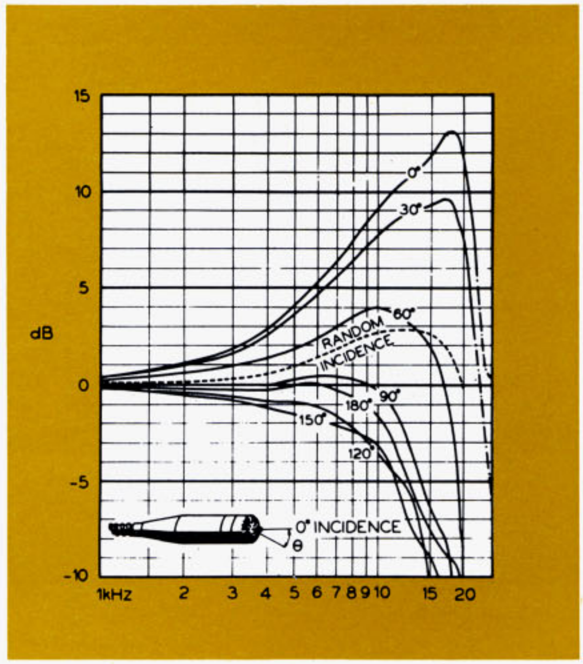

Figure 6—Free field corrections for B&K 1 in. microphones equipped with protective grids. One of the curves is selected based on the angle of incidence and added to the pressure response of the microphone to be used.

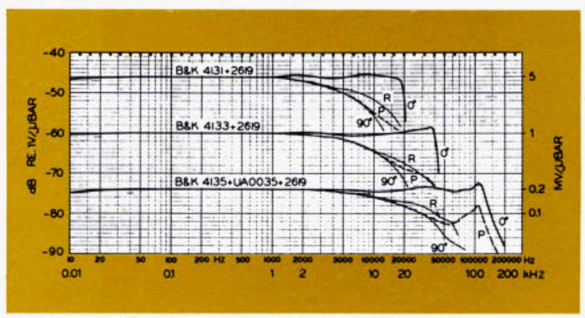

Figure 7—Composite frequency response curves for typical B&K free field microphones. The pressure, random incidence, 0° incidence, and 90° incidence frequency response curves are shown as a function of microphone sensitivity.

Choice and Orientation of Microphone

The complete background has been presented. Now we can evaluate the microphones for use under the five measurement conditions that were identified previously.

Perpendicular Free Field. Most acoustic measurements must determine the sound directly radiated from the source to the microphone. The microphone is expected to measure *only* the directly radiated sound. Typical situations occur in measuring machinery, air conditioners, electric motors and jet engines. Such measurements are easiest within an anechoic chamber. Sound propagated in other directions will be absorbed at the walls. The majority of measurements, however, are made in laboratory or production areas where the radiated sound waves reflect from floors, walls and nearby objects. They are seen by the microphone as added sources. Yet the objective is to measure one source exclusively. Under these conditions, the ideal microphone is one that is *unidirectional* and does not respond to sound incident from off-axis. No instrumentation microphones of this type are available so the user must select the class of microphone which will best protect him against errors due to reflection additions.

The free field microphone is best for this application. Above 1.2 kHz, the 1 in. microphone begins to attenuate off-axis signals. A typical free-field response curve is shown by the solid line in Figure 8. Its attenuation for off-axis incidence is shown by the broken lines. With 0° incidence, the 1 in. micro-

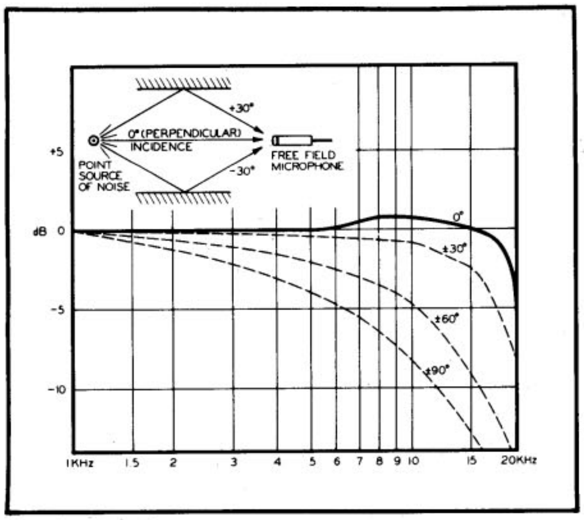

Figure 8—Perpendicular (0°) incidence and off-axis frequency response curves of typical B&K 1 in. free field microphones.

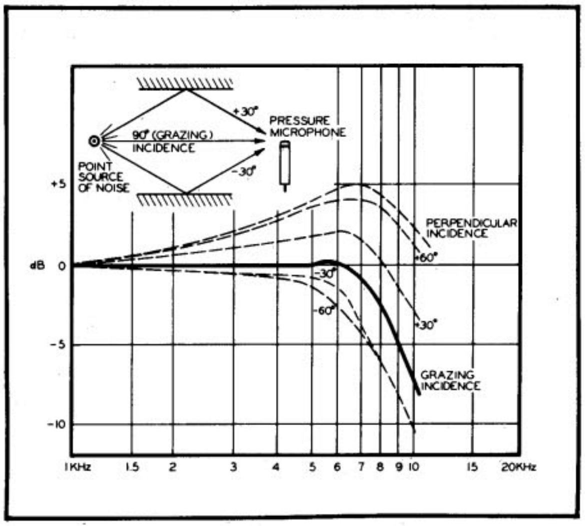

Figure 9—Grazing (90°) incidence and off-axis frequency response curves of typical B&K 1 in. pressure microphones.

phone covers the audio range up to 18 kHz. Without a free-field microphone, the user would need a ¼ in. pressure microphone to do the same job accurately. What's more, he would not have any protection against reflected sound waves. The user points the free field microphone at the sound source, a natural thing to do. Because the most sensitive axis is aimed at the source, he can orient the microphone for a maximum reading and ensure accurate data.

A pressure microphone in a free field must be mounted at 90° (grazing incidence) to the sound source to obtain a relatively flat response over its entire frequency range. Reflections from walls or objects in a room incident upon the face of the microphone may be amplified when sound wave lengths are less than ten times the diameter of the microphone (frequencies higher than 1.2 kHz for a 1 in. microphone). Furthermore, one cannot ensure accuracy by maximizing the reading. The response of a pressure microphone in a semireverberant field is shown in Figure 9. The pressure microphone must not be pointed at the sound source. The microphone's perpendicular incidence response is also shown in Figure 9.

Omnidirectional Field. An omnidirectional microphone is one which responds to sounds equally, irrespective of the angle of incidence. *Do not confuse this with a microphone having a flat random incidence response.* Flat Random Incidence means only that the average deviation for all angles of incidence is zero and says nothing about particular angles of incidence. Industrial noise measurements require omnidirectional microphones. The safety engineer should measure all sound to which a worker is exposed. Measurements of auditorium noise and street noise are similar problems. To obtain such a nondirectional response, choose a small sensor which will not interfere with the acoustic field within the audio range. As an alternate method, a random-incidence corrector may be used on a 4131 or 4145 free-field microphone. This device replaces the standard protective grid and controls the response at any angle of incidence to less than ± 3 dB from the random incidence response up to 10 kHz.

Constant Pressure Field. A pressure microphone provides the highest possible flat frequency response when closely coupled to the sound source. Applications include the reference microphone used in artificial ears to calibrate earphones and audiometers, the reference microphone used to regulate the sound source when calibrating "close-talking" microphones for communication headsets, and sensors used to probe the near field of a sound source. The size must be selected to produce a relatively flat response within the frequency band of interest.

Grazing Free Field. A pressure microphone should be used, oriented for grazing (90°) incidence, where there is a moving source such as a vehicle or an airplane moving along a runaway. There are two advantages to this approach: (1) Omnidirectional response to the moving source (the angle of incidence is always 90°) and, (2) Good attenuation of higher frequency ground reflections because they are incident from below the diaphragm. A completely omnidirectional sensor is undesirable because it will not attenuate ground reflections.

An excellent example of microphone selection exists in the FAA proposed noise standard for aircraft certification. It recommends grazing incidence to an aircraft along a runaway. For aircraft flying directly overhead, the specification also recommends grazing incidence with the axis of the microphone perpendicular to the vertical plane of the flight path. Omnidirectional response is assured and the microphone will respond equally to reflections from the ground.

Reverberant Field. Product noise tests call for measurements in a reverberant room. The ASHRAE standards are excellent examples. Here the concern is to determine the total sound power radiated by a source.

A pressure microphone is adequate because its random incidence response is relatively flat. Since the room is highly reverberant, sound direction can be ignored. Some will prefer a small sensor which is truly omnidirectional. They will say that reverberant rooms are not perfect, that some angles of incidence may predominate and that the random incidence response may not be the average response of the microphone. They will choose a smaller pressure microphone which will not interfere with the sound field within the desired frequency range.

Summary

The engineer responsible for the selection and use of sound level meters or microphone systems must be certain that he obtains an instrument which is designed for his measurement purpose. A single class of microphone is not adequate for all measurements. The requirement for free field and pressure microphones and their proper orientation can be summarized in the Table below.

Measurement Condition	Class of Microphone	Typical Application
Perpendicular Incidence	Free Field	Product Noise
Omnidirectional Incidence	Pressure (small size) or Corrected Free Field	Factory Noise
Pressure	Pressure	Calibrate Earphones
Grazing Incidence	Pressure	Moving Sound Source
Random Incidence	Pressure	Total Acoustic Power

Proper application of measurement microphones can provide acoustical data that are of maximum reliability and accuracy. Fortunately, appropriate instruments are available to accommodate all of the common measurement procedures.