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# SOUND PROPAGATION IN FACTORIES

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## 1. Introduction

In the course of the work on acoustical scale modelling of factories it became necessary to investigate theoretically the factors influencing sound propagation in factories. This theory provides the basis for the prediction of factory SPL distributions and is important in noise control. Despite the fact that in most factories, as discussed below, a classical constant reverberant field does not exist, acoustical consultants still predict the efficacy of noise control measures using Sabine's theory. Use of this theory in such cases leads to very inaccurate predictions. Theories developed to date predict sound propagation in 'ideal' empty and fitted factories and show the effects of the various acoustical parameters. However, they must be extended to deal with real factories. This paper discusses sound propagation and its prediction, with the written paper concentrating on theory and discussion. Experimental results will be presented and discussed in the spoken paper.

## 2. Factories vs. Semi-Reverberant Rooms

Regarding sound propagation, factory spaces differ from regular rooms in the following ways:

a. Shape and size - most factories are large and disproportionate having length much greater than height and/or width and having high cross-sectional aspect ratio. Often the roof is not flat, being pitched or sawtooth. The large dimensions mean that air absorption is significant.

b. Fittings - generally factories are not empty but contain machines, stockpiles and offices that scatter and absorb incident sound.

c. Absorption - is irregularly distributed. Often the main absorbent surface is the roof which can act as a large suspended panel. Such a roof can have a high low frequency absorption due to vibration. Further, roof absorption may vary significantly with incident angle. Large areas of glazing act in the same way.

d. Sources - factories contain many complicated noise sources distributed over its floor.

## 3. Propagation in Ideal Factories

Geometrical acoustic image methods can be used (since dimensions are large) to predict sound propagation in 'ideal' factories - i.e. rectangular factories with uniform absorption on any surface and containing a point source. Air absorption effects can be included. The contribution to the total mean square sound pressure at a position from the ith source image is given by:

$$\frac{\overline{P_i^2}}{\rho c} = \frac{W.A_i}{4\pi R_i^2} e^{-mR_i}$$

where W is the source output power, Ai is a factor describing sound absorption by surfaces, m is the air absorption exponent and $R_i$ is the image source/receiver distance.

Two factory idealisations are useful to study the effect of shape - the flat room of large length and width and the duct room with width and height approximately equal and large length. The range of sound propagation in typical empty flat and duct rooms is shown in the figure. The exact propagation depends on the surface absorption. Of course air absorption reduces levels at large distances. Typical reduction is 6dB at 100m and 4kHz.

Image methods can include the effect of source directivity and angularly varying surface absorption by incorporating weighting functions to effectively reduce the source power according to the image source, receiver and surfaces' relative positions. Both effects decrease with distance from the source.

The effect of fittings in a factory can be included in an image prediction if the propagation function for a space with fittings is known. Jovicic [1] used Kuttruff's work on sound propagation through spaces with randomly distributed scattering centres to derive such a function. The theory applies for a uniform distribution of spherical scatterers of dimensions greater than the wavelength which scatter omnidirectionally. Propagation is calculated as the sum of scattered and unscattered contributions - the latter dominating near the source the former, far from the source. The contribution to the mean - square pressure from an image in a fitted space is:

$$\frac{\overline{P_i^2}}{\rho c} = \frac{WA_i}{4\pi R_i^2}\left[\underbrace{e^{-(Q+m)R_i}}_{\text{unscattered}} + \underbrace{3QR_i e^{-R_i\sqrt{3Q(\alpha_s Q+m)}}}_{\text{scattered}}\right]$$

where Q is the average scattering cross-section (calculated from the average scattering surface area per unit volume) and $\alpha_s$ is the average absorption coefficient of the fittings. The effect of fittings is to increase levels near the source due to back-scattering (typically up to 3dB within 20m) and exponentially reduce levels far from a source (typically 10dB at 100m). Sound propagation in typical long, wide factories with low and high surface absorption, for both the empty and fitted case, is shown in the figure. The general characteristics of factory sound propagation can be seen. Near the source ($R <$ roof height) approximately free-field propagation occurs. At medium distances (typically $5m<R<50m$) back-scattering from fittings produces a plateau in the curve. Farther from the source levels drop-off exponentially especially in the fitted factory.

The above theory predicts ideal factory sound propagation within a few dB if all variables are known exactly.

## 4. Real Factory Prediction

In real factories the average scattering cross-section, to which sound propagation is highly sensitive, is difficult to estimate. Further, no information is available on sound absorption by factory fittings. Measurements in empty and fitted factories are planned in order to determine these parameters. Also, if the factory roof is a panel its absorption must be measured in-situ, presenting considerable difficulties. Finally, as was discussed in [2] the radiation characteristics of industrial noise sources are difficult to determine. Accuracies of sound power estimates can be as low as ± 2dB in typical measuring situations. The accuracy of directivity measurements is worse.

Real factories differ in several ways from ideal factories. The effects of these differences on sound propagation are being investigated to determine to what extent the above theory must be extended if it is to be of use to the consultant. The main differences are:

a. Shape-factories are seldom rectangular. A sawtooth roof can be treated as a flat roof with scatterers. Pitched roofs and, for example, L and T-shaped factories have been dealt with using ray-tracing techniques. Acoustic models may be a better solution.
b. Fittings - in real factories most fittings are near the floor and may be irregularly distributed. There is usually a large void between fittings and roof. Thus the scattering cross-section varies. Also, as in the case of screens and for certain ratios of scatterer dimensions to wavelength, scattering is not omnidirectional.

## 5. Conclusion

Geometric acoustic theories predict sound propagation in empty and fitted 'ideal' factories and show the effects of the various acoustic parameters. They also show that Sabine predictions can be very inaccurate. It is likely that the theory can be extended to predict propagation in real factories with some success, but acoustic scale modelling may be a better solution in difficult cases.

## References

1. S. JOVICIC, Untersuchungen zur Vorausbestimmung des Schallpegels in Betriebsgebauden, Müller-BBN Report No. 2151, 1971.
2. M. HODGSON, Characterisation and scale modelling of industrial noise sources, Proc. Acoustics'80 (1980) 9-12.

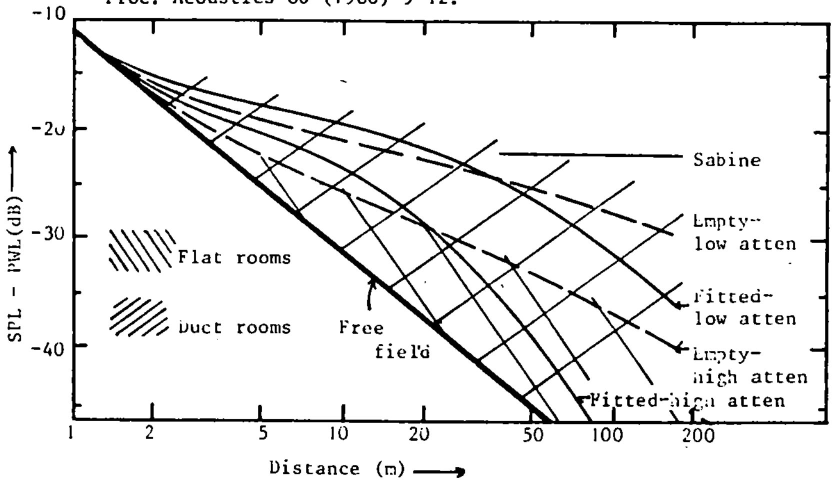


**Figure- Sound propagation in ideal and real factories.**