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ZORBA

sound absorption prediction software

Users Manual

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Contents

Introduction

It is important to be able to predict the sound absorption properties of slatted and perforated absorbers. These types of absorbers are frequently used to control the acoustics of rooms, and it is often found that there is no test data available for a particular design, or it is necessary to design an absorber to achieve specific characteristics.

Zorba is a program that can calculate the acoustic performance of common materials and some simple systems such as slot or slat absorbers, or absorbers covered with a perforated facing or panel absorbers. Zorba will calculate the acoustic impedance, the normal incidence absorption coefficient and within certain limitations the random incidence absorption coefficents of common materials and systems. Materials are assumed to be locally reacting , with properties determined by their static flow resistivity . The effect of facings is modelled by adding the reactance of the facing to the normal acoustic impedance of the material. The random incidence coefficients are predicted from normal incidence impedance using diffraction theory. Within certain limits good agreement is obtained between predictions and experiments.

The absorption of sound is a topic on which many text books have been written. This help file is not a substitute for learning about the theory of sound absorption. Users should be aware of the general principles which can be found in such books as :

- Beranek Noise and Vibration Control (1971 edition),
- Beranek Noise and Vibration Control Engineering (1992

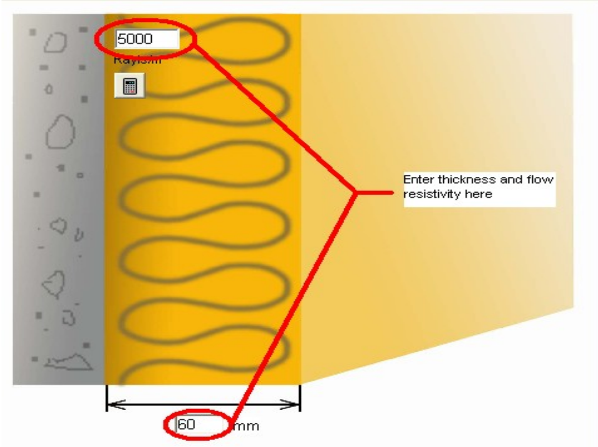
An indication of inter-laboratory variability can be seen from the graph below from ISO 354-1985. Note that in general the model gives reasonable agreement for perforation ratios as low as 5% and porous absorption thicknesses between 10mm and 150mm. It should be used with caution outside these limits. It can not be used for absorbers with a significant air cavity as these arrangements are not locally reacting. It can not be used with porous materials which have a porosity less than about 80% or a flow resistivity of more than 100,000 Rayls/m or less than 1,000 Rayls/m.

Edition),
- Meyer and Newman Physical Principles of Acoustics (1970),
- Allard Propagation of Sound in Porous Media (1994);

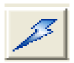
to mention just a few possibilities.

Getting Started

Start Zorba. You will see a picture representing a concrete wall with a layer of acoustic absorber placed in front of it.



You can enter the thickness of the material and the flow resistivity of the material by clicking in the appropriate box and typing in the desired value. Click on the calculate button



and Zorba will calculate the random incidence sound absorption in 1/3 octave bands and display on the graph to the right. The weighted sound absorption

coefficient αw (or for North Americans the NRC) will also be
displayed in a box above the graph, with the octave band absorption just to the right of that.
You can calculate the properties of a system consisting of two different absorptive materials by clicking on the checkbox at the bottom of the screen "Two layers".

Next Steps

Once you have seen how easy it is to predict the properties of an absorptive material you can quickly explore some other features of Zorba. Click on the tabs above the main picture and the main picture will

rockwool was measured in 21 different laboratories in Australia and New Zealand. The difference between laboratories was large, and even when only those six rooms which conformed to the ISO test standard were included the agreement was still not exact. Remember this is for the same sample, measured with the same equipment. So it can be seen that we can not hope to achieve "exact" agreement between theory and a single set of measurements.

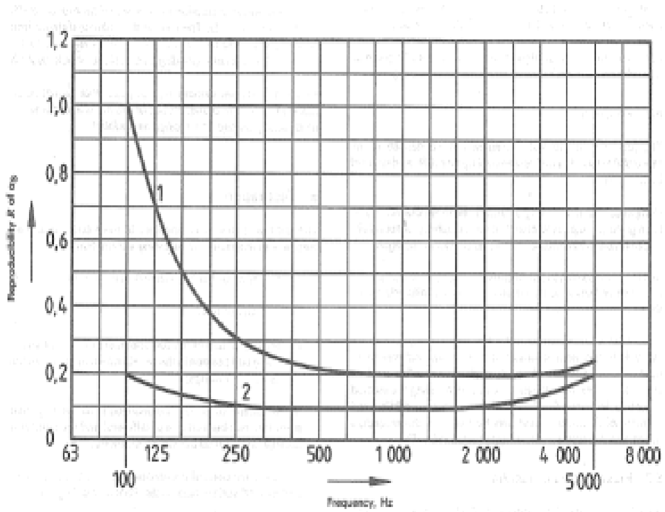


Figure — Assessment of reproducibility R of α_S for
a) sample 1 having a high absorption coefficient (α_S = 1,00), and
b) sample 2 having a low absorption coefficient (α_S ≈ 0,05) in all one-third octave bands

Note that provided the absorptive blanket is more than about 1000 Rayls/m and more than 25 mm thick then the absorption of the system is not very sensitive to the cavity absorber properties.

Porous facings

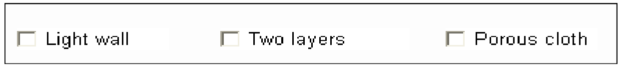
It is common to have a porous cloth covering over acoustic materials. This can have an influence on the absorption coefficient particularly where a perforated or slotted panel is placed in close contact with the cloth. The flow resistance of the cloth (in Rayls) can be entered into the appropriate box. Note that this flow resistance must usually be measured for the cloth concerned as it is a function of the closeness of the weave of the fabric and is difficult to predict from looking at the fabric.

Limitations

Users should be aware of the limitations, like any prediction tool Zorba is not a substitute for test data. Measurements of the random incidence coefficients are carried out in standardised test rooms with standardised configurations of materials, but even so the spread of results between laboratories is rather large. In a series of round robin experiments a sample of 50mm thick

display different facings on top of the absorption blanket. The absorption coefficient prediction is automatically calculated for the particular arrangement of slots shown. The size and spacing of the perforations/ slats/slots can be entered into the appropriate box

- slatted or
- Perforated ,



- slotted facing
- Panel absorber

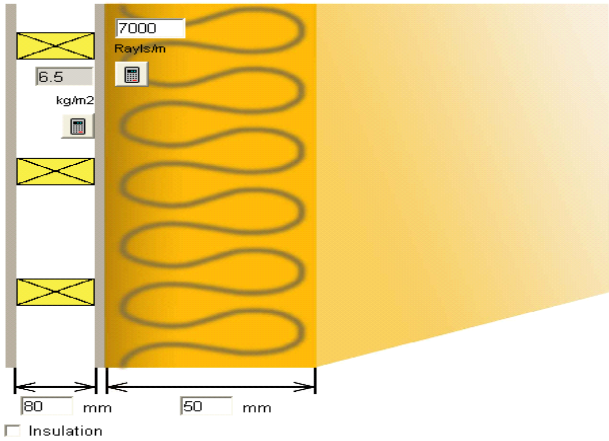
Or click on the boxes along the bottom of the picture

- Solid or light weight backing
- Two layers of different materials
- Porous fabric facing

Rigid Backing

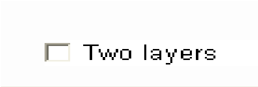
The default arrangement in Zorba is for the absorptive material to have a solid backing such as a concrete or brick wall or other heavy structure. However in many countries walls are commonly constructed as cavity walls with relatively light-weight linings such as plasterboard. Zorba can predict the performance of porous materials with a lightweight backing by clicking on the check box at the bottom of the main picture.

The picture changes to reflect the panel backing and you can now enter the width of the air cavity and the mass of the wall lining and choose whether the cavity contains an absorptive blanket

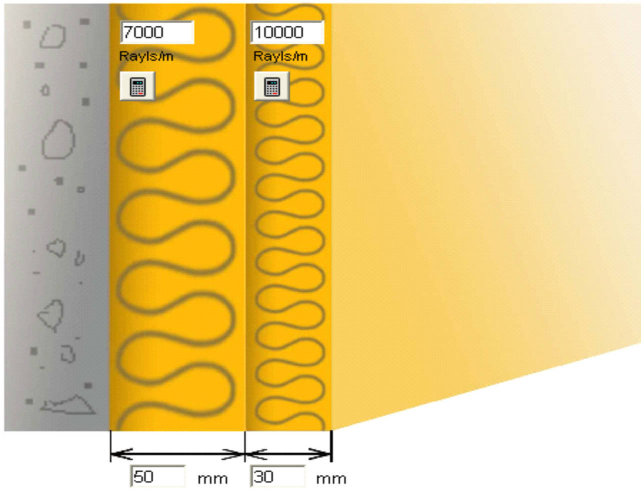


Double layers

To predict the performance of two layer absorbers you click on the check box at the bottom of the main picture.



The picture changes to reflect the two layers, now enter the flow resistivity and thickness of each material.



Acoustic Models

Researchers have developed impressive theoretical models for predicting acoustical properties of a wide range of materials . However Zorba uses a simple class of model in which the porosity is high, the frame or skeleton of the material is infinitely rigid, and the tortuosity of the material is not great. These models are applicable to a wide range of common materials, fibreglass, rockwool, polyester, wool, etc. A fundamental assumption of Zorba is that most acoustic materials can be modelled as equivalent fluids with a complex density and complex compressibility which are functions of frequency. This is a good assumption for a wide range of common materials such as fibreglass, mineral fibre (sometimes called mineral wool), polyester fibres, wool, hessian fibres, and in fact most porous materials that have a porosity of greater than 90% and a reasonably rigid frame. Some materials that can not be accurately represented this way are polyurethane foams where the structure of the material can not be considered rigid, or low porosity materials such as closed cell foams or the ground or road pavements which might be only 10 to 30% porosity. For materials which have low porosity and high tortuosity (e.g. medium density wood chip board, acoustic plasters, wet felted mineral fibre) this model as it stands is not accurate. A model which is more accurate for these conditions is that developed by Wassilieff.

Bazley model, but once built into a
computer algorithm can thenceforth be ignored.

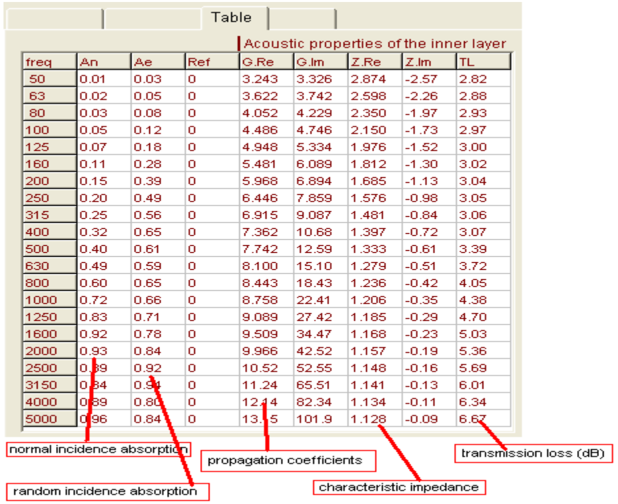
For room acoustics purposes it is desired to know the sound absorption coefficients as a function of frequency. The usual way of doing this is to first predict the characteristic impedance and complex propagation coefficient and then to derive the normal incidence absorption for a particular thickness and mounting arrangement.

Locally Reacting Materials

The concept of a locally reacting material is often used because it simplifies theoretical analysis.
A locally reacting material's acoustic impedance is independent of angle of incidence. Thus the behaviour of sound at a particular point on a materials surface is not affected by the sound at other points nearby. Most porous absorbers can be approximated as locally reacting because the attenuation of sound in the material is sufficiently high to reduce lateral transmission. But an air-gap can not be considered locally reacting and so Zorba can not model absorber systems with significant air-gaps.

Acoustic Properties page

Various acoustic properties are displayed on this page such as the columns headed Z.re and Z.im which are the real and imaginary parts of the acoustic impedance of the given thickness of material backed by a rigid surface and the columns headed G.re and G.im which are the real and imaginary parts of the propagation constants . The column marked An is the normal incidence absorption coefficients, the column marked Ae is the random incidence absorption coefficients. The
column headed TL is the transmission loss of the inner layer of material.



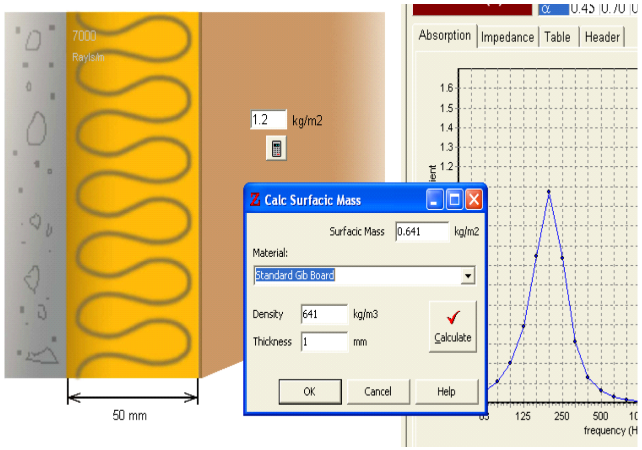
Acoustic properties of the inner layer

freq	An	Ae	Ref	G.Re	G.Im	Z.Re	Z.Im	TL
50	0.01	0.03	0	3.243	3.326	2.874	-2.57	2.82
63	0.02	0.05	0	3.622	3.742	2.598	-2.26	2.88
80	0.03	0.08	0	4.052	4.229	2.350	-1.97	2.93
100	0.05	0.12	0	4.486	4.746	2.150	-1.73	2.97
125	0.07	0.18	0	4.948	5.334	1.976	-1.52	3.00
160	0.11	0.28	0	5.481	6.089	1.812	-1.30	3.02
200	0.15	0.39	0	5.968	6.894	1.685	-1.13	3.04
250	0.20	0.49	0	6.446	7.859	1.576	-0.98	3.05
315	0.25	0.56	0	6.915	9.087	1.481	-0.84	3.06
400	0.32	0.65	0	7.362	10.68	1.397	-0.72	3.07
500	0.40	0.61	0	7.742	12.59	1.333	-0.61	3.39
630	0.49	0.59	0	8.100	15.10	1.279	-0.51	3.72
800	0.60	0.65	0	8.443	18.43	1.236	-0.42	4.05
1000	0.72	0.66	0	8.758	22.41	1.206	-0.35	4.38
1250	0.83	0.71	0	9.089	27.42	1.185	-0.29	4.70
1600	0.92	0.78	0	9.509	34.47	1.168	-0.23	5.03
2000	0.93	0.84	0	9.966	42.52	1.157	-0.19	5.36
2500	[illegible]	0.92	0	10.52	52.55	1.148	-0.16	5.69
3150	[illegible]	0.94	0	11.24	65.51	1.141	-0.13	6.01
4000	[illegible]	0.80	0	[illegible]	82.34	1.134	-0.11	6.34
5000	0.96	0.84	0	[illegible]	101.9	1.128	-0.09	6.67

Panel Absorbers

A panel absorber is formed by an impervious material such as plywood or gypsum plaster-board fixed over an airgap. There can some-times be an acoustic blanket in the airgap. Panel absorption is often an unintended byproduct of a wall or ceiling construction and is mostly a low frequency phenomenon. Typical panel absorbers are plasterboard on timber studs, or plywood or timber panelling over a masonry wall.

Zorba will model with reasonable accuracy panels as light as 0.1 kg/m2 up to panels of 20 kg/m2. There is a built in calculator for estimat-ing the panel mass for different materials and thicknesses.



Flow Resistance

It is rather amazing (but very convenient) that for most common sound absorbing materials the principal acoustic properties can be predicted over the most important frequency range (50 Hz to 4 kHz) just by knowing the flow resistivity of the material. From the flow resistivity one may use theoretical or empirical models to predict the characteristic impedance and propagation coefficients of the material, which then tells you most of what you need to know about that material. From these two properties one may predict the acoustic impedance and for a given thickness of material the normal incidence absorption coefficients. Furthermore, provided the material can be considered locally reacting the random incidence absorption can be estimated accounting for diffraction by the sample edges.

The flow resistance of a porous material such as fibreglass is defined as the pressure drop across a sample of material when a steady airflow is passed through the material. There is an ASTM standard (C522) for measuring flow resistance. The unit of flow resistance is the Rayl (or Pa·s·m-1). Beware that older studies have used a unit of flow resistance based on the cgs system, this is usually spelt with a lower case r as rayl, or referred to as cgs rayl (1 rayl = 10 Rayls).

The flow resistivity is the flow resistance for a metre thickness with units of Rayl/m. In some instances it may be estimated from the materials density and there is a built in calculator in Zorba that can be used to estimate the flow resistivity from the absorptive materials density for fibreglass, mineral fibre, and polyester materials. Many manufacturers of acoustic materials measure their products flow resistivity and either publish this data or have it available on request.

Flow Resistivity Calculator

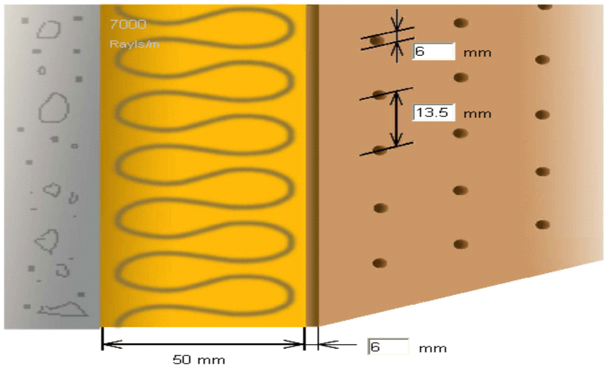
For some materials the flow resistivity may be calculated from their density. (see for instance Beranek's Noise and Vibration Control) . This box allows one to calculate for some common materials. Generally speaking the flow resistance increases as something like the 1.5 power of the density and the inverse square of the fibre diameter.

Characteristic Impedance

The characteristic impedance of a material is the ratio of sound pressure to particle velocity for sound waves travelling inside the material. For air it is equal to the density of air times the speed of sound. Its main use is in calculating other more directly useful properties such as the absorption coefficients.

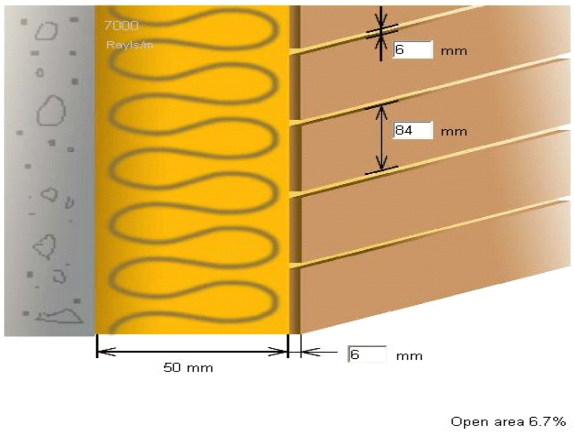
Perforated Absorbers

A common method of architecturally protecting sound absorbing materials is to cover them with a panel material (eg plywood) that has a series of holes or perforations to allow the sound waves to penetrate into the absorbing material. The effect of this is to produce a mildly tuned resonator which slightly enhances low frequency absorption, causes a peak in the absorption around the resonant frequency and significantly reduces the absorption above the resonant frequency. The thickness of the panel and the diameter and spacing between holes are entered in the appropriate boxes. Zorba has been verified with absorption thicknesses from about 20mm to 100mm, with hole spacings from 10mm to 100mm and hole diameters from 3 mm to 12 mm. Do not use outside this range without verifying with measurement data.



Slat Absorbers

A common method of architecturally protecting sound absorbing materials is to cover them with slats (strips of timber for instance). The effect of this is to produce a mildly tuned resonator which slightly enhances low frequency absorption, causes a peak in the absorption around the resonant frequency and significantly reduces the absorption above the resonant frequency. The width and thickness of the slats and the spacing between slats are entered in the appropriate boxes. Zorba has been verified with absorption thicknesses from about 20mm to 100mm and with slats of 20 to 150mm wide with spacings from 3mm to 75mm. Do not use outside this range without verifying with measurement data.



It can also be defined as the product of the effective complex density and the complex speed of sound. It may also be derived from the complex compressibility and complex density (see Beranek Noise and Vibration Control Chapter Ten).

Propagation Constant

The complex propagation constant is the product of j and the angular frequency (ω) divided by the complex speed of sound. The real part gives the attenuation of sound in Nepers per metre as the sound travels through the material. The imaginary part is the angular frequency divided by the magnitude of the speed of sound in the material.

Acoustic Impedance

The acoustic impedance is usually defined at the front surface of a material and is the sound pressure divided by the acoustic particle velocity at that point. It is usually a complex quantity and is almost always frequency dependant. The values of acoustic impedance can be used to provide an understanding of the behaviour of the material and hence ways in which the absorption can be improved. Note that for a plane wave at normal incidence an absorption coefficient of 1 is only obtained for a material whose acoustic impedance has a real part equal to the characteristic impedance of air (= 410 Rayls) and an imaginary part equal to zero.

It is often convenient to divide acoustic impedances by the characteristic impedance of air to get a dimensionless quantity called the specific acoustic impedance. An absorption coefficient of 1 is then obtained for a specific acoustic impedance of (1,0).

Some insight into the absorber can be gained from a plot of real and imaginary parts of the acoustic impedance at different frequencies (this is sometimes called a Smiths Chart). For plain porous absorbers the plot will be a spiral starting at the bottom left of the complex plane and spiraling into the point (1,0). To see this behaviour choose a thick material (say 100 mm) of relatively low flow resistivity (say 1500 Rayls/m) and then click on the calculate button then on the impedance tab. The plot will show a typical impedance spiral. Note that with increasing frequency this spirals into a specific impedance value of (1,0) which will give an absorption coefficient of 1.

properties and require a rating greater than a certain minimum value. In North America a single number rating was developed in the 1950's, it was the arithmetic average of the absorption coefficient in the 4 octave bands (250Hz, 500 Hz, 1 kHz and 2 kHz) rounded to the nearest 0.05. This is referred to as the Noise Reduction Coefficient (NRC).

Europe was a lot later in adopting single number rating, but now uses ISO 11654-1997 to derive a single number rating. This is a more complex rating method, and uses a weighting method that compares the absorption curve as a function of frequency against a reference curve to produce a weighted sound absorption coefficient αw. Shape indicators are also used to indicate whether an absorber is a low frequency, mid frequency or high frequency absorber.

Zorba calculates the single number rating according to both methods and displays either NRC or αw. You can toggle between the two displays by double clicking on the number.

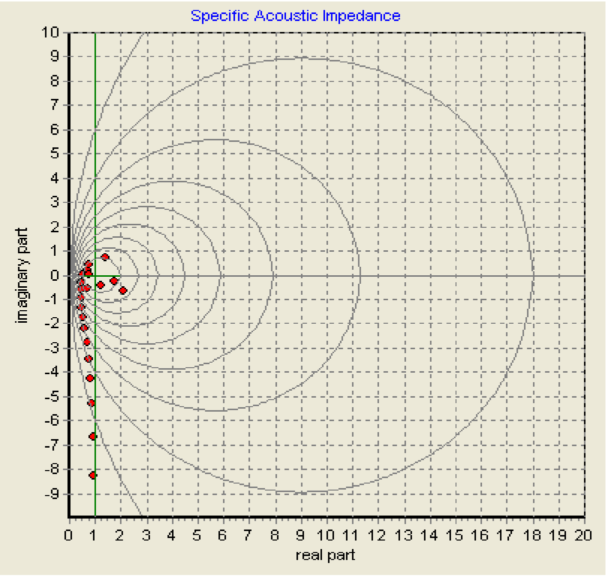
An early attempt at predicting diffractive effects was made by Northwood, which involved predicting the diffraction for an infinitely long strip. More recently Thomassen has developed a theory for predicting the diffraction of square patches of material which is relatively easy to apply and which appears to be reasonably successful for a useful range of material aarrangements.

Transmission Loss

Because the materials modeled by Zorba are porous the transmission loss can not be modeled by the mass law and for typical materials the transmission loss is low for thickness less than about 100mm. However for certain situations where you have large thicknesses of porous material you can achieve quite worthwhile transmission losses due to the propagation losses due to friction in the material. Zorba will calculate the TL through the material and displays the results on the Table page.

Single number ratings

While the sound absorption coefficient is usually a strong function of frequency human nature being what it is we often want a single number representation of a material. For instance an architectural specification may refer to a material's acoustic



Some quick points to help with interpreting the impedance plot:

- A depth of air or porous material which is less than 1/4 of a wavelength deep will exhibit a negative imaginary impedance.
- A solid surface such as a layer of plywood over an air cavity will exhibit a positive imaginary impedance.

- For a resonant system at the resonant frequency the imaginary part of the impedance equals zero.

- Increasing the flow resistivity of a material will usually increase the real part of the acoustic impedance.

Normal Incidence Absorption

The normal incidence absorption coefficient is the fraction of energy absorbed when a plane wave hits a surface at normal incidence. This can be approximated for test purposes in a traveling wave tube (sometimes called an impedance tube or Kundt's tube) at frequencies below the first cross mode. For a typical 100 mm diameter tube this would be frequencies up to 1600 Hz.

This value can not exceed 1. It is a useful quantity for research and also for comparing materials, but is not useful in architectural or room acoustic calculations as the values do not agree with the apparent absorption as measured for instance by Sabine's equation relating reverberation and absorption within a room.

Random Incidence Absorption

The most useful quantity in most room acoustics applications is the random incidence absorption coefficient. With this you can predict the reverberation time of the room or the sound level for a known sound power level. Sabines equation is the most well known relationship between absorption and reverberation.

The random incidence absorption differs from the normal incidence absorption for a number of reasons; firstly the absorption coefficient will vary with different angles of incidence, secondly, the absorption coefficient will depend on the area of the absorber due to diffraction effects at the edge of the material. Zorba can calculate the effect of these influences and estimate the random incidence absorption coefficient for the system . Note that at present the area of the absorber is assumed to be 12 m2 which is the standard test area for measuring absorption coefficients to ISO 354.

For most materials which are so called locally reacting, the absorption coefficient varies in a predictable way with the angle of incidence of the sound wave. Paris developed an equation for averaging the absorption coefficient over all angles of incidence, unfortunately this does not agree with measurements because of the effects of diffraction around the edges of the sample. In certain cases the measured absorption coefficient can exceed unity, a fact which is intuitively difficult to understand. For normal test samples the diffraction effects are strongest between 100 and 1000Hz.