wearing courses may provide the noise reduction that is needed. Such surfaces are briefly described in Table 1. This list is certainly not exhaustive and new products are regularly being developed. Most of these systems exhibit an indented or 'negative' surface texture similar to that found with porous asphalt.

In the course of my investigations, I have referred to TRL Report 314 Road trials of Stone Mastic Asphalt and other thin surfacings by JC Nicholls. I have also referred to selected unpublished reports supplied by the manufacturers and have produced some general advice in Table 2. This cannot be considered as definitive and some caution is needed when quoting the manufacturers' data. The results have been obtained in a variety of ways and have not always been independently verified. Having said that, it seems that most products when new give a 3 to 4dB reduction over conventional hot rolled asphalt (HRA). Again, I must warn the reader that there are no long-term data to confirm whether these benefits are maintained over the life of the surface and whether they apply in all traffic conditions. However, I have been informed that recent observations indicate that the performance does not deteriorate as fast as porous asphalt. More testing and research is needed to determine this.

Many of these thin surfaces have been in use in Europe for some time and official data are available. However, the specifications of these materials are not necessarily the same. The UK practice is to use a material with a higher polished stone value in order to give a longer life with better skid resistance.

Finally, it is evident that the development of new products is proceeding apace. This survey should be taken as an indication of the situation in Spring 1999. A more detailed table is available on our website at http://www.noise.wsatkins.co.uk or on request. This will be updated from time to time and I welcome all feedback from readers including any recent observations you may have.

Method:

(1) IS011819-1 Statistical Pass-by Method

(2) CRTN- 88 Comparative Method

(3) Other.

Physical Basis for Sound Absorbing Materials Using a Medium with a Complex Density

R.N. Viktorova and V.V. Tyutekin

N.N. Andreev Acoustics Institute of Russian Academy of Sciences, Moscow

The paper gives the results a theoretical and experimental study of human made composite media in the form of a rubber–like material with rigid compact spherical or cylindrical inclusions. It is shown that in contrast to rubber–like materials with voids, which can be described by a complex compressibility, materials with solid compact inclusions can be described by a complex density. On the basis of a material with inclusions of spherical shape, the example is given of the synthesis of a wideband absorber whose properties are practically independent of the static pressure.

The problem of producing human made composite materials is of interest from the point of view of both theory [1–8] and of practical applications. Thus, for example, composite materials which provide effective sound absorption over a wide range of frequencies and static pressures find wide application in measurement technology for lining the walls of various types of high pressure tanks and chambers [9, 10].

The sound absorbing materials used for this purpose are as a rule rubber–like materials with voids of various shapes and sizes [2, 11]. Rubber–like materials are used because while they possess a bulk elasticity, equal approximately to the bulk elasticity of water, they have a shear moduli two orders of magnitude smaller, and the shear loss coefficient can have values of from 0.1 to 1. This relationship between the two moduli makes it possible by means of conversion of the bulk deformations into shear deformations to introduce significant changes in the effective parameters of the original material. This effect is usually achieved by the production of voids to obtain a complex compressibility with a sufficiently high loss coefficient.

Another type of human made composite materials is the so called voidless materials produced on the basis of media with a complex density [1, 5–7, 12, 13] in which the role of absorbing elements is played by compact inclusions of various shapes and sizes. The small shear moduli of a rubber–like material and the relatively high mass of the inclusions creates the possibility of resonance effects in these media as in media with voids. While a transition from an elastic reaction to an inertial reaction is observed in media with voids near the resonance frequency, in media with a complex density there is an inverse phenomenon a change from an inertial reaction to an elastic one – and this leads to an actual reduction in the effective density of the medium.

It should be remembered, however, that the degree of transformation of sound waves into shear waves in a human made medium in the presence of voids which produce the compressibility is proportional to the quantity λ/μ, where λ and μ are the Lame coefficients and in a medium with solid inclusions to the quantity ρ_2/ρ_1, where ρ_2 and ρ_1 are the densities of the rubber and inclusions respectively. If we assume that the concentrations of the voids and inclusions are the same, then in the first case the ratio λ/μ is of the order of a few hundred and in the second case ρ_2/ρ_1 is an order of magnitude smaller. This fact leads to certain difficulties in the creation of effective sound absorption materials out of elements of a medium with compact inclusions. Nevertheless, the problem of using this method, which differs in principle from those used earlier, is of great theoretical and practical interest. This problem acquires a special importance when it is necessary to retain a high effectiveness over a wide range of static pressure, which in practice cannot be satisfied for materials developed on the basis of media with a complex compressibility since the properties of these media depend to a significant extent on the size of the voids, the reduction in which under pressure leads to a rearrangement of the sound absorbing material and hence to a change in its acoustic effectiveness.

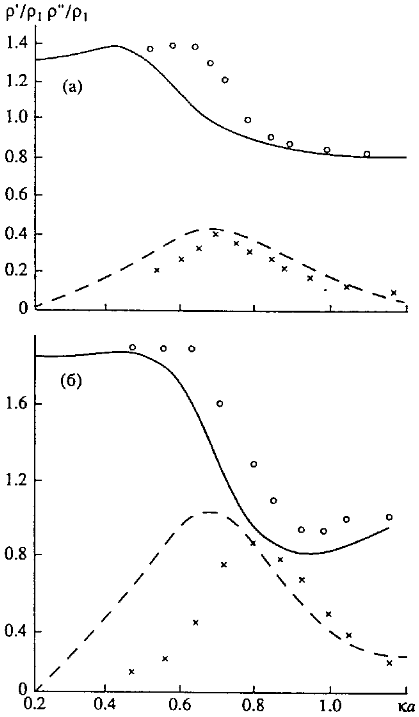

Fig. 1. Frequency characteristicsof the real (ρ") parts of the complex density of a human made medium with spherical inclusionsfor volume concentrationse= 0.036 (a) and e= 0.082 (b)

In the process of studying voidless materials with the aim of finding the effective parameters of such a medium, we have given detailed consideration to this question both within a rigid theoretical framework [1, 5, 13] and in a particular physical model [14]. These papers considered human made media based on a rubber–like material with inclusions of the two most typical shapes – spherical and cylindrical – under the following assumptions: the radii of the inclusions a and the distances between the inclusions s are small compared to the length of a longitudinal wave ($k_1a << 1$, $k_1s << 1$) and are comparable with the wavelength of a transverse wave ($ka \leq 1$, $ks \leq 1$); here k_1 and k are the wave numbers of longitudinal and transverse waves respectively. In this case the medium can be considered as macro–homogeneous and we can talk of the effective parameters of the medium for a longitudinal wave with allowance for resonance effects in the oscillations of the inclusions as a whole.

According to [1, 5, 14], the effective complex density of a medium with inclusions of spherical shape can be expressed by means of the equation

$$\frac{\bar{\rho}}{\rho_1} = \rho' + i p'' =$$

$$1 + \frac{\varepsilon(\rho_2/\rho_1 - 1)}{1 - (ka)^2/(ka)_p^2 + i[(ka/(ka)_p)^2\eta' + ka]},$$

where $\rho_1$and ρ_2 are the densities of the rubber and the inclusion respectively, ε = Nv/V is the bulk concentration coefficient (N is the number of inclusions, v is the volume of an inclusion and V is the overall volume); (ka)p = Ψ(ka)o, and η' = $\Psi\eta$, where η is the shear loss coefficient, Ψ = I + $(\eta/2)(ka)_0$, and $(ka)_0 = \sqrt{[9\rho_1/(2\rho_2 + \rho_1)]}$ is the dimensionless resonance frequency without allowance for shear losses.

As can be seen from the quoted expressions, $(ka)_p$ is determined mainly by the ratio of the densities of the rubber and the inclusions ρ_2/ρ_1; the greater this ratio the smaller the value of $(ka)_p$.

The term ka in the denominator of (1) arises as a result of the transfer of longitudinal wave energy into transverse wave energy; the smaller this quantity the sharper the resonance. The same effect on the resonance is produced by the quantity η', which is in practice equivalent to the shear loss coefficient of the containing medium. To this must be added the fact that the presence of solid compact inclusions moving as a whole with the propagation of a longitudinal wave has an effect only on the effective density of the medium, leaving its elastic parameters almost unchanged.

Figure 1 shows as an example the calculated values of the real (ρ') and imaginary (ρ") parts of the effective density for two samples of a human made medium with spherical inclusions of a single radius but with different volume concentrations. In the region of small ka values the effective density of the medium is equal to the static value.

$$\rho'_s = 1 + \varepsilon(\rho_2/\rho_1 - 1).$$

There is then a sharp reduction in (ρ') to values less than unity; this is connected with the transition from an inertial to an elastic reaction; the imaginary part (ρ"), which is proportional to the effective losses, has a typical resonance shape. The resonance point corresponds to ρ' = 1 and the maximum value of the effective losses θ = ρ'/ρ".

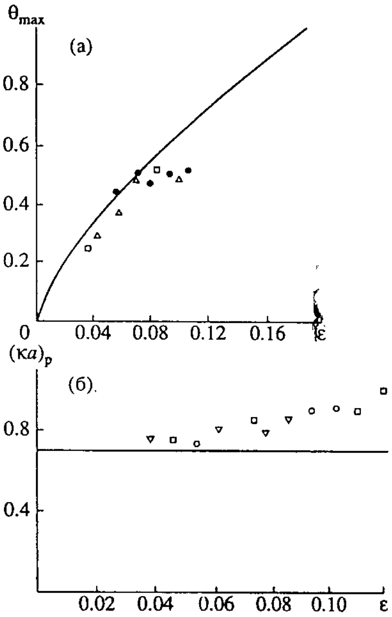

Fig. 2. Maximum values of the effective losses at the resonance point (a) and the dimensionless resonance frequency (b) as functions of the volume concentration of spherical inclusions

An experimental study of the properties of human made medium samples with different combinations of inclusion radii and volume concentrations in the form of washer of standard diameter was carried out on the 'pulsed tube' apparatus [15] used to measure the acoustic impedance of the samples under test, from which the real and imaginary parts of the complex density were determined. As the initial material we used rubber with appropriate values of the elastic parameters and fairly low values of shear losses; as the inclusions we used lead shot of different diameters. (The ratio of the densities r2/r1 had a value of about 10.) In the preparation of the human made medium samples, the raw rubber mass filled with uniformly distributed spheres of a single diameter was subjected to vulcanization in a standard mold.

The experimental results corresponding to the computational variants considered above (the points and crosses in Fig. 1) indicate good qualitative agreement between experiment and theory. In order to obtain quantitative estimates, we carried out measurements of a large set of samples with different combinations of inclusion radius and volume concentration. Figure 2 shows calculated (continuous curves) and experimental values of the characteristic parameters of such media – the effective loss coefficient at the maximum θ (a) and the dimensionless resonance frequency (b) as functions of the volume concentration coefficient for spherical inclusions of different diameters (different symbols in the figure). A comparison of the theoretical and experimental data (Fig. 2a) reveals satisfactory agreement up to concentrations not exceeding 0.1 and then a halt in the growth of the experimental values of the effective losses as the concentration rises. For the dimensionless resonance frequency $(ka)_p$, as can be seen from Fig. 2b, the low concentration region involves a very small constant deviation of the experimental data from the calculated values. This might be caused either by an inaccurate determination of the elastic parameters of the rubber or by the special features of the vulcanization process in the presence of inclusions. However, for volume concentrations greater than 0.08–0.1, there is a linear rise in the values of $(ka)_p$.

The results indicate a fairly good agreement between the calculated and experimental data in the region of low concentrations (less than 0.08–0.1). The increasing divergence with higher concentrations is apparently caused by the reduction in the distance between the inclusions s and hence a transition from the region considered – ks ≤ 1 – to the region ks << 1, which requires special theoretical treatment.

Thus our experimental study of a medium with compact spherical inclusions has in the main confirmed the conclusions from theory. However, the discrepancies revealed in the studies require refinement of the theory in the higher concentration region.

A theoretical study of a medium with solid compact cylinders was made in a way similar to that used for the spherical inclusions. With the same assumptions being used, we obtained the following expression for the effective density of a human made medium with cylinders of infinite length placed in rows in a rubber–like medium parallel to the front of an incident plane wave [13]:

$$\frac{\bar{\rho}}{\rho_1} = \rho' + i\rho'' = 1 + \varepsilon(\rho_2/\rho_1 - 1)\frac{2 - \Phi(\bar{k}a)}{1 + \rho_2/\rho_1 - \Phi(\bar{k}a)}$$

where e is the volume concentration coefficient of the cylindrical inclusions, a is their radius, and $\Phi(\bar{k}a) = 4H_1(\bar{k}a)/\bar{k}aH_0(\bar{k}a)$, where $H_0(\bar{k}a)$ and $H_1(\bar{k}a)$ are Hankel functions of the first kind.

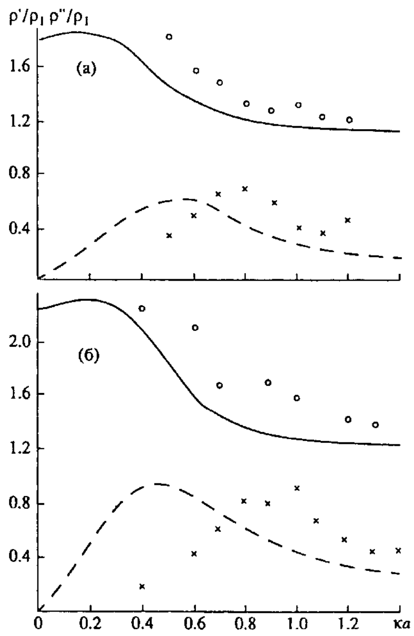

Fig. 3. Frequency characteristics of the complex density for inclusions of cylindrical shape for volume concentrations ε = 0.09 (a) and ε = 0.14 (b)

The continuous and dashed curves in Fig. 3 show the calculated values of ρ' and ρ" for cylindrically shaped lead inclusions, also for two concentrations. As in the case of spherical inclusions, the frequency characteristics have the typical resonance form – the values of ρ" pass through a maximum while p' varies from the static value given by equation (2) and asymptotically approaches ρ' = 1. The maximum effective losses correspond to the resonance point ρ".

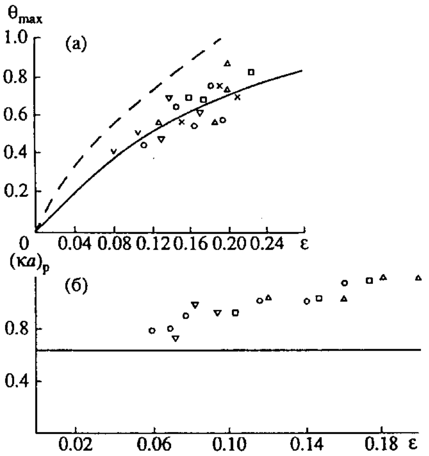

Fig. 4. Maximum values of effective losses (a) and dimensionless resonance frequencies (b) as functions of the volume concentration of cylindrical inclusions.

Figure 4a gives the theoretical values of the effective losses at the maximum for cylinders as a function of the volume concentration (continuous curve). For comparison, the analogous relationship from Fig. 2a for spheres is given as a dashed curve.

The continuous curve in Fig.4b corresponds to the calculated values of the dimensionless resonance frequency for cylinders of different radii and volume concentration. It should be noted here that the calculated values of the dimensionless resonance frequencies for cylinders and spheres are almost the same. The curves show the greater effectiveness of spherical inclusions (Fig. 4a). It should be noted, however, that concentrations greater than 0.1–0.12 are practically unachievable for spheres while for cylindrical inclusions volume concentrations of the order of 0.25 are practicable and easily realizable.

An experimental study of a medium with cylindrical inclusions was made on samples of rubber with the same elastic parameters as in the case of spheres; metallic rods of cylindrical shape were placed in layers of rubber in rows parallel to each other.

As an example, Fig. 3 gives the results of the experimental study of the complex density of samples with inclusion volume densities of 0.09 and 0.14; these indicate fairly good qualitative agreement between theory and experiment.

Quantitative comparisons as in the previous case were made of the values of the effective losses at the maximum obtained as a result of measurements on a large series of uniforrn samples differing in the cylinder radius and the volume concentration. The various symbols in Fig. 4a represent the average values of the maximum effective losses, indicating good agreement between the theoretical and experimental data over the whole range of volume concentrations. However, for the resonance values $(ka)_p$, a significant and systematic deviation of the experimental data is observed from the calculated values (as in the case of spherical inclusions), with the experimental values up to a factor of two higher. The possible causes of the observed discrepancy are discussed below.

From the results quoted above, it follows that uniform human made media are effective over a comparatively narrow frequency range. The creation of wideband voidless sound absorbing materials presupposes a set of uniform acoustic elements with a definite distribution of resonance frequencies. As the basis for the synthesis of such materials we took the principle of the minimization of the reflection coefficient, in accordance with [16, 17]. According to this method the synthesis of a wideband sound absorbing material consists in the selection of an inclusion distribution law (radii and concentrations) across the thickness of the absorber which would produce as far as possible total absorption of a sound wave. The possible laws must be subject to certain additional conditions which are determined by the physics of the phenomenon and the possibility of practical realization.

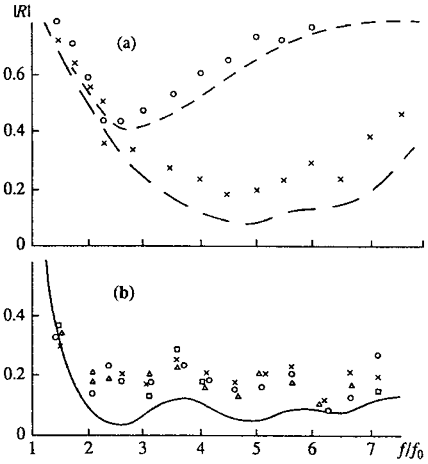

Fig. 5. Calculated (continuous curves) and experimental values of the reflection coefficient of a one–layer, three–layer (a) and five–layer (b) synthesized sound absorber as a function of the dimensionless frequency (f) is the lower frequency of the band)

In the choice of the optimum distribution of inclusions over the thickness of the absorbing layer we limited ourselves to the class of piecewise constant functions, i.e. we found the optimum distribution among functions that were piecewise constant over the section O–L, where L is the overall length of the absorber. This limitation on the class of permissible functions is justified on two grounds: firstly it greatly simplifies the task of choosing the optimum distribution and secondly the practical realization of piecewise constant distributions is much simpler than with continuous functions since a layer with a piecewise constant distribution across the thickness can be made up of layers each of which contains inclusions of a single size. Physically, this corresponds to the fact that the synthesized material should consist of n layers of equal thickness with a uniform distribution over the thickness of each layer of inclusions of a particular radius and concentration.

For a quantitative estimate of the effectiveness of the absorber we used the following mathematical optimality criterion:

$$|R| = \int_{\omega_1}^{\omega_2} a(\omega)|R_n(\omega)|d\omega = \min,$$

where $|R_n|$ is the modulus of the reflection coefficient of the n–th layer, loaded by (n – 1) layers (the load on the first layer is absent). The limits ω_1 and ω_2 are the upper and lower frequencies of the band, and $a(\omega)$ is a weighting factor taken in the form $a(\omega) = \omega^{\angle 1}$.

The synthesis of the sound absorbing material was carried out on the basis of a medium with spherical inclusions. To calculate the input impedances of the layers we used the analytical expressions of the complex density (1) with the empirical corrections obtained as a result of the comparison between the theoretical and experimental data. The task of finding the optimum distribution reduced to determining a set of numbers ε satisfying the conditions $a_{\min} < a_n < a_{\max}$, $\varepsilon_n < 0.1$ corresponding to the minimum value of the optimally condition. The problem was solved numerically on a computer. The solution algorithm consisted in a stage–by–stage selection of the parameters an, en. The first stage consisted in the selection of the parameters successively of the first, second and so on up to the n–th layer in the absence in each case of higher number layers. In this process the radii of the inclusions were varied at intervals of Da while the concentration ey takes all possible values with some small interval De. After the variation of the parameters of the n–th layer the first stage of the calculation is completed.

The second stage consisted in a repeat of the operations described above, with as initial parameters the set obtained as a result of the first approximation stage of the calculation. If after any stage of the calculation the layer parameters obtained do not differ from the parameters of the previous stage, this means that further optimization is impossible and any change in the parameters of any of the layers will lead to an increase in the optimality criterion. The distribution thus obtained must be considered as optimum.

As an example, Fig. 5 shows the results of the first stage of theoretical calculations of the moduli of the reflection coefficient of a five–layer sound absorbing material based on a human made medium with spherical inclusions. The computational curves given in Fig. S indicate a fairly rapid reduction in the level of the reflection coefficient and a broadening of the frequency band on a transition from a single element first layer to the subsequent layers already as a result of the first stage of the calculations. Figure S also shows the experimental values of the reflection coefficient corresponding to the computational data. It can be seen that for a single layer there is a discrepancy between the experimental and calculated data, which increases from layer to layer as a result of the accumulation of errors. A similar effect was observed in [16, 17]. Nevertheless, the reflection coefficient corresponding to five layers (b), although it differs from the theoretical value by a factor of two, becomes fairly small (of the order of 0.2) over a frequency band of about two octaves, which corresponds to values of absorption coefficient close to 0.96–0.97. The different symbols in Fig.5 show the experimental values for static pressures of from 1 to 50 atm, in dicating that the effectiveness of the absorber is practically independent of this parameter.

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Modern Approaches to the Problem of Noise as an Ecological Factor in Aviation Medicine

O.A. Vorob'ev, Yu.V. Krylov, V.V. Zaritskii, S.V. Skrebnev and G.E. Shcherbachenko

Institute of Aviation and Space Medicine, Moscow

The aim of our work was to assess the specific effect of noise on the body of aviation specialists servicing modern aircraft by means of a dose related approach; the determination of ND24; the search for correlation dose effect relationships and the development of a system of preventing the effect of noise on the specialists.

In aviation the problem of preventing the harmful effect of noise and protecting the flight and technical engineering staff and also the civil population living near airports is of high current importance 12. 3. 5. 7]

The effect of noise has noticeably increased in recent years in connection with the rise in the engine power of modern aircraft [4]. The noise which reaches levels of 130–140 dBA in the near sound field acts not only on the hearing but also on the body as a whole reducing the quality and reliability of the activities of aviation experts [6. 7]. The most unfavourable acoustic conditions are experienced by engineering service ersonnel (ESP) since they spend a long time in the zone of action of intense aviation noise [5 6]. In addition to the acoustic load during the period of work a considerable fraction of aviation personnel are also subjected to the effect of noise in the off–work time because of the increase in noise levels particularly in residential towns situated near airfields.

In this connection all approach to noise as an ecologically significant factor has been formulated in recent decades. It foresees calculation of the total 24–hour average noise dose (ND_{24}) with allowance for the nature of the work rest and sleep of the subject ($ND_{24} = ND_{wrk} + ND_{rest} + ND_{slp}$) [1. 8]. However at present the approach to noise as an ecologically significant factor using the concept of ND_{24} has not receive the necessary development in aviation medicine.

The aim of our work was to assess the specific effect of noise on the body of aviation specialists servicing modern aircraft by means of a dose related