United States Patent [19]

Derry

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[54] **SOUND BARRIER**

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[52] **U.S. Cl.**........ **181/33 G,** 181/33 HE, 244/114 B, 256/13.1, 256/24

[51] **Int. Cl.** **B64f 1/26,** E01f 15/00

[58] **Field of Search**.................. 181/30, 33 R, 33 G, 181/33 GB, 33 GD, 33 GE, 33 HE; 244/114 R, 114 B; 256/13.1, 24

[56] **References Cited**

UNITED STATES PATENTS

1,825,465	9/1931	MacDonald	181/30
2,936,040	5/1960	Rennard	181/33 HE UX
3,382,947	5/1968	Biggs	181/30
3,630,310	12/1971	Federer	181/33 HE X
3,656,576	4/1972	Gubela	181/33 HE X

FOREIGN PATENTS OR APPLICATIONS

37,063	7/1968	Finland	181/33 GB
1,658,664	12/1970	Germany	256/13.1

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[57] **ABSTRACT**

A sound barrier comprising a plurality of hollow, wedge-shaped, energy dissipating cells mounted in parallel, side-by-side, spaced relationship as inverse-acting acoustic horns, first sides of all cells being coplanar. Each of the cells has a plurality of openings in the remaining two sides thereof along the edges which are adjacent the first side and a plurality of elongated openings along the apex defined by the intersection of the two sides. Each cell is made in two interlocking parts, one part forming the first side and the other part forming the remaining two sides. Each part comprises a thin outer shell of structurally rigid material and an inner lining of sound deadening material, such as polyurethane closed cell foam.

17 Claims, 6 Drawing Figures

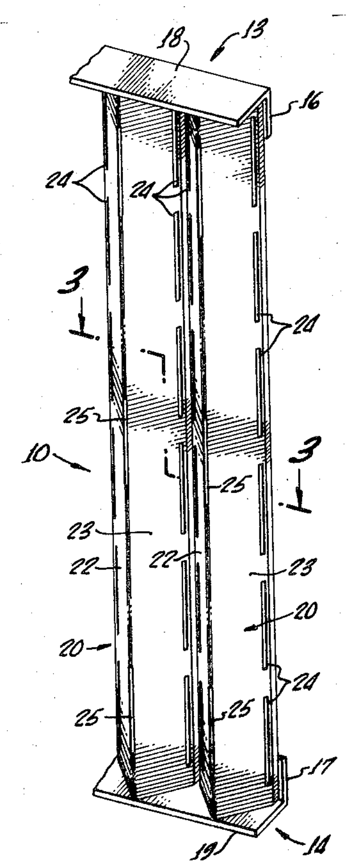

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FIG. 1.

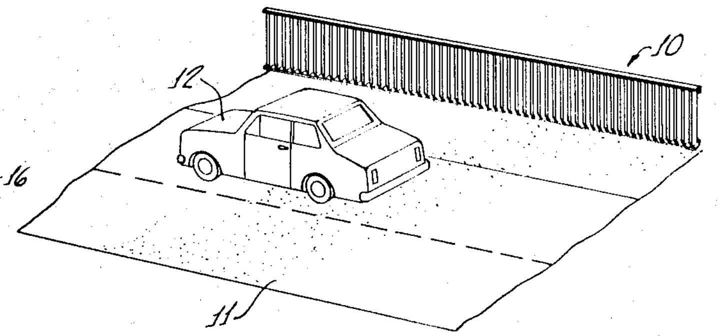


FIG. 2.

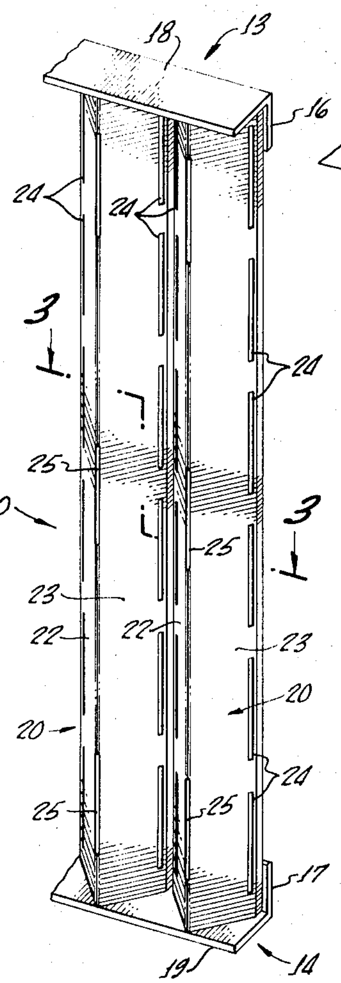
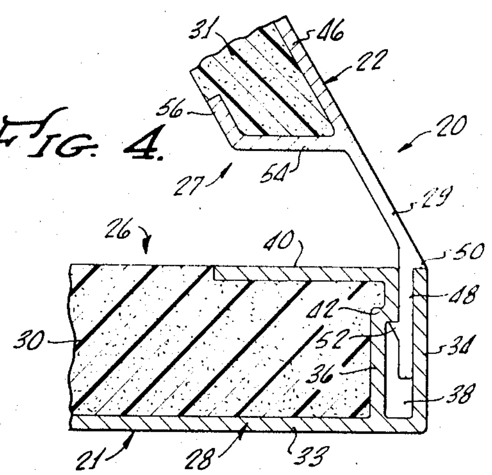


FIG. 4.



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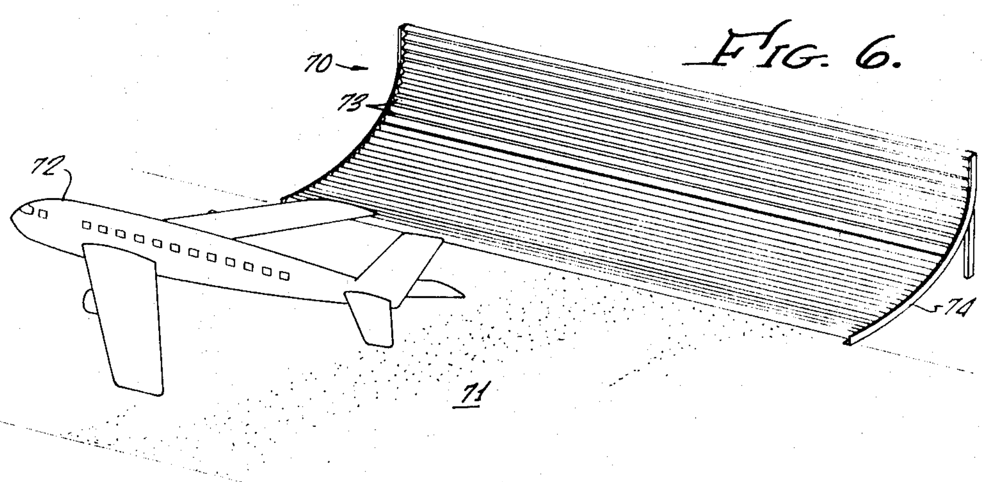
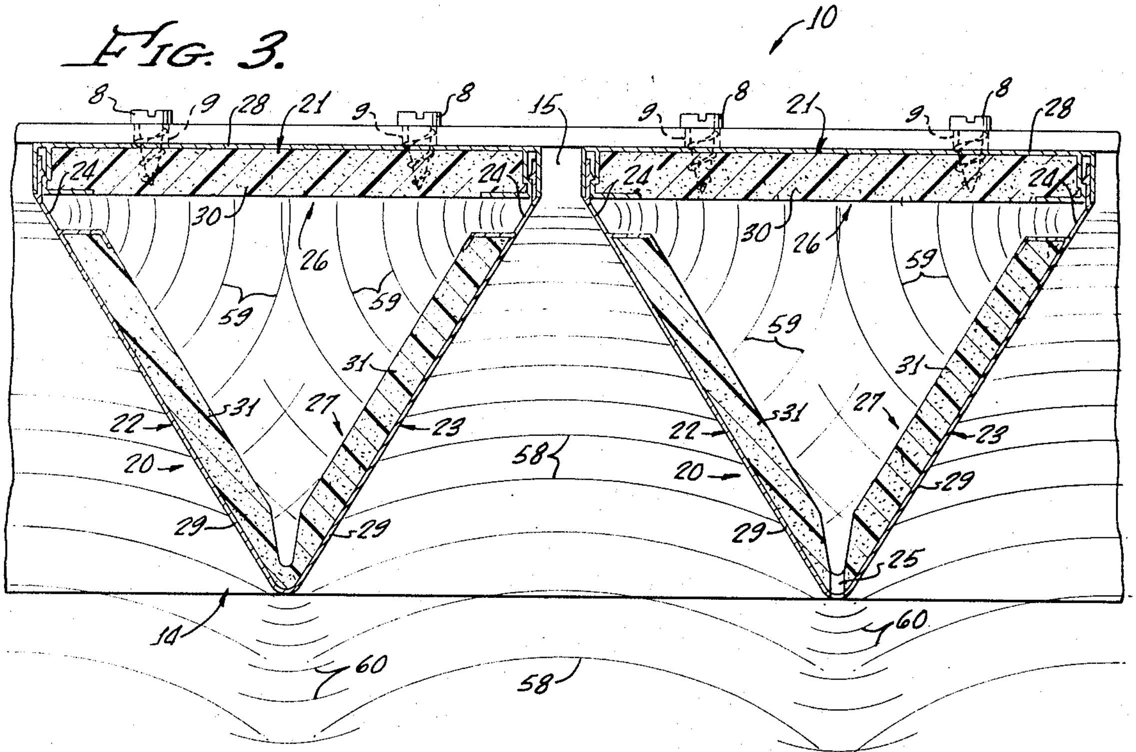


FIG. 3.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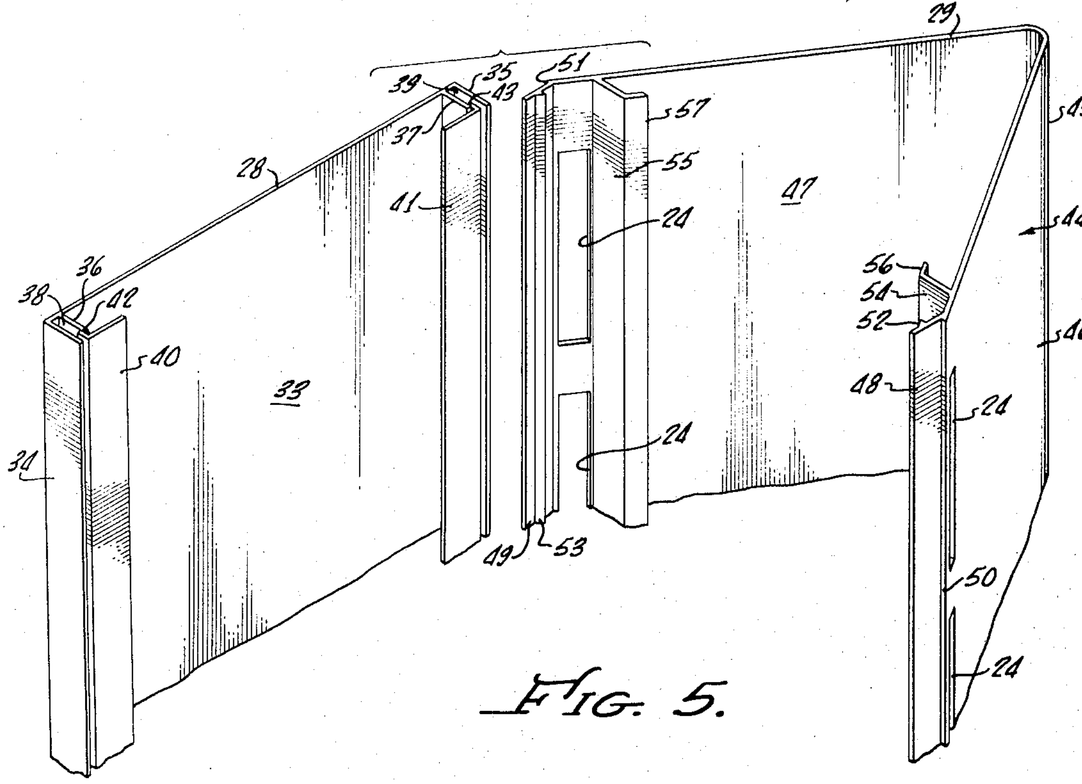
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FIG. 5.

SOUND BARRIER

BACKGROUND OF THE INVENTION

1. Field of the Invention.

The present invention relates to sound barriers and, more particularly, to an inexpensive, effectively optically transparent, sound barrier which is capable of reflecting, absorbing, and converting sound energy to substantially lower levels under all atmospheric conditions.

2. Description of the Prior Art

Noise as a product of traffic flow patterns on urban highways, freeways, and streets is properly becoming of major interest to traffic engineers due to public concern over the increase in noise pollution and the rapidly increasing numbers of vehicles on our streets and highways. It is becoming increasingly more evident that the level of noise one is willing to tolerate on an intermittent level, such as from railroads, low flying aircraft, factory whistles, etc., is much greater than in those cases where the noise source is maintained at a steady level with only mild fluctuations. This becomes significant as the pressing need for increasingly complex urban transportation networks brings freeways and highways near greater numbers of residential communities. Thus, the traffic noise level which can be tolerated while using a freeway going to and from work often becomes intolerable when it is a constant component of the background noise level in a residential area.

A recent study performed regarding the attitudes prevailing in several major U. S. cities on the part of urban residents towards various noise sources in the environment supported the proposition that the public objects to traffic generated noise more than all other sources combined. It is for this reason that the present invention will be described primarily in its application to the reduction of traffic noise on highways, freeways, and other heavily traveled thoroughfares. However, it will be evident that, and examples will be given how, the present invention is applicable to the reduction of noise from other sources such as aircraft, construction, industry, and the like.

Many attempts have been made to provide sound barriers between heavily traveled thoroughfares and residential areas, schools, churches, hospitals, offices, and the like. A conventional barrier is in the form of a solid wall which can be in the form of earth or an upright barrier, the latter often made from concrete. In the former case, an effective earth barrier may be provided by constructing depressed roadways. Whatever barrier is used, tests have shown that with simple barries, significant noise level reductions are achievable only at extreme wall heights, in excess of 25 feet, and at higher frequencies, in excess of 1 kHz. With lower barrier heights, a maximum attenuation of 15 dB is attainable, due to the influence of defraction effects over a barrier.

Therefore, conventional barriers for traffic noise attenuation have several significant disadvantages. In the first instance, effective sound reduction is dependent upon barrier height and barrier heights of 25 feet or more do not blend aesthetically with the surrounding landscape. Furthermore, construction costs for high level barriers, such as earth berms, depressed roadways, and concrete walls, are in the range of $50.00 to $500.00 per running foot. Finally, with such barriers, the motorist has the impression that he is captured within a tunnel and therefore looses his perspective on distance and speed.

One attempt to solve this problem is described in a report entitled "Kinematic Sound Screen Research Project," Report No. 2, July, 1972, prepared by John Hauskins of Engineering Corporation of America for the Arizona Highway Department, Research Division. The Hauskins report describes a sound screen which, at least in theory, goes a long way in eliminating the disadvantages inherent with conventional highway noise barriers. Such disadvantages are purportedly eliminated by the use of a sound barrier incorporating several features. In the first instance, the proposed kinematic sound screen consists of a plurality of Helmholtz resonating chambers which are mounted in parallel, side-by-side, spaced relationship. By providing each chamber with a triangular cross-section and positioning the chambers with first sides coplanar and the remaining two sides extending in the same direction, towards a source of sound, the walls of the chambers act as inverse-acting acoustic horns which focus the sound energy toward the openings of the Helmholtz resonating chambers, thus greatly increasing their efficiency. Each chamber has a plurality of openings in each side thereof, at the focal point of the acoustic horns, which act as filters for the incident sound waves. It is stated that on the basis of laboratory experiments, the net effect of the attenuation phenomenon will exceed 25 dB, effectively 10 dB down from the defracted component of noise reported for conventional solid barriers.

Such sound barriers have a unique feature in the development of roadside barriers for at freeway speeds, it is possible to see through the barrier via the apertures. In other words, the proposed kinematic sound screen consists of a series of wedges separated by thin apertures. An observer sees only a narrow angle of view through each aperture, but as the observer moves along a line of travel, the angle of view changes. Thus, an observer traveling at freeway speeds receives overlapping views of the field beyond the barrier within the time which the retina of the eye stores an image. By means of a serial strobe effect, the observer sees a series of views of the field which he interprets in much the same way as we view a TV or movie picture.

The use of the exterior walls of the wedge-shaped resonating chambers as multiple inverse-acting acoustic horns significantly effects the overall performance of the sound screen. The acoustic horn is essentially a transformer, acting more efficiently than the oscillating mass alone because the horn creates a better impedance match between the resonating chamber and the external air. This means that high pressures are created in the throat area, causing the vibrating air mass at the neck of the Helmholtz chamber to achieve maximum resonant amplitudes in frequency bands near the resonant frequency of the chamber. The net result of this "air coupling" effect is to maximize viscous energy losses for sound waves entering the Helmholtz chamber.

An integral part of the proposed kinematic sound screen is the Helmholtz resonating chamber. According to the theory developed by Helmholtz, a rigid enclosure of volume V connected to the external air mass through a small opening of effective length L and cross-sectional area A has a resonance frequency ω_o which can be expressed by the formula:

$$\omega_o = c \sqrt{A/LV},$$

where c equals the speed of sound in air. At this resonance frequency, the acoustic reactance of the chamber equals zero and the energy impinging on the resonator is radiated back to the external medium exactly in phase except for some viscous energy losses at the neck. The result is, theoretically, cancellation of the energy impinging on the resonator.

While the above described kinematic sound screen is theoretically effective, problems have been encountered in practice because of the use of the Helmhotz resonating chambers. The theoretical operation of the Helmholtz resonating chamber is that the air in the cavity opening moves in and out as a unit under fluctuating pressure from the external air. The pressure of the air inside the cavity changes as it is alternately compressed and expanded due to movement of the air in the cavity opening. Furthermore, patterns of standing waves are generated within the chambers in addition to the oscillating mass of air at the cavity opening. These standing waves generate additional resonance frequencies which are higher than the fundamental frequency ω_o and have a significant effect on the frequency range over which damping occurs. However, when positioned in the atmosphere, the phenomenon of oscillating air masses and standing waves within the chamber and at the chamber openings is substantially effected by wind currents and other atmospheric conditions. For example, not only do the exterior walls of the chambers focus the incoming sound energy on the chamber openings, but they also focus wind currents thereon. These wind currents apparently modify substantially the pressure of the air inside the resonator cavities, thereby substantially modifying and often eliminating or at least effectively reducing the energy cancellation properties of the chambers. Changes in temperature and humidity also result in changing operating characteristics of the resonator chambers. Therefore, while such a sound barrier appears highly desirable and practical in theory, it is not as effective in practice.

Finally, the attempts that have been made to generate sound barriers of the above described type have used concrete or wood to form the chambers thereby forming a structure which is almost as expensive as conventional barriers.

SUMMARY OF THE INVENTION

According to the present invention, there is provided a sound barrier which offers the potential for eliminating not only the above described disadvantages of conventional highway noise barriers but also for solving the problems inherent in sound barriers using Helmholtz resonating chambers and inverse-acting acoustic horns. The present sound barrier is not only relatively inexpensive but is capable of reflecting, absorbing, and converting sound energy to substantially lower levels under all atmospheric conditions. With the present sound barrier, effective sound reduction is only slightly dependent upon barrier height and barrier heights of only 6 feet are capable of achieving attenuations of 20 dB and more. The present sound barrier blends aesthetically with the surrounding landscape and the motorist is not given the impression that he is captured within a tunnel since at freeway speeds, the present sound barrier is visually transparent. Finally, the present sound barrier is not effected by wind currents and other atmospheric conditions and operates as well in the field as in a testing chamber.

Briefly, the present sound barrier comprises a plurality of hollow, energy dissipating cells, each having a triangular cross-section, mounted in parallel, side-by-side, spaced relationship as inverse-acting acoustic horns, first sides of all cells being coplanar or aligned with a continuous, arcuate surface. Because of the spacing between adjacent cells, the barrier appears optically transparent at freeway speeds. Each of the cells has a plurality of openings in the two remaining sides thereof along the edges which are adjacent the first side, which openings act as side branch filters for the incident sound waves and permit entrance of the pressure waves into the energy dissipating cells. Furthermore, each cell has a plurality of elongated openings along the apex defined by the intersection of the two sides, which openings direct the incoming sound waves back upon themselves and prevent pressure buildups within the cells in the presence of air currents. Thus, each cell acts as a sound energy exchanger, receiving air and sound waves, decreasing the level of the latter, and re-directing both in a definite, prescribed direction.

Each cell is made in two interlocking parts, one part preferably forming the first side and the other part forming the remaining two sides. Each part comprises a thin outer shell of structurally rigid material, such as aluminum, steel, or plastic, and an inner lining of sound deadening material, such as polyurethane closed cell foam or other sound absorbing material. The cells may be mounted horizontally or vertically along a highway, freeway, or other heavily traveled thoroughfare or along the side of any other noise producing source.

OBJECTS

It is therefore an object of the present invention to provide a novel sound barrier.

It is a further object of the present invention to provide a highly effective, yet inexpensive sound barrier which is capable of reflecting, absorbing, and converting sound energy to substantially lower levels under all atmospheric conditions.

It is a still further object of the present invention to provide a sound barrier which is effectively optically transparent.

It is another object of the present invention to provide a sound barrier which may be quickly assembled, disassembled, and retrofitted and which is lightweight and easy to handle.

It is still another object of the present invention to provide a sound barrier which will blend aesthetically with the surrounding landscape.

Still other objects, features, and attendant advantages of the present invention will become apparent to those skilled in the art from a reading of the following detailed description of the preferred embodiments constructed in accordance therewith, taken in conjunction with the accompanying drawings wherein like numerals designate like parts in the several figures and wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a portion of a traffic thoroughfare with the present barrier in position along the side thereof;

FIG. 2 is an enlarged perspective view of a portion of the barrier of FIG. 1;

FIG. 3 is an enlarged cross-sectional view taken along the line 3—3 in FIG. 2;

FIG. 4 is an enlarged cross-sectional view of a portion of the structure of FIG. 3 showing the interlocking connection between the two subassemblies of the present sound barrier;

FIG. 5 is an exploded view showing the construction of the thin outer shells of structurally rigid material of which the sound barrier of FIGS. 1–4 is partially constructed; and

FIG. 6 is a perspective view showing the manner in which the present sound barrier may be used along the side of an aircraft runway.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Sound propagates through air as a series of fluctuations in the local air density, pressure, and temperature, as well as disturbances in the positions of air particles. Since each set of fluctuations is repeated at regular intervals, this form of disturbance can be characterized as wave motion and treated as such for purposes of description.

It is the magnitude of the fluctuations in pressure that make a sound appear to be loud or soft. At a standard frequency of 1,000 Hz, the minimum audible sound has been determined to be 0.0002 microbar. At the other extreme, the maximum tolerable sound pressure with a frequency of 1,000 Hz that can be safely endured is 200 microbars. Since this represents a very broad spectrum, it has proven useful to express relative sound pressure in logarithmic units, which also approximates the manner in which the human ear judges loudness. The logarithmic measure of sound pressure is called the pressure level and is expressed in decibels (dB). The conventional reference used for measuring sound pressure levels has been arbitrarily set at the threshold of hearing at 1,000 Hz, or 0.0002 microbar. The sound level expressed in decibels then increases 20 dB for every 10 times increase in sound.

Tests have shown that sound pressure levels in the range of 70 to 90 decibels exist on highways, freeways, and other heavily traveled thoroughfares. On the other hand, recommended sound pressure levels for residential areas, schools, churches, hospitals, offices, and the like are in the range of 40 to 50 decibels. This represents a difference in pressure levels between the actual and the desired of approximately 30 to 40 dB. However, conventional earthwork and solid wall barriers positioned on both sides of urban freeways can be expected to give effective sound reduction in adjacent areas of 15 dB or less. Barrier heights of 25 feet or more, which obviously do not blend aesthetically with the surrounding landscape, would be necessary to achieve attenuations of 20 dB or more.

Referring now to the drawings and, more particularly, to FIG. 1 thereof, there is shown a sound barrier, generally designated 10, positioned adjacent the side of a highway, freeway, or other heavily traveled roadway 11 on which cars 12, buses, trucks and the like travel. It is the function of sound barrier 10 to substantially attenuate the noise level passing laterally from roadway 11 to the adjacent surroundings. However, it will be evident that the present invention is applicable to the reduction of noise from sources other than traffic, such as aircraft, construction, industry, and the like.

With reference now to FIGS. 2–5, sound barrier 10 consists of an assembly of hollow, energy dissipating cells, generally designated 20, each having a triangular cross-section, which are mounted in parallel, side-by-side, relationship with a narrow breathing slot 15 therebetween. Each cell 20 is identical and includes a first side 21, all of sides 21 typically being coplanar, as shown in FIGS. 2 and 3. Each cell 21 has two remaining sides 22 and 23 which all extend in the same direction, so that all of sides 22 are parallel and all of sides 23 are parallel.

Each cell 20 has a plurality of inlet openings 24 in each of sides 22 and 23, openings 24 being spaced along the edges of sides 22 and 23 which are adjacent sides 21. Each of cells 20 further has a plurality of outlet openings 25 along the leading edge or apex thereof defined by the intersection of sides 22 and 23. As will be described more fully hereinafter, the size, area, and number of openings 24 and 25 are chosen to determine the correct efficiency of sound barrier 10.

According to the preferred embodiment of the present invention, and as shown most clearly in FIGS. 3, 4, and 5, each of cells 20 consist of two subassemblies, a rectangular subassembly 26 from which side 21 is constructed and a triangular subassembly 27 from which sides 22 and 23 are constructed. Subassemblies 26 and 27 preferably comprise thin outer shells 28 and 29, respectively, of structurally rigid material, such as fiberglass, plastic, wood, concrete, or a sheet or extruded metal such as aluminum. Subassemblies 26 and 27 are also preferably lined with sound deadening materials 30 and 31, respectively. Many suitable sound deadening materials are known but a preferred material is polyurethane closed cell foam, foamed in place, and containing a bonding agent to assure a secure bond to shells 28 and 29, respectively.

With reference primarily to FIGS. 4 and 5, shells 28 and 29 may be extruded continuously in the shape shown and then cut to any desired length. Each of shells 28 includes a rectangular back portion 33 and two side portions 34 and 35 which extend at 90° angles from the side edges of back portion 33. Shell 28 further comprises flanges 36 and 37 which extend outwardly from back 33, parallel but spaced from sides 34 and 35, respectively, to define narrow slots 38 and 39. The ends 40 and 41 of flanges 36 and 37 are bent through an angle of 90° so as to extend towards each other, ends 40 and 41 being coplanar with each other and with the ends of sides 34 and 35. Finally, approximately two-thirds of the distance between back 33 and ends 40 and 41, flanges 36 and 37 have short dog-legs 42 and 43, respectively, for reasons which will appear more fully hereinafter.

Shell 29 includes a base portion 44 which is bent through an angle of 120° at the exact center thereof to form an apex 45 and two sides 46 and 47. The free ends 48 and 49 of sides 46 and 47, respectively, are bent through angles of 30° relative to sides 46 and 47, respectively, so that they are parallel to each other, as shown. The spacing between ends 48 and 49 is exactly equal to the spacing between slots 38 and 39 in shell 28 and the lengths of ends 48 and 49 are slightly smaller than the depths of slots 38 and 39. Thus, ends 48 and 49 of shell 29 extend into slots 38 and 39, respectively, of shell 28. In order to retain ends 48 and 49 in slots 38 and 39, respectively, sides 46 and 47 of shell 29 include outwardly projecting ears 50 and 51, respectively, at the intersection between sides 46 and 47 and ends 48 and 49, respectively, and inwardly projecting ears 52 and 53, respectively, centrally located along ends 48 and 49. The distance between ear 50 and ear 52 and between ear 51 and ear 53 is equal to the distance between dog-legs 42 and 43 and ends 40 and 41, respectively, of flanges 36 and 37, respectively, of shell 28. Thus, when ends 48 and 49 of shell 29 are inserted into slots 38 and 39, respectively, of shell 28, ears 50 and 51 will rest on the ends of sides 34 and 35, respectively, and ears 52 and 53 will be captured beneath dog-legs 42 and 43, respectively. The resiliency within the material from which shell 28 is formed will permit a slight deflection of flanges 36 and 37 as ears 52 and 53, respectively, pass between flanges 36 and 37 and sides 34 and 35, respectively.

Each of shells 29 further includes flanges 54 and 55 which extend inwardly from the inner surfaces of sides 46 and 47, respectively, thereof. Flanges 54 and 55 are coplanar and are spaced from ends 40 and 41, respectively, of shell 28 by an amount which is slightly greater than the desired width of inlet openings 24. The ends 56 and 57 of flanges 54 and 55, respectively, are bent through an angle of 60° so as to extend parallel to sides 46 and 47, respectively, towards apex 45. The spacing between ends 56 and 57 and sides 46 and 47, respectively, as well as the spacing between ends 40 and 41 and back 33 is determined by the thickness desired for sound deadening material 30 and 31, respectively.

Finally, each of shells 29 has a plurality of elongated openings 24 in each of sides 46 and 47, between ears 50 and 51 and flanges 54 and 55, respectively. The length, width, location, and spacing between openings 24 will be discussed more fully hereinafter. At the present time, openings 25 are not formed in shell 29.

Ends 40 and 41 of flanges 36 and 37, respectively, of shell 28 and ends 56 and 57 of flanges 54 and 55, respectively, of shell 29 define the areas of shells 28 and 29 which are to be lined with sound deadening materials 30 and 31, respectively. As mentioned previously, any suitable sound deadening material may be used although a polyurethane closed cell foam is highly effective and most desirable. A polyurethane closed cell foam may be applied to shells 28 and 29 in the manner described in copending U. S. Patent Application Ser. No. 181,703 filed Sept. 21, 1971, by Carl E. Derry and William A. Childs for Thermally Insulated Building Material and Method and Means for the Manufacture Thereof. For example, and as described more fully in such application, shells 28 and 29 may be positioned on their backs, with the sides to be lined with foam facing upwardly, and passed beneath a plurality of spray nozzles which inject a polyurethane foam, in liquid form, thereon. Shells 28 and 29 would then be passed beneath conveyor belts which permit rising of the foam to the desired shape.

In the case of shell 28, a flat conveyor belt resting on top of ends 40 and 41 of flanges 36 and 37, respectively, will permit the foam to fill the area defined by back 33, flanges 36 and 37, and ends 40 and 41 thereof. In the case of shell 29, a triangular conveyor belt resting on top of ends 56 and 57 of flanges 54 and 55, respectively, and having a suitable cross-sectional shape would be required to permit the foam to line the inner surfaces of sides 46 and 47, from flange 54 to flange 55. Reference to the above-mentioned copending Patent Application may be had for a fuller explanation of the foaming process. In any event, the foam would have a suitable bonding agent included therein so as to form a rigid, unitary structure with shells 28 and 29.

It should be evident that using the above described manufacturing procedure, it would not be possible to initially form outlet openings 25 in apex 45 of each of cells 20 since to do so would permit escape of the liquid foam of which sound deadening material 31 is formed. Therefore, openings 25 would have to be cut through apex 45 of shell 29 after the foaming step is completed. This may be achieved in any suitable manner.

After the foaming step is completed and subassemblies 26 and 27 are completely formed, they may be connected together in the manner described previously by extending ends 48 and 49 of subassembly 27 into slots 38 and 39 in subassembly 26. Thereafter, cells 20 may be installed in any suitable manner. For example, if cells 20 are to be used along a roadway 11, as shown in FIG. 1, cells 20 may be formed in 4 or 6 foot lengths and mountee a short distance from the side of roadway 11. The cells 20 may also be stacked, one above the other, to any desired height. A suitable mounting technique would be to support, in any suitable manner, first and second horizontal, vertically spaced angles 13 and 14 along the side of roadway 11 with first sides 16 and 17 of angles 13 and 14, respectively, coplanar and with second sides 18 and 19 of angles 13 and 14, respectively, parallel and spaced by an amount slightly greater than the length of cells 20. Thereafter, cells 20 may be positioned between angles 13 and 14, with sides 21 thereof resting against sides 16 and 17 of angles 13 and 14, respectively. A plurality of sheet metal screws 8 may then be extended through a plurality of holes 9 formed in sides 16 and 17 of angles 13 and 14, respectively, and into backs 33 of sides 21 of cells 20. This simple procedure permits rapid and efficient assembly of barrier 10 along the side of roadway 11. Also, side 18 of angle 13 serves as a cover to prevent various forms of environmental precipitation from getting into cells 20. On the other hand, to the extent that such precipitation finds its way into cells 20, it will be drained therefrom via the space between the bottom of cells 20 and side 19 of angle 14.

In operation, and with reference to FIGS. 2 and 3, the improvement in noise attenuation performance of sound barrier 10 is attributable to the interaction of several phenomena. In the first instance, the exterior walls of sides 22 and 23 of cells 20 act as multiple inverse-acting acoustic horns which focus the sound energy toward openings 24 in cells 20 and 21. More specifically, sound or noise from a fixed or moving source produces successive waves 58 of compressed air which advance toward barrier 10. These waves undergo further compression as they travel along sides 22 and 23 between each set of cells 20. In other words, as a first wave enters the constricting area just beyond apices 45, there will be some scattering of energy. But if another wavefront enters the constricting area before the first has an opportunity to dissipate, then the first wave will be forced into an area of increasing pressure until it reaches openings 24 in cells 20. At this point, large amplitude vibrations of the air mass adjacent openings 24 are set up, which vibrations are damped by the remaining structure to be described immediately hereinafter. However, it is significant to note that the acoustic horns are essentially transformers, acting more efficiently than the oscillating mass alone because the horn creates a better impedence match between openings **24** in cells **20** and the external air. The net result of this "air coupling" effect is to maximize viscous energy losses for sound waves entering cells **20** and **21**.

The compressed air which serves as the media for sound energy propagation is now diverted from a high pressure zone, at each opening **24**, into the adjacent cells **20**, which are at a lower pressure, rapidly expanding within cells **20**, thereby dissipating additional energy. The opposing waves **59** of compressed air flowing within each chamber **20** now generate turbulent air swirls which produce additional energy dissipation. The swirling air patterns within each cell **20** impact against sound deadening material **30** and **31**, dissipating still additional sound energy.

Additional wavefronts **59** of compressed air entering cells **20** recompress the preceeding wavefronts, producing additional energy losses. Thus, the openings in sides **22** and **23** of cells **20** are a second phenomenon which contributes to the improvement in noise attenuation performance of sound barrier **10**.

The compressed, expanded, and recompressed sound waves within each cell **20** now respirate through outlet openings **25** in apices **45** of cells **20** to a low pressure zone immediately in front of each apex **45**. More specifically, when the successive waves **58** of compressed air reach apices **45** of cells **20**, they are broken up and directed along sides **22** and **23**, between each pair of cells **20**. This has the effect of creating a partial vacuum adjacent each apex **45**, which partial vacuum draws the air within cells **20** out through openings **25**. The compressed air which serves as the media for sound energy propagation is now again diverted from a high pressure zone, within cells **20**, adjacent openings **25**, back into the atmosphere, which is at a significantly lower pressure, rapidly expanding and dissipating additional energy. Furthermore, the wavefronts **60** exiting from openings **25** propagate in a direction opposed to the incoming waves **58** which, by molecular impact, cause additional energy dissipation.

In other words, the first wavefronts **58** impinging upon sound barrier **10** are substantially reduced in energy level and a substantial portion of the remaining energy level is directed back upon the incoming sound energy, thereby decreasing the level of such sound energy before it even reaches barrier **10**. The new wavefronts, which have now been decreased in magnitude, are recirculated through cells **20**, as described previously, with corresponding energy losses, and a substantial portion of the remaining energy is then directed back against successive wavefronts **58**. This phenomenon, integrated together, produces the desired substantial lowering of sound energy levels.

It should be particularly noted that in theory and in practice, very little of the incident sound energy is transmitted through slots **15** between cells **20**. Many factors effect the ratio of the power transmitted to the input power, such as the area of inlet openings **24**, the characteristic acoustic reactance of cells **20**, the characteristic acoustic resistance of cells **20**, the volume of cells **20**, and the like. It has been found that as long as the width of slots **15** is small relative to the width of sides **21** of cells **20**, very little of the incident sound energy is transmitted through slots **15**. By way of example, each of sides **21**, **22**, and **23** of cells **20** may be approximately 4 inches wide and slots **15** may be one-eighth inch wide. Openings **24** may be 6 inches long and one-quarter inch wide and spaced longitudinally by 1½ inches. Such a configuration has been found to produce superior operating characteristics.

On the other hand, slots **15** are necessary since they permit air circulation between each pair of cells **20**, so as to prevent unwanted air circulation or air pressure build-up near inlet openings **24**. Slots **15** also subdue diaphragm-like vibrations of the rear walls **33** of cells **20**, which otherwise would act as secondary noise sources.

The relationship between the area of openings **25** to the area of openings **24** significantly effects the operation of cells **20**. More specifically, since openings **25** are intended to be outlet openings to permit air pressures within cell **20** to respirate, the combined area of inlet openings **24** should be large compared to the combined area of outlet openings **25**. Also, if outlet openings **25** were too large, the turbulent air swirls which produce energy dissipation within cells **20** would be inhibited. By way of example, outlet openings **25** may be 6 inches long by three thirty-second inches wide and may be spaced longitudinally by 1 foot. With such dimensions, the ratio of the combined area of inlet openings **24** to the combined area of outlet openings **25** is 10.77 to 1 and this ratio has been found through tests to be highly effective. In other words, the ratio of the combined area of inlet openings **24** in each cell **20** to the combined area of outlet openings **25** should be at least approximately 10 to 1.

It can therefore be seen that in accordance with the present invention, there is provided a sound barrier **10** which offers the potential for eliminating not only the disadvantages of conventional highway noise barriers but also for solving the problems inherent in sound barriers using Helmholtz resonating chambers and inverse-acting acoustic horns. Sound barrier **10** is not only inexpensive, but is capable of reflecting, absorbing, and converting sound energy to substantially lower levels under all atmospheric conditions. With sound barrier **10**, effective sound reduction is only slightly dependent upon barrier height and barrier heights of only 6 feet are capable of achieving attenuations of 20 dB and more. Sound barrier **10** blends aesthetically with the surrounding landscape and a motorist in vehicle **12** is not given the impression that he is captured within a tunnel since at freeway speeds, sound barrier **10** is visually transparent.

Of greatest significance, sound barrier **10** is not effected by wind currents and other atmospheric conditions and operates as well in the field as in a testing chamber. The wind currents which are focused by walls **22** and **23** towards openings **24** in cells **20** respirate not only through slots **15** but also through cells **20** via inlet and outlet openings **24** and **25**, respectively. Thus, these wind currents do not modify or reduce the energy cancellation properties of barrier **10**. Rather, each cell **20** acts as a sound energy exchanger, receiving air and sound waves and redirecting them, the latter in decreased form, in a definite, prescribed direction. Cells **20** are thus distinguishable from Helmholtz chambers which function only as resonators.

In the embodiment of FIG. **1**, cells **20** are shown having a length of approximately 4 feet and as being mounted vertically along the side of roadway **11**. However, it will be apparent to those skilled in the art that other configurations are possible. For example, and with reference to FIG. **6**, there is shown a sound barrier, generally designated 70, positioned adjacent the side of an airport runway 71 on which aircraft 72 take off and land. Barrier 70 consists of a plurality of hollow, wedge-shaped, energy dissipating cells 72 which are identical in construction and operation to cells 20. However, each of cells 73 is quite long and cells 73 are mounted horizontally in parallel, side-by-side, spaced relationship along the sides of runway 71. Cells 73 may be mounted with first sides coplanar or may be mounted with first sides positioned along an arcuate supporting surface 74. This latter configuration has the advantage of redirecting some of the incident sound energy upward and not back towards aircraft 72. Other configurations and orientations of energy dissipating cells constructed in accordance with the teachings of the present invention will be apparent to those skilled in the art.

While the invention has been described with respect to the preferred physical embodiments constructed in accordance therewith, it will be apparent to those skilled in the art that various modifications and improvement may be made without departing from the scope and spirit of the invention. Accordingly, it is to be understood that the invention is not to be limited by the specific illustrative embodiments, but only by the scope of the appended claims.

I claim:

1. A sound barrier comprising:
- a plurality of hollow, energy dissipating cells, each having a triangular cross-section, mounted in parallel, side-by-side, spaced relationship with first sides of all of said cells being coplanar or aligned with a continuous, arcuate surface and the remaining two sides of all of said cells extending in the same direction, towards a source of sound;
- each of said cells having a plurality of inlet openings in each of said remaining two sides thereof, said inlet openings being spaced along the edges of said two sides which are adjacent said first side;
- each of said cells further having at least one elongated outlet opening along the apex thereof defined by the intersection of said two sides, the combined area of said plurality of inlet openings in each cell being substantially greater than the area of said elongated outlet opening in each cell.

2. A sound barrier according to claim 1 wherein the spacing between adjacent cells is substantially smaller than the width of said first sides thereof.

3. A sound barrier according to claim 1 wherein the lengths of said inlet openings are at least four times greater than the spacing between adjacent openings.

4. A sound barrier according to claim 1 wherein the combined area of said plurality of inlet openings in each cell is approximately ten times the area of said elongated outlet opening in each cell.

5. A sound barrier according to claim 4 wherein each of said cells has a plurality of said outlet openings spaced along said apex thereof.

6. A sound barrier according to claim 1 wherein each of said cells comprises:
- a thin outer shell of structurally rigid material and an inner lining of sound deadening material.

7. A sound barrier according to claim 6 wherein said outer shell is made from sheet metal.

8. A sound barrier according to claim 6 wherein said outer shell is made from aluminum.

9. A sound barrier according to claim 8 wherein said sound deadening material is polyurethane closed cell foam.

10. A sound barrier according to claim 6 wherein said sound deadening material is polyurethane closed cell foam.

11. A sound barrier according to claim 1 wherein each of said cells consists of two subassemblies, a first generally rectangular subassembly from which said first side is formed and a second generally triangular subassembly from which said remaining two sides are formed, said first and second subassemblies including means for forming an interlocking connection therebetween.

12. A sound barrier according to claim 11 wherein each of said subassemblies comprises:
- a thin outer shell of structurally rigid material and an inner lining of sound deadening material.

13. A sound barrier according to claim 12 wherein said shell of said first subassembly comprises:
- a rectangular back portion;
- two perpendicular side portions; and
- first and second flanges which extend outwardly from said back portion, parallel to and spaced from said side portions to define narrow slots therebetween; and wherein said shell of said second subassembly comprises:
- a base portion which is bent through an angle of 120° at the exact center thereof to form said apex and said two remaining sides, the free ends of said sides being bent through angles of 30° so as to be parallel to each other, the spacing between said ends being exactly equal to the spacing between said slots in said first subassembly whereby said ends extend into said slots.

14. A sound barrier according to claim 13 wherein said means for forming an interlocking connection between said subassemblies comprises:
- a dog-leg in said flanges of said first subassembly;
- an outwardly projecting ear at each intersection between said sides and said ends of said second subassembly; and
- an inwardly projecting ear centrally located along each of said ends of said second subassembly, the distance between each outwardly projecting ear and each inwardly projecting ear being equal to the distance between said dog-legs and the ends of said flanges whereby said outwardly projecting ears rest on the ends of said side portions of said first subassembly and said inwardly projection ears are captured beneath said dog-legs in said flanges of said first subassembly.

15. A sound barrier according to claim 13 wherein said lining of sound deadening material of said first subassembly extends between said first and second flanges thereof.

16. A sound barrier according to claim 13 wherein said shell of said second subassembly further comprises:
- first and second flanges extending inwardly from the inner surfaces of said sides thereof, said flanges being coplanar and spaced from said ends of said sides by an amount which is slightly greater than the width of said inlet openings, said lining of sound deadening material of said second subassembly extending along the inner surfaces of said sides of said shell, between said flanges thereof.

17. A sound barrier according to claim 16 wherein said inlet openings extend between said first and second flanges and the adjacent ends of said sides of said base portion of said shell of said second subassembly.

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