

July 7, 1959

J. J. BARUCH ET AL

2,893,508

METHOD OF AND APPARATUS FOR ACOUSTIC SILENCING

Filed July 14, 1955

6 Sheets-Sheet 1

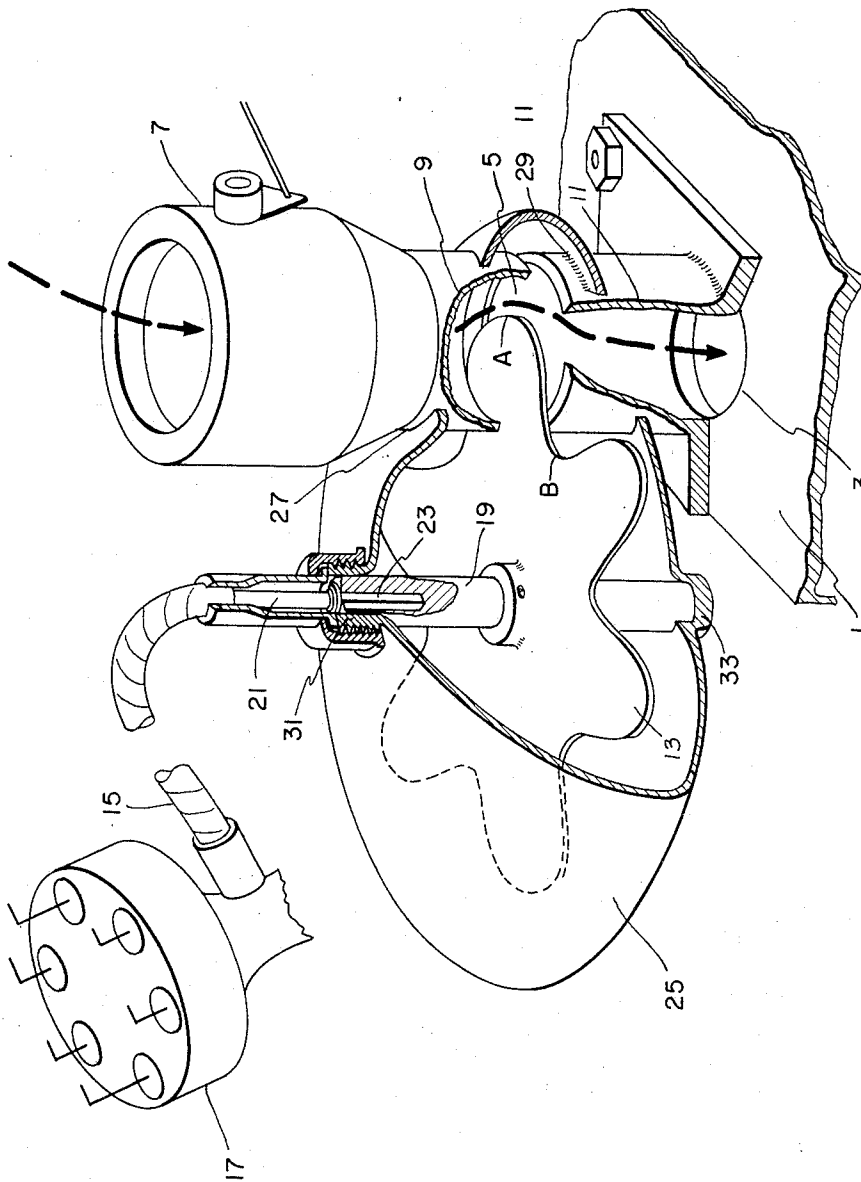


FIG. 1

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6 Sheets-Sheet 2

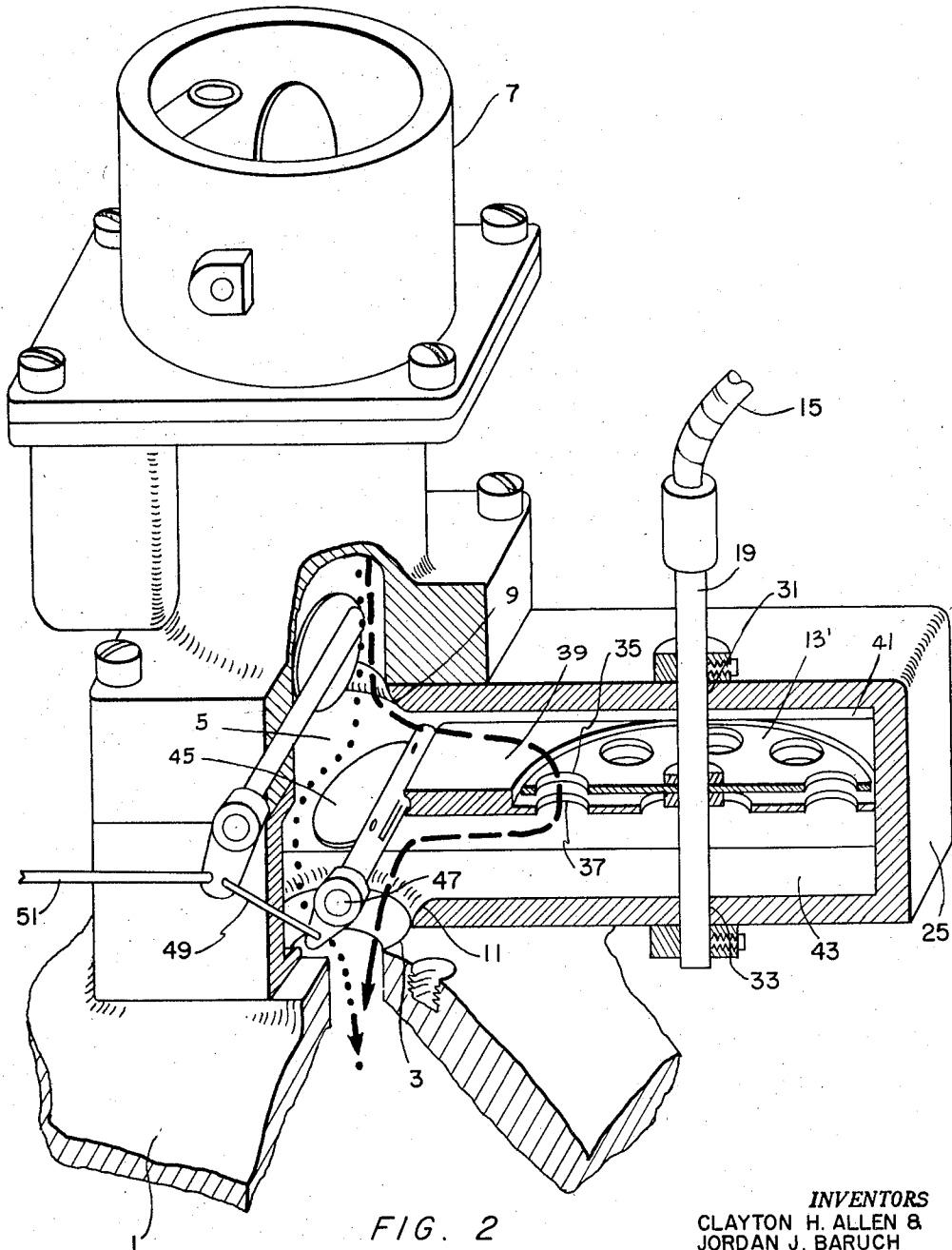


FIG. 2

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6 Sheets-Sheet 3

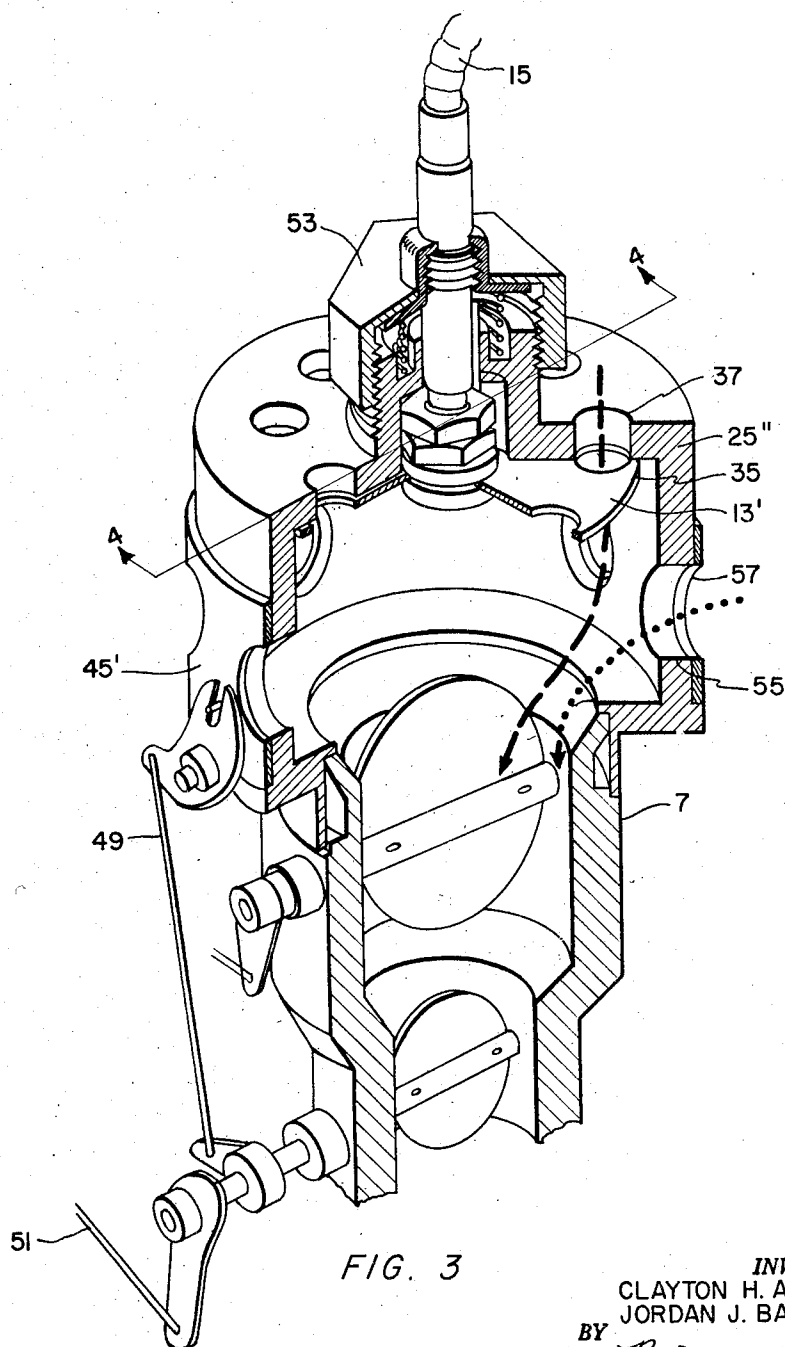


FIG. 3

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6 Sheets-Sheet 4

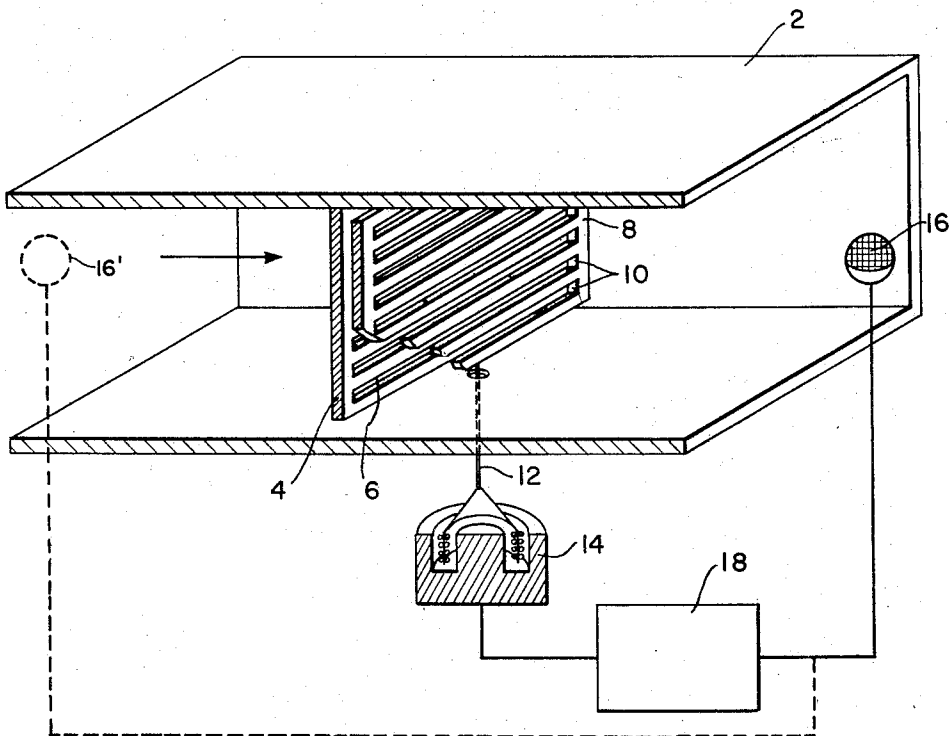


FIG. 6

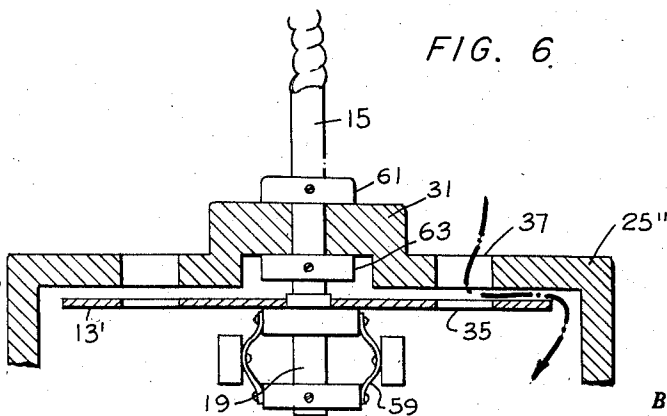


FIG. 4

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6 Sheets-Sheet 5

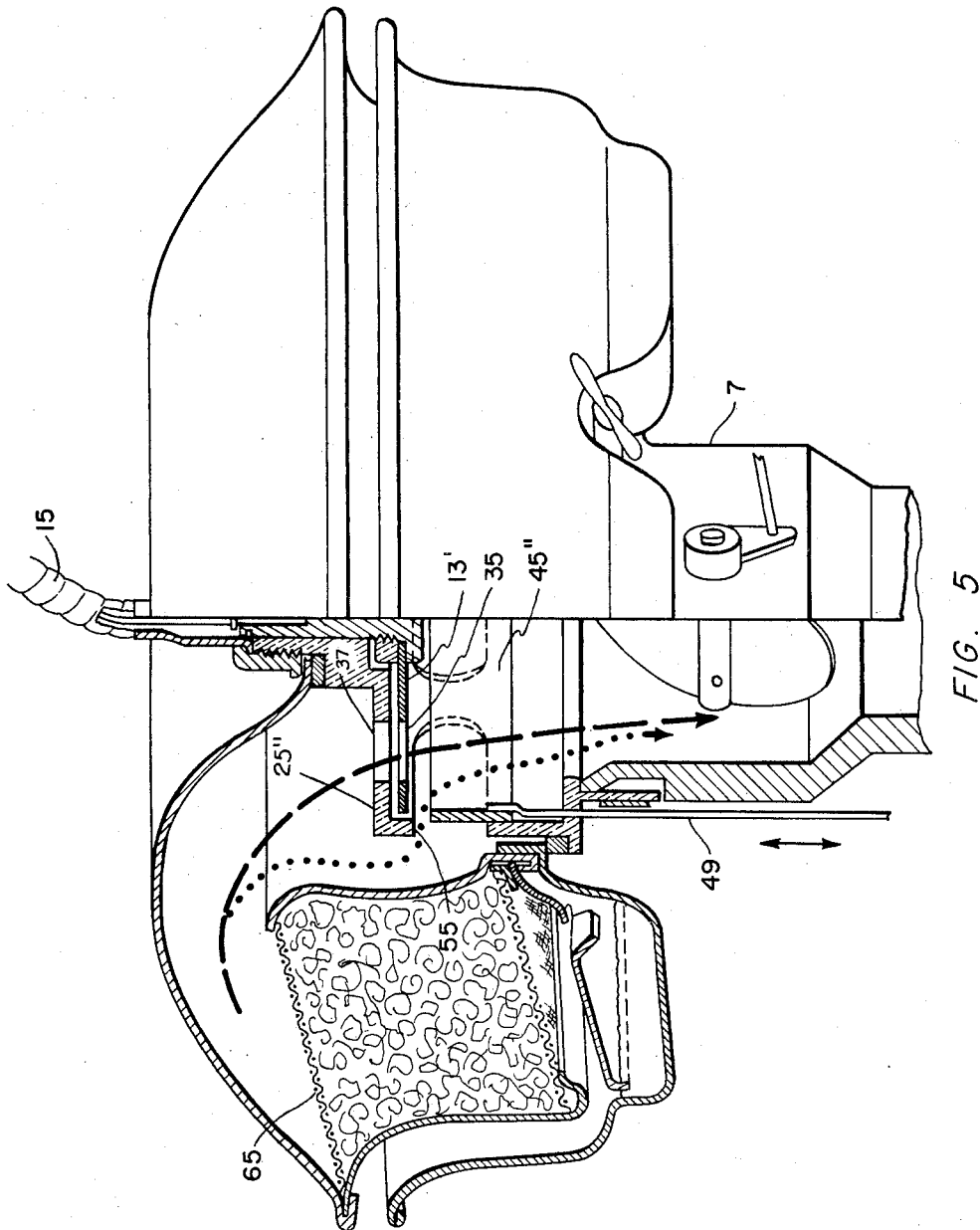


FIG. 5

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1

2,893,508

METHOD OF AND APPARATUS FOR ACOUSTIC SILENCING

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Application July 14, 1955, Serial No. 522,153

43 Claims. (Cl. 181—45)

The present invention relates to methods of and apparatus for acoustic silencing, and more particularly, to the silencing of pressure variations produced in fluid-flow conduits.

Many techniques have been proposed throughout the years for silencing pressure variations produced in fluid media flowing along conduits and the like. As an illustration, in applications such as the in-take system of automotive engines, resort has heretofore been had to such expedients as fibrous materials disposed in air filters, sizable resonant chambers connected with the air-filtering mechanism, and porous baffles, screens and similar devices. While these proposals have been workable, they have not provided a high degree of attenuation over the relatively wide sound-energy spectrum produced by the operation of the automotive engine over widely varying speeds and that escapes through the air in-take system. Such prior-art systems, moreover, have not produced as low a pressure drop in the fluid medium passing through the conduit of the air in-take system as is desirable. In addition, these devices have occupied a relatively large volume under the hood of automobiles which has rendered them further undesirable in view of the trend toward reducing the size of the volume under the automobile hood. Other prior-art silencing devices are similarly undesirable in one or more of these or other particulars.

An object of the present invention, accordingly, is to provide a new and improved method of, and apparatus for, acoustic silencing that shall not be subject to any of the beforementioned disadvantages and that is of broad general utility in fluid-flow systems. It is to be understood that the word "silencing" is herein employed in its broad sense to embrace not only the actual quieting of audible sounds, but also the smoothing-out of fluctuations in fluid flow of any frequency range, including super-audible frequencies.

A further object of the present invention is to provide such a novel method and apparatus that are particularly adapted for application to the silencing or smoothing-out of fluid-flow pulsations in the air in-take system of an automotive engine. In this connection, the present invention affords not only wide-band acoustic-frequency smoothing or silencing, but it does so with a high degree of attenuation, and with equipment that is not only of relatively small dimensions, but that introduces a relatively small pressure drop. While the invention, moreover, will be hereinafter described in connection with its application to the important problem of silencing the acoustic energy accompanying the flow of air in the in-take system of an automotive engine, it is to be understood that this is for purposes of illustration only, and that the techniques and apparatus hereinafter described are equally applicable for use in other types of systems requiring the silencing of a varying, pulsating or other irregular flow of a fluid medium in a conduit.

Other and further objects will be explained herein-

2

after and will be more particularly pointed out in connection with the appended claims. In summary, however, from a broad aspect of the invention, it relates to a method of and apparatus for eliminating sound produced by pressure variations at a predetermined region of a fluid medium the flow of which varies with time in accordance with some function, that comprises, increasing and decreasing the impedance to the fluid flow at the predetermined region in accordance with substantially the said function. The increase and decrease in impedance is preferably adjusted to correspond substantially to the amplitude of the pressure variations at the said predetermined region, but within limits such that the impedance never becomes so great as to prevent substantially all fluid flow at the said predetermined region, and the impedance increasing and decreasing is synchronized with the pressure variations. Preferred details are hereinafter fully treated.

The invention will now be described in connection with the accompanying drawings.

Fig. 1 of which is a perspective view, partly broken away in order to illustrate details of construction, of an apparatus constructed in accordance with the present invention and adapted particularly for the silencing of acoustic energy that would normally be transmitted from an automotive engine through its air in-take system;

Fig. 2 is a similar view, upon a somewhat different scale, illustrating a modification;

Fig. 3 is a similar view of still a further modification;

Fig. 4 is a fragmentary section, taken upon the line 4—4 of Fig. 3, looking in the direction of the arrows, and illustrating still a further modified construction;

Fig. 5 is a sectional view illustrating a preferred mounting of the type of apparatus of Figs. 2 through 4;

Fig. 6 is a schematic perspective view of an additional modification particularly adapted for operation with fluid-flow pressure variations of an irregular or non-recurring nature; and

Figure 7 is a cross sectional view of still a further modification adapted for purposes similar to that for which the system of Fig. 6 may be utilized.

Referring to Fig. 1, the manifold 1 of an automotive engine is shown provided with an air inlet 3 to which an air in-take conduit 5 from a carburetor 7 is connected. The air in-take conduit 5, in accordance with the present invention, is preferably segmented or divided into two sections, shown as an upper conduit section 9 and a lower conduit section 11. The upper and lower conduit sections 9 and 11 of the air in-take conduit 5 are spaced from one another to a sufficient degree to permit the insertion therebetween of a substantially planar rotor plate 13 having a scalloped or smoothly varying curved periphery A, B, the precise nature of which will be hereinafter discussed. The rotor 13 may be driven from a flexible-drive tachometer take-off 15 connected with, for example, the distributor 17 of the automotive system. The shaft 19 of the rotor 13 is illustrated as coupled to the flexible shaft 21 of the take-off 15 by the key 23. The shaft 19 is shown supported in upper and lower bearings 31 and 33 within a housing 25 of, for example, ellipsoidal configuration. The upper conduit section 9 of the air in-take conduit 5 is supported in an opening 27 in the upper portion of the ellipsoidal housing 25 to which it may be soldered, or otherwise sealed. The lower conduit section 11 is similarly secured to and passes through a bottom opening 29 in the lower portion of the housing 25. The rotation of the before-mentioned rotor 13 within the ellipsoidal housing 25 will cause the scalloped periphery of the rotor 13 to vary the area of the available aperture

3

for fluid-flow communication between the conduits 9 and 11 for a purpose later explained.

In the operation of the automotive engine, air is drawn inward through the upper end of the carburetor 7, in the direction of the arrows, and downward through the conduits 9 and 11 into the manifold opening 3 for use in the combustion process. As the successive pistons of the automotive engine, not shown, draw air thusly downward during their successive strokes, the flow of the air into the manifold opening 3 is caused to occur periodically. Pressure fluctuations or pulsations are thereby produced in the air flowing into the manifold opening 3 that give rise to corresponding sound frequencies that are disturbing to the automotive operator, and which disturbance it is the object of the silencer of the present invention to eliminate. For present purposes, it will be sufficient to consider the fundamental frequency of the sound or acoustic-wave phenomenon that is produced in the air flow in response to the successive operation of the successive pistons, and it will be assumed that it is desired to eliminate only this fundamental acoustic wave. In accordance with the present invention, the air in the conduit region 9 of the air in-take conduit 5 is rendered substantially free of these pressure fluctuations or pulsations that give rise to the undesirable sound. This is accomplished by rotating the rotor 13 so that it varies the previously described area of available aperture for fluid flow between the upper and lower conduits 9 and 11, in a particular manner synchronously with the operation of the distributor 17 and hence with the firing of the pistons. When the downward force drawing the air into the manifold 3 is greatest, it is desired that one of the outwardly extending scallops A of the peripheral edge of the rotor 13 pass between the conduits 9 and 11, as shown in Fig. 1, in order to cut down the available area for the passage of the air and thereby to offer a maximum impedance or resistance to the fluid flow so as to permit only a predetermined volume flow of air at the region 9. When, on the other hand, the piston stroke is such that air is not being drawn into the carburetor 7 to any appreciable degree, it is necessary that the rotor 13 be then rotated such that a valley B in the periphery passes between the conduits 9 and 11 to expose a large area between the conduits 9 and 11. This will offer little air resistance so that more air, though under less pressure, may pass into the manifold opening 3, maintaining substantially the same predetermined volume flow of air at the region 9. The carburetor 7 and/or the manifold chamber below the opening 3 act as a compliance or reservoir for the taking-up of the non-uniform air flow between the piston-controlled source of the pressure or flow variations and the region of the aperture 9. If the periphery is properly shaped so that the resistance or area continuously varies or is modulated in accordance with substantially the fundamental pressure or sound-wave frequency and to an extent corresponding substantially to the amplitude of the pressure variations or sound wave, and if the take-off 15 synchronizes the rotor rotation with the cylinder operation, in proper phase, therefore, the volume flow of air at the region 9 will be maintained substantially constant and thus free of the before-described pressure variations or pulsations that give rise to the undesirable sounds. Stated in other terms, an increase or decrease in fluid flow velocity past the rotor 13 into the manifold opening 3 in response to an increased or decreased pressure drop, respectively, produced through operation of the cylinders, will be offset by a corresponding decrease or increase, respectively, in the effective flow area between the conduit sections 9 and 11 such that the product of the effective flow area and the fluid velocity through this area will be substantially constant. Silencing of the sound resulting from the fluid pressure variations at the region 9 has thereby been achieved.

4

In the above illustration, the sounds generated by the reaction of the cylinder piston movement upon the incoming air will be constituted of a strong fundamental sinusoidal frequency component and various less strong harmonic frequency components. The fundamental frequency will correspond to the firing rate of the pistons of the automotive engine. There may also be sub-harmonic frequencies resulting from crank-shaft rotation and the rotation of other parts, and there will also be harmonics of these sub-harmonics, as well. Of all these frequency components, however, the fundamental, corresponding to the frequency of the firing of the cylinder pistons, is by far the most intense and the most troublesome. Operating on the before-mentioned assumption that it is this fundamental only that it is desired to eliminate, the curve of the edge or the variation of the periphery of the rotor 13 will be designed so that it will produce an area variation or modulation following substantially a sinusoidal function corresponding to the substantially sinusoidal fundamental pressure variation at the region 9 which it is desired to eliminate. The shape of this periphery may be varied in accordance with the addition to this fundamental of whatever harmonics it may be desired to superimpose, in accordance with Fourier analysis, thus to provide, also, for the elimination of the less-bothersome harmonic frequencies, as well.

It is desired to stress the fact that, in accordance with the present invention, as contrasted with prior-art proposals to attempt to muffle sounds through the opening and closing of exhaust ports, the rotor 13 never completely closes off the conduit 9 so as to prevent substantially all fluid flow at that region. If it did completely close off the fluid flow, there would result a rush or pulse of fluid flow upon the re-opening of the conduit 9 which would itself give rise to the production of sound and would not produce the muffling action of the present invention. It is through the control of the percentage of the open area between the conduit sections 9 and 11, above described, within limits such that the fluid flow is never substantially one-hundred percent modulated or stopped, that the pulsating fluid variations appearing at the manifold opening 3 are converted into the substantially constant direct-current volume flow at the conduit region 9.

While the system of Fig. 1 is particularly well suited to devices that operate at substantially constant speeds, such as, for example, certain types of engines including motor-boat engines, aircraft engines and stationary diesel engines, and the like, if the speed of the engine varies within wide limits, there must be introduced a compensating factor that, in effect, changes the law of variation of the curve of the rotor 13 in accordance with the speed variations of the engine. In such cases, it is necessary to control the percentage of variation of the area between the conduit sections 9 and 11 synchronously with and in accordance with the change in speed of the engine. In automotive engines, for example, that are operated at relatively low speeds, say 20 to 25 miles per hour, more or less, the percentage area variation required from maximum degree of area closure to minimum degree of area closure by the rotor 13 must be of the order of about 30 percent to 50 percent, more or less, for the type of arrangement illustrated in Fig. 1. The exact value will depend on the number of cylinders in the engine, the volume of the manifold, the size of the pistons, the location of the cylinders, the horsepower of the motor, and other factors. For high speeds, on the other hand, say of the order of 60 to 75 miles per hour, more or less, the percentage area variation must be very much less; say, for example, of the order of about 3 percent, more or less. For a speed variation of the order of about 3 to 1, therefore, the percentage area variation must be of the order of about 10 to 1 if a substantially constant volume flow is to be produced at each speed. While the total volume flow, of course, changes with speed, the

important feature is that, for any one speed, the volume velocity of the air flow must be rendered substantially constant with time. The law of variation of the percentage of area modulation, therefore, appears to vary somewhat as the inverse of the square of the engine speed. The percentage modulation of area required for the silencing of a specified sound pressure is substantially proportional to the inverse of the square of the air velocity in the conduit. In an engine where the air velocity is proportional to the engine speed and the pressure variations which are to be eliminated are substantially constant over the range of speeds, therefore, if 30 percent modulation is required at 20 miles per hour, essentially 3 percent modulation will be required at 60 miles per hour. Departures from this substantially square law may be necessary when acoustic resonances occur in the air in-take system.

The control of the percentage of effective flow area variation with engine speed may be accomplished with the aid of a system such as that illustrated in Fig. 2. In Fig. 2, the carburetor 7 is again connected through the upper and lower conduit sections 9 and 11 of the air in-take conduit 5 to the manifold opening 3. A rotor 13' is provided, however, that differs from that illustrated in Fig. 1. The rotor 13' is provided with a peripherally disposed array of properly shaped apertures, such as circular apertures 35, that are displaced from the conduits 9 and 11, to the right, within a substantially cylindrical housing 25'. The conduit sections 9 and 11 are illustrated as integral portions of the housing 25' and the housing is divided into upper and lower compartments 41 and 43, respectively, by a septum 39. The septum 39 is apertured at 37 in a manner similar to the rotor 13'. The openings 35 and 37 of the rotor 13' and the septum 39, respectively, may, in the embodiment of Fig. 2, be of substantially the same diameter or dimensions so that periodic rotation of the rotor 13' will permit periodic fluid communication between the conduits 9 and 11 along the path of the dash-line arrow. At the time, however, that the openings 35 and 37 are not in alignment, the fluid medium cannot travel along the path of the dash-line arrow. In accordance with the system of Fig. 2, however, a second or by-pass path is provided directly in line between the upper and lower conduits 9 and 11, as illustrated by the dotted-line arrow, so that, as before specified, the fluid flow from the carburetor 7 into the manifold opening 3 is never completely shut off. The resistance to the flow in the auxiliary by-pass path of the dotted-line arrow is controlled by a valve 45 shown pivotable about a shaft 47 at the inner edge of the septum 39. The shaft 47 is, in turn, driven by link arms 49 from, for example, the throttle-control arm 51 of the automotive engine. As the throttle is varied to control the speed of the engine, accordingly, it controls the position of the valve 45 and thus the degree of resistance to, as well as the area of, the flow of the fluid medium along the path of the dotted-line arrow. Thus, the flow of the fluid medium along the dashed-line arrow is modulated synchronously with the operation of the cylinder pistons to increase and decrease the resistance to, or available area for, the flow of the fluid medium in accordance with the pressure increases and decreases caused by the operation of the successive cylinders. Simultaneously with this variation, the by-pass path is controlled by the valve 45 for two purposes: first, to provide a continuous path for the flow of a direct-current component of the fluid so that there is no stoppage of fluid flow when the apertures 35 and 37 are out of alignment; and, secondly, to introduce a correction factor for each successive different speed under the control of the throttle link 51, in order to cause the percentage of variation of the available flow area between the upper and lower conduits 9 and 11 to vary with the varying speed. This variation, as before stated, may be substantially a square-law variation.

It is to be understood, however, that this variation may also be accomplished in other ways, such as, for example, by causing the valve 45 to operate against a spring or other device, not shown, so as to make the average pressure drop across the valve 45 equal to or substantially equal to the sound pressure value of the fundamental pressure. This results in the pressure drop across valve 45 remaining substantially constant with speed. Slight alterations in the link arms or the spring, not shown, may be made to compensate for the beforementioned resonances that may occur in the engine system at particular frequencies.

Figs. 1 and 2 have been described in connection with the utilization of the silencer of the present invention between the manifold opening 3 and the carburetor 7. This, however, is by no means necessary. In Fig. 3, for example, a modified cylindrical housing 25'' is shown mounted above the carburetor 7 and provided with the rotor 13', the apertures 35 of which may become successively aligned with corresponding apertures 37 in the upper face of the housing 25''. The rotor 13' may again be driven from the flexible drive shaft 15, and its position from the upper face of the housing 25'' may be preset to any desired degree by the threaded adjustment 53. The air thus flows in the direction of the dashed-line arrow into the carburetor 7 in a flow modulated in response to the rotation of the rotor 13'. A by-pass path is provided, as shown by the dotted-line arrow, through a circular arrangement of side apertures 55 in the housing 25'' below the rotor 13'. The resistance or area afforded by this by-pass path is controllable by the use of a rotatable sleeve valve 45' provided with openings 57 and mounted concentrically with the housing 25'' to cover, in various degrees, the openings 55. This control of the area or impedance afforded by the by-pass path may be effected in the same way as the control of the valve 45 of Fig. 2, namely, by link arms 49 and 51 associated with the throttle control of the engine. There is again provided not only the increasing and decreasing of the flow resistance to, or available flow-communication area of, the air by means of the rotation of the rotor 13', but automatic and synchronous compensation for the necessary variation in percentage modulation of the air flow in accordance with the speed of the engine is also effected by means of the by-pass valve 45'.

It is to be understood that the showing of the regulation of the valves 45 and 45' of Figs. 2 and 3, respectively, by a throttle control, is illustrative of only one type of synchronous control that may be effected. As another illustration, control may be effected from a speed generator or similar device. This is shown in the Fig. 4, in connection with rotor 13', for purposes of illustrating the flexibility of the invention. A governor 59 is shown mounted below the rotor 13' on the shaft 19. The shaft 19 is provided with a pair of upper collars or stops 61 and 63 disposed on opposite sides of the bearing 31 to limit the upward and downward movement of the rotor 13' toward or away from the upper surface of the housing 25'' that is provided with the communicating openings 37. The shaft 19 can not, of course, move up or down as a result of the collars 61 and 63, but the action of the governor 59 will move the rotor 13' toward or away from the openings 37 in the top of the housing 25'' in accordance with the speed of the engine. This will provide more or less of a by-pass path through the apertures 37 and around the periphery of the rotor 13', as shown by the dash-dot line arrow in Fig. 4. Thus, again, compensation may be had for the speed variation of the engine. If it is desired, there may be further apertures, not shown, in the upper surface of the housing 25'' which may normally be covered by the periphery of the rotor 13' or an extension thereof, not shown, when the rotor 13' is adjacent the upper surface. As the rotor 13' is lowered by the governor 59 in response to the increased speed of the engine, such apertures would provide further by-pass

action. If desired, furthermore, both relative movement between the plane of the rotor 13' and the plane of the openings 37 and relative movement of the valve mechanism 45' with respect to the openings 55 may be simultaneously effected as in Figs. 3 and 4. Either or both the rotor 13' and the valve mechanism 45' may be operated by the governor type of control 59 of Fig. 4, or the throttle type of control 51 of Fig. 3. Controls from other drive mechanisms may also similarly be effected such as, for example, manifold-pressure or spark-advance controls.

In the case of the system of Figs. 3 and 4, it is preferable, for purposes of economy and space limitations, to mount the housing 25'' within the center of a toroidal air filter or cleaner 65. In the system of Fig. 5, a slightly different valve mechanism 45'' is shown assuming the form of a solid circular band disposed within the housing 25'' to open or close portions of the side openings 55 in the housing in response to movement in the direction of the solid-line arrows under the control of the by-pass control link arm 49, from, for example, the throttle, previously described.

This disposition of the by-pass openings provides the advantageous use of the difference between the ram or stagnation pressure and the dynamic pressure in a flowing fluid stream to enhance the effective pressure differential across the rotor, thereby reducing the necessary pressure drop across the silencer. The modulated air stream following in the path of the dashed-line arrow impinging upon the housing 25'' and the rotor 13'' produces a relatively high stagnant pressure P_0 substantially equal to atmospheric pressure, whereas the unmodulated by-pass stream, following somewhat the path of the dotted-line arrow, will pass to the underside of the rotor developing there a relatively reduced pressure P_1 due to its velocity. The difference in pressure developed by this means is related to the effective velocity V of the air stream past the underside of the rotor approximately as the relation

$$P_0 - P_1 = \frac{1}{2} \rho V^2$$

where ρ is the density of the air.

As a typical illustration of a practical silencer constructed in accordance with the present invention and embodying the form of, for example, Fig. 3, the outside diameter of the housing 25'' may be about four inches; the apertures 37 and 35, about one-half inch in diameter and spaced about one-half inch apart to provide arrays of eight apertures; the spacing of the rotor 13' from the upper surface of the housing 25'', from about five-thousandths of an inch to about two hundred thousandths of an inch; and the apertures 57 and 55, about three-quarters of an inch in diameter, spaced about three-quarters of an inch apart to provide arrays of eight apertures. With such a silencer operating above the carburetor 7 of an eight-cylinder gasoline automotive engine, twenty to thirty decibels of cancellation of the fundamental sound frequency, corresponding to the firing frequency of the pistons, was obtained over a range of from twenty to sixty miles per hour engine speed. Pressure drops, measured across the silencer, of from about two inches of water up to about eight to ten inches, more or less, were employed.

In summary, therefore, the systems of Figs. 2 to 4 embody two paths for the flow of the fluid medium. The by-pass path with a constant resistance provides for the passage of a steady or direct-current flow containing the undesirable pressure fluctuations. The rotor-modulated path provides a variable resistance for the introduction of a substantially equal amplitude and oppositely-phased flow modulation (that is of phase 180 degrees different from that of the pressure variations) that effectively cancels the pressure fluctuations passing along the by-pass path, thereby producing a resultant steady flow that is quiescent. Exactly equal and opposite phase and pressure-amplitude relationships are desirable, but the inven-

tion is operable, in practice, with departures from such a condition. Satisfactory operation can be obtained, for example, in some cases, with a pressure-amplitude difference as great as $\pm 10\%$, more or less; or with a phase difference which differs from 180 degrees by as much as ± 20 degrees, more or less; or with both pressure-amplitude and phase differences as great as $\pm 5\%$ and ± 10 degrees, respectively, more or less. The operation of this device as a silencer pre-supposes a substantially continuous unidirectional flow of the fluid medium through the silencer, such as is obtained in automotive air in-take or exhaust systems. The pressure drop produced across the by-pass path is of substantially the same magnitude as that produced by the peak pressures of the rotor-modulated flow which are, in turn, substantially equal to the peak-pressure amplitude of the unwanted pressure variations. In an automotive engine, this peak-pressure amplitude is, in theory, substantially constant over a wide range of engine speeds. In practice, however, resonance effects at particular frequencies may occur that will increase or decrease the said peak-pressure amplitude and may be compensated for, if desired, as before explained.

In the systems of Figs. 1 through 5, pressure variations of known character are produced. The invention is also useful, however, where the pressure variations are in accordance with a function of an entirely random or fluctuating nature. In the system of Fig. 6, for example, fluid flow may be passing through a rectangular or other conduit 2, shown partly in section, and through a valving mechanism comprising a fixed-screen or grid 4 provided with a plurality of horizontal apertures 6, and an adjacent cooperating movable grid 8 provided with corresponding apertures 10. The grid 8 may be oscillated up and down with respect to the grid 4 to permit the apertures 10 to become aligned, more or less, with the apertures 6 and thus to provide increasing or decreasing impedance to and area for the flow of the fluid medium along the conduit 2. This control may be effected by an armature 12 driven vertically by an electromagnet 14. The armature movement and grid alignment movement could, of course, be effected in other directions than the illustrated vertical operation, and other types of grid apertures could also be utilized. A microphone or other pressure-detecting device 16 may be placed within the fluid medium to respond to the pressure variation therein and thus to produce a signal that may be amplified in an amplifier 18 and may be fed to control the electromagnet 14, thereby synchronously moving the grid 8 in accordance with the pressure variations. As the pressure increases, therefore, in accordance with any type of variation, the grid 8 is synchronously and correspondingly moved with respect to the stationary grid 4 to produce corresponding impedance or area variations, thus to achieve a substantially constant flow that gives rise to the silencing results of the present invention. It may be advisable, under some circumstances, as where more complete silencing is desired, to place the microphone or other detector ahead of the valving mechanism 4, 8, as shown dotted at 16' in Fig. 6.

While it has before been demonstrated that the method underlying the present invention is capable of being practiced with widely differently types of apparatus, such as the peripherally shaped mechanical rotor system of Fig. 1, the uniform-periphery apertured rotor and in-line by-pass valve of Fig. 2, the cylindrical by-pass valve of Fig. 3 and the electrically controlled shutter of Fig. 6, this fact is even more clearly demonstrated by the entirely different type of mechanical system illustrated in Fig. 7.

A cylindrical end plunger 20 is there shown provided with circumferential slots 22 in its cylindrical surface and disposed within a larger tubular conduit 24 provided with corresponding apertures 26. The cylindrical plunger 20 is mounted resiliently at its ends by springs 28 and 30 between stops 40 at the uppermost end of the conduit 24 and the end plate of the plunger 20, and between the

lower stops 42 of the plunger 20 and stops 44 in the conduit 24, respectively. The plunger 20 may thus move forward and backward in response to pressure variations in the flow of fluid medium along the direction of the dash-line arrow. A by-pass path may be provided between openings 32 provided in the rearward or lower portion of the conduit 24 and corresponding openings 34 in a main conduit 36. The conduit 24, in turn, is resiliently mounted within the main conduit 36 by a spring 38 between the stops 46 of the conduit 24 and the stops 48 of the main conduit 36. By-pass flow will occur in the direction of the solid-line arrow. The by-pass might alternatively be provided through the slots 22 and 26 by properly adjusting the rest position of the plunger 20 so that the apertures 22 and 26 are partly open. Pressure variation would then tend to close and open the apertures from that rest position, tending to increase or decrease the flow impedance synchronously and in proper phase with the pressure variations. It is a further property of this device that, if the plunger 20 is mass-controlled, i.e., operating above its natural resonant frequency, as the frequency of the pressure variations or sound increases, the displacement of the plunger 20 will decrease. When this device is applied to an automobile in-take system, therefore, it will provide automatic compensation for increase in speed by reducing the percentage of modulation at higher frequencies. In such case, moreover, the direct-current flow of air will cause a static pressure against the end of the plunger 20 which will displace it from its rest position as the pressure drop across the apertures 22 and 26 increases, thereby automatically providing increased by-pass as the speed increases, which is required for providing the necessary pressure-variation cancellation. This same phenomenon may be utilized for controlling the by-pass in the other embodiments of the invention, as well.

While the invention has been described in connection with the flow of a gaseous fluid medium, it is, of course, to be understood that this technique and this type of device may be utilized with other fluid media, such as liquids. The present invention, indeed, has particular utility in silencing liquid pumps such as water pumps, circulating pumps, refrigeration circulating systems, hydraulic-drive systems and the like. Other illustrations of uses of the invention are in air compressors, vacuum pumps, jack hammers and the like.

Further modifications will occur to those skilled in the art. As a further example, while the rotors of Figs. 2 to 4 have been illustrated as driven from the distributor, they may equally well be driven from other parts in synchronism with the pressure pulsations. For more exact synchronized control, indeed, the rotors may be geared to the drive shaft of the motor, if desired. All such modifications are considered to fall within the spirit and scope of the present invention as defined in the appended claims.

In addition, it is to be understood that instead of employing the carburetor and/or the manifold chamber for acting as a compliance or reservoir for the taking-up of the non-uniform fluid flow between the predetermined aperture region and the source of the pressure or flow variations, as in the various illustrated embodiments, any other suitable chamber, cavity or extension of the conduit may be similarly utilized.

What is claimed is:

1. A method of eliminating sound produced by pressure variations at a predetermined region of a fluid medium the flow of which varies with time at sound frequencies in accordance with some function, that comprises, increasing and decreasing at the rates of the said sound frequencies the impedance to the fluid flow at the predetermined region in accordance with substantially the said function while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region, and synchronizing the impedance increasing and decreasing with the said pressure variations of sound-frequency rates.

2. A method of eliminating sound produced by pressure variations at a predetermined region of a fluid medium the flow of which varies with time at sound frequencies in accordance with some function, that comprises, increasing and decreasing at the rates of the said sound frequencies the resistance to the fluid flow at the predetermined region in accordance with substantially the said function while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region, and synchronizing the resistance increasing and decreasing with the said pressure variations of sound-frequency rates.

3. A method of eliminating sound produced by pressure variations at a predetermined region of a fluid medium the flow of which varies with time at sound frequencies in accordance with some function, that comprises increasing and decreasing at the rates of the said sound frequencies the impedance to the fluid flow at the predetermined region in accordance with substantially the said function, adjusting the extent of the increase and decrease in impedance to correspond substantially to the amplitude of the pressure variations at the said predetermined region while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region, and synchronizing the impedance increasing and decreasing with the said pressure variations of sound-frequency rates.

4. A method of eliminating sound produced by pressure variations at a predetermined region of a fluid medium the flow of which varies with time at sound frequencies in accordance with some function, that comprises, increasing and decreasing at the rates of the said sound frequencies the impedance to the fluid flow at the predetermined region in accordance with substantially the said function while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region, and adjusting the phase and extent of the increasing and decreasing to produce a pressure drop across the said predetermined region that is substantially equal in magnitude and opposite in phase to the said pressure variations of sound-frequency rates, thereby to effect substantial cancellation of the said pressure variations at the said predetermined region.

5. A method of eliminating sound produced by pressure variations at a predetermined aperture region of a chamber through which may flow a fluid medium the flow of which varies with time at sound frequencies in accordance with some function, that comprises, increasing and decreasing at the rates of the said sound frequencies the area of the aperture region in accordance with substantially the said function while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined aperture region, and synchronizing the said area increasing and decreasing with the said pressure variations of sound-frequency rates.

6. A method of eliminating sound produced by pressure variations at a predetermined aperture region of a chamber through which may flow a fluid medium the flow of which varies with time at sound frequencies in accordance with some function, that comprises, increasing and decreasing at the rates of the said sound frequencies the area of the aperture region in accordance with substantially the said function, adjusting the extent of the increase and decrease in the said area to correspond substantially to the amplitude of the pressure variations at the aperture region while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined aperture region, and synchronizing the said area increasing and decreasing with the said pressure variations of sound-frequency rates.

7. A method of eliminating sound produced by pressure variations at a predetermined aperture region of a chamber through which may flow a fluid medium the flow of which varies with time at sound frequencies in accordance with some function, that comprises, passing the

fluid medium along two paths in the vicinity of the aperture region that determine the effective area for the flow of the fluid medium at the aperture region, increasing and decreasing at the rates of the said sound frequencies the area of one of the said paths in accordance with substantially the said function and synchronously with the said pressure variations of sound-frequency rates, and controlling the size of the area of the other path in accordance with changes in the total volume flow of the fluid medium.

8. A method of eliminating sound produced by pressure variations at a predetermined aperture region of a chamber through which may flow a fluid medium the flow of which varies with time at sound frequencies in accordance with some function, that comprises, passing the fluid medium along two paths in the vicinity of the aperture region that determine the effective area for the flow of the fluid medium at the aperture region, increasing and decreasing at the rates of the said sound frequencies the impedance to the fluid flow along one of the said paths in accordance with substantially the said function and synchronously with the said pressure variations of sound-frequency rates, and controlling the impedance to the fluid flow along the other path in accordance with changes in the total volume flow of the fluid medium.

9. A method of eliminating sound produced by a pulsating flow of a fluid medium at a predetermined region thereof which pulsating flow results from the pressure of sound waves of sound frequency, that comprises, increasing and decreasing at the rate of the said sound frequency the impedance to the fluid-medium flow at the predetermined region synchronously and substantially out-of-phase with the sound-frequency-rate increasing and decreasing pressures produced by the pulsations of the fluid-medium flow, while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region.

10. A method of eliminating sound at an aperture region of a chamber produced by a sound-frequency pulsating flow of a fluid medium through the chamber, that comprises, reducing the size of the aperture region when the flow of the fluid medium within the chamber increases at the rate of the said sound frequency, while maintaining an auxiliary path providing continuous flow of fluid medium through said aperture region, and increasing the size of the aperture region when the fluid-medium flow decreases at the said rate.

11. A method of eliminating sound at an aperture region of a chamber produced by a sound-frequency varying flow of a fluid medium through the chamber, that comprises, detecting the sound-frequency pressure variations produced by the varying flow of the fluid medium, and responding to the sound-frequency pressure-variation detection to reduce the size of the aperture region when the flow of the fluid medium within the chamber increases, while maintaining an auxiliary path providing continuous flow of fluid medium through said aperture region, and to increase the size of the aperture region when the fluid-medium flow decreases.

12. A method of eliminating sound produced by a sound-frequency varying flow of a fluid medium at a predetermined region thereof, that comprises, detecting the sound-frequency pressure variations produced by the varying flow of the fluid medium, and responding to the sound-frequency pressure-variation detection to increase and decrease the impedance to the fluid-medium flow at the predetermined region synchronously with the detected increasing and decreasing pressures produced by the sound-frequency pulsations of the fluid-medium flow, while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region.

13. A method of eliminating sound produced by a sound-frequency varying flow of a fluid medium at a predetermined region thereof, that comprises, detecting the sound-frequency pressure variations produced by the vary-

ing flow of the fluid medium, and responding to the sound-frequency pressure-variation detection to increase and decrease the impedance to the fluid-medium flow at the predetermined region synchronously with the detected increasing and decreasing pressures produced by the sound-frequency pulsations of the fluid-medium flow, while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region.

14. A method of eliminating sound produced by pressure variations at a predetermined aperture region of a chamber through which may flow a fluid medium the flow of which is unidirectional and varies with time at sound frequencies in accordance with some function, that comprises, passing the fluid medium along a first path in the vicinity of the aperture region and of substantially constant impedance, passing the fluid medium along a second path paralleling the first path and of variable impedance, and varying at the rates of the said sound frequencies the impedance of the second path substantially in accordance with the said function to modulate the fluid flow therealong with an amplitude substantially equal to and a phase substantially opposite to that of the said pressure variations of sound-frequency rates, thereby to effect substantial cancellation of the fluid pressure variations passed along the first path.

15. A method of eliminating sound produced by pressure variations at a predetermined aperture region of a chamber through which may flow a fluid medium the flow of which is unidirectional and varies with time at sound frequencies in accordance with some function, that comprises, passing the fluid medium along a first path in the vicinity of the aperture region and of substantially constant area, passing the fluid medium along a second path paralleling the first path and of variable area, and modulating at the rates of the said sound frequencies the variable area of the second path substantially in accordance with the said function to modulate the fluid flow therealong with an amplitude substantially equal to and a phase substantially opposite to that of the said pressure variations of sound-frequency rates, thereby to effect substantial cancellation of the fluid pressure variations passed along the first path.

16. A method as claimed in claim 15 and in which the value of the said substantially constant area is controlled in accordance with changes in the velocity of the fluid medium to cause the percentage of area modulation to vary substantially as the inverse of the square of the fluid-medium velocity.

17. Apparatus of the character described having, in combination, means for passing a fluid medium the flow of which may vary with time at sound frequencies in accordance with some function to produce undesirable corresponding sound-frequency pressure variations, means disposed at a predetermined region of the medium and operable at the said sound frequencies for increasing and decreasing the impedance to the fluid flow at the predetermined region in accordance with substantially the said function, and means for synchronizing the operation of the impedance increasing-and-decreasing means with the said sound-frequency pressure variations, said second-mentioned means including by-pass means providing an auxiliary flow path for maintaining a minimum fluid flow.

18. Apparatus of the character described having, in combination, means for passing a fluid medium the flow of which may vary with time at sound frequencies in accordance with some function to produce undesirable corresponding sound-frequency pressure variations, means disposed at a predetermined region of the medium and operable at the said sound frequencies for increasing and decreasing the resistance to the fluid flow at the predetermined region in accordance with substantially the said function, and means for synchronizing the operation of the resistance increasing-and-decreasing means with the said sound-frequency pressure variations, said second-mentioned means including by-pass means providing an

auxiliary flow path for maintaining a minimum fluid flow.

19. Apparatus of the character described having, in combination, means for passing a fluid medium the flow of which may vary with time at sound frequencies in accordance with some function to produce undesirable 5 corresponding sound frequency pressure variations, means disposed at a predetermined region of the medium and operable at the said sound frequencies for increasing and decreasing the impedance to the fluid flow at the predetermined region in accordance with substantially the 10 said function, and means for synchronizing the operation of the impedance increasing-and-decreasing means with the said pressure variations, said second-mentioned means including by-pass means providing an auxiliary 15 flow path for maintaining a minimum fluid flow, the impedance increasing-and-decreasing means being adjusted in phase and extent of operation to produce a pressure drop across the said predetermined region that is respectively substantially opposite in phase and equal in 20 magnitude to the phase and magnitude of the said pressure variations, thereby to effect substantial cancellation of the said sound-frequency pressure variations at the said predetermined region.

20. Apparatus of the character described having, in combination, conduit means for passing a fluid medium 25 the flow of which may vary with time at sound frequencies in accordance with some function to produce undesirable corresponding sound-frequency pressure variations, means disposed at a predetermined region of the conduit means and operable at the said sound frequencies 30 for increasing and decreasing the fluid-medium flow area of the conduit means in accordance with substantially the said function, and means for synchronizing the operation of the area increasing-and-decreasing means with the said sound-frequency pressure variations, said second-mentioned means including by-pass means providing an 35 auxiliary flow path for maintaining a minimum fluid flow.

21. Apparatus of the character described having, in combination, conduit means for passing a fluid medium 40 the flow of which may vary with time at sound frequencies in accordance with some function to produce undesirable corresponding sound-frequency pressure variations, means disposed at a predetermined region of the conduit 45 means and operable at the said sound frequencies for increasing and decreasing the fluid-medium flow area of the conduit means in accordance with substantially the said function, and means for synchronizing the operation 50 of the area increasing-and-decreasing means with the said sound-frequency pressure variations, said second-mentioned means including by-pass means providing an auxiliary flow path for maintaining a minimum fluid 55 flow, the area increasing-and-decreasing means being adjusted in phase and extent of operation to produce a pressure drop across the said predetermined region that is respectively substantially opposite in phase and equal in magnitude to the phase and magnitude of the said 60 pressure variations, thereby to effect substantial cancellation of the said sound-frequency pressure variations at the said predetermined region.

22. Apparatus of the character described having, in combination, conduit means for passing a fluid medium 65 the flow of which may vary with time at sound frequencies in accordance with some function to produce undesirable corresponding pressure variations, first and second paths for the flow of the fluid medium at a predetermined region of the conduit means, the first path 70 having a substantially constant area, and means disposed in the second path and operable at the rates of the said sound frequencies for increasing and decreasing the fluid-medium flow area thereof to modulate the said flow area in accordance with substantially the said function.

23. Apparatus of the character described having, in combination, conduit means for passing a fluid medium 75 the flow of which may vary with time at sound fre-

quencies in accordance with some function to produce undesirable corresponding sound-frequency pressure variations, first and second paths for the flow of the fluid medium at a predetermined region of the conduit means, 5 the first path having a substantially constant area, means disposed in the second path and operable at the said sound frequencies for increasing and decreasing the fluid-medium flow area thereof to modulate the said flow area in accordance with substantially the said function, and 10 means for operating the area increasing-and-decreasing means synchronously with the said sound-frequency pressure variations and in phase and magnitude such as to produce a pressure drop across the said predetermined region that is respectively substantially opposite in phase 15 and equal in magnitude to the phase and magnitude of the said pressure variations, thereby to effect substantial cancellation of the said sound-frequency pressure variations at the predetermined region.

24. Apparatus of the character described having, in combination, conduit means for passing a fluid medium 20 the flow of which may vary with time at sound frequencies in accordance with some function to produce undesirable corresponding sound-frequency pressure variations, first and second paths for the flow of the fluid 25 medium at a predetermined region of the conduit means, the first path having a substantially constant area, means disposed in the second path and operable at the said sound frequencies for increasing and decreasing the fluid-medium flow area thereof to modulate the said flow 30 area in accordance with substantially the said function, and means for operating the area increasing-and-decreasing means synchronously with the said sound-frequency pressure variations to produce area modulation of ampli- 35 tude substantially equal to and of phase substantially opposite to that of the said pressure variations, thereby to effect substantial cancellation of the fluid pressure variations passed along the first path.

25. Apparatus as claimed in claim 24 and in which the value of the said substantially constant area is controlled 40 in accordance with changes in the velocity of the fluid medium to cause the percentage of the area modulation to vary substantially as the inverse of the square of the fluid-medium velocity.

26. Apparatus as claimed in claim 25 and in which 45 the conduit means is the air-intake system of an engine, the pressure variations are produced by operation of the engine and the fluid-medium velocity varies with the speed of the engine.

27. Apparatus as claimed in claim 17 and in which 50 the impedance increasing-and-decreasing means comprises a rotor.

28. Apparatus as claimed in claim 19 and in which 55 the impedance increasing-and-decreasing means comprises an apertured rotor.

29. Apparatus as claimed in claim 17 and in which 60 the fluid-passing means is the air-intake system of an engine.

30. Apparatus as claimed in claim 29 and in which 65 the said predetermined region is between the carburetor of the said air-intake system and the engine.

31. Apparatus as claimed in claim 29 and in which 70 the said predetermined region is displaced from the carburetor of the said air-intake system.

32. Apparatus as claimed in claim 23 and in which 75 the conduit means is the air-intake system of an engine and the pressure variations are produced by the operation of the engine.

33. Apparatus as claimed in claim 32 and in which the area-modulating means comprises an apertured member that cooperates with a correspondingly apertured further member and is relatively movable with respect thereto.

34. Apparatus as claimed in claim 33 and in which 80 means is provided for changing the substantially constant area of the first path to different values.

15

35. Apparatus as claimed in claim 34 and in which the first-path-area changing means is a substantially planar valve.

36. Apparatus as claimed in claim 34 and in which the first-path-area changing means comprises a cylindrical member that cooperates with a further cylindrical apertured member and is relatively movable with respect thereto.

37. Apparatus as claimed in claim 34 and in which the first-path-area changing means comprises an additional member cooperative with and relatively movable with respect to a corresponding further apertured member, such relative movement being effected by static pressure thereupon resulting from the flow of the fluid medium.

38. Apparatus as claimed in claim 17 and in which the fluid-passing means is an air-intake system of an engine provided with an annular air filter, and the impedance increasing-and-decreasing means is disposed within the filter.

39. A method of eliminating unwanted sound produced by relatively rapid pressure variations of sound frequencies at a predetermined region of a moving fluid medium the flow of which is unidirectional and the average value of which is substantially constant or relatively slowly varied, that comprises, increasing and decreasing at the said sound frequencies the impedance to the fluid flow at the predetermined region in accordance with the amplitude of and synchronized in proper phase with said sound-frequency pressure variations, while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region.

40. A method of eliminating unwanted sound, at and beyond an aperture region in a chamber, produced by a sound-frequency pulsating flow of a fluid medium through said chamber, that comprises, reducing at the rate of the said sound frequency the size of the aperture region when the flow velocity of the fluid medium increases while maintaining an auxiliary path providing continuous flow of fluid medium through said aperture region and increasing at the said rate of the sound frequency the size of the aperture region when the flow velocity decreases, so that the product of the flow velocity and the aperture area is constant.

41. A method of preventing the passage of unwanted relatively rapid pressure variations of sound frequencies beyond a predetermined region in a conduit through which a stream of fluid is flowing with a unidirectional and otherwise substantially constant or slowly varying velocity, that comprises, varying relatively rapidly at the said sound frequencies the flow impedance at the

16

predetermined region in controlled phase with the unwanted sound frequency pressure variations such that the effective pressure drop across the impedance has an average component whose value is equal to or larger than the peak amplitude of the unwanted sound and has a variable component whose frequency is the same as that of said unwanted sound and whose peak amplitude is substantially equal to the peak amplitude of said unwanted sound, while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region.

42. A method of eliminating relatively rapid variations of sound frequencies in the otherwise unidirectional substantially constant or slowly varying volume flow of a fluid in a conduit at and beyond a predetermined region, either upstream or downstream from said region in the direction opposite from the source of such fluctuations, that comprises, varying at the rates of the said sound frequencies the effective area of said conduit at the predetermined region so that the instantaneous product of the velocity through the aperture and the area of the aperture is substantially constant or varies slowly as the average volume flow may be required to increase or decrease in performing the normal functions demanded of the fluid stream, while maintaining an auxiliary path providing continuous flow of fluid medium through said predetermined region.

43. Apparatus as claimed in claim 17 and in which a fluid reservoir chamber for taking-up non-uniform fluid flow is provided associated with the fluid-passing means.

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