

United States Patent

[11] 3,543,876

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1965, abandoned.
[45] Patented **Dec. 1, 1970**

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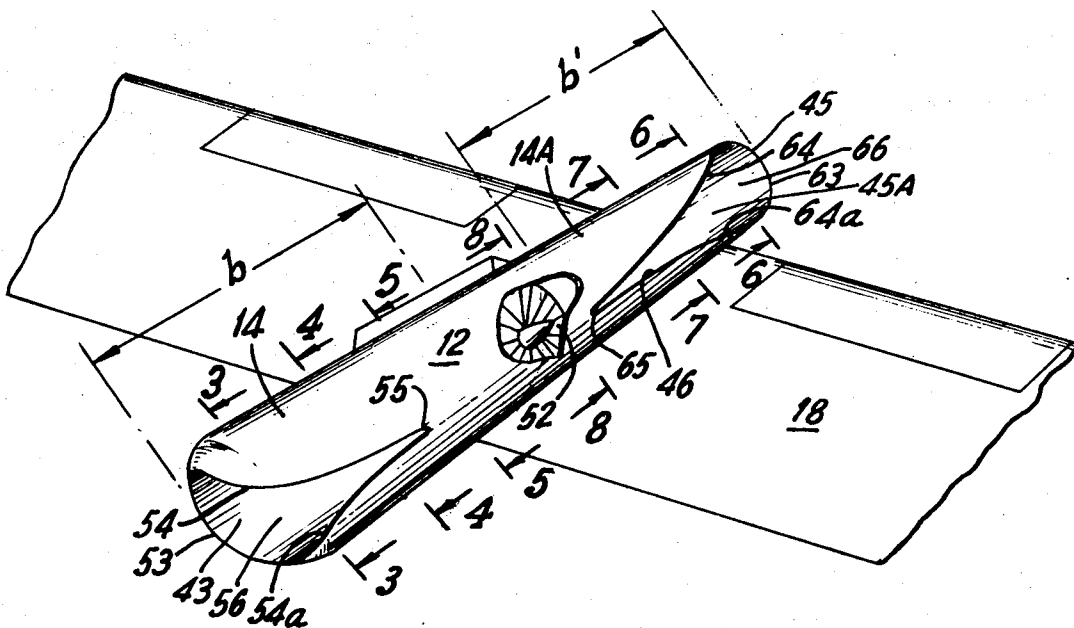
[54] **JET ENGINE SILENCER NOZZLE STRUCTURES
WITH TAPERED APERTURES IN OUTER WALLS**
14 Claims, 22 Drawing Figs.

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181/72
[51] Int. Cl. **F01n 1/14,**
F01n 7/20
[50] Field of Search.....239/265.11,
601, 589; 137/1, 15.1, 15.2; 115/16, 14;
181/33.22, 33.21, 47.2, 41, 33.221, 43, 51, 72;
244/53.8

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ABSTRACT: This invention relates to a design for conditioning the flow of fluid passing through a tubular structure, and to a method of controlling the pressure and velocity of fluids and the accelerations thereof. Specifically, the design is a tapered aperture in the wall of the tubular structure through which the flow of fluid is passing. The aperture or slot is substantially longitudinal and has its greatest transverse width dimension at the general opening of the tubular structure. From the region of maximum width it continuously converges to a point of minimum width and closure.



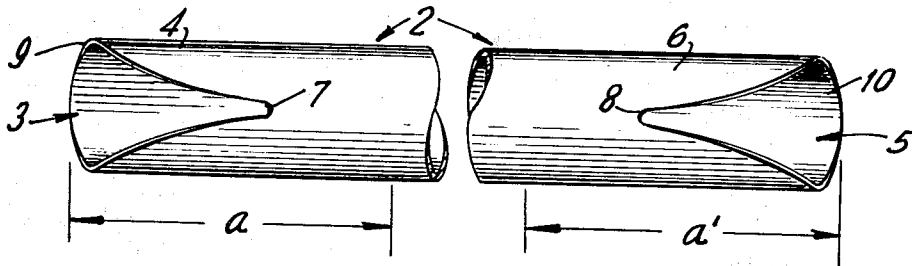


FIG. 1

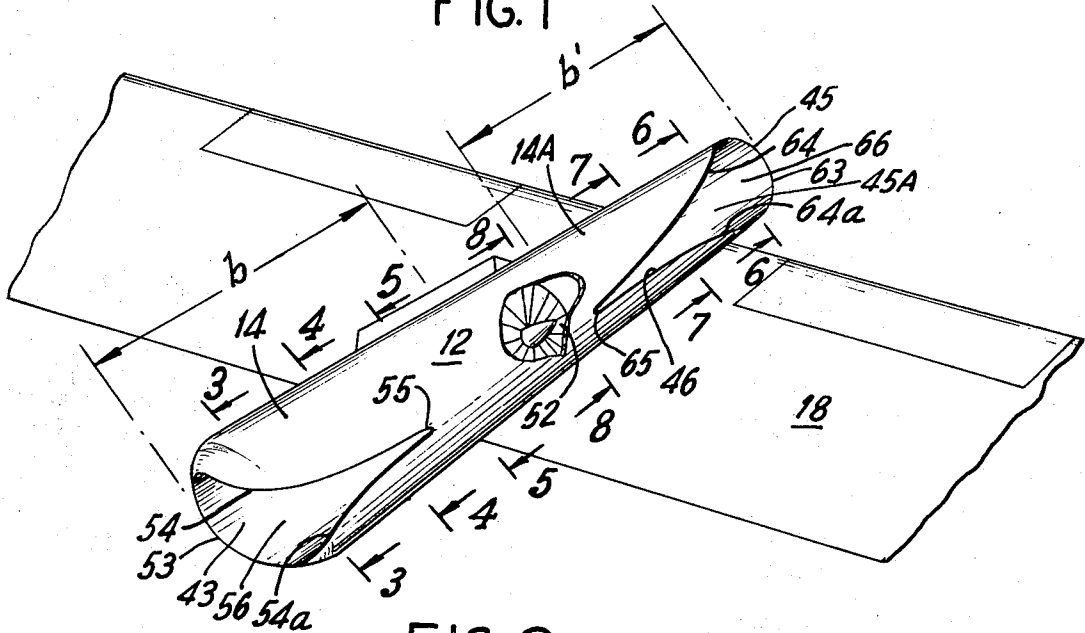


FIG. 2

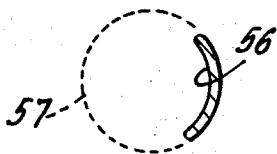


FIG. 3

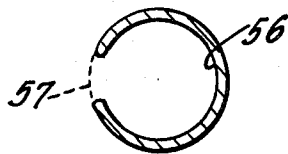


FIG. 4

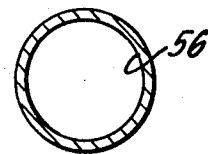


FIG. 5

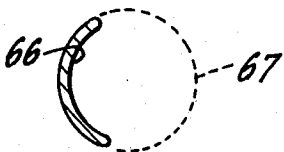


FIG. 6

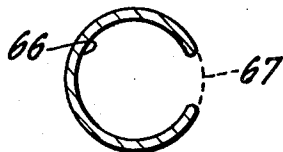


FIG. 7

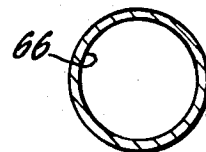


FIG. 8

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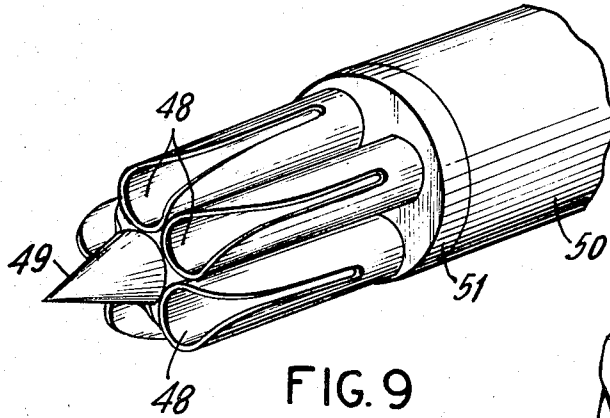


FIG. 9

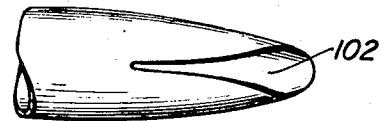


FIG. 11A

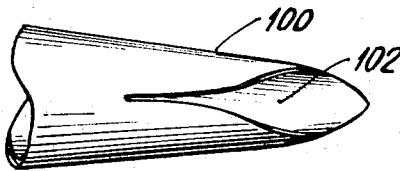


FIG. 10

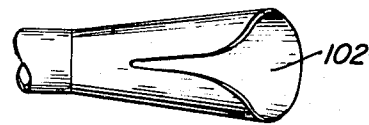


FIG. 11B

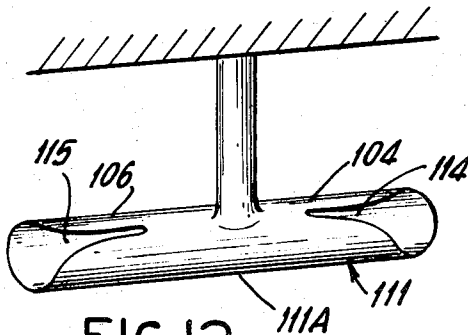


FIG. 12

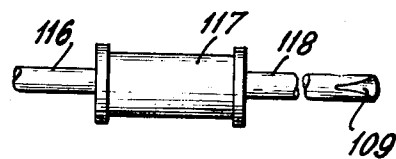


FIG. 13

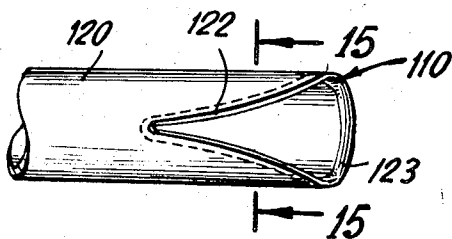


FIG. 14

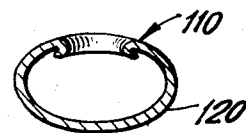


FIG. 15

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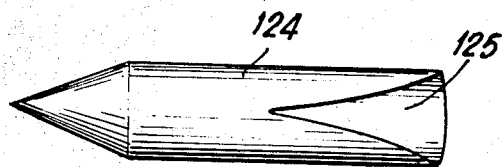


FIG. 16

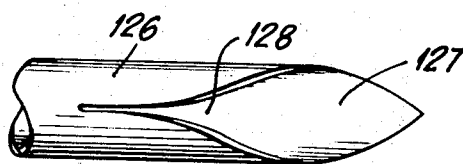


FIG. 17

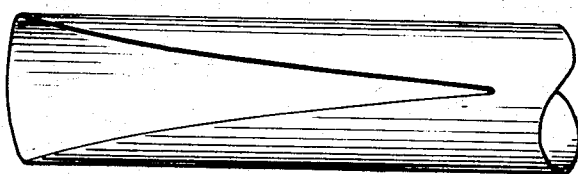


FIG. 18

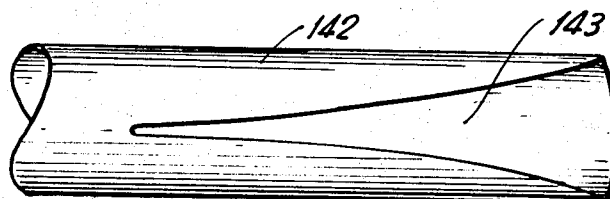
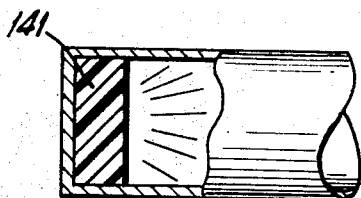
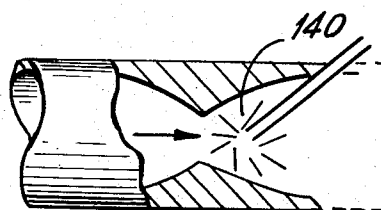


FIG. 19

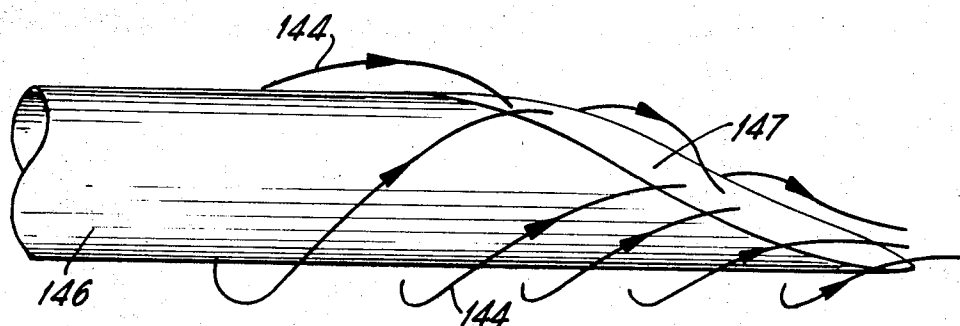


FIG. 20

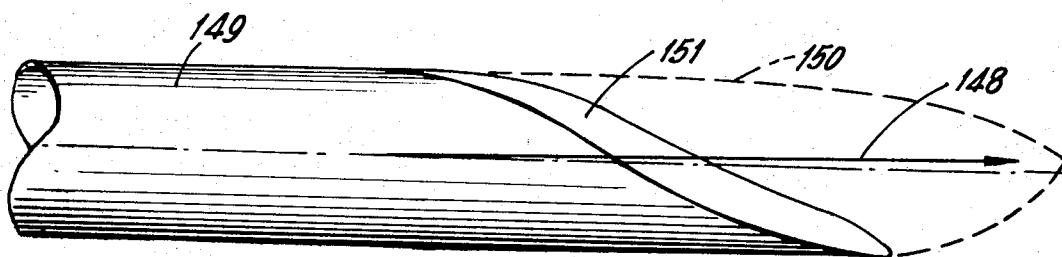


FIG. 21

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JET ENGINE SILENCER NOZZLE STRUCTURES WITH TAPERED APERTURES IN OUTER WALLS

CROSS REFERENCE TO RELATED APPLICATIONS

This invention is a continuation of application Ser. No. 486,392 filed Sept. 10, 1965 by John E. Karlson and now abandoned. Other continuation applications of said application Ser. No. 486,392 are being filed simultaneously herewith and are entitled "Microwave Energy Conditioning Device" and "Improvement in Acoustic Transducers".

FIELD OF INVENTION

This invention is directed to the provision of exhaust nozzle ducts for jet or rocket propulsion power plants, and also to the provision of air inlets for jet power plants. It has been found to have application to the field of fluid flow generally, and in any environment wherein fluid flow is entering or leaving a tubular structure.

DESCRIPTION OF THE PRIOR ART

The prior art includes jet engine exhaust nozzles and air inlets which are provided with perforations or slots in the walls. None of these designs suggest the use of tapered apertures, particularly not those which have their maximum width at the inlet or exit opening, nor the use of such nozzles, inlets or fluid handling methods as disclosed herein.

The present state of the art lacks and utterly fails to recognize the use and usefulness of a fluid flow structure which is formed with a tapered aperture at either the inlet or exit, a design that is uniquely suited to achieving an increase of air intake or thrust, and also to reducing the noise that attends the passage of fluid flow in such situations. This lack is particularly noteworthy since considerable time and money has been expended in jet engine development to effect designs that will increase thrust and reduce noise.

A tapered aperture in a coupling chamber for loudspeakers and other acoustical systems is disclosed in U.S. Pat. No. 2,816,619, issued on Dec. 17, 1957 to John E. Karlson. Triangular apertures have also been applied on loudspeaker systems. See, for example, German Pat. application No. 1,137,483 issued on Oct. 4, 1962 to Lothar Cremer.

That patent is directed to providing a design for coupling chambers having acoustical application which incorporate the critical geometry of the subject tapered aperture. The utility of providing a tapered aperture in a pipe through which sound waves are passing is explained as is the theory of the phenomenon occurring as sound waves pass through the tapered opening.

An acoustic coupling chamber differs markedly from any structure through which a flow of fluid might pass. The acoustic art is not analogous to the fluid flow art. Consequently, the Karlson U.S. Pat. No. (2,816,619) cannot be read to teach or suggest placing a tapered aperture in either the inlet or exhaust of a structure through which fluid flow passes. Moreover, it cannot be said to be obvious to one skilled in the art of fluid mechanics to construct a fluid conveying tubular structure with a tapered aperture at either terminus from the disclosure of the Karlson U.S. Pat. No. (2,816,619).

BACKGROUND OF INVENTION

The reduction of noise in jet aircraft has been regarded as an almost impossible problem. This invention presents the possibility for a considerable reduction in such for equivalent thrust. Jet engines have noisy air intakes and jet exhausts. Most of these appear to be of relatively elementary acoustic design. Through the use of structures configured to include a tapered aperture and shown in FIGS. 2 and 9, the noise attendant to such air intakes and jet exhausts can be materially reduced. In addition, the efficiency of such engines can also be improved.

The first requirement in reducing the noise from such engines is that of minimizing the factors which will tend to produce noise in the presence of rushing gases. These rushing gases occur both in the intake and exhaust. The factors which will add to any inherent noise present are turbulences, resonances, and mechanical vibrations. If these can be minimized, naturally the overall noise level will be reduced. Turbulences are caused by sudden changes in pressure in a gaseous flow. Methods of handling flow with gradual accelerations avoid such changes, and turbulences because they avoid creating such sudden changes of pressure. In this instance, the gaseous flow is inside a tubular structure.

While such a flow is along a continuous length, and the rate of flow and pressure is relatively constant, there is apparently a minimum degree of turbulence created in this air flow. However, as soon as the rapidly flowing gases reach the end of the tube, abrupt changes occur in the pressure contours within the tube and severe turbulences are generated.

Studies have shown that the noise generated by such turbulences increases as the eighth power of the rate of flow. Control of such turbulences therefore presents the greatest opportunity for improvement in reducing jet noise.

A reflective flow is created at the end of the tube due to abrupt transition at the end of the tube, which reflective flow travels down the tube in opposition to the main flow. This creates additional turbulences and a reduction in the rate of flow.

To compound the situation reflected waves create the conditions for resonance and still more noise. The noise generated by such turbulences and the resonances represent lost energy and a subsequent loss in efficiency in the engine, in addition to the annoyances created by the high level noise in the vicinity of such engines. Lost efficiencies must be made up by still higher velocities and still more noise.

FIG. 2 shows how a tapered aperture can be included in both air intake and jet exhaust of a jet engine. During operation the high pressures developed by the combustion of the fuel will create a flow toward the region of minimum pressure. The greater the pressure differential, the higher will be this rate of flow, and the greater the efficiency of the jet engine.

If a curved focusing wall and a low-pressure starting (starter) region can be established near the center of combustion, the directivity of such flow can be established with a minimum of turbulence. Also, if the jet chamber region presents over lower pressures in a smooth continuous fashion, the flow thus started will accelerate to the maximum degree. This smooth continuous change in pressure will simultaneously eliminate or strongly reduce the principal cause for turbulence, namely, abrupt changes in pressure. Similarly, since no abrupt change in pressure occurs, the conditions for acoustic resonance in the exhaust tube are also removed. As a result, under these conditions, the noise attendant to such combustion and exhaust will be reduced to a minimum. In addition, the increased rate of flow will improve the efficiency of the engine.

By experimentation, the inventor has discovered that a tapered aperture located as shown in the drawings in the wall of a tube through which fluid flow energy is passing will effectively reduce the deleterious noise associated with the passage of fluid energy through the tube. In addition, the inventor has discovered that providing a tapered aperture in either the air inlet or exhaust nozzle of a jet or rocket propulsion engine through which fluid energy is adapted to pass will improve the engine efficiency, intake of air and thrust and that higher velocities of exhaust can be obtained and higher pressure applied to the nozzle without choke.

It is an object of the present invention to provide a method of handling fluid flow and a design for a tubular structure to practice the method through which a flow of fluid will pass at high velocities with a maximum intake or thrust, and minimum turbulences, resonance, and noise.

It is a further object of the invention to provide a critical geometrical configuration for air inlets and exhaust nozzles

which will increase the efficiency of the engines in addition to reducing the attendant noise.

These objects and others, as will be apparent from the disclosure and discussion hereof, can be achieved by providing this structure through which a flow of fluid is passing. Basically, the tapered aperture will be identically configured regardless of whether it is in the inlet or the exit of the tubular structure. Specifically, the aperture is configured to have its largest width dimension at the inlet or exit opening and taper inwardly, rearwardly or forwardly respectively, to a point at which it terminates. The length of the tapered aperture is understood to be more than one-half the effective length of the tubular structure associated with the inlet or exhaust nozzle and the width of the aperture at the opening, wherein the width is greatest, must be greater than one-half the width of the inlet or nozzle opening.

DESCRIPTION OF DRAWINGS

The invention will be described further by way of example with reference to accompanying drawings wherein:

FIG. 1 is a side view of a tubular structure through which a flow of fluid passes which has the subject invention incorporated therein;

FIG. 2 is a perspective view of a jet propulsion engine showing the tapered aperture of the subject invention in both the air inlet and exhaust nozzle, with wing segment. It is to be understood that the orientation of the tapered apertures has been selected for convenience of illustration;

FIG. 3 is a cross-sectional view taken through lines 3-3 of FIG. 2;

FIG. 4 is a cross-sectional view taken through lines 4-4 of FIG. 2;

FIG. 5 is a cross-sectional view taken through lines 5-5 of FIG. 2;

FIG. 6 is a cross-sectional view taken through lines 6-6 of FIG. 2;

FIG. 7 is a cross-sectional view taken through lines 7-7 of FIG. 2;

FIG. 8 is a cross-sectional view taken through lines 8-8 of FIG. 2;

FIG. 9 is a perspective view of the exhaust section of a jet of rocket engine provided with tapered apertures of the subject invention;

FIG. 10 is a perspective view of a fire hose configured to include the tapered aperture of the invention;

FIGS. 11A and 11B are perspective views of fluid injector nozzles configured to include tapered apertures of the subject invention.

FIG. 12 is a perspective view of a hydrojet configured to include the tapered aperture of the subject invention.

FIG. 13 is a side view of a muffler with the noiseless exhaust outlet configured to include the tapered aperture of the subject invention.

FIG. 14 is a side view of the subject invention shown provided with inwardly rolled edges.

FIG. 15 is a sectional view of FIG. 14 through lines 15-15.

FIG. 16 is a side view of a rocket having an exhaust nozzle according to the present invention.

FIG. 17 is inlet or nozzle having a sound shield turbulence suppressor thereon.

FIG. 18 is a side schematic drawing of the front portion of a jet engine having an inlet according to the present invention.

FIG. 19 is a side schematic drawing of a rocket having an exhaust nozzle of the present invention.

FIG. 20 is a drawing showing the aspiration achieved by a nozzle of the present invention.

FIG. 21 is a drawing showing the predominate flow, believed to be laminar in nature, from a nozzle of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A general design of the subject invention is shown in FIG. 1 which depicts a tubular structure 2 through which a flow of fluid is to pass. The tubular structure 2 is constructed to provide an inlet chamber 4 and an exit chamber 6 which have tapered apertures 3 and 5 respectively formed therein.

The tapered aperture 3 of the inlet chamber 4 converges from inlet opening 9, its point of maximum width, to point 7, wherein it terminates.

Conversely, the tapered aperture 5 of the exit chamber 6 converges forwardly from exit opening 10 to point 8 wherein it terminates.

It is important that the length of the tapered aperture 3 and 5 be greater than one-half the effective length of the respective chambers 4 and 6 if the chamber is to be substantially detuned or nonresonant. The approximate effective length of inlet chamber 4 is indicated by dimension a while the effective length of exit chamber 6 is shown by dimension a' .

The length of a chamber as described in this invention may be defined as the distance from the position where the widest portion of the tapered aperture occurs (near the end) to the position where the prevailing continuity of said chamber ends. That continuity ends at a substantial sudden change in unobstructed cross-sectional area of the chamber, a change usually of about at least 50 percent of the total such area. For example, in turbojet engines the length of this chamber would include that section which is normally regarded as the nozzle structure, while it would not include the complex structure and turbines involved in the turbojet engine itself. Location 52 illustrates one end of such a chamber, while Location 45 illustrates the other end of the same chamber and the distance between these positions constitutes the length. Similarly, at the air intake the length involved would not include any volume internal to the turbofan. Where a multiplicity of tubes is used as in FIG. 9, the length of the chamber would be that of each individual tube as qualified by the above definition.

Another important dimension for the configuration of the apertures 3 and 5 is the maximum width. As seen in FIG. 1, the maximum width of the tapered apertures 3 and 5 is located at the respective openings 9 and 10 of chambers 4 and 6 and is desirably the full width of the chamber as shown. The maximum width of the tapered apertures 3 and 5 should be at least greater than one-half the diameter of the tubular structure at the point of such maximum width.

Another important criterion for the configuration of the apertures is that they be tapered. The desirable taper configurations which have been used are shown in the attached drawings, which have been drawn to scale as closely as possible for the different configurations which are shown. It will be appreciated that there can be deviations from the optimal curvatures, the best now known being shown, but that substantial deviation will be accomplished by a deterioration in performance. This curvature can be readily applied to various nozzles in different design applications by those skilled in the art by the teaching therein.

As previously indicated the tapered aperture has application in any structure through which a flow of fluid is passing. However, it has been found in practice to produce particularly good results when used in a vacuum cleaner analog for the air inlet and exhaust nozzle section of a jet propulsion engine. This vacuum cleaner analog is constructed of an ordinary tank-type vacuum cleaner, with the bag and any air filters or dust filters removed, and with the nozzles adapted to be attached directly at either or both ends, without use of intervening hose or extension pieces. The vacuum cleaner may be mounted on frictionless bearings and, for example, large lightweight rollers, and a spring scale held against the front of the cleaner to record thrust.

The tapered aperture of this invention is shown in FIG. 2 embodied in a jet propulsion engine 12 mounted on an aircraft wing 18.

The tapered aperture of this invention is depicted in air inlet section 14, seen in FIG. 2, as slot 43 which extends from the air inlet opening 53 to a point 55. For optimum inlet performance, the length of the slot or aperture 43 should be greater than one-half the effective length b of air inlet section 14. In addition, slot 43 must have its greatest width dimension at the inlet opening 53. The dash line 57 seen in FIG. 3 indicates the size of the tapered aperture air inlet at line 3-3 of FIG. 2. The width of the opening of the slot 43 while not limited to any exact size, should be greater than the width w of the tube to afford optimum performance. FIGS. 4 and 5 which are sectional views taken through the air inlet section 14 show the taper of aperture 43 along lines 4-4 and 5-5 to point 55 where it terminates.

The provision of a curved surface as shown at 56 opposite aperture 43 will improve the directivity of the flow therethrough. However, it is not imperative that the air inlet or exhaust nozzle provided with the tapered aperture of the subject invention have a curved inner surface opposite the tapered aperture.

The nozzle section 14A of the jet engine is provided with a tapered aperture 45A similar to the aperture 43 in the inlet structure 14. Aperture 45A extends from the nozzle discharge opening 63 to a point 65 upstream on the exhaust section. Again, the width of the aperture opening 45A should be greatest at terminal opening 63 while the slot 45A tapers along lines 64 and 64a to point 65 where they converge and terminate. FIG. 6 shows dashline 67 which indicates the size of the aperture at section 6-6. The width of the opening 45A should be greater than the width w of the exhaust or nozzle section 14A at the point of its greatest width. FIGS. 7 and 8 show the cross sections of the nozzle at sections 7-7 and 8-8.

Again, it is preferred that the inner surface 66 of the exhaust nozzle 14A opposite the aperture 45A be curved. This is again to afford optimum operational results and as previously noted, the slot 45A will serve some function of conditioning energy passing through opening 63 without this configuration of the wall opposite it.

FIG. 9 shows how the same principles can be applied to a multiplicity of jet nozzles 48 in the event that a very short nozzle assembly is required in relationship to the total width of the jet exhaust opening. The width and length (and rate of flare) of the tapered apertures used must then be related to the width and length of the individual exhaust tubes, as described and shown in order to realize the full effectiveness of this approach. The conical tip on this assembly will assist in reducing turbulences at the end of the array. Various groupings of these individual exhaust tubes may be made to attain the most favorable directivity patterns for the particular applications involved. In application, such assemblies may be attached to the jet engine 50 with the aid of an adapter section 51.

In reviewing this invention in relationship to propulsion, and in view of the experimental data now accumulated and shown herein, it is now obvious that this invention may be adapted and used in a great many related applications such as rocket engines, automobile mufflers and their kin, hydrojet engines, and a great number of nozzle applications where the cited characteristics are of value.

The tapered aperture termination of the exhaust tube, FIG. 2-45 shown can perform these functions and therefore when incorporated into such engines should perform these very desirable results. The exact design of such tapered aperture nozzles would, of course, depend on many variables including the final directivity and concentration of gaseous flow considered optimum for a particular application. In this respect, the discussions relative to the directivity of sound waves emanating from tapered apertures in the aforementioned copending applications Ser. No. 486,392 and "Improvement in Acoustic Transducers" have been found to also apply to this case insofar as propagation of noise is concerned even though the velocities (of flow) involved may well exceed the velocities of sound. In any event, the effect of such tapered aperture nozzles will be to fan out the gaseous flow in one

plane and to concentrate it in the other plane. This effect can be used to advantage in noise control since if little of the energy is directed downwardly and the major portion of it fanned out, the intensities in the vertical plane will be minimized and those in the horizontal plane less concentrated. This is of particular value in flying over heavily populated areas, since the loudest noise will occur at the height at which the plane is traveling, and relatively little will be propagated downwardly. Control of this thickness and fanned flow are accomplished by varying the length of this tapered aperture 45A and the contour of the walls 66 opposing the tapered structure. In order to avoid resonance to the maximum degree, the length of this tapered aperture should be at least a major portion of the effective length of the combustion chamber and nozzle, and the final width of this tapered aperture should be a major portion of the effective internal width at the end of the nozzle. These latter requirements coincide with those cited in my original patent on acoustic transducers, previously mentioned. The rate of flare at this taper may vary with different requirements. Early experimentation established that when the width across the taper varies as the square of the length, very effective results are achieved.

Under the conditions of air intake, the reciprocal relationships of this projector-receptor are again realized. Because of the larger intake area, more air can be scooped up at a given speed and altitude, and since this tapered aperture 43 is non-resonant and will gradually pack the air until maximum pressures are realized, there will also be a minimum turbulence and noise attendant to this operation. Also, since this scooping process has a gradual packing effect, more air can be moved through the engine and thus again improve its efficiency and capabilities for operation at very high speeds. Also, since the air intake will be strongest at the level of the engine due to the fanned input effect, there will be less hazard to personnel working on decks in the vicinity of such air intakes.

FIG. 10 shows the tapered aperture 102 of the invention embodied in a fire hose nozzle 100.

FIG. 11A and B show the tapered aperture 102 of the subject invention embodied in fluid injectors.

FIG. 12 shows the tapered apertures 115 and 114 of the subject invention embodied in the inlet section 106 and exhaust section 104 of a hydrojet assembly 111 respectively. The bottom 111A of the assembly 111 can be shaped to provide a planar surface, and the aspiration at inlet tapered aperture 115 and exhaust tapered aperture 114 will help provide it.

FIG. 13 shows the tapered aperture 119 of the subject invention embodied in an automobile and tail pipe 118 with muffler 117 and exhaust pipe 116.

A sophistication of the basic tapered aperture design is the inwardly rolled edge 110 presented in FIGS. 14 and 15 in nozzle or inlet 120. This modification will much eliminate edge tone noise. This is most important in the tapered aperture 122, but can also be helpfully employed at the end of the opening at 123.

FIG. 16 shows a rocket 124 including a tapered aperture 125, while FIG. 19 illustrates a rocket 141 including a nozzle portion 142 having a tapered aperture 143.

As noted previously, in addition to the reduction in noise created by fluid propulsion engines, the subject invention improves the efficiency of the engine. It has been found that the tapered aperture when incorporated in the exhaust nozzle of a jet engine will effectively improve the thermal exchange by the mixing of a greater amount of ambient air with the exhaust flow well in advance of the exhaust opening.

Additional thrust efficiency is realized by the aspiration effect the exhaust gases have on the ambient air and the boundary layer air adhering to the nozzle exterior. The aspiration effect reduces the drag on the nozzle surface and in addition creates a negative pressure on the surface about the tapered aperture. Consequently, when the tapered aperture is on the upper side of the nozzle, a negative pressure is formed on the upper surfaces, thereby directly improving lift.

A final direct benefit of the strong aspiration effected by exhaust gases passing over the tapered aperture is the addition of a component of mass to the propelling force. This effect is similar to the introduction of bypass air into the exhaust to increase total propelling mass.

Similarly, additional thrust efficiency is realized by providing the tapered aperture in the air inlet. First of all, the increased efficiency of the inlet affords means for greater air intake. Also, air can be accepted from many angles while avoiding acceptance of air from other angles. This feature is particularly desirable to avoid ingestion of foreign matter or turbulent streams into the turbine section of an engine.

By proper orientation of the tapered aperture in the inlet the compressor noise can be directed away from approach areas.

In addition, the aperture directly reduces the weight of the inlet and exhaust sections and provides a smaller surface to which friction forces may adhere.

Another benefit of the tapered aperture is the fact that thrust is not limited by supersonic choke since the throat section in the inlet advances or retreats automatically as a function of the speed of the aircraft and conditions attendant thereto.

In determining the effectiveness of these devices as air inputs and exhausts an analogue in the jet engine is found to be helpful. An ordinary tank-type vacuum cleaner was found to be suitable as such an analogur. Test factors using the tapered aperture design described in this specification were employed in comparison with simple tubular structures representing the typical exhaust and intake systems of jet engines. In conducting these tests it was found that as an exhaust nozzle, the tapered aperture described herein resulted in approximately a 12 percent increase in thrust relative to a straight tube of the same long length (3 feet long). Exhaust nozzles of the tapered design increased the thrust by almost equal amounts (1 foot long). An exhaust nozzle of the tapered design is shown in FIG. 17, with the nozzle 126 including an aperture 128 and a tapered extension 127. In conducting tests on the noise characteristics of these exhaust nozzles it was found that the tapered aperture nozzle was able to create an acoustic shielding effect in one direction and selective dispersion of the high frequency content of the sound in the other direction. It was also found that the basic character of the sound generated in this exhaust was considerably different from that of a straight tube. Its nature might be described as having a random or white noise spectrum which is similar to the hiss of escaping steam, whereas the straight tube was inclined to generate noise of a specific frequency content relative to its length, and this is the one-note roar to be characteristic of jet engines. The dispersion characteristics of a straight tube were relatively omnidirectional about its axis with maximum intensities occurring at approximately 45° off axis. This phenomenon is shown in FIG. 18 wherein the noise dispersion 140 of a straight tube is directed 45° to the longitudinal axis. In a flight on a plane this would mean that the maximum intensities of the sound would be directly propagated down into residential areas whereas the pattern of the tapered aperture is asymmetrical relative to the axis with a preponderance of the sound occurring in a radial dispersion pattern displaced from the axis toward the side of the tapered aperture and if the tapered aperture is facing upwardly, the sound will be dispersed upwardly. By comparison it can be seen that the greatest intensities of the tapered aperture nozzle can be directed upward away from the ground, although the tapered aperture can be differently oriented, if desired. This acoustic shielding effect of the tapered aperture nozzle is further accentuated by an increase in the length of the tapered opening, therefore, it can be anticipated that larger engines using this device can be provided with greater acoustic shielding. The acoustic shielding has been found to be a function of the number of wave lengths included in the length of the tapered opening, therefore, greater acoustic shielding is afforded of the high frequencies.

Since these high frequencies are most annoying to those who hear this noise, and since they can be directed upward, and since they are subject to the greatest attenuation in the air, and since the spectrum of the resulted noise of the exhaust has been changed, the overall effect on those who listen to or hear the properly oriented vacuum cleaner analog, (and it is believed to be the expected effect on those who will hear the effect of the jet engine equipped with this nozzle), will be considerably more tolerable and less noisy.

One of the important functions of an exhaust nozzle is the ability to handle exhaust gases at a considerable variety in velocities. In examining this feature relative to that of a standard tube of the same diameter, it was found, for example, that a two inch tube would choke in the vicinity of 20 to 30 pounds stagnation pressure. In conducting this same test with the tapered aperture nozzle, pressures as high as 100 pounds stagnation pressure were impressed on this nozzle without any evidence of choke effects. This signifies the possibility that this type of exhaust may be instrumental in creating miniature designs for a jet engine or in the realization of a much greater latitude in thrust of existing jet engines. It is also thought that this nozzle will give more uniform high efficiency over a wide range of power and thrust applications so that oxygen enriched after burner assemblies can be provided for without sacrificing efficiency of operation at normal levels of power application, all enabling jet aircrafts to operate more freely in emergencies and accelerated climbs from an airfield.

Another feature to be taken into consideration in the operation of any exhaust nozzle is the effective line of thrust of the exhaust gases. Using the vacuum cleaner analog it was found by suspending a light string in the exhaust fluid that this string stretched out at approximately an angle of 1° to 2° above the axis of the tapered aperture nozzle, and further studies using the string as a guide for differentiating between laminar flow and turbulent flow it was seen that laminar flow occurred substantially axially with that of the configuration itself. Some turbulence was observed above this flow, whereas below the tapered aperture there appeared to be a complete absence of turbulence. This indicates that the noise created by the turbulence above the tapered aperture may also be shielded by the laminar flow of the nozzle itself still further reducing the noise propagated downward. This feature is illustrated in FIG. 21 wherein a nozzle 149 includes a tapered aperture 151, with dotted line 150 depicting the boundary between the laminar flow and the turbulent flow, while line 148 depicts the effective line of thrust of the exhaust gases.

Still another characteristic of the tapered aperture nozzle 146 (See FIG. 20) as found in the vacuum cleaner experiments was its unusual aspiration qualities. Air 144 would be drawn into the aperture 147 as a result of the higher velocity flow within the aperture and instead of air exhausting from the narrow portion of the exhaust it was actually found that air would be drawn into it, and pressure profile tests were conducted to substantiate this fact and it was found that this aspiration occurred quite uniformly along the entire length of the tapered aperture just above the laminar flow lines. This aspiration has three principle advantages in that, (1) it increases the thermal exchange between the exhaust gases and the ambient air, (2) in that it creates additional lift and (3) it increases thrust in that greater mass is set into motion by virtue of the exhaust velocities within the exhaust nozzle.

The thermal exchange characteristics of the tapered aperture nozzle are interesting in that there is half as great a distance at which a return to ambient occurs than with a straight tubular nozzle. In practice, this means that jet engines can be housed in more confined quarters and operated with greater safety toward associated personnel. Since the rate of thermal exchange is consequently much greater, the jet engine will therefore operate at a greater overall thermal efficiency and economy of fuel.

The lift characteristics of the tapered aperture nozzle may be particularly advantageous in fast liftoff from an air field and may also reduce wing size required at other velocities.

Reduced wing size in turn would cut down on their drag and thus create the possibilities for still greater speeds.

The increased thrust through aspiration can be explained as being created by added mass of air set into motion by the tapered aperture. In another sense, the tapered aperture nozzle creates a greater coupling between the engine and the ambient air.

The velocity pressure profiles were taken of both the straight tube nozzle and the tapered aperture nozzles. As a result of these tests it was shown that the terminal velocities of the air exhausted from the vacuum cleaner analog with the tapered aperture exhaust nozzle were considerably less than those exhausted from the same analog but from the straight tube nozzle with the same vacuum cleaner supplying the pressure in both cases. At the same time the tapered aperture demonstrated an increase in thrust of approximately 12 percent over that of the straight tube nozzle.

An examination of the velocity profiles in both instances showed that the greatest velocity accelerations in the tapered aperture nozzle were realized within its confines whereby the nozzle structure shielded and directed the noise. The straight tube nozzle on the other hand produced its greatest velocity change at some point external to the tube itself, whereby noise characteristics generated by these higher velocity changes occur too late to be shielded by the nozzle construction.

A study of the temperatures within the tapered aperture nozzle showed that the areas closest to the aperture opening were considerably cooler than those at the opposite wall. This combined with the velocity profile measurements indicated that a vena contracta existed within the nozzle itself to form an automatic convergent-divergent nozzle with the shape of such convergence and divergence being variable with the velocities involved. With the presence of this vena contracta within the tapered aperture nozzle it is possible to operate nozzles of a relatively fixed diameter at supersonic velocities. In addition, the shape of the tapered aperture nozzle is such that it will have less drag than that of a bell-shaped convergent-divergent nozzle as is commonly used with supersonic aircraft. Again, this feature will increase the resultant net thrust of existing exhaust configurations.

Air inlets using the tapered aperture design also have some very strong advantages. When a tapered aperture air inlet was used in combination with a tapered aperture exhaust in the analog vacuum cleaner system, the increased thrust compared to a corresponding combination in straight tubing amounted to approximately 18 percent. One of the problems with air inlets is that of scooping air that is incident to the inlet at varying angles, the angles normally varying as the plane's angle of attack. A straight tube inlet would be receptive to relatively narrow angles of attack by the ambient air, whereas the tapered aperture inlet has demonstrated that it can accept air from a great variety of angles and can also reject air from other angles. The action in a sense is similar to that of its use as an exhaust nozzle with the exception that the flow characteristics are such that air at these greater angles of attack can be accepted. Again the tapered aperture nozzle can also act as a shielding from undesired turbulences by facing the solid section toward these undesirable turbulences. Because the effective area of the tapered aperture inlet is greater than that of a simple tube of the same diameter and because it can accept air at greater angles, it will therefore accept a greater quantity of air than that of the straight tube design. In addition, because of air inlet is again of a nonresonant structure, it is capable of operation at a great range in velocities without the necessity of adjustment of the configuration of the air inlet as with some supersonic planes now in use. The resultant action as an air inlet is to gradually increase the pressure as the air is taken into the inlet, and with this increased pressure, velocities are gradually reduced until a stagnation pressure can be approximated. Since the thrust of a jet engine is also strongly a function of the efficiency of the air inlet, the use of a tapered aperture inlet is highly desirable both for increasing thrust and for use of a plane at a range of velocities from the supersonic to

the hypersonic. It is understood that most air inlets now in use do not have this range of operation without the necessity for adjustment in flight.

The air inlet also can be used to reduce noise by virtue of the fact that again it is nonresonant and would therefore produce very little noise due to its structural configuration and also since it is capable of radiating the sounds originating from a compressor in a direction upward of the axis of the nozzle and thus away from the ground when the inlet's tapered aperture is oriented upwardly. This upward angle increases as the plane slows, and its angle of attack increases, as is usually the case in the low altitude maneuvering and landing and taking off. The uniform acceptance of air at all velocities also contributes to the safety of operation in a plane as there are no discontinuous effects which can serve to choke the air inlet.

In the foregoing discussion and drawings, an attempt has been made to disclose the inlet and nozzle construction which has been found to work, to produce increased thrust with lessened noise of a more desirable frequency spectrum that may be directed away from sensitive areas. Many experiments have been conducted which establish that as a practical matter, dramatic results are achieved. In addition, there has been an attempt to set forth the present best understanding of how and why this inlet and nozzle operate to achieve these advantages. It should be understood that the phenomenon are difficult of understanding and not completely understood. They are included in an effort to give those skilled in the art the full benefit of the present thinking, and with the understanding that it is to be expected that with additional experimentation, data, and analysis, some of this understanding will quite possibly prove to be inadequate and in need of modification.

I claim:

1. Ducting associated with a fluid reaction propulsion engine for transmitting a flow of fluid generally along the longitudinal axis thereof and with an opening at one end thereof, said ducting having an aperture disposed therein, which aperture extends from said opening substantially parallel to the longitudinal axis of said ducting for a major portion of the effective length of said ducting, and said aperture having a width adjacent said opening of at least a major portion of the transverse width of the ducting and which converges to gradually close over the ducting in a direction extending from said opening to a terminal location where the transverse width of the aperture is a minor portion of the transverse width of the ducting in the vicinity of said terminal location, whereby said aperture defines with said opening a flow passage environment for said flow of fluid.

2. Ducting as recited in claim 1 wherein said aperture has a width adjacent said opening which is substantially as large as the width of the ducting.

3. Ducting as recited in claim 1 wherein the width across the aperture varies as the square of the length of said aperture.

4. Ducting as recited in claim 1 wherein the width across the aperture varies at a gradually increasing rate from a point toward the end of the apparatus opposite the opening in said ducting to a width greater than one-half the width of said ducting whereby the development of standing waves in said ducting is impeded and the sound noise generated in ducting is dissipated evenly and the impedance of the ducting is thus coupled and matched to that of the atmosphere.

5. An exhaust nozzle for transmitting a flow of fluid with respect to a fluid reaction propulsion engine comprising a tubular body member extending for a predetermined effective length along the longitudinal axis thereof from said engine, said tubular body member having a discharge opening at one end portion thereof, said tubular body member having an aperture disposed therein and extending from said discharge opening substantially parallel to the longitudinal axis of said body member for a distance at least one-half the effective length of the tubular body member toward said engine, said aperture being tapered and having a width which converges with respect to the corresponding width of the tubular body member in a direction extending from said discharge opening

to a terminal location where said width is a minor portion of the width of the tubular body member in the vicinity of said terminal location, whereby said aperture defines with said discharge opening a passage for said flow of fluid.

6. An exhaust nozzle as recited in claim 5 wherein said aperture in said tubular body has a width at said discharge opening which is greater than one-half the width of the tubular member.

7. An exhaust nozzle as recited in claim 5 wherein the width across the tapered aperture varies as the square of the length of said aperture.

8. An air inlet associated with a fluid reaction propulsion engine for transmitting a flow of fluid with respect to said fluid reaction propulsion engine comprising a tubular body member extending for a predetermined effective length along the longitudinal axis thereof to said engine, said body member having an inlet opening at one end portion, said body member having an aperture disposed therein, which aperture extends from said inlet opening substantially parallel to the longitudinal axis of said body member for a distance at least one-half the effective length of the body member toward said engine, said aperture being tapered and having a width which converges with respect to the corresponding width of the tubular body member in a direction extending from said inlet opening to a terminal location where said width is a minor portion of the width of the tubular body member in the vicinity of said terminal location, whereby said aperture coacts with said inlet opening to provide a flow passage for said flow of fluid.

9. An air inlet as recited in claim 8 wherein the width of said aperture at said inlet opening is greater than one-half the width of the body member.

10. An air inlet as recited in claim 8 wherein the width across the tapered aperture varies as the square of the length of said aperture.

11. A nozzle device for gas jet propulsion apparatus comprising structure forming a tubular body member, said body member having an inlet opening at the upstream end portion thereof for receiving a flow of gas from the propulsion apparatus and an outlet opening at the downstream end portion of said body member positioned opposite said upstream end portion for discharging the flow of gas in the form of a jet, the opposite edge portions of said outlet opening forming, from a point of closure of the transverse cross section of said body member, a vertex in the wall of said body member at a location upstream of said downstream end portion thereof and progressively diverging from one another in the downstream direction until they are separated by the corresponding maximum width of the body member and then further opening the aperture by converging until said edge portions of said outlet opening join one another at said downstream end portion of said body member at a point on the opposite side of the body member from the point of closure, whereby the portion of said outlet opening having a progressively increased area in response to the progressively diverging then converging edge portions thereof is adapted to condition the gas flow in a manner to attenuate the noise level therefrom.

12. A nozzle device as recited in claim 11 in which said body member has a substantially circular transverse cross section and in which said opposite edge portions of said outlet

opening extend downstream from said vertex at one side of said duct to the joining of said edge portions at said downstream end portion at the opposite side of said body member, said edge portions progressively diverging from one another in a downstream direction to a point along each of said edge portions intersecting a common diameter of said body member and progressively converging toward one another in a downstream direction until they join.

13. A sound suppression exhaust nozzle for a fluid reaction propulsion engine comprising an elongated tubular body member of predetermined effective length and having an upstream end for connection to said engine and a downstream end forming a discharge opening, said tubular body member having a single unobstructed tapered aperture disposed therein and extending from said discharge opening substantially parallel to the longitudinal axis of said body member for a distance at least one-half of the effective length of the tubular body member, said aperture having a width which gradually converges with respect to said tubular body member in a direction extending from said discharge opening and which is greater than one-half the width of the body member in the vicinity of the discharge opening to a terminal location which is a minor portion of the width of tubular member in the vicinity of said terminal location, whereby said aperture defines with said discharge opening a flow passage for the engine exhaust gases thereby preventing the development of resonances in the body member, enabling the aspiration of free stream air into the engine exhaust gases, and controlling the directivity of the resultant sound.

14. A sound suppression exhaust nozzle for a fluid reaction propulsion engine comprising:

an elongated substantially tubular duct having an engine end adapted for connection to said engine and a free end in communication with the ambient fluid in which said engine is designed to operate;

said duct having inner and outer surfaces;

a single elongated gradually tapered aperture providing a gradually enlarging opening between the inside and outside of said duct;

said aperture extending from said free end substantially parallel to the longitudinal axis of said duct for at least one-half the effective length of said duct;

said aperture having an width which, adjacent the free end, is substantially as large as the duct in the vicinity of the free end;

said aperture having a width which approaches a minimum width at its opposite to said free end; and

said aperture having a width which progressively diverges in a direction extending from said terminal location to said free end, so as to gradually open the passageway inside the duct to the ambient fluid outside the duct, the width of the aperture being a gradually increasing proportion of the corresponding width of the duct as the free end of the duct and aperture are approached, whereby the inner surface of the duct is in uninterrupted gradually increasing communication with the medium surrounding the outer surface thereby preventing the development of resonances in the duct, and controlling the directivity of the resultant sound.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,543,876 Dated December 1, 1970

Inventor(s) Karlson, John E.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

At Column 4, line 55, "accomplished" should be --accompanied--

At Column 9, line 54, following footnotes omitted:

*From the tapered aperture side
**Opposite the tapered aperture side

Signed and sealed this 13th day of April 1971.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents

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