A sonic jet engine noise suppressor having a relatively short horizontally disposed conduit for reception of exhaust gases from the tail pipe of a jet engine, and for conveying these gases into the side of a tall stack via a perforated conical diffuser. The side walls of the conduit and stack are acoustically treated for sound absorption, and the stack contains a vertical core which is also acoustically treated for sound absorption. The core also contains resonator chambers for attenuation of selected frequency bands. The stack is of a special structure having a perforated tubular liner, sub-divided into a vertical stack of interfitting sections, and provided with flexural supports at the joints of these sections so as to facilitate expansion and contraction with large changes in temperature.
JET ENGINE NOISE SUPPRESSOR

BACKGROUND OF THE INVENTION

The present invention relates generally to suppressors for absorbing high intensity sound emitted by the high velocity stream of exhaust gases from the jet engine of a jet aircraft, with the engine either in the aircraft on the ground, or on a test stand. A number of such suppressors have been provided and examples are shown in U. S. Pat. No. 3,187,835 and No. 3,525,628. See also my co-pending application Ser. No. 874,259.

In general, such suppressors receive the exhaust gases into a generally horizontal conduit, wherein the gases are cooled by aspiration of secondary air, and sometimes by water spraying. By the uses of diffusers and various sound absorption devices, their velocity and sonic energy content are materially reduced. The lower energy gases are commonly finally turned upwardly by a reflector into a stack, from which they are discharged. The vertical discharge is relatively directional, and personnel at ground level are thus safeguarded against the remaining sonic energy of the upwardly emitted gages.

The horizontal conduits of such suppressors may be quite long, as for example, thirty or more feet. Oftentimes this much horizontal space is not available at an existing facility, and a general purpose of the invention is to produce an effective suppressor of the class described, but which has a relatively short horizontal length of suppressor conduit, and a relatively tall stack, using shorter sound attenuation means in the horizontal section, and a substantial length of sound attenuation structures in the stack.

A further objective of the invention is to provide such a suppressor, which is also readily convertible to larger size, both in the region of the horizontal conduit, and also in both the cross-sectional area and the height of the stack.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings show an illustrative embodiment of the invention, wherein:

FIG. 1 is a longitudinal vertical section of an exhaust suppressor in accordance with the invention;
FIG. 2 is a transverse section taken through the stack, on line 2-2 of FIG. 1;
FIG. 3 is an enlarged fragmentary view taken within the circular arrow 3 in FIG. 1;
FIG. 4 is an enlarged fragmentary view taken within the circular arrow 4 in FIG. 2;
FIG. 5 is an enlarged fragmentary view taken within the circular arrow 5 in FIG. 1;
FIG. 6 is an enlarged fragmentary view taken within the circular arrow 6 in FIG. 1;
FIG. 7 is a detail, enlarged, taken within the circular arrow 7 of FIG. 1; and
FIG. 8 is a detail perspective showing a modified stack.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

In FIG. 1, the reference numeral 10 designates generally the position of the tail pipe of a jet engine, which may be installed either in an airplane, or mounted on a test stand. The noise suppressor, designated generally at 12, comprises a horizontally disposed cylindrical conduit 13, axially aligned with the tail pipe 10, and joined with a tail stack 14 near the lower end of the latter. As illustrated, the stack is substantially larger in cross section than the horizontal conduit 13. The general dimensions of the illustrative suppressor may be gathered from the fact that the longitudinal center line of the cylinder 13 is 13 feet above
the designated ground level. In this connection, also, the structure of the suppressor has been contrived so that the cross-sections of its passages may be enlarged to adapt to jet engines of larger volumetric discharge.

A longitudinally adjustable augmentor 16 is received inside the front end of cylinder 13, and a convergent, perforated diffuser 18 projects from the rearward end of cylinder 13 into stack 14. The diffuser functions to attenuate the low frequency range of the sonic energy, and to shift the energy to higher frequencies but also interrupts the forward velocity of the gases, and they thus easily, in a state of turbulence, at elevated pressure, turn up the stack. A diffuser is generally a divergent rather than a convergent conduit. The member 18 is referred to broadly as a diffuser because of its essential function of reducing longitudinal gas velocity, making use of its fro the most part laterally opening perforations, which discharge the gas turbulently, to a region of large volume, at high pressure, and with a minimum of remaining axial velocity. The convergency of the present diffuser is thus only moderate, if used, with the included angle between opposite sides of the diffuser sharply acute. The inside walls of the stack have acoustic treatment, as will be explained. In addition, an acoustically treated attenuator core 20 extends up the stack, and is of such makeup as to act together with the acoustically treated inner wall of the stack to attenuate dominantly the intermediate and high frequencies. The core 20 preferably incorporates also resonator chambers of different sizes to attenuate particular frequency bands of sonic waves in the gases travelling up the annulus or annular gas space between the outer wall and the core.

The cylinder 13 and stack 14, which may also, though not necessarily, be cylindrical, are preferably of similar wall construction, comprised of an outer sheet steel plate, an inner perforated sheet steel plate spaced, for example, 6 inches inside the outer plate, with a layer of fibrous acoustic absorbent material therebetween, the latter consisting of mineral or rock wool, or fiber glass, for instance, and being adhesively bonded to the outer plate. Thus, in the case of the stack 14, FIG. 3 in my preferred construction, there is an outer steel plate shell 22, and an inner perforated sheet plate steel wall or liner 24, and between the outer shell and liner is a sound absorbent fiber glass, or mineral or rock wool layer 26. The perforated liner 24 is preferably a stack of liner sections, as will be described further hereinafter. The layer 26 is bonded to the inside surface of the shell 22 by a cement suitable to the purpose, preferably a non-hardening, elastomeric mastic. Immediately adjacent the perforated wall 24 is a wire mesh screen 28, and inside it is wall or layer 29 of fiber glass cloth, which forms a flexible containing film for the fibrous material of the layer 26. The sound absorption treatment between the annularly spaced outer and perforated inner walls 30 and 32 of the cylinder 13 may be similar, with an intervening packing of fibrous material 31, as stated earlier. In both the cylinder 13 and the stack, sonic waves reaching the sound absorption material via the perforated gas conduit are absorbed and converted to heat by the fibrous material.

A similar treatment is used between later described outer and inner walls of the core 20. The screen and glass cloth layers are omitted from the drawings excepting FIG. 3, by reason of their small scale. They should be used in all cases, however, in order to protect the fibrous sound absorbent material from being torn out and blown away by the hot gases moving with high velocity adjacent the perforated steel walls.

In the structural makeup of the illustrative embodiment, the double-walled horizontal conduit 13 has a bolted flange joint at 35 (see FIG. 5) and a short section 13a is joined to a stack base cylinder 14a, as indicated. The base cylinder 14a is double-walled, and provided with acoustic treatment, the same as the cylinder or conduit 13 and the stack proper (FIGS. 3 and 6). The stack base cylinder 14a has a bolted flange coupling at 36 with the outer stack wall 22. Stack base 14a stands on a foundation on the ground, as indicated.

Annularly spaced inside the inside perforated wall 32 of conduit 13 is a cylinder 40, which may be supported from the double wall 13 by ring plate 42. The cylinder 40 has a rearward divergent section 43, which is joined to the wall 32 just short of the coupling at 35 (FIG. 5). Just beyond the coupling at 35, the front cylindrical end 45 of perforated diffuser 18 is joined to the inside wall of conduit section 13a, and this diffuser projects into and nearly across the base section 14a of the stack. As shown, the diffuser is conically convergent within the stack, and contains perforations throughout, as indicated at 48. The cylinder 40 and its section 43 are also perforated, as at 49. Preferably, the end wall 49 of the diffuser is imperforate, to avoid the effect of a pointed termination, from which gas velocity from the perforations thereof otherwise tends to rise.

Longitudinally movable, for the purpose of adjustment, in the cylinder 40, is the cylinder 50 of augmentor 16, equipped with conventional bell mouth 51. The augmentor cylinder has a support stand 52 with wheels 53 running on foundation 54 enabling positioning of the augmentor for optimum performance.

The outer stack wall 22 is continuous from the bottom coupling at 36 to the top, but the inner perforate wall 24, which is subject to high heat, is made in ring sections 24a, which are supported from outer stack wall 22 through a number of resiliently bendable support rings 60. An upper end portion 24b of each wall section 24a is radially offset in an inward direction, so as to receive and furnish a seat for the lower end portion of the wall section 24a immediately above. Each support ring 60 is in the general form of a frustum of a cone, with an angularly disposed wall 61 spanning the annular space between walls 22 and 24, the wall 61 angling downward and inward, i.e., converging downwardly. The lower edge of wall 61 has bent therefrom an annular flange 63, which is connected by bolts and nuts to the overlapping portions of adjacent inner wall sections 24a and the upper edge thereof has an annular flange 64 which is connected to the outer wall 22. Expansion and contraction of the inner wall sections or rings 24a in response to temperature variations is thus accommodated by flexure of the rings 60. Longitudinal as well as radial thermal expansion is accommodated by the flexural capabilities of the support rings 60.

The inner wall made up of the separate ring segments 24a, being composed of a plurality of the segments 24a, is not stiff and unyielding from end to end, but rather, to
some extent, contractive or expansive in the region of the overlap joints, and thus permits a degree of inherent vertical thermal expansion.

Concentrically mounted inside the stack above the stack base, and at an annular spacing as shown from the inside perforated wall 24, is the aforementioned attenuator core 20. This core has an outer perforated steel cylinder 70, with an upper generally conical point 71, rising to substantially the height of the stack, where it is hung from a supporting pipe 72 extending across the upper end of the stack. Such a support pipe is shown in the fragmentary perspective of FIG. 8, showing a modification. Annularly spaced inside the cylinder 72 is a similarly formed inner steel cylinder 74, which however is perforated in only selected regions, as will presently explained. The space between the two cylinders 70 and 74 is provided with acoustic fibrous material 75, positioned in back of a wire mesh screen and a layer of fiber glass cloth, in an arrangement like that shown in FIG. 3, and described earlier.

Radial braces 80, three in number, support the perforated outer cylinder 70 from the stack at different vertical levels.

The inner cylinder 74 has partitions 82 at selected locations to form resonator chambers 84, and the walls are perforated in selected regions, as typically indicated at 85, 86 and 87, for access of sound transmitted to the surface of the cylinder 74. Sound entering these resonator chambers through the described perforations is damped or attenuated selectively in frequency bands determined by the lengths of the resonator chambers. Thus, a plurality of such chambers, of different lengths, can attenuate a substantial range of frequencies.

Operation of the suppressor is as follows: With the augmentor adjusted to a position between the limits indicated in full and phantom lines in FIG. 1, the jet engine is placed with its tail pipe 34 in position to discharge its jet stream of exhaust gases concentrically into the bell mouth of the augmentor 16. Secondary cooling air is aspirated into the mouth of the augmentor around this stream of hot gases, and mixes therewith, both cooling the gases, and reducing the average kinetic energy and velocity of the gas particles. The gases are somewhat expanded and further reduced in velocity in traversing the diverging conduit wall 43, and then enter the perforated conical, convergent diffuser 18. The gas is emitted from the diffuser through the perforations therein, in a complex action involving turbulence and diffusion of the gas, reduced velocity and increased expanded plenum chamber space 90 around the diffuser, accompanied by a shift in sound frequency to elevated frequency levels, and corresponding large reductions in the intensity of the lower frequency sound. This upward shift in frequency results in an attenuation of sonic energy, dissipated as heat.

The velocity of the gases in the axial direction of the jet stream is greatly reduced as the gas passes through the perforations of the diffuser and into the plenum chamber 90, and the gas thus turns readily up the stack, without the necessity of the turning vanes often used for this purpose. The stack gases, with their sonic energy already substantially dissipated, particularly in the lower frequencies, rise in the annular stack space between the concentric sound absorbers instituted by the fibrous absorbent material between the double wall structures of the stack wall and the core wall. The sonic energy of these rising remaining gases, after transmission through the diffuser, is particularly that owing to intermediate and high frequency content, and the sound absorber structures in the stack are especially contrived to attenuate these frequencies.

The resonator chambers 84 dissipate additional sonic energy, particularly at resonant frequencies related to their length, and may be designed to remove particularly low frequency bands, or higher. The sound entering the resonator chambers is that which has passed through the fibrous core layer 84, in the vicinity of the entrance holes at 85, 86 and 87.

The gases are finally discharged at the top of the stack through an expanding annulus region between the conical point 71 of the core, and a tapered upper end portion of the bore of the stack. The gases, sonically attenuated within the suppressor, thus have their final discharge velocity further reduced at the point of exit.

The suppressor as now described has a very large attenuation factor. It also is characterized by an unusually low horizontal space requirement, with a novel arrangement of sonic attenuation devices to fit the geometry of a short horizontal intake conduit and a tall stack.

The suppressor of the invention is further constructed to facilitate simple enlargement of its capacity when required. For example, the conduit 40 and augmentor tube 50 can readily be enlarged, as required or the conduit 40 eliminated using the same intake conduit 13. The stack and its base, which are split into two halves and bolted together on a diametrical plane, may also be enlarged by means of insert panels 97 introduced between its two original halves, as suggested in FIG. 8.

From the foregoing description, it will be understood that various changes in the detailed construction and arrangement of the parts constituting the jet engine noise suppressor of the present invention may occur to those skilled in the art without departing from the spirit and scope of the present invention. Accordingly, it is to be understood that the foregoing description is considered to be illustrative of, rather than limiting upon, the invention as defined by the appended claims.

I claim:
1. In a noise suppressor for a stream of jet engine exhaust gases, the combination of:
   a generally horizontal gas flow conduit adapted at its forward end to receive said stream of exhaust gases;
   a vertical stack joined to the aft end of said horizontal conduit;
   a perforated diffuser conduit joined peripherally to the aft end portion of said horizontal gas conduit and projecting generally horizontally therefrom into and substantially entirely across said vertical stack; and
   sound attenuator means in said stack exposed to exhaust gas transmitted through the diffuser perforations and rising in said stack.

2. The noise suppressor of claim 1, wherein said horizontal conduit joins said stack above the lower end of said stack.
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3. The suppressor of claim 1, wherein said stack is of substantially larger cross section than the cross-sectional area of said horizontal conduit at the junction of the horizontal conduit with the stack, in such manner that lower end of the stack, around the diffuser conduit, functions as a plenum chamber, and the cross-sectional flow area up the stack is larger than the flow area of said horizontal conduit at said junction of the latter with the stack.

4. The subject matter of claim 1, wherein said diffuser conduit is convergent at a relatively sharp acute angle, such that components of gas discharge from said perforations are relatively large in directions transversely of the diffuser conduit, and relatively small axially of the diffuser conduit.

5. The subject matter of claim 4, including an imperforate end wall terminating said convergent diffuser conduit to prevent axial divergence from the convergent end portion of the diffuser conduit.

6. The subject matter of claim 1, wherein said stack is of an effective cross-sectional area substantially exceeding the cross-sectional area of said horizontal conduit at the junction of the latter with the stack, whereby to effect a large increase in pressure and a large reduction in velocity within and up the stack as compared with the velocity and pressure at the junction of the horizontal conduit with the stack.

7. A stack for noise suppressor for a jet engine discharging a stream of highly heated exhaust gases, comprising:
   a vertical, imperforate outer pipe;
   a vertical stack of individual, perforated, rings stacked ring-to-ring inside said outer pipe, at a spacing distance therewithin; and
   flexural support means supporting said rings from said outer pipe with yielding capability for both longitudinal and radial thermal expansion.

8. The subject matter of claim 7, wherein the stacked rings are radially inwardly offset at their upper ends to be received within the lower extremity of the ring immediately above and thereby afford a lapped joint.

9. The subject matter of claim 8, wherein the flexural support means comprise frusto conical rings having outer rims secured to the outer pipe and inner rims connected to the lapped joints between adjacent rings.

10. In a noise suppressor for a jet engine discharging a stream of heated exhaust gases, an enlargeable gas conduit, comprising:
    two semi-cylindric side walls having semi-cylindric end edges, and longitudinal edges meeting edge to edge to define an open conduit, each of said semi-cylindric walls terminating at each end in a semi-circular end edge of substantially the same radius as the side walls, whereby to afford a continuous conduit;
    said longitudinal edges having mating flanges; and
    bolts connecting said flanges.

11. In a noise suppressor for a jet engine discharging a stream of heated exhaust gases, an assembled gas conduit, comprising:
    two opposed, spaced apart semi-cylindric side walls, each having two straight parallel longitudinal side edges, and two semi-circular end edges of the same curvature at the ends of said semi-cylindric side walls, the longitudinal edges of each semi-cylindric side wall being parallel to the corresponding longitudinal edges of the other such side wall;
    two opposed extension side panels, each having two parallel longitudinal edges, fitted in the spaces, edge-to-edge, between said spaced, opposed, semi-cylindric walls, the longitudinal edges of said walls and extension panels having mating flanges; and
    bolts connecting opposed flanges.

12. In a noise suppressor for a stream of jet engine exhaust gases, the combination of:
    a generally horizontal conduit adapted at its forward end to receive said stream of exhaust gases;
    a vertical stack joined to the aft end of said horizontal conduit;
    a perforated diffuser conduit projecting from said horizontal conduit transversely into said vertical stack;
    said stack comprising wall means including sound absorber means exposed to the exhaust gas travelling upwardly therein;
    a sound absorber core inside said sound absorber means and extending upwardly from a point above said perforated diffuser conduit, there being a gas passage between said sound absorber means of said stack and said core;
    said core comprising an outer perforate sheet metal cylinder, a sheet metal cylinder annularly spaced inside said outer cylinder, and sound absorbent material between said outer and inner cylinders of said core; and
    said inner cylinder being longitudinally sub-divided into separate chambers by transverse partitions, and each of said chambers having sound inlet means at a predetermined point along the length thereof.

13. In a noise suppressor for a stream of jet engine exhaust gases, the combination of:
    a generally horizontal conduit adapted at its forward end to receive said stream of exhaust gases;
    a vertical stack joined to the aft end of said horizontal conduit;
    a perforated diffuser conduit projecting from said horizontal conduit transversely into said vertical stack;
    a cylinder annularly spaced inside said generally horizontal conduit;
    a conical divergent conduit leading beyond said cylinder to said diffuser; and
    an augmentor longitudinally movable within said cylinder.

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