June 13, 1961 J. A. LAWLER 2,987,883

JET ENGINE NOISE SUPPRESSION NOZZLE WITH AERODYNAMIC SUPPLEMENTAL FLUTING

Filed June 22, 1959 2 Sheets-Sheet 1

Fig. 1.

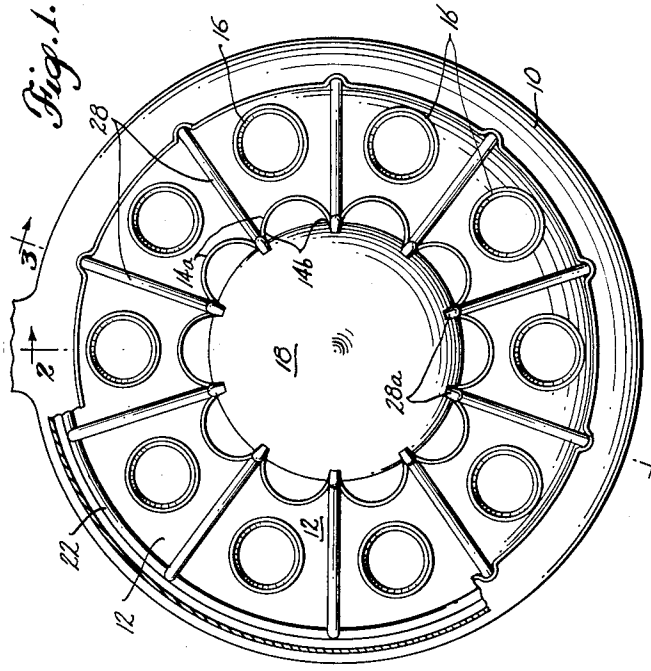


Fig. 6.

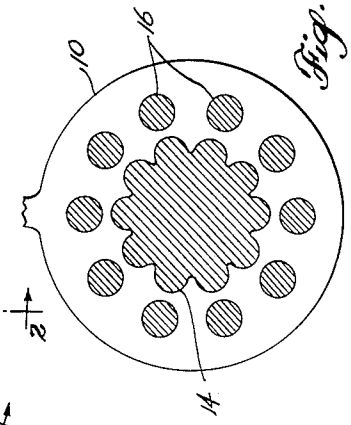


Fig. 2.

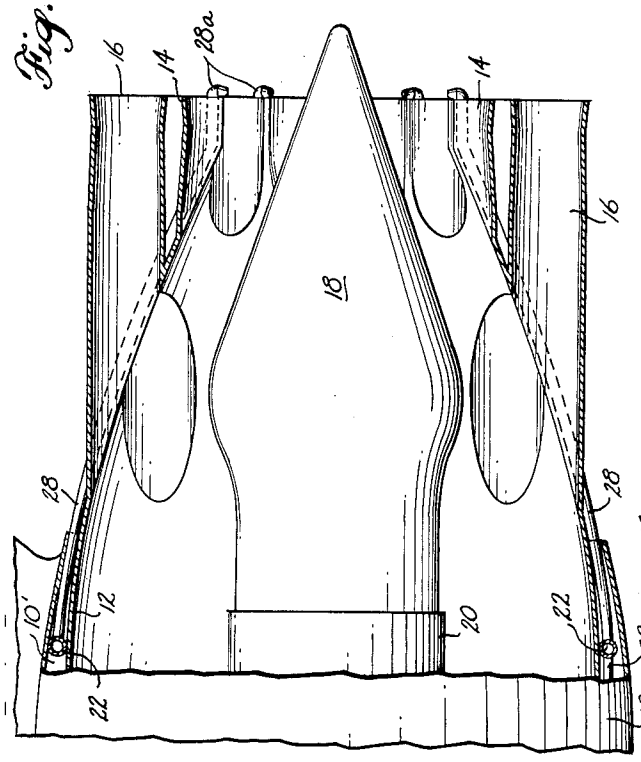
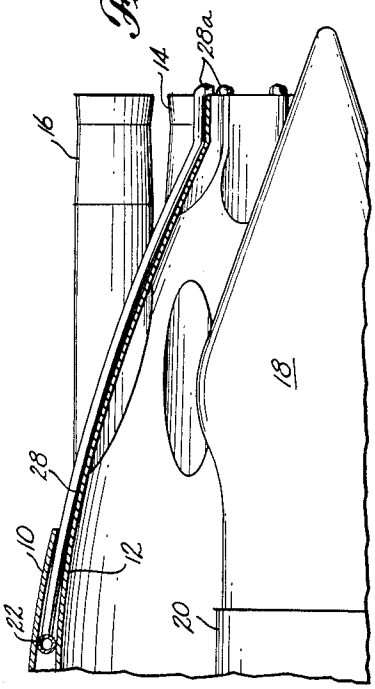


Fig. 3.



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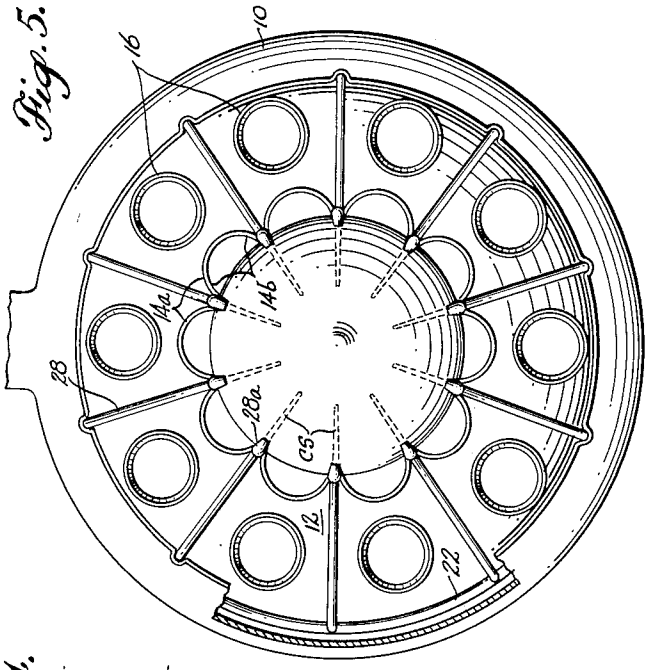
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Fig. 5.



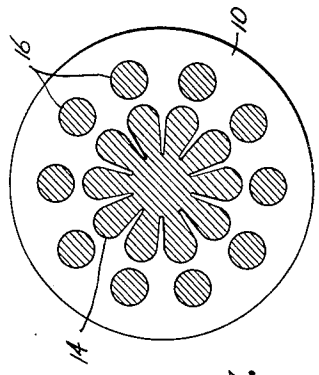
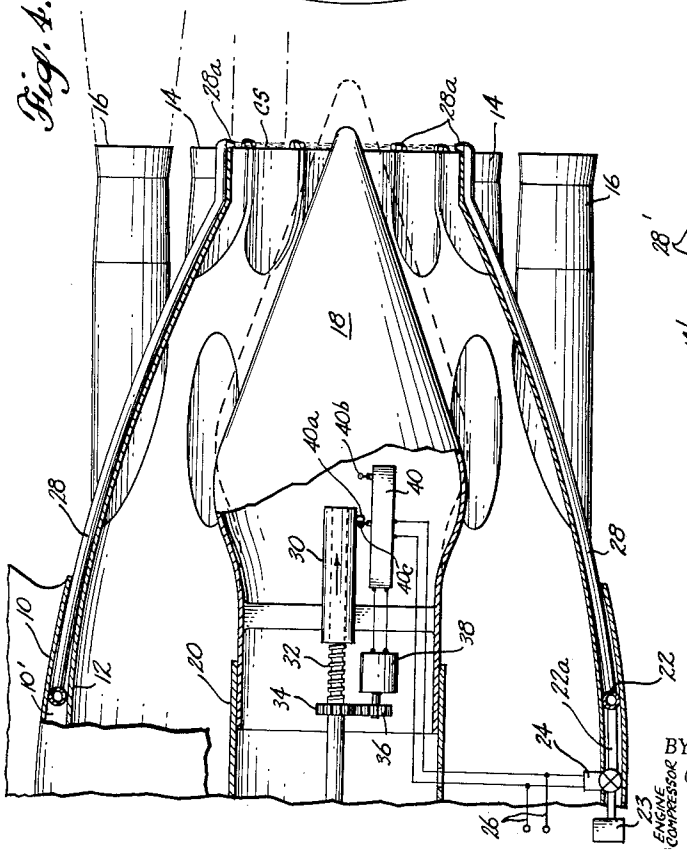


Fig. 7.

Fig. 4.



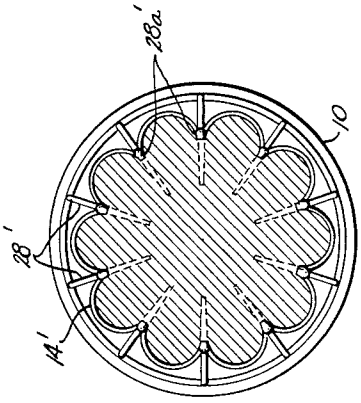


Fig. 8.

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2,987,883

JET ENGINE NOISE SUPPRESSION NOZZLE WITH AERODYNAMIC SUPPLEMENTAL FLUTING

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8 Claims. (Cl. 60—35.6)

This invention relates to improvements in jet engine nozzles of the corrugated or fluted type designed to operate at relatively low noise level, and more particularly concerns improvements which permit recovering the maximum nozzle thrust by reducing the effective corrugation depth upon termination of the suppression requirement. The invention is herein illustratively described by reference to the presently preferred form thereof; however, it will be recognized that certain modifications and changes therein with respect to details may be made without departing from the essential features involved.

It is now well established in the art that a jet engine, as for aircraft applications, may be caused to operate at relatively low noise level by employing a corrugated or fluted nozzle form which divides the discharge into a plurality of peripherally spaced branch streams permitting in-flow of surrounding air and thereby more rapid mixing of such air with the discharged gases. Various nozzle configurations achieving this result have been proposed. However, most of these configurations incur thrust loss and increase the base drag. Prior attempts to overcome these defects have resulted in relatively complex, expensive and bulky nozzle apparatus with mechanically movable orifice parts.

An object of the present invention is to provide a jet engine nozzle combination which requires no objectionable moving orifice parts, incurs minimum base drag and minimum thrust loss yet may be converted at will into a configuration which operates at a relatively low noise level. Another object is a simple and reliable nozzle structure which may be of rugged and durable form and overcomes most of the disadvantages of the more complex mechanically convertible types heretofore devised.

The present invention combines in a unique manner two effects which have, in themselves, been recognized separately in the past but which, when combined in the described manner, produce beneficial results not expected or predictable on the basis of previously known considerations. One of these component effects is the broad principle of a corrugated nozzle configuration producing a jet discharge at relatively low noise level. It has been recognized that with such a configuration, total noise is reduced and some of the noise energy normally appearing in the more objectionable low frequency part of the audible spectrum is caused to appear in the upper region thereof where it is less objectionable because of atmospheric attenuation. The other technique heretofore separately attempted, in an effort to simulate a corrugated nozzle form using a plain circular form as the basis, is the use of air jets directed radially inward at successively spaced locations about the periphery of the circular orifice.

In a corrugated or fluted nozzle capable of producing substantial noise attenuation according to the basic concept first mentioned above, the resulting thrust loss and increase in base drag proved excessive for efficient cruise operation of the engine. On the other hand, the former attempts to create or simulate a corrugated effect solely by use of radially directed air jets, which could be turned on and off as and when required, yield no appreciable noise suppression.

In accordance with this invention, a moderately corrugated basic nozzle form is utilized, augmented by inwardly directed fluid (preferably air) control jets mounted at the orifice in the reentrant corrugation spaces. With the control jets turned off, the basic physical configuration of the nozzle while provided with corrugations of moderate depth produces little or no base drag and no appreciable thrust loss during cruise; yet when the added effect of the control jets is employed to deepen the corrugations, as during take-off and climb, an unexpectedly and disproportionately great reduction of noise occurs as a result of the combined aerodynamically and physically induced fluting of the jet discharge.

These and other features, objects and advantages of the invention will become more fully evident from the following description thereof by reference to the accompanying drawings.

FIGURE 1 is a rear end view of a nozzle made pursuant to the invention.

FIGURE 2 is a longitudinal sectional view taken on line 2—2 in FIGURE 1.

FIGURE 3 is a longitudinal sectional view at reduced scale and with parts broken away, taken on line 3—3 in FIGURE 1.

FIGURE 4 is a view similar to FIGURE 2 illustrating the action of the fluid control jets and showing means for coordinating application of the compressed fluid with positioning of the nozzle tail cone.

FIGURE 5 is a view similar to FIGURE 1 illustrating the action of the fluid jets in modifying the form of the discharge.

FIGURE 6 is a diagrammatic rear view at reduced scale showing by cross hatching the approximate engine jet stream configuration at the point of discharge from the nozzle with the control jets turned off.

FIGURE 7 is a view similar to FIGURE 6 illustrating the stream configuration with the control jets active.

FIGURE 8 is a simplified rear view of a modified nozzle in which the outer row of discharge tubes is eliminated and the engine discharge takes place through a single large corrugated duct.

Referring to the drawings, FIGURES 1 through 7, the first illustrated embodiment comprises the outer shell or cowl **10** which surrounds and extends rearwardly along a portion of the length of the nozzle duct **12**. This duct tapers in diameter rearwardly to a central relatively large discharge orifice **14** surrounded by a cluster of discharge tubes **16**. These tubes have convergent-divergent discharge ends and are mounted in parallel relationship on the tapered portion of the nozzle wall **12**, as shown. A convergent-divergent orifice effect in the central discharge orifice **14** is produced by the cooperative relationship of the tail cone **18** and the surrounding orifice wall. In this embodiment, the tail cone **18** is mounted telescopingly for longitudinal adjustment on an island **20** to permit adjustable longitudinal positioning of the tail cone in order to compensate for changes in effective orifice area caused by the action of the control jets to be described.

In the annular service space **10***a* between the nozzle wall **12** and the shell **10** is mounted an air supply pipe **22** which is in communication with the usual jet engine air compressor **23** shown only symbolically in Figure 4. The annular pipe **22** is connected to the compressor through a supply pipe **22***a* in which is interposed a solenoid-operated valve **24**. A pair of electrical conductors **26** are subject to energization at will by means not shown in order to actuate the solenoid valve and thereby apply and cut off the source of pressure to and from the pipe **22**.

Leading rearwardly from the pipe **22** are a plurality of branch pipes **28**. The nozzle discharge duct **12** terminates in a corrugated orifice represented by convoluted portions **14***a* and intervening valleys or involuted portions **14***b*. The pipes **28** extend rearwardly in along the

valley portions 14*b* to the end of the orifice and terminate in nozzles 28*a* which are directed inwardly across the discharge through the orifice 14 immediately aft of such orifice. Preferably, one control nozzle 28*a* is mounted at the location of each of the valley portions 14*b* as shown.

It will be noted in the drawings that the depth of the corrugations measured radially of the nozzle at the end of the orifice is a small fraction of the total nozzle orifice diameter. These relatively shallow corrugations, which are preferably in the form depicted, comprising broadly rounded convolutions and fairly sharply reentrant or narrow involutions or valleys, have negligible effect on the base drag of the nozzle and produce negligible reduction in the nozzle thrust thereof during cruise operation, as compared with a nozzle of similar size and general form but lacking the corrugations. A minor amount of noise reduction is achieved by this nozzle configuration, which in itself is immaterial for present purposes.

In order to cause the nozzle to operate at relatively low noise level, the valve 24 is opened by appropriate energization of the supply leads 26, which causes delivery of air or other fluid (i.e. gas, vapor, water, etc.) under high pressure through the pipes 28 to the control nozzles 28*a*. This air, discharged inwardly in the form of the control jet streams CS, sets up aerodynamic barriers effectively equivalent to inwardly projecting mechanical barriers or fingers interposed in the path of discharge through the main orifice 14. As a result of these control jets, the discharge through the main orifice is converted from the efficient cruise configuration depicted approximately in Figure 6 to the efficient noise suppression configuration depicted approximately in Figure 7.

Former attempts to produce this deeply corrugated stream effect for efficient noise suppression by the sole action of control jet nozzles and without the aid of the partial or modified corrugated nozzle form as the starting point were practically useless. It is the combined effect of a moderately corrugated nozzle orifice, which in itself does not have sufficient depth of corrugation to reduce thrust or increase base drag, with the action of the control jets that yields the desired results. Moreover, it is found that the air compressor of a conventional jet engine yields adequate pressure and volumes of air for this purpose, without impairing engine efficiency during the temporary conditions of noise suppression operation. Other fluids and other appropriate fluid sources may be used in the alternative, however, from the broad standpoint.

In order to compensate for the effective reduction of orifice area through the action of the control jets CS, the tail cone 18 is automatically moved rearwardly by the correct distance when the jets are inactive and thereby constricts the main opening by the necessary offsetting amount, and vice-versa when the jets are active. This may be accomplished in the illustrated manner by causing the tail cone to be mounted on a feed nut 30 which is threaded on a transversing screw 32. The latter carries a gear 34 which is turned by a spur gear 36 driven by an electric motor 38. Control of motor energization is effected through a control circuit apparatus 40 preferably energized simultaneously with energization of the solenoid valve 24, with such control circuit apparatus including switch operating elements 40*a* and 40*b* establishing the limits of travel of the tail cone as a result of the contact between the moving abutment 40*c* and either of such elements.

In the modification shown in Figure 8, the cluster of outer tubes 16 is eliminated and the size of the main orifice 14' is increased in order to produce the desired total orifice area. The air supply pipes 28' extend to the control nozzles 28'*a* as before and the action generally is similar to that described previously with respect to the central duct comprising part of the total nozzle configuration in the first embodiment.

While different angles of discharge of the control nozzles 28*a* with relation to the longitudinal axis of the engine have been tried, it is found that a perpendicular relationship is preferable and produces the greatest noise suppression. It will be understood, however, that lesser angles may be used, if desired, and the control jets will still have a substantial effect on noise suppression in the nozzle although decreasingly with angle reduction.

These and other aspects of the invention will be evident to those skilled in the art.

I claim as my invention:

1. A jet engine noise suppression nozzle combination comprising an engine discharge duct terminating rearwardly in an orifice having a corrugated wall configuration with peripherally spaced alternate convoluted and involuted portions forming a rearward discharge stream having ridges and valleys alternating about the periphery thereof, a plurality of fluid discharge control nozzles mounted on the nozzle proper at the respective locations of said involuted portions in the vicinity of the orifice, said control nozzles being directed inwardly transverse to the direction of engine discharge, a source of compressed fluid under relatively high pressure separate from the nozzle discharge duct, means connecting said source to said control nozzles, and means operable at will to control application of said compressed fluid to said control nozzles, thereby selectively to deepen the valleys in the discharge stream by the inwardly directed discharge effect of said control nozzles and thereby increase the suppression of noises generated by the engine.

2. The jet engine noise suppression nozzle combination defined in claim 1, wherein the engine has an air compressor and the source of compressed fluid comprises said air compressor connected to the control nozzles.

3. The jet engine noise suppression nozzle combination defined in claim 1, wherein the control nozzles are directed radially inwardly at substantially 90 degrees to the direction of jet engine nozzle discharge.

4. The jet engine noise suppression nozzle combination defined in claim 1, wherein the control nozzles are directed radially inwardly at substantially 90 degrees to the direction of jet engine nozzle discharge and are located immediately aft of the orifice.

5. The jet engine noise suppression nozzle combination designed in claim 1, further comprising a tail cone mounted centrally within said nozzle duct and projecting rearwardly therein through said orifice, said tail cone tapering rearwardly and, cooperatively with the nozzle duct defining a convergent-divergent orifice form, and means operable to extend and retract said tail cone, thereby to vary the effective area of said orifice, said latter means being controlled for operation to increase said area compensatively in relation to the decrease thereof effected during operation of said control nozzles.

6. A jet engine noise suppression nozzle combination comprising an engine discharge duct terminating rearwardly in an orifice having a corrugated wall configuration, said duct tapering rearwardly to said orifice, a cluster of discharge tubes mounted in rearwardly projecting position on said tapered duct surrounding and directed parallel to said orifice, a plurality of control nozzles mounted in the spaces between the corrugations of said orifice and directed inwardly therein transversely to the direction of discharge through the said orifice, a source of compressed fluid under pressure, and means for delivering such fluid to said control nozzles thereby to enhance the effect of said corrugations in the separation of the discharge through the orifice into a plurality of peripherally spaced branch streams of gas.

7. The combination defined in claim 7, wherein said control nozzles are directed inwardly at substantially right angles to the direction of discharge through the orifice and are located immediately aft of said orifice.

8. A jet engine noise suppression nozzle comprising a nozzle discharge duct of corrugated form having convexly rounded corrugations interconnected by relatively sharply reentrant valleys, control nozzles mounted on said nozzle at the orifice in the locations of the respective valleys, said control nozzles being directed inwardly transverse to the direction of discharge through said nozzles, and means for delivering gas under relatively high pressure to said control nozzles, thereby to effectively deepen the indentations of the orifice affecting the form of discharge issuing therefrom.

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