May 29, 1962 G. S. SCHAIRER 3,036,429

CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

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Fig. 1.

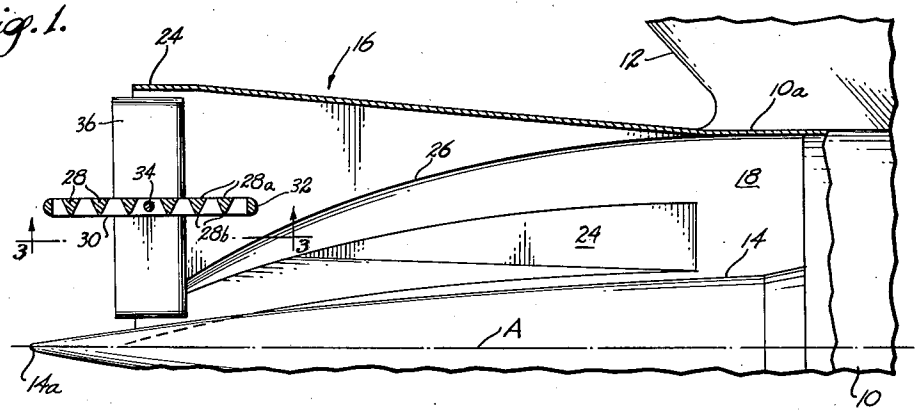
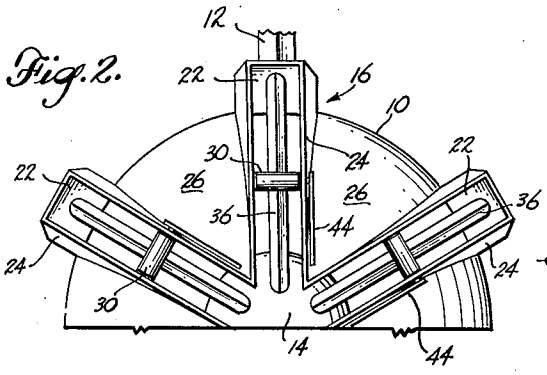


Fig. 2.



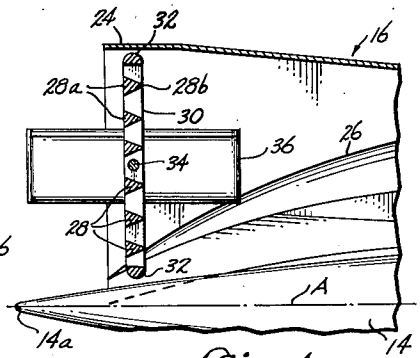
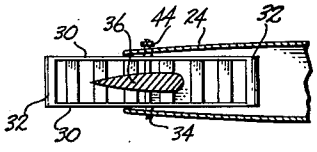


Fig. 4.

Fig. 3.



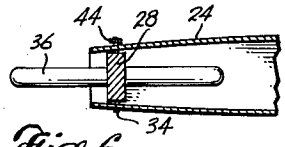


Fig. 6.

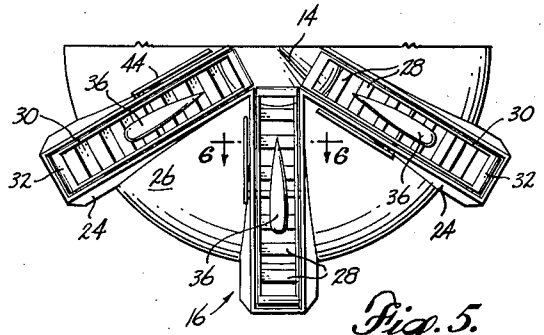


Fig. 5.

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CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

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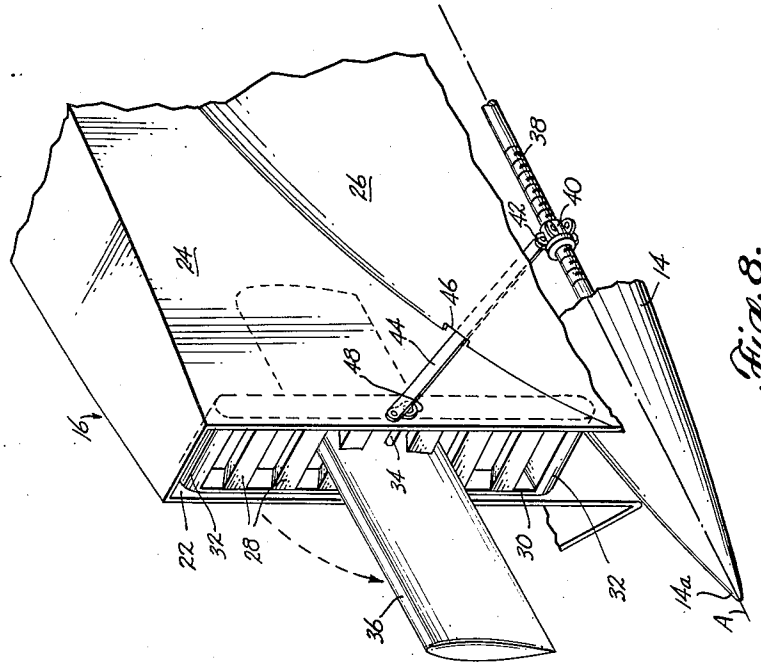


Fig. 8.

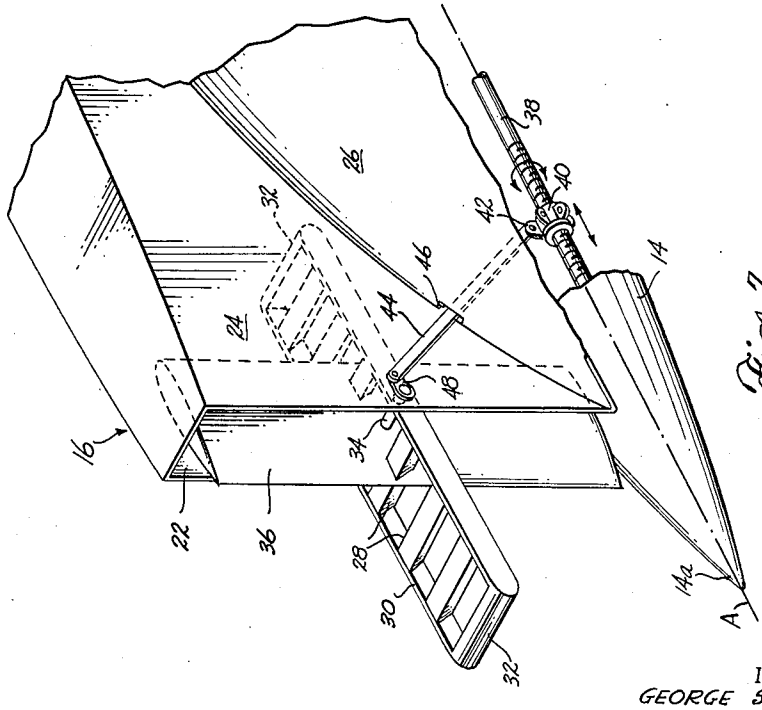


Fig. 7.

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May 29, 1962 G. S. SCHAIRER 3,036,429

CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

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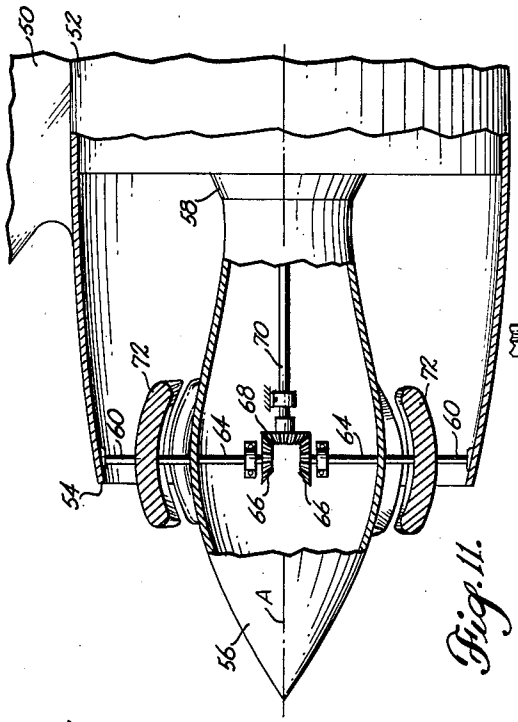


Fig. 11.

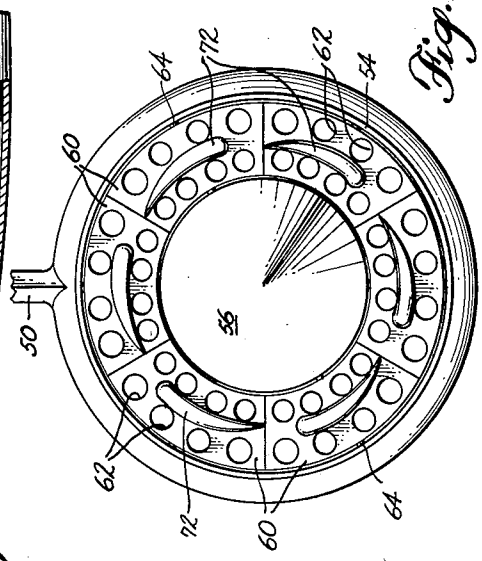


Fig. 12.

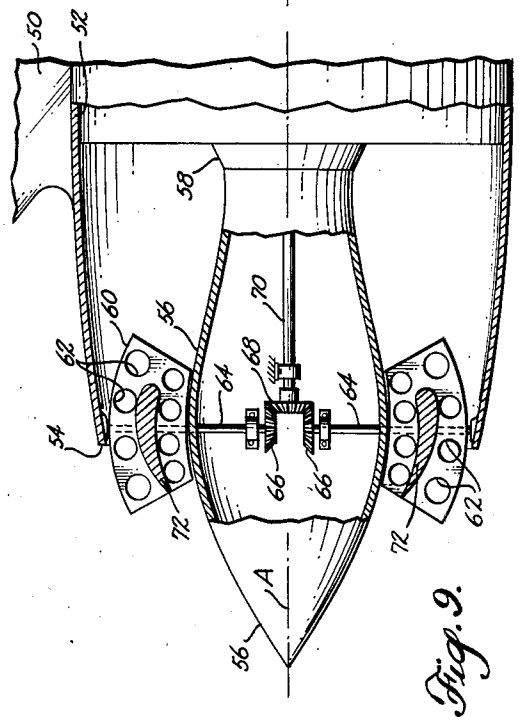


Fig. 9.

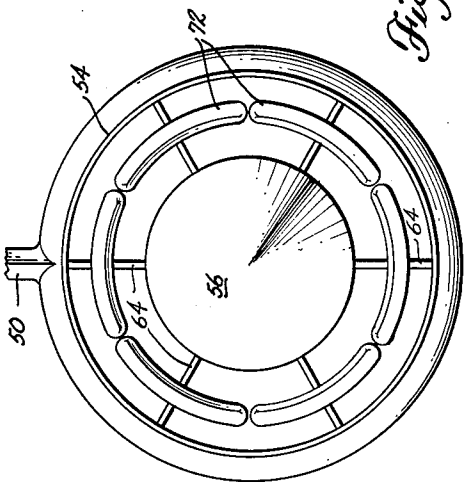


Fig. 10.

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CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

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Fig. 13.

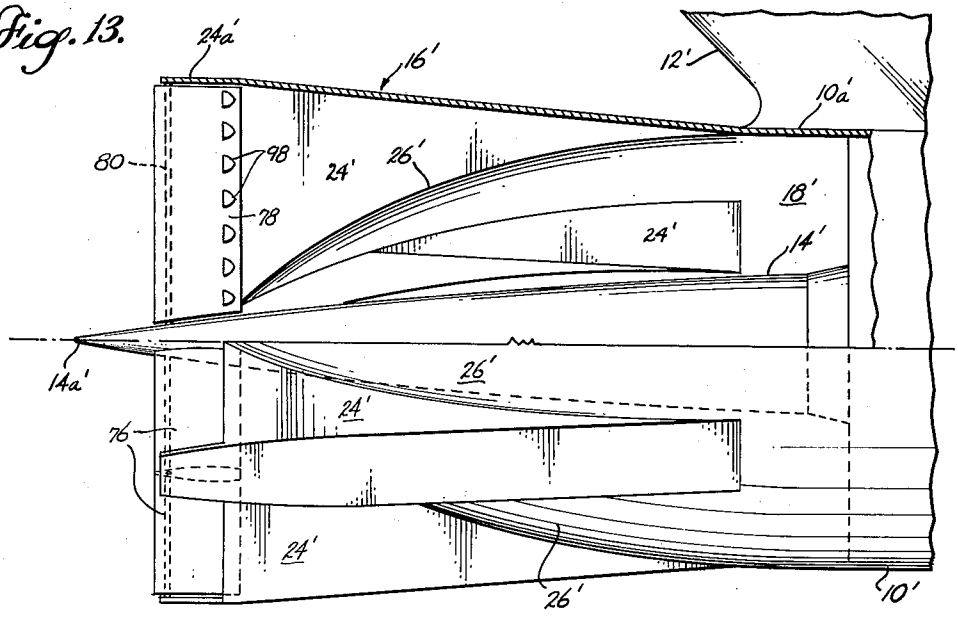


Fig. 14.

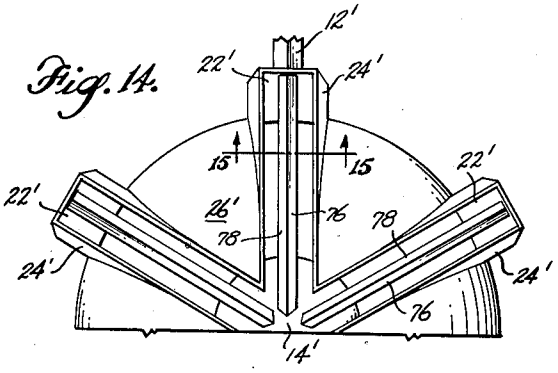
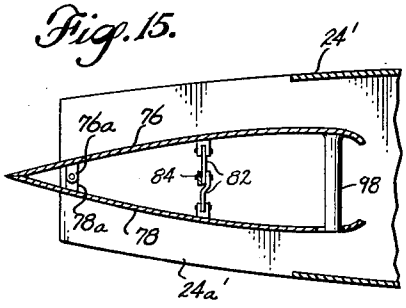


Fig. 15.



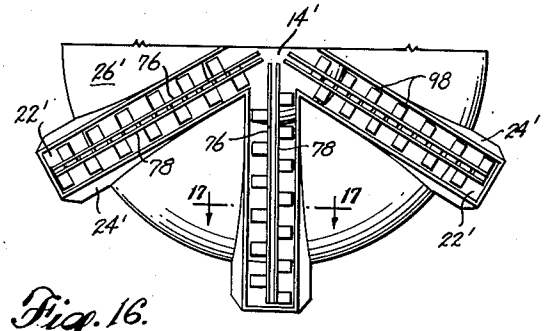


Fig. 16.

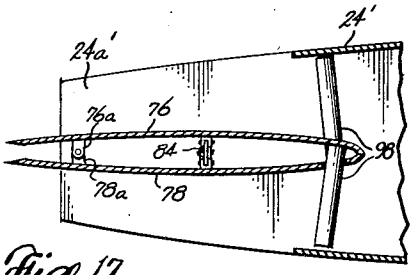


Fig. 17.

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CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

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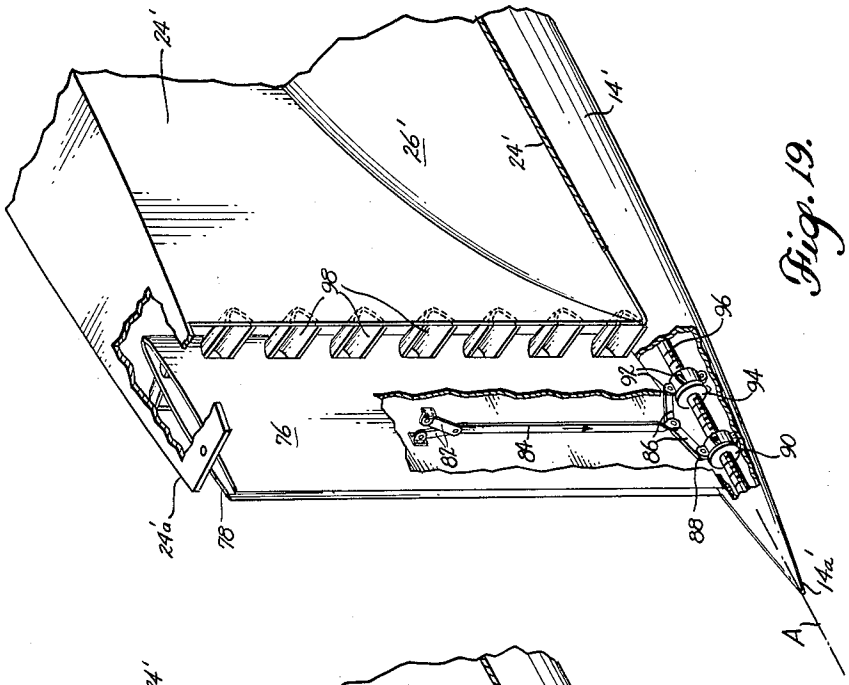


Fig. 19.

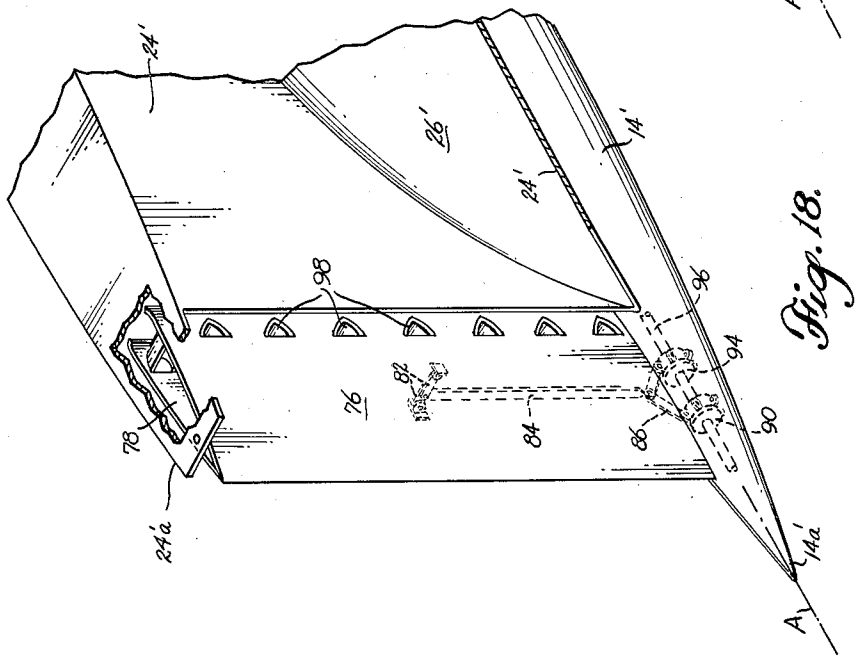


Fig. 18.

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May 29, 1962 G. S. SCHAIRER 3,036,429

CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

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Fig. 20.

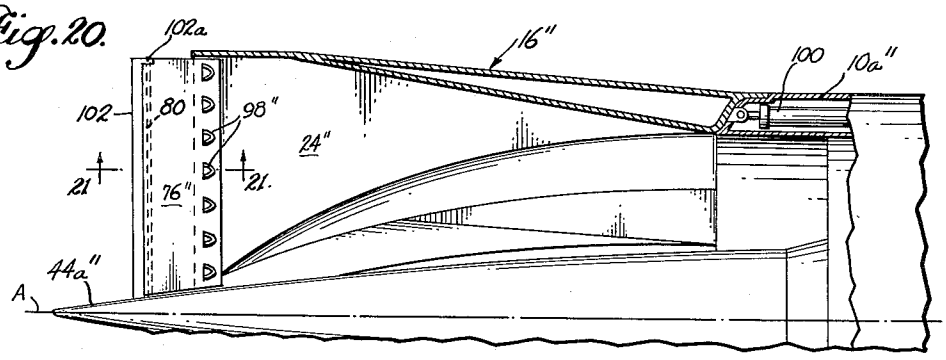


Fig. 23.

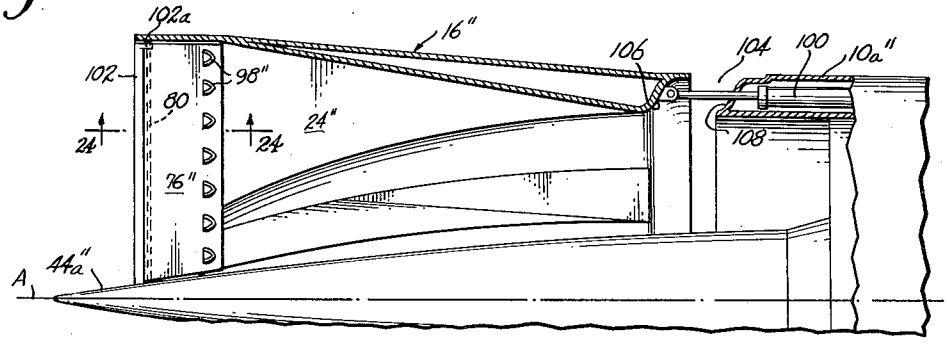


Fig. 21.

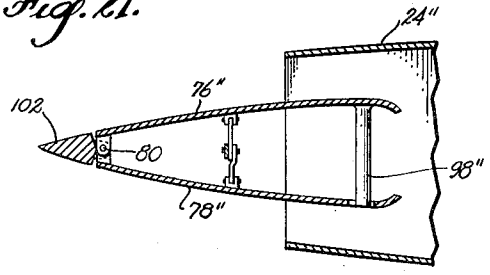
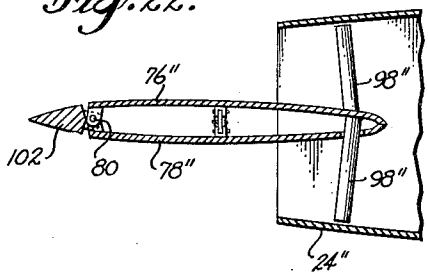


Fig. 22.



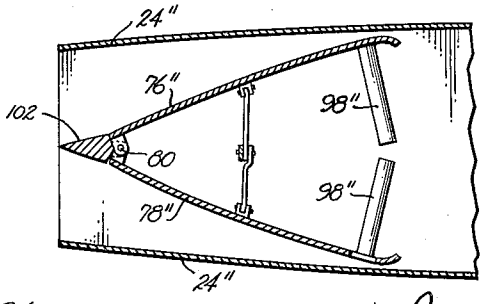


Fig. 24.

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May 29, 1962 G. S. SCHAIRER 3,036,429

CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

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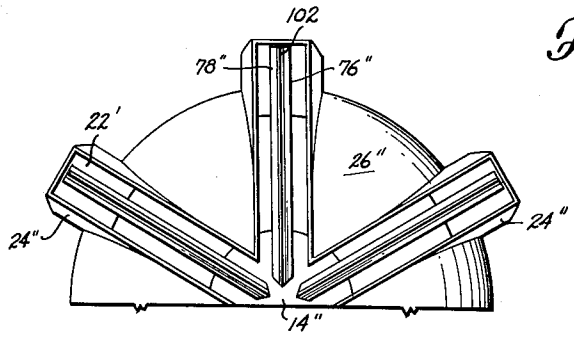


Fig. 25.

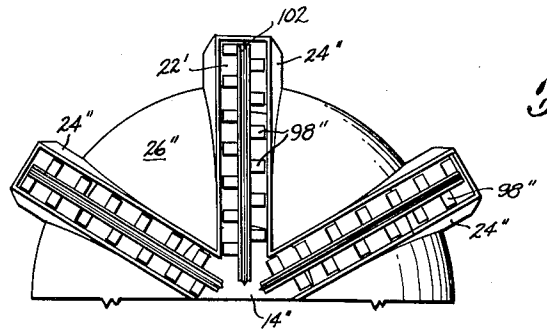


Fig. 26.

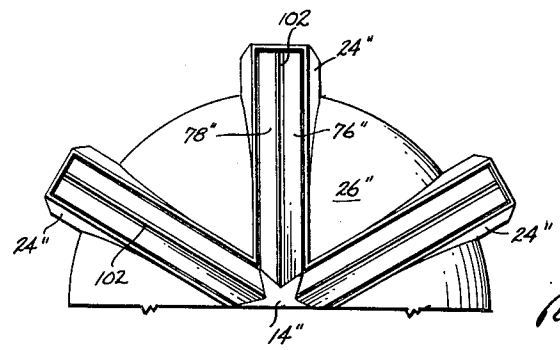


Fig. 27.

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CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

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Fig. 28.

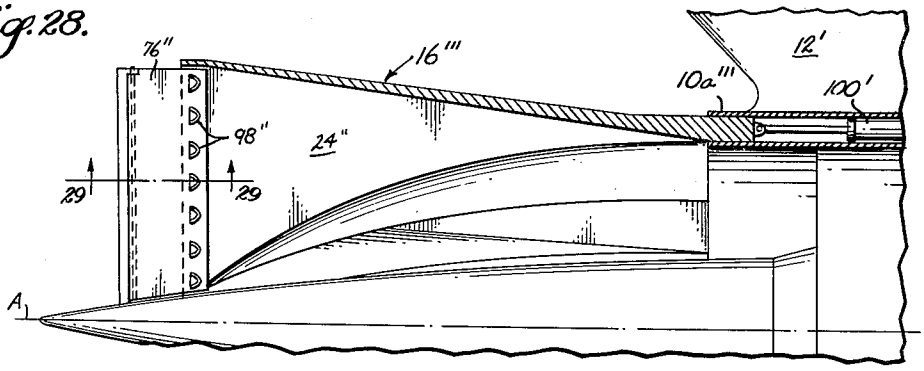


Fig. 31.

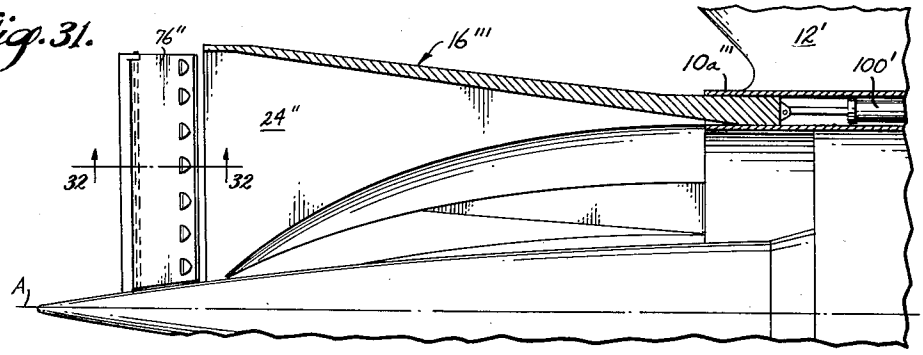
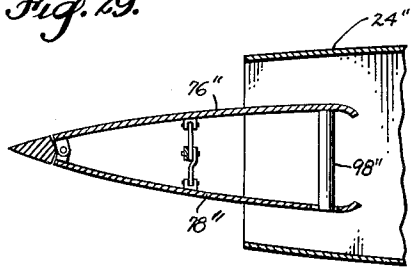


Fig. 29.



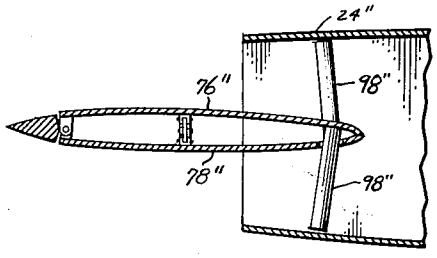


Fig. 30.

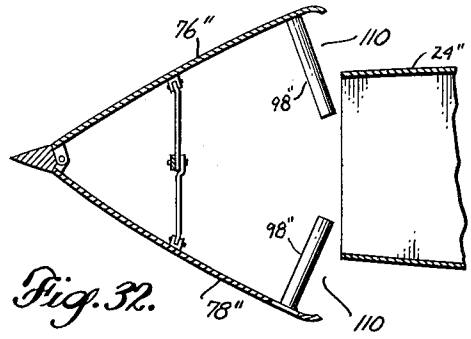


Fig. 32.

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United States Patent Office

3,036,429

Patented May 29, 1962

3,036,429

CONVERTIBLE LOW-NOISE JET ENGINE NOZZLES

George S. Schairer, Bellevue, Wash., assignor to Boeing Airplane Company, Seattle, Wash., a corporation of Delaware

Filed Nov. 25, 1957, Ser. No. 698,724
18 Claims. (Cl. 60—35.6)

This invention relates to improvements in jet engine low-noise nozzles and more particularly concerns such nozzles having noise suppression elements which may be retracted in order to increase nozzle efficiency and thereby engine thrust when required. Furthermore, orifice area compensating elements movable simultaneously with the noise suppression elements are provided in order to maintain substantially the same nozzle orifice opening in both the operative or extended position and the retracted position of the noise suppression elements and create a nozzle orifice form producing maximum thrust. If desired such area compensating elements in a modified version of the nozzle may additionally serve as thrust reverser elements by moving the same through an additional range. The invention is herein illustratively described by reference to the presently preferred forms 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 found that most of the objectionable noise attending operation of a jet engine develops not within the engine itself but in the atmospheric region into which the nozzle discharges. This noise apparently results from the pressure disturbances caused by the turbulence and mixing of the emerging hot gases with atmospheric air. Consequently, the problem is basically different from that of muffling the internal noises of internal combustion engines.

It is found that much of the objectionable jet engine noise components may be eliminated or suppressed by dividing the nozzle discharge into a plurality of separate or segmental streams so arranged in spaced relation to each other that surrounding air is permitted to flow readily into the spaces therebetween, promoting rapid mixture thereof with the issuing gases commencing immediately behind the orifice. Not only is the total noise level reduced in this manner but the predominant noise frequencies are shifted into the upper region of the noise spectrum where they are more readily attenuated by the atmosphere and present less of a problem in their effect as a source of vibrations in airplane parts.

One of the complications arising in constructing an efficient multistream low-noise jet engine nozzle is that of minimizing the thrust loss and base drag under cruise conditions, found in nozzle forms heretofore proposed. Silencing is important primarily at low speeds and near airports and communities. Under these conditions the engine ordinarily is not required to operate at maximum pressure ratio as it must under cruise conditions. A nozzle pressure ratio of less than 2.5 is usually sufficient to sustain flight at the low speeds encountered when noise reduction is important. A difficulty is that nozzle configurations which have been successful in producing the greatest noise suppression are those which tend to produce a relatively high base drag at all speeds and particularly so at cruise velocities. Also those low-noise configurations generally reduce the velocity coefficient or thrust factor of a nozzle above nozzle pressure ratios of about 2.5. Consequently, above pressure ratios of 2.5 for cruise operation a revised, preferably divergent nozzle form should be employed.

Low-noise nozzles employing the present invention are convertible between divergent-orifice, high-thrust, low-drag forms for cruise operation, and low-noise forms

possessing ample velocity coefficient for low-speed flight near airports and populated areas. Further, such nozzles may be adapted for reverse thrust operation producing deceleration on landing.

It is therefore a general object of the invention to provide a satisfactory and practical convertible nozzle achieving the foregoing and related objectives.

Another object is to provide such a nozzle which maintains substantially the same orifice opening throughout its range of adjustment or in its different settings so that the control relationships are maintained substantially constant, eliminating the danger of engine overspeeding due to wide fluctuations of orifice opening.

A further object is a convertible nozzle achieving the described purposes in a simple and effective manner and by means which are readily operated by application of relatively small forces.

A related object is such a nozzle requiring no large nozzle parts to be moved in order to convert the nozzle from its maximum noise suppression setting to its maximum thrust setting and vice versa.

Still another object is to provide a reversible thrust nozzle employing the same movable elements for thrust reversal as those which are actuated in order to convert the nozzle between its cruise and noise suppression settings.

One feature of the invention is the provision of an orifice opening in which is mounted a noise suppression stream dividing grid structure including a plurality of stream divider elements having bluff downstream faces which provide a material spacing between the divisional gas streams issuing between the divider elements and permit outside air to enter such spaces for rapid admixture with the gases, such grid means being movable from a position disposed transversely to the flow through the orifice to a retracted position wherein it is feathered in the flow or otherwise unobstructively positioned in relation thereto. Preferably such grid structure supports or is supported by means forming a cruise plug which is retracted when the grid means are operatively extended into the stream dividing position, and which is extended when the grid means are retracted, whereby the cruise plug cooperatively with the orifice sides produces a rearwardly divergent nozzle effect conducive to attaining maximum thrust with the grid means in the retracted position.

In one described embodiment the cruise plug comprises an elongated bar which is streamlined transversely of its length and which is mounted intermediate its ends on a noise suppression grid structure at a location intermediate the ends of the latter, and the two are mounted to swing conjointly on an axis transverse to the flow through the orifice at the intersection of the cruise plug and the grid means, whereby rotation of the composite structure through 90 degrees converts the nozzle from a maximum noise suppression setting to a maximum thrust setting, and vice versa. Two forms of jet engine nozzles incorporating this type of combination are disclosed, one a multilobe nozzle in which each of the arms comprises a radially extending elongated orifice opening disposed at an angle to the adjacent openings, as the spokes of a wheel, there being a separate grid structure and cruise plug in each such lobe opening in the composite nozzle. The second variation comprises an annular orifice form in which the noise suppression grid comprises a plurality of sectoral plates multiply apertured and arranged end-to-end around the circumference of the nozzle opening and normally blocking flow therethrough except for the small streams permitted to discharge through the apertures. These multiply apertured plates are mounted intermediate their ends to swing about radial axes into feathered positions and carry arcuately formed cruise plugs at right angles thereto which are then disposed transversely of the direc-

tion of flow to produce the rearwardly divergent nozzle effect.

In still another embodiment of the invention the cruise plug comprises a pair of rearwardly convergent fairing surface members which are pivoted near their rearward ends to permit swinging of the forward ends thereof together for reducing the effective thickness of the cruise plug and thereby to convert the orifice to a convergent form, these fairing surface members each carrying a series of stream divider elements which project from the inside faces thereof toward the opposite fairing surface member and which in the normal or separated position of the fairing surface members forming the rearwardly divergent nozzle are retracted within the outline of the cruise plug for cruise operation. By moving the fairing surface members relatively together to produce a convergent orifice for low-noise operation the stream divider elements are projected laterally through or beyond such members into the path of discharging gases and thereby divide the issuing stream into a plurality of separate stream portions between which spaces are established to permit inflow of outside air therebetween.

In still other embodiments wherein reverse thrust may be produced by operation of the orifice-forming elements the fairing surface members are movable further apart beyond the normal cruise positions thereof into extended positions wherein they substantially obstruct flow through the orifice opening to the end that the gases issuing ahead of the nozzle may be directed forwardly to create reverse thrust.

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 sectional side view of a nozzle installation employing the first-described embodiment, the view showing a portion of the engine and supporting struts therefor, with parts broken away for convenience of illustration; FIGURE 2 is a corresponding rear view of the same; and FIGURE 3 is a sectional detail taken on line **3—3** in FIGURE 1, the movable orifice-forming elements in each of these three views being in the cruise position.

FIGURE 4 is a fragmentary view similar to FIGURE 1 with the orifice-forming parts in the maximum noise suppression setting; FIGURE 5 is a fragmentary rear view of the lower portion of the nozzle in the setting shown in FIGURE 4; and FIGURE 6 is a sectional detail taken on line **6—6** in FIGURE 5.

FIGURE 7 is an enlarged perspective detail view illustrating one of the orifice opening arms with the orifice-forming elements in cruise position, the view illustrating a suitable actuating means for the orifice-forming structure; and FIGURE 8 is a similar view with the orifice-forming structure in the maximum noise suppression position.

FIGURE 9 is a longitudinal sectional view of the second mentioned variation of the first described embodiment, with the orifice-forming structure in the cruise position; and FIGURE 10 is a rear view of the same.

FIGURE 11 is a sectional side view of the same variation with the orifice-forming structure in the maximum noise suppression setting; and FIGURE 12 is a rear view of the same.

FIGURE 13 is a side view partly in section of a multi-lobe orifice nozzle installation employing the second described embodiment of the invention, the view illustrating the orifice-forming structure in the cruise position; FIGURE 14 is a rear view of the upper portion of the same; and FIGURE 15 is a sectional detail taken on line **15—15** in FIGURE 14.

FIGURE 16 is a rear view of the lower portion of the same nozzle, with the orifice-forming structure in the maximum noise suppression setting; and FIGURE 17 is a sectional detail taken on line **17—17** in FIGURE 16.

FIGURE 18 is an enlarged perspective view of one portion of the nozzle in the cruise condition shown in FIGURE 13; and FIGURE 19 is a similar view with the nozzle in the maximum noise suppression setting.

FIGURE 20 is a fragmentary top view of an adaptation of the nozzle configuration illustrated in FIGURES 13 to 19, inclusive, for purposes of thrust reversal, this view illustrating the parts in a forward-thrust or cruise setting; FIGURE 21 is a sectional detail taken on line **21—21** in FIGURE 20, with the orifice-forming structure in the cruise position; and FIGURE 22 is a similar sectional view with the parts in the maximum noise suppression setting.

FIGURE 23 is a view corresponding to FIGURE 20, with the nozzle in the reverse-thrust setting; and FIGURE 24 is a sectional detail taken on line **24—24** in FIGURE 23, illustrating extension of the fairing surface members to obstruct flow through the orifice opening, as would be done during thrust reversal.

FIGURES 25, 26 and 27, comprise rear views of the upper portion of the same nozzle, with the orifice-forming elements respectively in the cruise, noise-suppression and reverse-thrust settings.

FIGURE 28 is a fragmentary sectional side view of a variation of the embodiment illustrated in FIGURES 20 to 27, inclusive, wherein thrust reversal is effected by employing the fairing surface members themselves to direct the gases in a forward direction, the view showing the parts in the normal or forward-thrust position; FIGURE 29 is a sectional detail taken on line **29—29** in FIGURE 28, with the orifice-forming structure in the cruise setting; and FIGURE 30 is a similar sectional detail with the orifice-forming structure in the maximum noise suppression setting.

FIGURE 31 is a view similar to FIGURE 28, with the shroud or nozzle proper drawn forwardly to the reverse-thrust setting; and FIGURE 32 is a sectional detail taken on line **32—32** in FIGURE 31, with the orifice-forming structure in the corresponding reverse-thrust setting.

Referring to FIGURES 1 to 8, inclusive, only the after portion of the jet engine **10** is shown in the drawings, the engine being supported by a vertical strut **12**. The illustrated engine includes a center cone or plug **14** tapering rearwardly to the tip **14***a* in accordance with established principles of nozzle design. An annular duct space **18** is formed between the forward portion of the conical plug **14** and the outer annular wall **10***a* of the engine to which the forward end of the nozzle structure is joined. The space **18** in a conventional turbojet engine is located just to the rear of the turbine wheel which drives the compressor. It will be recognized, however, that the invention is not necessarily limited to turbojet engines nor to jet engine nozzles incorporating a tail cone.

The nozzle form in connection with which this first embodiment is illustrated is of the radial-lobe orifice type the composite orifice opening consisting of a series of six radially extending relatively narrow segmental openings or lobes **22** arranged as the spokes of a wheel about the central axis A. The number of these radial lobes may vary, and it is not the intent herein to indicate that the number involved is a part of this invention nor that the novel principles of the invention depend for their application on any specific number of nozzle openings. The radially extending, rearwardly directed ducts **24** which define these lobes preferably terminate in a common transverse plane perpendicular to axis A and their side walls extend forwardly into the rearwardly convergent annular nozzle wall **26** which, at its forward end, joins or merges with the engine shell **10***a*. The generally conical and rearwardly tapered nozzle shell **26** supporting ducts **24** terminates substantially at the discharge ends of the radial ducts **24**, and at that point only slightly exceeds the tail cone diameter, as shown. The radially outside wall of the ducts **24** flare outwardly and rearwardly from the nozzle axis A in order to provide the requisite total

orifice opening for a given width of the radial openings 22 in the circumferential direction. Excessive width of these openings reduces the noise suppression effect of such a radial arm nozzle, it being desirable to maintain a relatively high ratio between the distance separating adjacent gas streams and the thickness of those streams.

A nozzle of the radial lobe type having a center plug or cone for achieving noise suppression without a large reduction of thrust is disclosed and claimed in the copending application Serial No. 563,952, filed February 7, 1956, by William A Reinhart and entitled Noise Suppression Nozzles for Gas Stream Thrust Reaction Engines, now abandoned. That development was based on noise suppression nozzle concepts disclosed and claimed in my copending application Serial No. 562,050, filed January 30, 1956 and entitled, Jet Engine Noise Suppression, also now abandoned. In the last-mentioned application there is also disclosed certain basic nozzle configurations by which the branch streams defined by the radial orifice lobes are themselves segmented or divided into a plurality of smaller streams further increasing the noise suppression effect of the nozzle. The present invention employs these teachings in a convertible nozzle configuration adapted in one setting to produce maximum thrust and in another setting to produce maximum noise suppression.

In the embodiment shown in FIGURES 1 to 8 the noise suppression grid structure comprises a series of successively spaced stream divider elements 28 mounted in substantially parallel relationship extending between the parallel grid side bars 30. The ends of the side bars 30 are interconnected by nosings or bars 32. The stream divider elements 28 are formed with bluff or flat downstream faces 28*a* and pointed or rounded nosings 28*b* facing upstream. The flat downstream sides of the stream divider elements insure separation of the branch streams emerging from between successively adjacent divider elements so that outside air flowing inwardly and rearwardly of the nozzle in the spaces between the branch ducts 24 may flow laterally into the spaces between the small streams passing through the grid spaces. The grid is shown cross-sectionally in its operative position in FIGURE 4, and in this position it will be seen that the plane of the grid is perpendicular to the direction of flow of gases through the associated branch duct 24 and that the grid is located substantially at or near the discharge end of the branch duct so as to insure that the small streams separated by the divider elements 28 will remain separated for a distance extending downstream at least some distance beyond the rearward edge of the branch duct 24 so as to permit the outside air to gain access to the spaces between these separated streams before a material recombining of the small streams can occur.

Each branch orifice 24 is provided with a similar noise suppression grid structure.

Each of the grid structures comprising the divider elements 28 is pivotally mounted on a transverse shaft or supporting pin 34 which define a pivot axis extending perpendicularly to the generally radial flat sides of the associated branch ducts 24 at a location intermediate the ends of the grid structure. Because of the intermediate location of the pivot axis for each noise suppression grid, rotation of the grid from its noise suppression position shown in FIGURE 4 to its feathered position shown in FIGURES 1 and 3 requires only a small amount of torque, since the gas stream forces acting on the grid structure about the pivot axis substantially balance out. In the feathered position of the grid structure it has little if any effect on the flow of gases through the associated branch duct 24, since its projected area fore and aft is but a small fraction of the total open area of the branch duct.

Rotation of the noise suppression grid from its operative position of FIGURE 4 to its feathered position of FIGURE 1 is accompanied by an increase of the velocity coefficient of the nozzle, hence in the thrust of the nozzle under cruise conditions. This is true inasmuch as the composite effect of the stream divider elements 28 in the operative position of the grid structure is to produce a substantially convergent orifice effect due to the bluff aspect of the downstream faces 28*a* of the stream divider elements, whereas the convergence of the nozzle is correspondingly reduced by feathering the grid. In order to improve further the nozzle efficiency for cruise operation each branch duct 24 is provided with a cruise plug 36 of substantially flat elongated form and streamlined in cross-section (FIGURE 3). The general plane of this cruise plug is substantially parallel to the radially extending sides of the associated branch duct 24 and is perpendicular to the general plane of the noise suppression grid. Such cruise plug is mounted on the grid at a central location intermediate the ends of each, with the length of the cruise plug extending perpendicular to the length of the noise suppression grid. Consequently, with the noise suppression grid in its operative position as shown in FIGURE 4 the cruise plug extends lengthwise parallel to the direction of flow of gases through the associated branch ducts and has very little effect upon relative convergence of the orifice. However, when the noise suppression grid is rotated into its feathered or retracted position, as shown in FIGURE 1, the cruise plug is operatively oriented with its length dimension extending radially of the nozzle and with its streamlined cross-section presented to the flow of gases so as to present negligible impedance to flow while changing the form of the nozzle to a more divergent form. Opposite faces of the cruise plug cooperate with the adjacent sides of the branch duct to produce the desired divergent orifice effect conducive to generation of maximum thrust. Moreover, viewed in the direction of flow, the projected area of the cruise plug 36 in its operative position plus the projected area of the noise suppression grid in its inoperative position is substantially the same as the similar projected area of the cruise plug in its inoperative position plus that of the grid in its operative position. Consequently, the total orifice area of the nozzle is substantially the same in both settings of the orifice-forming structure, and it will be evident that such area also remains substantially constant throughout the range of adjustment of such structure between those positions. This is of significant value inasmuch as it tends to prevent material change of the control characteristics of the engine during adjustment of the nozzle elements.

FIGURES 7 and 8 illustrate in simplified form one of various possible actuating mechanisms which may be used for rotating the orifice-forming structure between its two operative positions. In this case a lead screw 38 extending lengthwise of the engine along the axis A carries a traversing nut 40 having a number of lugs 42 thereon which correspond to the number of branch ducts 24 in the nozzle, each such lug extending in an axial plane separated from the adjacent lugs by the angle of separation of the branch ducts. Links 44 are pivotally connected to the respective lugs 42 and extend therefrom radially outwardly and somewhat rearwardly through longitudinal slots 46 in the nozzle cowl or shell 26. A crank arm 48 on each grid and cruise plug structure is pivotally connected to the outer end of the associated links 44. Rotation of the screw 38 causing forward or rearward travel of the nut 40 thereby turns the cranks 48 one way or another in order to rotate the associated orifice-forming structures between their two operative positions. A total rotation of 90 degrees is required in this case. In FIGURE 7 the parts are positioned with the noise suppression grid feathered and the cruise plug disposed operatively in the discharge orifice 22 for cruise operation, whereas in FIGURE 8 the crank arm 48 has been rotated through 90 degrees and the noise suppression grid is now operatively disposed and the cruise plug is feathered.

In converting the nozzle from the noise suppression setting shown in FIGURE 4 to the cruise setting shown in FIGURE 1 not only is the velocity coefficient of the nozzle materially increased but the base drag of the nozzle,

imposed by the bluff end faces of the divider elements 28, is reduced. The nozzle efficiency and thrust, therefore, increases from both of these causes. A further thrust increase is achieved, as already mentioned, by the provision of the cruise plug 36 moved conjointly with the noise suppression grid structure.

In the variation of the first embodiment, shown in FIGURES 9 to 12, inclusive, the orifice is of generally annular form instead of the radial-lobes form previously described. Engine supporting strut 50 is connected to the outer shell 52 which extends rearwardly with a moderate taper to the annular lip 54. In cooperation with the central plug 56, the rearwardly tapered shell 52 forms a convergent-divergent nozzle effect. The forward end of the plug 56 may extend to the turbine hub 58.

The noise suppression grid structure comprises one of a number of similar segmentally formed plates 60 having a plurality of openings or apertures 62 therein which permit flow through the plates with the latter disposed in a plane perpendicular to the engine axis A. In this position of the plates 60 the nozzle discharge therefore consists of a plurality of separate streams permitted to pass through the respective openings 62. In effect, therefore, the noise suppression plates comprise grids the stream divider elements of which consist of the webs of plate material between openings 62. Such webs, having bluff downstream faces, maintain separation between individual streams issuing from the nozzle so as to permit outside air to flow into the spaces between the streams for noise suppression purposes.

In this illustration six similarly formed segmental plates 60 are mounted in the annular space between the outer shell 52 and the plug 58, substantially at the location of the plane of the lip 54. Each of the plates 60 is mounted on a radial shaft 64 having journals which permit rotation of the plate between its operative position (FIGURE 11) extending transversely to the engine axis A and its feathered or retracted position (FIGURE 9) extending parallel to the direction of flow through the nozzle. As shown best by a comparison of FIGURES 9 and 12, each of the plates 60 is formed with an inner edge following a circular arc of slightly larger radius than that of the plug at the same location. At this location along its length the plug preferably has the same longitudinal curvature as it does circumferentially (i.e., is spherical) so that a constant clearance is maintained to the inner edges of the plates in all positions of the latter. The outer edge of each plate 60 has a circular arc curvature of slightly lesser radius than that of the inside of the lip 54. Of course nozzle forms other than annular forms having a center cone or plug of circular cross-section may be used, in which case plates of shapes differing from that shown may be required.

In order to rotate the plates simultaneously each of the shafts 64 extends inwardly through the plug wall and carries a bevel gear 66 on its inner end. The bevel gears 66 mesh with a common bevel gear 68 mounted on the rearward end of a longitudinal drive shaft 70 extending along the axis A. Rotation of the shaft 70, therefore, rotates the plates simultaneously between the two positions thereof illustrated.

In order to complete the illustrated form of this structure the cruise plugs 72 of generally elongated, flat configuration are mounted on the respective noise suppression plates 60. Each cruise plug is curved in an arcuate form along its length (FIGURES 10 and 11) and is of streamlined form in cross-section, such that when disposed transevrsely to the flow of gases the cruise plug, in cooperation with the adjacent duct walls, it creates the desired convergent-divergent nozzle effect. The cruise plug is mounted intermediate its ends on the associated noise suppression plate 60 so that in the inoperative or feathered position of the plates 60 the cruise plugs 72 are aligned circumferentially end-to-end creating an annulus or ring extending around the nozzle opening generally intermediate the lip 54 and the plug 56, as shown best in FIGURES 9 and 10. Because of the rearward taper of this ring cross sectionally, the entire nozzle becomes convergent-divergent in the well known manner. In its feathered position the plates 60 have little if any effect upon the flow of gases through the nozzle because their projected area, fore and aft, is relatively small. In the operative position of the plates 60 the cruise plugs in turn are substantially feathered to the flow and have little if any effect thereon because of their small projected area, fore and aft. Moreover the projected area of the cruise plugs in their operative position preferably equals or substantially equals the projected solid area of the noise suppression plates in their operative position, whereby nozzle opening is substantially constant at all times. The principles of operation and convertibility of this annular nozzles are generally the same as in the radial-arm form previously described.

In FIGURES 13 to 19, inclusive, the cruise plug effect and the noise suppression grid effect are obtained by different means than in either of the previously described embodiments, but with reference to a radial-lobe type nozzle configuration generally similar to that shown in FIGURES 1 to 8, inclusive. In FIGURES 13 to 19, inclusive, nozzle and engine parts which correspond generally to those shown in the first described embodiment are designated by similar reference numerals single-primed. The basic nozzle configuration is or may be substantially identical with that shown in the first embodiment with the exception in this instance of rearward extensions 24*a'* of the outer walls of the radial ducts 24' to serve as pivot supports for the pairs of fairing surface members 76 and 78 in the form of slightly curved plates of generally rectangular form mounted in the respective branch ducts 24'. Each such pair of fairing surface plates 76 and 78 is disposed substantially radially within a branch duct 24' intermediate opposite sides of the branch duct. The respective plates 76 and 78 carry and are supported by tabs 76*a* and 78*a* pivotally mounted by means of a radially extending shaft 80 secured at its inner end to the plug 44 and at its outer end to the extension tab 24*a'*, as shown in FIGURES 13 and 15. The shafts 80 are located substantially in the longitudinal mid-planes of the respective ducts 24'. The sets of tabs 76*a* and 78*a* and the pivot axes defined by the shafts 80 are located near the rearward edges of the convexly curved plates 76 and 78, so that swinging of such plates about their common pivot axis produces substantial variation in the distance of separation between the forward edges of the plates without great variation in the separation between the rearward edges thereof. In the separated positions of the plates of each pair as shown in FIGURE 15 they cooperatively define a cruise plug of elongated generally flat form extending parallel to the flow and radially of the associated branch duct 24', and in cooperation with the sides of the branch duct produce a rearwardly convergent-divergent nozzle effect. On the other hand when the plates are drawn together as shown in FIGURE 17 they present a substantially flat form with very small projected area in the direction of flow, and then have minimum effect on flow through the branch opening.

Actuation of the plates of each pair is effected by means of a toggle linkage 82 pivotally connected to the outer end of a radially extending link 84. The inner end of the link 84 is pivotally connected to the intermediate point of a second toggle linkage 86. The rearward link of the toggle linkage 86 is pivotally connected to a lug 88 on a stationary member 90. The forward end of the forward link in toggle linkage 86 is pivotally connected to a lug 92 on the collar 94. The collar 94 is mounted on the end of a reciprocable actuating rod 96 adapted to be moved fore and aft along the axis A. Such movement of the rod, hence of the collar 94, causes the link 84 to

be reciprocated radially inwardly or outwardly and thereby to actuate the toggle linkage 82 in order to vary the distance of separation between the fairing surface plates 76 and 78 as required for retracting the plates into feathered or inoperative position from their extended or operative position producing a cruise plug effect. Similar toggle linkages and connecting links are provided for the other pairs of fairing plates and are connected to the remaining lugs 92 on the reciprocative sleeve 94.

In this embodiment the noise suppression grid structure comprises a plurality of substantially parallel stream divider bars 98 arranged in substantially parallel successively spaced radial series relationship. The individual bars project from the inside faces of one of the plates 76 or 78 near the forward edge of the latter, each bar projecting transversely to the direction of flow through the branch duct and substantially perpendicular to the fairing surface plate 76 or 78 supporting the bar. Alternate bars in each series are mounted on the opposite plates 76 and 78 of a pair and each such plate has openings therein aligned with the bars projecting toward it from the opposite plate. When the fairing surface plates 76 and 78 are relatively separated as in FIGURE 15 the bars 98 are contained within the space defined by and between the plates so as to present no obstruction to flow of gases through the open spaces of the nozzle on opposite sides of the cruise plug defined by the two plates. However, when the two plates are drawn together as in FIGURE 17 the stream divided bars project through the openings in the opposing plates and form a two-part noise suppression grid disposed across the path of flow of gases through the nozzle opening. Because of the bluff form and finite width of the downstream sides of the bars, a substantial separation is established between adjacent segmental streams of gas that flow through the resulting grid structure. This separation of gases permits inflow of outside air and thereby promotes rapid admixture of such air with the gases and the desired reduction of engine noise. The upstream faces of the stream divider bars 98 are preferably of convergent streamlined form so as to minimize the resistance to flow through the composite grid structure.

In this embodiment, therefore, as in the previous embodiments the noise suppression grid structure is mounted in conjunction with the cruise plug means in order for the grid structure to be retracted when the cruise plug is operatively positioned and for the cruise plug to be retracted or rendered inoperative when the noise suppression grid elements are operatively positioned. By proper design of the bars and cruise plug assembly in this embodiment as in the others described, the orifice opening of the nozzle will be substantially the same in the different positions of the orifice-forming elements so as to maintain substantially constant control characteristics in the engine.

In the modification shown in FIGURES 20 to 27, inclusive, a basically similar orifice-forming structure comprising the fairing surface plates and the grid bars forming stream divider elements is employed as in the last described embodiment. However, means for producing reverse thrust have been incorporated in the nozzle, making use of the fairing surface members for obstructing the rearward discharge of gases in order to reverse the direction of flow. Again, a multilobe nozzle configuration is employed. In this instance the entire outer wall structure of the nozzle proper 16″ is mounted for longitudinal movement in relation to the remainder of the engine structure. Support and movement of the outer nozzle structure in that manner is accomplished by means including a plurality of engine-mounted hydraulic or pneumatic jacks 100 connected to the forward end of the nozzle structure 16″ as successively spaced locations around the periphery of the engine. In this instance the pairs of fairing surface members, designated 76″ and 78″, located in the branch ducts 24″ are mounted and pivotally actuated independently of the outer nozzle structure 16″. For this purpose radially extending posts 102, formed as rearwardly convergent tail fairings for the fairing surface members, are rigidly mounted on the tail come 44*a*″ to project radially therefrom. Each such post 102 carries a forwardly projecting arm 102*a* at its outer end which supports the outer end of the pivot shaft 80 for the associated pair of fairing surface plates 76″ and 78.″ In this case, therefore, the fairing surface plates receive their entire support from the cone or plug 44*a*″ although they are otherwise similarly mounted and actuated for swinging movement as in the previous example.

In the embodiment shown in these FIGURES 20 to 27, inclusive, the noise suppression stream divider grid elements or bars 98″ are mounted in the same manner and for the same purpose as in the previous embodiment. The principal difference in the actuation of the fairing surface plates 76″ and 78″ over the similar plates in the previous embodiment is the greater distance of separation which may be effected, in order to reverse engine thrust. As shown in FIGURE 24, these plates may be extended apart sufficiently substantially to block all flow of gases through the duct 24″. However, by actuation of the hydraulic jacks 100 the outer nozzle assembly is moved bodily rearwardly in order to open up an annular gap 104 between the forward edge thereof and the rearward edge of the engine shell 10*a*″. The adjoining forward end wall surface 106 and the opposing rear wall surface 108 of the separated ends of the nozzle structure 16″ and engine structure 10*a*″, respectively, are inclined outwardly and forwardly. Consequently, blockage of flow through the usual orifice openings in the nozzle and rearward shifting of the nozzle structure 16″ causes gases to discharge laterally outwardly and forwardly through the gap 104 so as to produce reverse thrust in the engine. By suitable means (not shown) operation of the hydraulic jacks is or may be coordinated with operation of the toggle linkages moving the fairing surface plates 76″ and 78″ apart into their flow obstruction position. Accordingly a substantially constant orifice opening through the nozzle during the transition between forward and reverse thrust settings is maintained, whereby the desired control relationships in the engine are maintained, as they are in converting the nozzle between its maximum noise suppression setting and its cruise setting. FIGURES 25, 26 and 27, respectively, illustrate the effect of actuating the fairing surface plate successively from the cruise setting, to the maximum noise suppression setting, and finally to the reverse thrust setting.

In the variation or modification shown in FIGURES 28 to 32, inclusive, the forward direction of discharging gases for reverse thrust is effected directly by the fairing surface plates 76″ and 78″ themselves, without requiring the opening of a gap in the outer wall of the engine, such as the gap 104 in the previously described embodiment. In this instance, however, forward movement instead of rearward movement of the outer nozzle wall structure 16‴ is required in conjunction with maximum separation of the fairing surface plates, in order to produce reverse thrust. To that end the forward generally annular edge of the nozzle wall structure 16‴ is received telescopingly in the outer shell 10*a*‴ of the engine and is connected to a plurality of hydraulic or pneumatic jacks 100′ at different locations around its periphery as in the previous embodiment. Actuation of such jacks produces forward or rearward movement of the duct structure 16‴ and to a degree sufficient, in the forward setting of the duct structure, to clear the forward edges of the fairing surface plates 76″ and 78″ as in FIGURE 32. Upon clearing these pairs of plates the members of each pair may be moved apart sufficiently to obstruct the direct rearward discharge through ducts 24″ and open side gaps 110 between their forward edges and the rearward edges of the sides of branch ducts 24″. As a result of the formation of these gaps and the forward and outward inclination of

now-separated plates 76'' and 78'', gases intercepted by the plates are directed forwardly of the engine and produce reverse thrust.

Reverse thrust is obtained in a somewhat similar way in the copending application Serial No. 562,051 of Holden W. Withington, filed January 30, 1956, and entitled, Gas Stream Thrust Reaction Nozzle Means With Noise Suppression and Thrust Reversal, now abandoned.

I claim as my invention:

1. A jet propulsion engine nozzle comprising a rearwardly directed discharge orifice, cruise plug means located in said orifice intermediate opposite walls thereof, said cruise plug means while in position of use being operatively positioned to present a substantially streamlined cross-sectional form representing a convergent-divergent restriction in relation to the orifice, dividing the orifice discharge, said cruise plug means thus positioned having a length dimension, extending transversely to the direction of discharge, over which length such cross-sectional form remains at least approximately uniform, noise suppression grid means also located in the orifice and comprising a plurality of flow dividers extending in successively spaced series relationship, mounting means for said cruise plug means for retractive positioning movement thereof reducing the restriction effect presented thereby to the discharge while maintaining the location of such cruise plug means substantially intermediate such opposite walls, and for said grid means for movement between an operative position wherein the series of dividers is disposed within and extends transversely across the orifice to restrict the orifice to a discharge comprising a plurality of transversely spaced streams at the orifice exit plane, and a retracted position wherein it reduces the flow restriction effect presented by the flow dividers while maintaining such flow dividers within the orifice, said mounting means being arranged to effect simultaneous retraction of the cruise plug means and extension of the grid means, and alternatively simultaneous extension of the cruise plug means and retraction of the grid means, whereby the increasing and decreasing restriction effect produced by movement of one such means at least partially offsets the opposing change of restriction effect produced by movement of the other means.

2. The jet engine nozzle defined in claim 1, wherein the mount for the noise suppression grid means is situated generally intermediate opposite sides of the orifice area, and comprises pivot means which defines a pivot axis therefor which extends across the orifice area generally intermediate said opposite walls thereof, whereby torque-producing forces of the discharge gases acting on the grid means during its retraction and extension movements and in its retracted and operative positions are substantially self-cancelling.

3. The jet engine defined in claim 1, wherein the mounting means for the cruise plug means is common to the mounting means for the noise suppression grid means, and comprises a pivot means which defines a pivot axis extending across the orifice area from one wall of the orifice to an opposite wall, intermediate the ends of each of the cruise plug means and the grid means, the two latter means being disposed in substantially mutually perpendicular relationship about said pivot axis.

4. A jet propulsion engine nozzle comprising spaced walls defining a rearwardly directed discharge orifice having a transverse exit plane, cruise plug means and cooperating but alternatively operable noise suppression grid means both supported within said discharge orifice for movement of each from an operative position with relation to the orifice while the other moves to a retracted position, and vice versa, said cruise plug means when in its operative position defining an elongated but substantially streamlined cross-sectional form which is at least approximately uniform throughout its length, and representing in cooperation with said walls a convergent-divergent restriction of and dividing the orifice, said grid means comprising a plurality of flow dividers oriented, in their operative position, transversely across the orifice in successively spaced series relation, to define spaced separate gas streams at the exit plane of the orifice, means to move the cooperating cruise plug means and grid means conjointly from the operative position of one thereof and the retracted position of the other, to the reverse position of each, and back at will to their original positions, and the cruise plug means and the grid means being each shaped to produce a restriction effect, when in its operative position, such that the increasing and decreasing restriction effect produced by movement of one such means between its two positions at least partially offsets the opposing change of restriction effect produced by the conjoint movement of the other.

5. A jet propulsion engine nozzle comprising spaced walls defining a rearwardly directed discharge orifice including a plurality of radially directed lobes each having two generally radially directed long walls and at least one short wall, a plurality of assemblies each having a noise suppression grid means and a cruise plug means, one assembly mounted in each lobe for movement between two alternative positions, the grid means of each assembly comprising a plurality of flow dividers oriented when in one such position of the assembly, transversely across its lobe, producing a restriction effect, and the cruise plug means of each assembly being then in its inoperative position, and the cruise plug means being elongated but of substantially streamlined cross sectional form which is approximately uniform throughout its length, and when in the other alternative position of the assembly dividing the gas flow and cooperating with the long walls of its lobe to define convergent-divergent restrictions, the grid means of each assembly being then in an inoperative position, means to move the several assemblies conjointly between such alternative positions, each such cruise plug means and grid means being so shaped that the increasing and decreasing constriction effect produced by the movement of one thereof between its two positions at least partially offsets the opposing change of restriction effect produced by the conjoint movement of the other.

6. The jet nozzle defined in claim 5, wherein each grid means constitutes a rigid planar structure pivotally mounted intermediate its short ends for bodily rotation between its operative position and its retracted position wherein it extends in the direction of gas flow, and the cruise plug comprises an elongated member extending lengthwise of the grid means, between the latter's long sides, and of streamlined form transversely to its length, and each rigidly fixed to the corresponding grid means in perpendicular relation to the plane of the latter.

7. The jet engine nozzle defined in claim 5, wherein the cruise plug comprises a pair of rearwardly convergent fairing surface members pivoted near their rearward ends to permit swinging of the forward ends together for reducing the effective thickness of said cruise plug, and apart to a normal cruise position, and wherein the noise suppression grid means flow obstruction elements comprise elongated elements mounted serially in successively spaced relationship on each of the fairing surface members projecting in generally parallel relationship from the relatively inner faces of each such member toward the other generally transversely to the flow through the orifice opening, said elongated elements and the respective fairing surface members being formed to permit projecting said elements in the flow stream passing by opposite sides of the cruise plug for noise suppression purposes by positioning the cruise plug members relatively together, and retracting such elements into unobstructive position substantially within the outline of the cruise plug with the cruise plug members moved relatively apart into their normal position.

8. A jet engine nozzle as defined in claim 4, wherein the orifice walls define an annular rearwardly directed discharge orifice, and the grid means comprise a plurality of segmentally formed multiply apertured plates extend-

ing, when in their operative position, serially end-to-end around said orifice in a common plane transverse to the line of flow through the orifice to obstruct flow therethrough except for the discharge permitted through such apertures, and the cruise plug means comprise an elongated transversely streamlined cruise plug mounted on each such plate generally centrally thereof in perpendicular relation to such plate, and wherein each such plate and cruise plug is pivotally mounted intermediate the ends of each, on radial axes, said cruise plug element being thereby rotatable into an operative position extending transversely to the flow through the orifice, with the corresponding plate positioned parallel to the flow, and in such position cooperating with the orifice and producing a rearwardly divergent nozzle effect, or being rotatable alternatively into a position wherein the plate partially obstructs flow, and the cruise plug element extends lengthwise of the direction of flow.

9. A jet engine nozzle comprising duct means forming a plurality of orifice openings of relatively elongated form each with opposite long sides and at least one short side, and arranged in different radial lines from a common center and spaced apart to permit outside air to flow into the spaces between the discharges from successively adjacent openings, noise suppression grid means mounted in each of such openings and adapted in shape and size when disposed perpendicularly to the direction of flow therein substantially to occupy such opening, each such grid means comprising a plurality of flow obstruction elements extending generally parallel to the short side of the associated opening and having a blunt downstream face separating the flow streams emerging from between adjacent obstruction elements to permit such outside air to enter the space therebetween, means pivotally supporting each of said grid means intermediate its short ends permitting pivoting thereof about an axis parallel to the short side of the associated opening into feathered position in the stream discharging through the opening, means to effect such pivotal movement of the grid means, and an elongated transversely streamlined cruise plug mounted intermediate its ends on each such grid intermediate the latter's sides and ends, substantially perpendicularly to such grid means, to swing into alignment with the stream passing through the associated opening with the grid means disposed transversely to such stream and to swing into position extending transversely of such stream along the length dimension of the opening with the grid means feathered, each such plug element in its latter position being of a shape to produce, in combination with the long sides of its opening, a divergent nozzle effect.

10. A jet propulsion engine nozzle comprising spaced walls defining a rearwardly directed annular discharge orifice, a plurality of assemblies each including a cruise plug means and a noise suppression grid means each occupying a portion of said annular orifice and collectively filling the same, each assembly being supported within its portion of the orifice for movement of its cruise plug means into an operative position with relation to the orifice walls, while its grid means are in an inoperative position, and conversely for movement of its grid means into an operative position with relation to its portion of the orifice while its cruise plug means are in an inoperative position, each cruise plug means defining an elongated and arcuate but substantially streamlined form which is at least approximately uniform in cross section throughout its length, and which in its operative position is disposed intermediate the walls of its portion of the orifice to divide such portion and to define convergent-divergent restrictions, and each grid means comprising a plurality of flow dividers oriented, when in the operative position of the assembly, to extend transversely across its portion of the orifice, in successively spaced relation, to define spaced separate gas streams exiting from such portion of the orifice, and to restrict such portion of the orifice, the several assemblies being each pivotally mounted for rotation about an axis disposed radially of its portion of the orifice, intermediate the ends of each of its cruise plug means and its grid means, intermediate two positions, and means to move all said assemblies conjointly from one such position, wherein the cruise plug means are all in their operative positions and the grid means are all in their inoperative positions, to the second position wherein all the grid means are in their operative positions and the cruise plug means are in their inoperative positions, and back again to the respectively opposite positions, the grid means and the cruise plug means of the several assemblies being shaped, each relative to the other, such that the increasing and decreasing restriction effect produced by movement of one thereof between its two positions at least partially offsets the opposing change of restriction effect produced by the conjoint movement of the other.

11. A jet engine nozzle as in claim 1, wherein the orifice is defined by duct means forming a rearwardly directed discharge opening for exhaust gases from the engine and wherein the cruise plug means comprises a pair of fairing surface members, pivotal support means supporting said fairing surface members disposed side by side extending generally across said opening normally in the direction of discharge, generally intermediate opposite sides of the duct means, said pivotal support means being connected to such members near the rear ends thereof to permit pivoting of each toward and from the other between a normal position extending generally in the direction of discharge and a separated position substantially obstructing direct rearward discharge through said orifice, and means cooperating with said fairing surface members and duct means to form an opening through said nozzle permitting forward discharge of such gases when said members are in said separated position.

12. The jet engine nozzle defined in claim 11, including means effecting relative movement of the duct means and fairing surface members whereby the latter are displaced relatively to the rear of said duct means, thereby permitting the forward edges of said fairing surface members to swing apart beyond the adjacent sides of said duct means for directing the gases forwardly.

13. The jet engine defined in claim 12, wherein the fairing surface members are formed with opposite convex curvature lengthwise thereof, forming, in cooperation with adjacent sides of the duct means, a rearwardly tapered cruise plug effect producing divergent-orifice flow rearwardly through the discharge opening in the normal position of said members.

14. The jet engine defined in claim 11, including means effecting rearward movement of the duct means relatively thereby to form an opening in the side of the engine, a forward portion of said duct means adjacent said side opening forming a forwardly and outwardly inclined directing surface for gases obstructed by the fairing surface members in their relatively separated position, whereby reverse thrust is produced.

15. The jet engine defined in claim 14, wherein the fairing surface members are formed with opposite convex curvature lengthwise thereof, forming, in cooperation with adjacent sides of the duct means, a rearwardly tapered cruise plug effect producing divergent-orifice flow rearwardly through the discharge opening in the normal position of said members.

16. The jet engine defined in claim 11, wherein the fairing surface members are formed with opposite convex curvature lengthwise thereof, forming, in cooperation with adjacent sides of the duct means, a rearwardly tapered cruise plug effect producing divergent-orifice flow rearwardly through the discharge opening in the normal position of said members.

17. The jet engine defined in claim 16, wherein the fairing surface members are adapted for movement more closely together from their normal position, thereby to feather the same in relation to rearward discharge through the nozzle, whereby the rearward divergence of the orifice is decreased.

18. The jet engine defined in claim 17, and a plurality of stream divider elements having bluff downstream sides, mounted on each of the fairing surface members to project therefrom toward the opposite such member, said stream divider elements extending in substantially linear series arrangement transverse to the direction of flow, said stream divider elements being disposed substantially wholly between said fairing surface members in the normal position of the latter and being adapted to project laterally beyond such members and across the flow of gases passing by such members in their feathered position, thereby to divide the discharge into a plurality of smaller separate streams, reducing engine noise.

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