

Feb. 13, 1962

D. M. DOLLIVER
REVERSIBLE-THRUST SOUND SUPPRESSION JET
NOZZLES WITH MOVABLE EJECTOR RINGS

3,020,712

Filed June 22, 1959

4 Sheets-Sheet 1

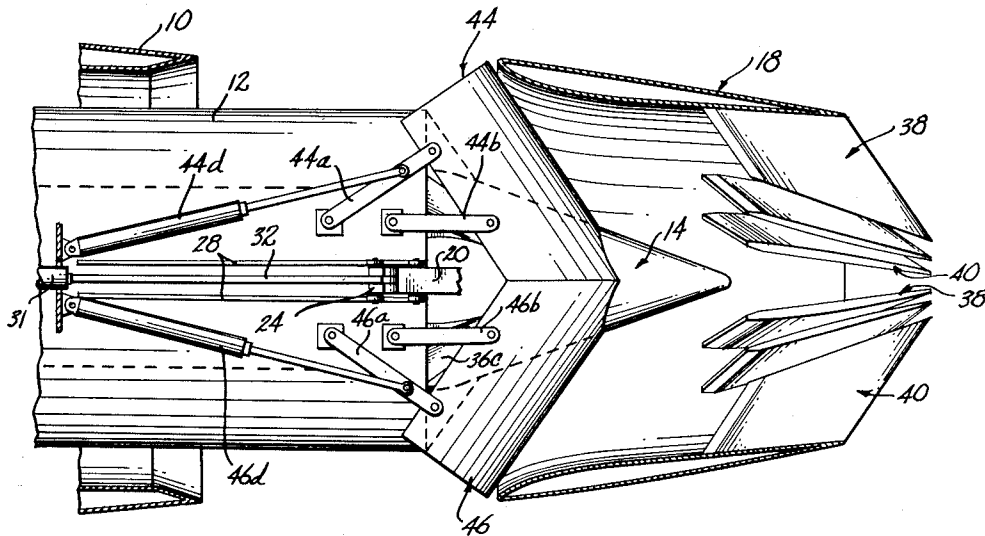
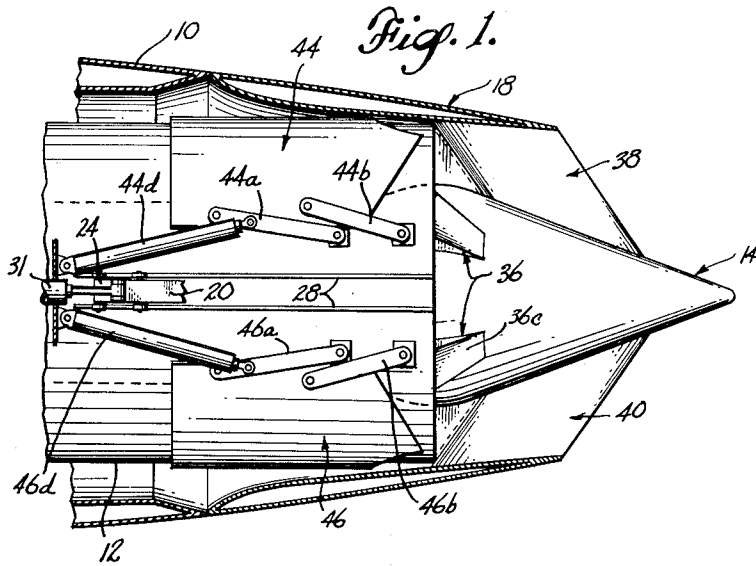


Fig. 5.

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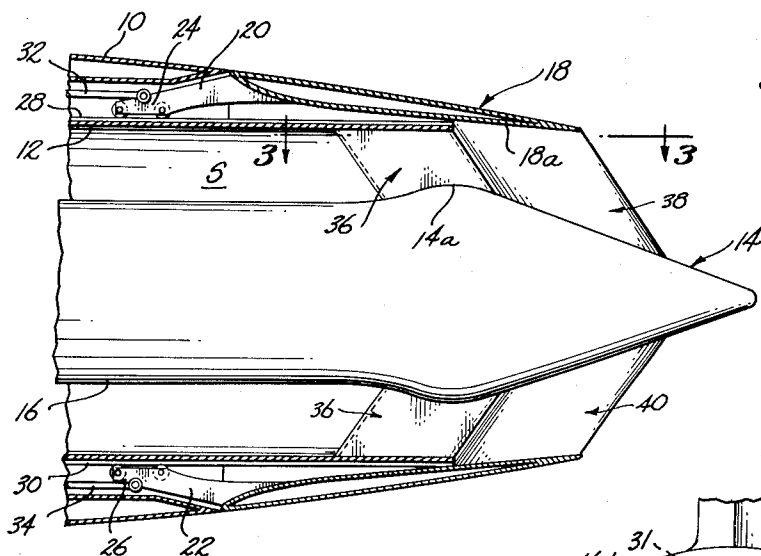


Fig. 2.

Fig. 4.

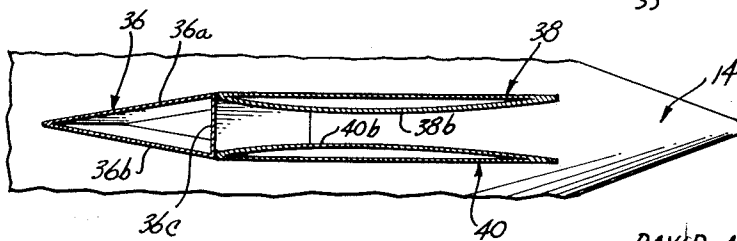
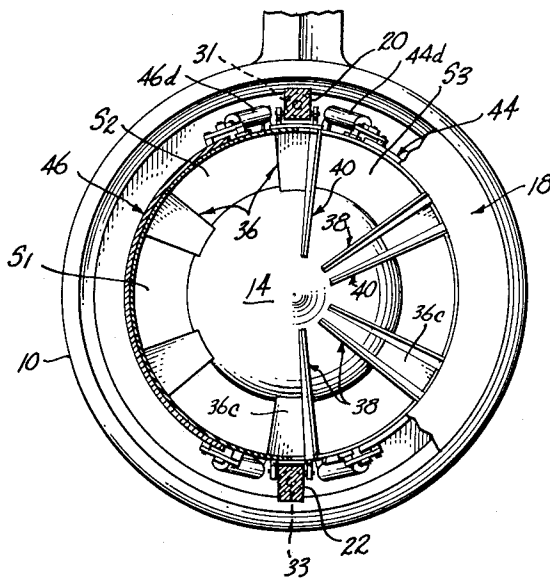


Fig. 3.

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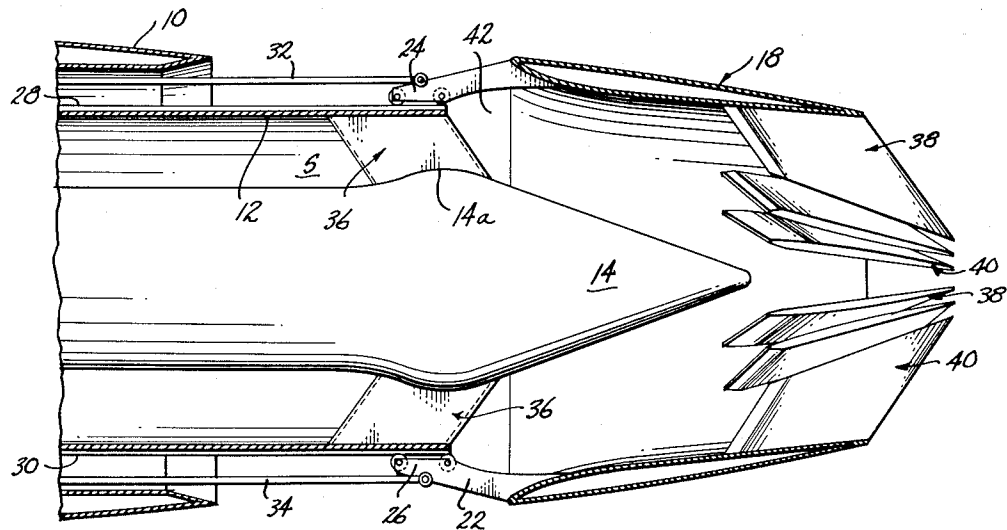
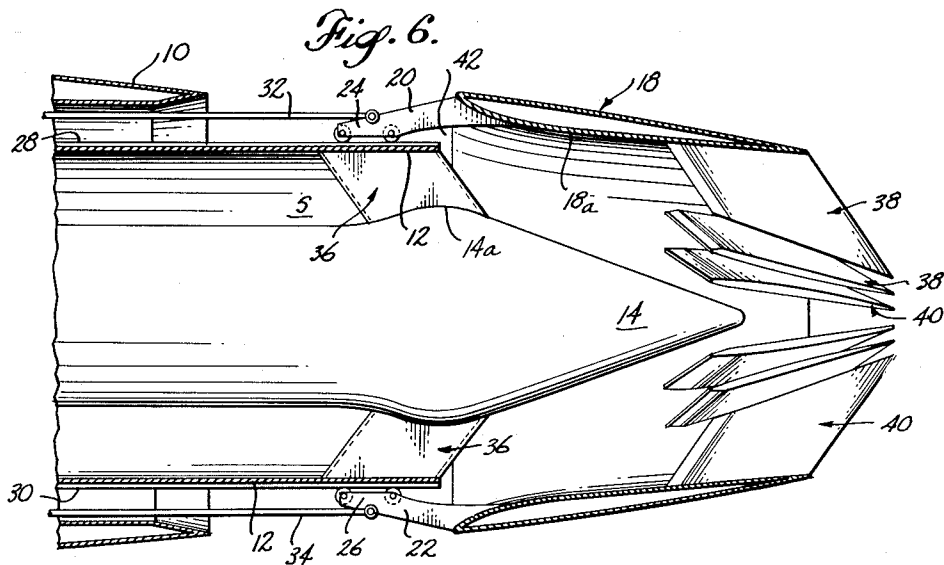


Fig. 7.

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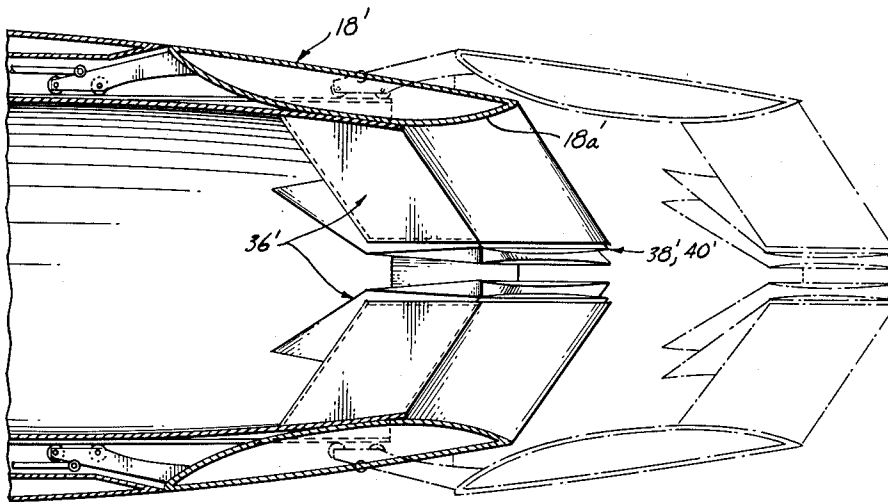


Fig. 8.

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REVERSIBLE-THRUST SOUND SUPPRESSION JET NOZZLES WITH MOVABLE EJECTOR RINGS

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This invention relates to improvements in jet nozzles and more particularly to airplane jet engine nozzle configurations which are convertible between substantially optimum forms effective for cruise, takeoff and climb, and thrust reversal operation, respectively. 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 underlying or essential features involved.

A broad object of the invention is to provide an improved nozzle configuration which may be set to produce a convergent orifice effect with maximum noise suppression for takeoff and climb operation, and which may be reset to an efficient convergent-divergent form, while retaining substantial noise reduction, for cruise or high-speed flight operation.

A related object is to provide such a nozzle with relatively low base drag in either of the two forward-thrust settings mentioned above.

A further object is to achieve a nozzle configuration wherein the components are organized compactly and so interrelated that the distances of movement of the ejector assembly required in converting between settings of the nozzle are relatively short and the actuating mechanism and guide means cooperating therewith are therefore comparatively short and may be relatively simple and well suited to rugged, durable and light-weight construction.

A further object, in more specific terms, is to provide a nozzle means which performs the multiple functions of boosting thrust and enhancing noise suppression in the takeoff setting of the nozzle while cooperating with the engine plug or tail cone in a unique manner to provide an efficiently formed convergent-divergent orifice having low-noise properties in the cruise settings.

Further the invention provides an effective nozzle configuration which makes efficient use of the clam shell door thrust reverser principle disclosed in the copending application Serial No. 740,721, June 9, 1958, of James and Pearson.

Various features of the invention will be recognized in an overall combination of components as well as sub-combinations thereof, the nature of which will be described in specific terms in conjunction with the drawings. In brief terms, one feature of importance resides in the provision of an annular ejector ring or sleeve having a forwardly retracted position wherein its forward end merges with the nozzle wall proper and thereby forms a rearward extension of the nozzle wall and, in cooperation with the tail cone or plug, provides a convergent-divergent orifice effect efficient for cruise operation. As a result of this relationship, only a minimum displacement of the ejector ring aft to its takeoff setting is required, permitting use of relatively short actuators. Preferably radially disposed and circumferentially spaced vortex generator plates are mounted within and upon the after portion of the ejector, and with the latter in its forward or cruise position serve as rearward extensions of fixed jet stream radial divider fingers mounted at circumferentially spaced locations in the nozzle proper. These divider fingers suppress engine noise during the takeoff conditions with the ejector ring extended rear-

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wardly. Such rearward positioning of the ejector ring not only converts the nozzle to a convergent form efficient for takeoff operation but opens an annular space aft of the nozzle which permits inflow of outside air induced or enhanced by the ejector. This, in turn, promotes more rapid mixture with discharge gases. Also, rearward positioning of the ejector ring places the vortex generator plates in a position to add their effect to the rapid mixture of gases with air and further suppresses noise.

A rearwardly tapered airfoil internal form of the ejector ring provides, in the ejector's extended position, not only efficient ejection but a desirable increase of nozzle thrust over that which would be produced with an equivalent convergent nozzle lacking the ejector.

Still other features reside in the combination wherein the thrust-reverser means comprises clam shell doors which, in their retracted position during cruise, nest compactly between the nozzle wall and the surrounding forward portion of the ejector ring and in their rearwardly extended or reverse-thrust position lie obliquely to the jet axis at a location immediately aft of such wall and ahead of the rearwardly displaced ejector ring.

These and other features, objects and advantages of the invention, together with preferred details of the illustrative embodiment thereof, will become more fully evident from the following description with reference to the accompanying drawings.

FIGURE 1 is a somewhat simplified longitudinal sectional view of the improved jet nozzle with components positioned in the cruise setting of the nozzle.

FIGURE 2 is a similar view taken in a plane at right angles to the plane of the view in FIGURE 1 and with the clam shell door reverser mechanism eliminated from the view to simplify and clarify the illustration, the view illustrating a suitable means for movably mounting the ejector assembly.

FIGURE 3 is a sectional detail view showing one of the stream divider fingers and cooperatively associated pair of ejector plates constituting rearward extensions of the fingers with the ejector assembly in its forwardmost or cruise position, the view being taken on line 3—3 in FIGURE 2.

FIGURE 4 is a rear view of the nozzle, with parts broken away to show certain details of construction, and with the nozzle setting as in FIGURES 1 and 2.

FIGURE 5 is a view similar to FIGURE 1 with the nozzle in the reverse-thrust position, the ejector assembly being moved aft by the maximum amount and the clam shell doors being positioned obliquely in the space opened up by rearward positioning of the ejector assembly.

FIGURE 6 is a view similar to FIGURE 2 illustrating the ejector assembly positioned for maximum noise-suppression during takeoff and climb operation.

FIGURE 7 is a view similar to FIGURE 6 showing the additional rearward displacement required in the illustrated design in order to make an opening for extension of the thrust reverser doors as in FIGURE 5.

FIGURE 8 is a view corresponding to FIGURE 2, showing a modification.

Referring to the drawings, the illustrated fragmentary end portion of the outer cowl 10 is spaced outwardly from the nozzle wall 12 which it surrounds in order to make room for actuating and guide means to be described by which the movable components of the convertible nozzle are controlled. The tail cone or plug 14 constitutes a rearward continuation of the central island 16 which extends therefrom forwardly to the turbine hub (not shown) where it is supported in the usual manner. In this case the tail cone is preferably of the type having a protuberant base portion 14a where it joins the cylindrical island 16. The confined orifice space defined between the tail cone and the surrounding cylindrical wall

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12 is extended by the inside surface 18a of the after portion of an elongated ejector ring 18, with such ring in its stowed or retracted position as shown in FIGURES 1 and 2. The surface 18a thus constitutes a rearward extension of the nozzle wall 12 and cooperatively with such wall and the tail cone produces a convergent-divergent orifice effect efficient for cruise operation of the engine when the pressure ratio is relatively high. In the retracted position of the ejector ring 18 the forward end of this ring abuts the after end of the cowl 10 and the ejector ring serves as a rearward continuation of such cowl as well as a rearward continuation of the nozzle wall 12.

For reasons to be described more fully hereinafter the inside surface of the ejector ring 18a is of an aerodynamic form characterized by a gradual increase in thickness rearwardly from its rather sharply defined forward annular edge followed by a more gradual decrease in thickness toward its sharply defined after edge. The general form of the ejector ring is rearwardly convergent at a small angle of the order of 10 degrees, a feature, which in conjunction with the airfoil configuration of the ejector, not only enhances the ejector action but imparts an increment of an additional thrust to the nozzle in the takeoff setting thereof (FIGURE 6). However, such rearward convergence of the inside ejector wall 18a is materially less than the rearward convergence of the major portion of the nozzle in the takeoff setting thereof, which effect is defined principally by the cooperative relationship between the extended ejector ring and the tail cone surface, is a convergent effect. This makes for efficient operation during takeoff and climb, when the pressure ratio is relatively low.

The ejector ring is mounted by cantilever arms 20 and 22 on wheeled carriage units 24 and 26 respectively which engage tracks 28 and 30 mounted on the nozzle wall exterior extending longitudinally in the annular space defined between the cowl 10 and nozzle wall 12 as shown. Movement fore and aft along these tracks is effected by actuator means 31 and 33 connected to the carriages through actuator rods 32 and 34 respectively. The ejector ring 18 is movable in this manner between its forwardly situated cruise position shown in FIGURES 1 and 2, its rearwardly displaced takeoff position shown in FIGURE 6 and its rearwardmost reverse-thrust position shown in FIGURES 5 and 7.

At the location of the base or bulge region of the tail cone, which represents the choke region of the nozzle in its cruise setting, the annular flow space S defined between the nozzle wall 12 and the island-cone assembly is divided circumferentially into segments or branches S₁, S₂, S₃, etc. by radially extending stream splitting fingers 36, of which there are six in the illustrated embodiment arranged at equal intervals around the circumference of the nozzle interior. A greater or lesser number of fingers may be used if desired. These fingers are of forwardly tapered wedge-like configuration as shown in FIGURE 3 and are conveniently formed by side plates 36a and 36b which meet at their forward edges and which diverge rearwardly therefrom to rearward edges which terminate at their outer ends substantially on the rear lip or edge of the nozzle wall 12 (FIGURE 2). A transverse stiffener plate 36c interconnects the side plates 36a and 36b near their rearward ends and closes off the space between side plates. The inner and outer edges of such plates are joined respectively to the island-cone assembly and to the nozzle wall 12, as by welding or other suitable technique. Preferably these fingers lean forwardly or against the stream from their inner edges in order to further minimize their impedance effect or drag, by delaying shock wave formation.

In the cruise setting of the nozzle shown in FIGURE 2 rearward extensions of the stream-dividing fingers 36 are provided by pairs of substantially parallel vortex generator plates 38 and 40 carried by the ejector ring

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18 at circumferentially spaced locations corresponding to the similar locations of respectively opposite sides of the individual fingers 36 (FIGURE 3). Preferably the members 38 and 40 of each pair of vortex generator plates have substantially flat and relatively parallel outside faces which are substantially flush with the outside rear edges of the finger side plates 36a and 36b, and have spaced-apart inside surfaces 38b and 40b which are of airfoil configuration. This airfoil configuration has no effect in the cruise setting of the nozzle, of course, wherein the ejector plates 38 and 40 are in abutment to the after edges of the fingers 36. However, in the takeoff or climb setting (FIGURE 6), they form open channels for flow of discharge gases and air, and under these conditions their airfoil configuration gives rise to the desired vortex action of the plates without introducing material drag or resistance to flow through the nozzle. As will appear in FIGURE 2 the breadth of the plates 38 and 40 measured lengthwise of the nozzle corresponds substantially to the free projecting length of the ejector ring 18 in its cruise position, i.e. that portion which projects beyond the after end of the nozzle wall proper 12, such that the forward edges of these plates abut the fingers 36. The after ends of the plates 38 and 40 lie at substantially the same angle of slope to a transverse plane perpendicular to the axis of the engine as their forward ends, and extend from the rearward extremity of the ejector ring 18 inwardly substantially to the surface of the tail cone 14 near the tip of the latter. The inner edges of the plates 38 and 40 preferably lie in contact with or in close proximity to the sloping surface of the tail cone along the entire length of these plates in the cruise setting of the nozzle.

In the cruise setting of the nozzle the gases discharging from the nozzle through the branch openings S₁, S₂, S₃, etc. emerge in substantially separated streams, the regions of separation being defined by the fingers 36 and rearward extensions thereof (38 and 40), so that outside air surrounding the nozzle is induced or drawn inwardly into these regions to promote rapid mixture thereof with the issuing gases. This process, as a means to reduce or suppress jet noise, is described in the co-pending applications Serial No. 562,050 of George S. Schairer filed January 30, 1956, now abandoned, and Serial No. 563,952 of William A. Reinhart filed February 7, 1956, now abandoned. Inward sloping of the after edges of the dividers is disclosed in the application of Merle B. McKaig, Serial No. 690,357 filed October 15, 1957. The effect is to reduce the total noise level of the jet stream and to shift much of the noise energy in the lower spectrum of the jet to a higher frequency so that atmospheric attenuation prevents this noise from reaching persons in the vicinity with the same high intensity as it would at a lower frequency.

In the takeoff and climb setting shown in FIGURE 6, the nozzle operates with maximum noise suppression and, with a purely convergent orifice form, yields relatively high thrust efficiency taking into consideration the relatively low pressure ratio at which the engine is then operating. In this setting of the nozzle, effected by rearward projection of the ejector sleeve to a position wherein its forward edge lies approximately at or slightly to the rear of the rearward edge of the nozzle wall 12, an annular opening 42 is defined between the ejector ring and nozzle wall through which outside air may flow freely into the region within the ejector ring. Such inflow of outside air is induced at a forced rate by the ejector action of the ring due to its location and form (i.e., its rearward convergence and its airfoil interior configuration). Due to this effect, greater volumes of air are drawn into the regions between the jet branch streams formed by the fingers S₁, S₂, etc., to promote the noise-reducing mixing action, than in the cruise setting. Moreover, further turbulence and mixing is caused immediately downstream by the now rearwardly displaced vortex

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generator plates 38, 40, so that the jet stream finally emerging does so with materially reduced noise intensity. It is also found that the airfoil configuration and the slight rearward convergence of the ejector ring in its takeoff setting (FIGURE 6) adds materially to the total thrust produced by the nozzle and more than offsets any slight reduction of thrust occasioned by the presence of the vortex generators in the jet stream, the comparison being based on the nozzle configuration with the ejector assembly removed altogether.

The improved nozzle as an overall combination further comprises arcuately-shaped clam shell reverser doors or plates 44 and 46 by which, in the reverse-thrust setting of the nozzle (FIGURES 5 and 7), the discharging gases are intercepted and directed generally outwardly and forwardly in order to provide dynamic braking for the airplane in accordance with well known principles. In this instance, however, the clam shell doors are normally stowed or nested compactly in the space between the nozzle wall 12 and the forwardly retracted ejector ring 18. For reasons of compactness such doors preferably have approximately the same cylindrical form and radius as the nozzle wall 12, so as to lie closely adjacent to such wall in their nested position.

These reverser doors are movably mounted to swing from their nested position to their extended or reverse-thrust position shown in FIGURE 5 wherein they lie obliquely to the engine axis, i.e., define an obtuse angle with such axis at their after sides. To accomplish the combined longitudinal and angular movements necessary in shifting the clam shell doors between nested and operating positions, each side of the door 44 is mounted on a pair of hinged arms or links 44a and 44b and each side of the door 46 is mounted on a similar pair of links 46a and 46b.

The inner ends of the links 44a, 44b, 46a and 46b are pivotally mounted on the nozzle wall 12 and their outer ends are pivotally mounted on the associated doors. For reasons which will appear in analyzing the trajectory of movement of the doors between positions, the pivoted inner ends of the links of each pair should be spaced apart by a lesser distance measured lengthwise of the nozzle than the spacing between the pivoted outer ends thereof measured lengthwise of the associated door. Hydraulic or air-actuated jacks 44d at each side of the door 44 are connected to the corresponding links 44a in order to swing the door 44 between positions, while a similar hydraulic or air-actuated jack 46d is connected in like manner to the link 46a of door 46. These jacks, of which there are two pairs, one on each side of the nozzle, are caused to move the doors between positions simultaneously so as to maintain a symmetry or balance in the delivery of gases from opposite sides of the nozzle. Suitable controls, including valves and valve actuators (not shown) will be readily envisaged for this purpose by those skilled in the art, and require no description herein.

In order to make room for positioning the clam shell doors operatively as in FIGURE 5 in the illustrated design, it is necessary to move the ejector assembly slightly rearwardly from its takeoff setting shown in FIGURE 6. Suitable controls for operating the ejector actuation mechanism are readily provided for this purpose as will be evident and likewise require no description herein. No movement of the clam shell doors is required, however, in converting the nozzle between the cruise setting (FIGURE 1) and its takeoff setting (FIGURE 6), as previously mentioned. Nor do the clam shell doors have any effect on the nozzle operation in either of these positions or in the transition between these positions inasmuch as the doors in their nested position are wholly outside the jet gas stream and are substantially shielded from the induced air stream as it enters the ejector.

It will further be observed that the effective orifice opening through the nozzle remains at all times substantially matched to the engine requirements. This is due to the

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fact that the orifice opening through the nozzle proper, i.e., through the space defined between the plug and the nozzle wall 12, is a substantially constant space or opening and that the shifting of the ejector assembly neither increases nor decreases this space. Consequently, the engine is permitted to operate stably and efficiently in all positions and during transitional movements of the movable portions of the nozzle. The interpositioning of the reverser doors in the gas stream so as to divert the gases in a forward direction is designed with this same consideration of a matched orifice in view, so that during the interpositioning movement there is comparatively little, if any, change in effective orifice area of the nozzle proper.

In some cases the convergent-divergent nozzle effect may be provided without use of a tail cone or plug. Thus, the rearward portion of the ejector ring assumes an increasing rearward divergence approaching the aft terminus thereof as depicted in FIGURE 8. As a result the ejector ring 18' in its forward position provides a divergent nozzle wall extension 18'a with the choke plane located forwardly of the exit plane, in its partially extended position or noise suppression setting (shown by dotted lines) its general rearward taper that of its forward portion and more particularly provides the desired ejector action. In FIGURE 8 the fingers 36' and pairs of plates 38', 40' extend radially inward substantially to the nozzle axis as shown.

While the invention has been described in its preferred embodiment, it will be recognized that the same in its full scope is not necessarily limited to the illustrated details which have been set forth herein for purposes of explanation.

I claim as my invention:

1. A jet engine noise suppression nozzle comprising a tubular nozzle duct having an exit end with a plurality of transversely disposed, peripherally separated stream dividers mounted in said duct, said stream dividers having bluff aft ends extending transversely to the direction of nozzle discharge and located substantially at said exit end, said stream dividers extending forwardly from said ends in said duct, a normally retracted ejector sleeve extending around said exit end and comprising a rearward extension from the exit end of said duct for confining the discharging gases issuing therefrom, means mounting said sleeve to permit rearward extension movement thereof from said duct to form a gap therebetween for admitting slipstream air into said sleeve, and a plurality of pairs of transversely disposed substantially parallel vortex generator plates mounted in said sleeve in substantially coplanar longitudinally extending alignment with the respective opposite edges of each of said bluff ends, the forward ends of said plates being located adjacent to said bluff ends with the sleeve retracted, and the aft ends of said plates extending aft in the sleeve at least substantially to the aft end thereof.

2. The nozzle defined in claim 1, wherein the plates are of airfoil configuration, each including a longitudinally convexly curved surface and an opposite less convex surface, the convexly curved surfaces of the plates of each pair facing each other.

3. The nozzle defined in claim 2, wherein the duct and sleeve are annular and the sleeve has a longitudinally convexly curved interior wall, and wherein the nozzle duct comprises a nozzle wall having an exit opening through which engine gases discharge, and an outer cowl having an after end surrounding and forwardly spaced and outwardly from said nozzle wall exit opening, the bluff stream divider aft ends extending radially inward from the peripheral edge of such nozzle wall at peripherally spaced locations therein.

4. The nozzle defined in claim 3, and a rearwardly tapered plug mounted centrally in the duct and extending aft therefrom at least part way through the length of the

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sleeve, the bluff ends of the stream dividers being sloped inwardly and rearwardly from the aft edge of said wall.

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