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3,346,193

SUPERSONIC EJECTOR TYPE EXHAUST NOZZLE

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3 Sheets-Sheet 2

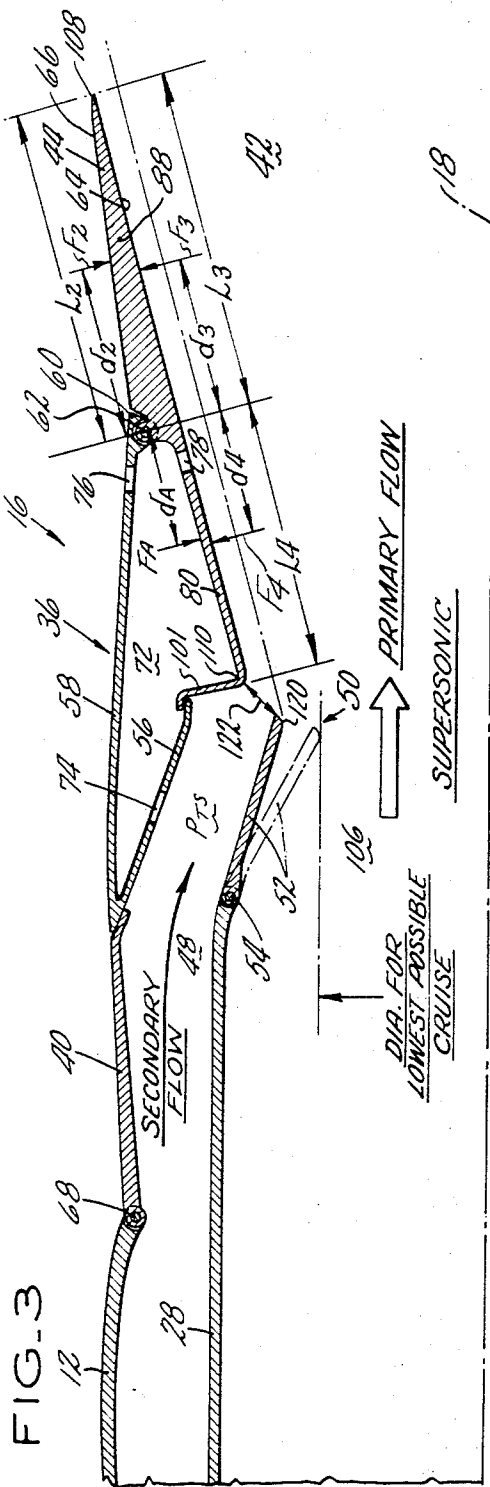
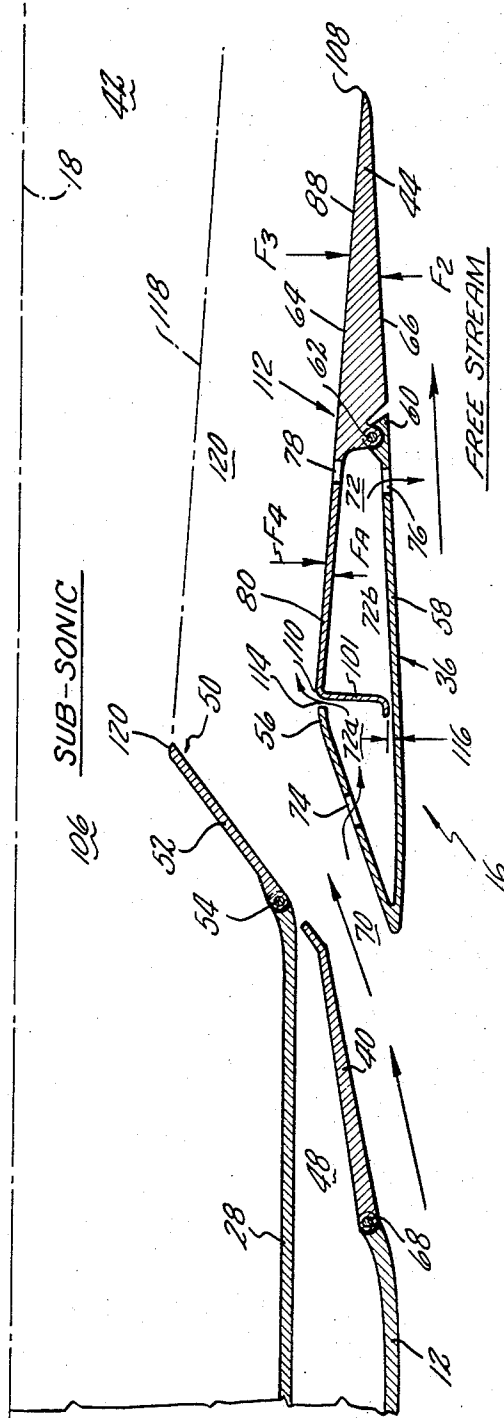


FIG. 2



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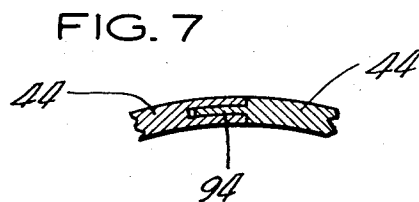
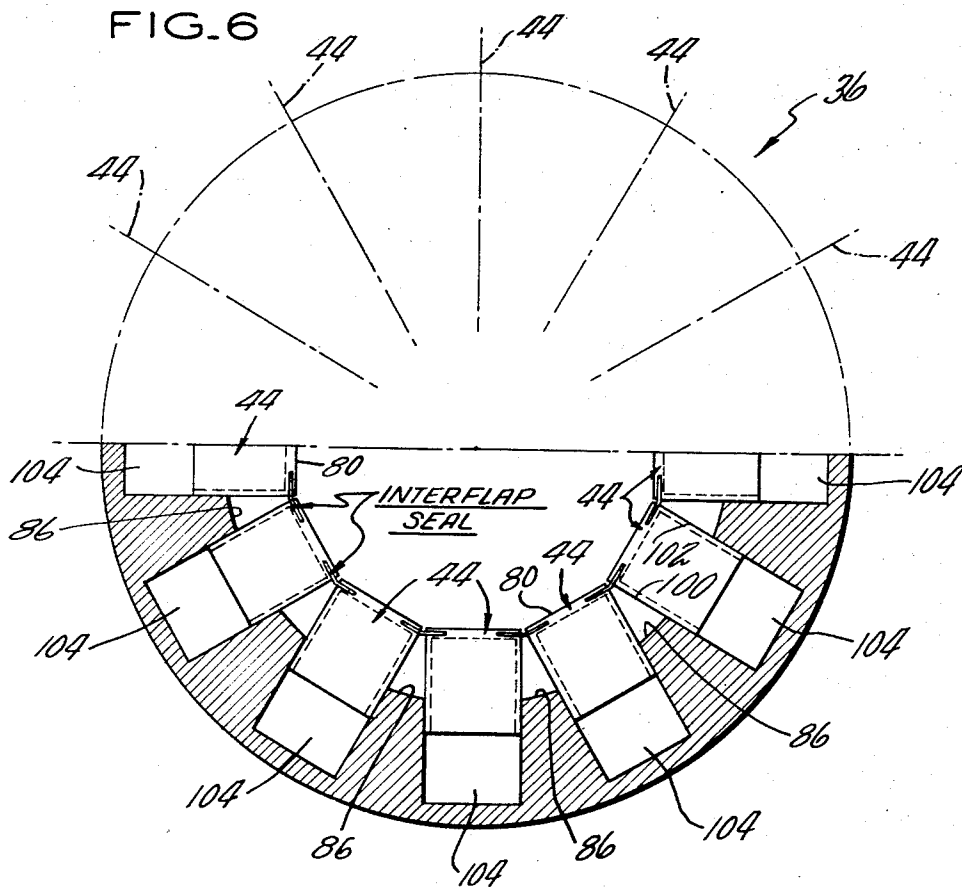
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3,346,193 SUPERSONIC EJECTOR TYPE EXHAUST NOZZLE

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10 Claims. (Cl. 239—265.17)

This invention relates to exhaust nozzles for supersonic vehicles and more particularly to exhaust nozzles of the ejector type.

It is an object of this invention to teach a supersonic exhaust nozzle which presents additional surface against which the engine exhaust gases may expand during supersonic operation and also which produces increased secondary flow pressure during supersonic operation both to assist in varying the geometry of the exhaust nozzle and also to act against the aforementioned expansion surface with the exhaust gas to produce added thrust.

It is a further object of this invention to teach a supersonic ejector type exhaust nozzle including a plurality of flaps which are pivotally attached to a fixed member at a selected position along their length so that the flaps extend both forwardly and rearwardly of the pivot point and so that the flaps cooperate with the fixed member to define a pressurizable chamber, the pressurization of which assists in the actuation of said flaps so that the flaps are aerodynamically actuated.

Other objects and advantages will be apparent from the specification and claims and from the accompanying drawings which illustrate an embodiment of the invention.

FIG. 1 is a side view of a power plant for a supersonic vehicle utilizing my exhaust nozzle and partially broken away to illustrate some interior construction.

FIG. 2 is a cross-sectional showing through the bottom half of my exhaust nozzle to illustrate the exhaust nozzle in its subsonic position.

FIG. 3 is a cross-sectional showing through the top half of my exhaust nozzle to illustrate the exhaust nozzle in its supersonic position.

FIG. 4 is a view taken outwardly from the center line of my exhaust nozzle, with the primary nozzle removed, to illustrate the position of the nozzle flaps in the fixed member when the exhaust nozzle is in the subsonic position.

FIG. 5 is a view taken outwardly from the center line of my exhaust nozzle to illustrate the position of the flaps in the fixed member when the exhaust nozzle is in the supersonic position.

FIG. 6 is a view taken along line 6—6 of FIG. 5.

FIG. 7 is a view taken along line 7—7 of FIG. 4.

Referring to FIG. 1 we seen supersonic engine, power plant or vehicle 10 which includes nacelle or fuselage 12, engine 14 and my exhaust nozzle 16, all of which are circular in cross section and concentric about axis 18. Engine 14 includes compressor 20, burner 22 and turbine 24 and optionally may include afterburner 26 all enveloped within casing 28, which is of circular cross section and concentric about axis 18. Engine 14 is a conventional design and may be of the type described in greater particularity in U.S. Patents Nos. 2,711,631, 2,747,367, 2,458,600, 2,610,465, 2,979,900 or 2,753,685.

Afterburner 26 includes fuel manifold 30 from which fuel spray bars 32 project to inject fuel into afterburner 26, and further includes flameholders 34, which create a combustion supporting zone downstream thereof.

My exhaust nozzle 16 includes fixed member or shroud 36, which is supported from fuselage or nacelle 12 by a plurality of struts 38, blow-in doors 40 and secondary exhaust nozzle 42, which is made up of a plurality of trailing edge flaps 44.

In operation, air enters supersonic vehicle 10 through supersonic inlet 46 and passes therefrom either through secondary flow passage 48 or engine 14. The air which passes through secondary flow passage 48 may be ram air only or may have compressed air from compressor 20 added thereto in conventional fashion (not shown) and may or may not include provisions for heating the secondary air by the burning of fuel in passage 48 by conventional apparatus (not shown). The secondary gas eventually joins the primary gas, which passes through engine 14, in exhaust nozzle 16 in a manner to be described in greater particularity hereinafter. The air which enters engine 14 is compressed in passing through compressor 20, has heat added thereto in passing through burner 22, and has sufficient energy extracted therefrom in passing through turbine 24 to drive compressor 20. After passing through turbine 24, the primary air or gas then passes into afterburner 26 where additional heat is added thereto due to the burning of fuel therein from spray bars 32, and then through exhaust nozzle 16 to be discharged as a high velocity jet of high energy gas to create thrust.

My exhaust nozzle 16 is an ejector type exhaust nozzle of the type disclosed in U.S. Patent No. 3,062,003, but constitutes an improvement thereover.

My exhaust nozzle 16 is shown in greater particularity in FIGURES 2-6. Referring to FIG. 2, we see my exhaust nozzle 16 in cross section in its subsonic position. Exhaust nozzle 16 includes primary exhaust nozzle 50, which comprises a plurality of circumferentially positioned flaps 52 pivotally attached at pivot point 54 to engine or afterburner case 28, and also includes fixed member or shroud 36 which is positioned concentrically outwardly of primary exhaust nozzle 50 and includes inner surface or wall member 56 and outer surface or wall member 58. Flaps 44 pivotally attach to the trailing, rearward or downstream end 60 of fixed member outer wall 58 at pivot point 62 and include an inner surface 64 which provides a conical, divergent exhaust gas and secondary gas expansion surface when in the FIG. 3 supersonic position and which also provides a conical expansion surface when exhaust nozzle 16 is operating in the FIG. 2 subsonic, ejector fashion for the ejector air to act against. Flaps 44 also includes outer surface 66 which forms a smooth continuation of the outer surface 58 of fixed member 36 when flaps 44 are in their subsonic, FIG. 2 position and which cooperates with outer surface 58 of fixed member 36, blow-in doors 40 and nacelle or fuselage 12 to present a substantially cylindrical and smooth exterior surface when the exhaust nozzle 16 is in its FIG. 3 supersonic position. Flaps 44 are circumferentially positioned about annular fixed member 36 so that the expansion surface 64 is conical in shape at all times. Flaps 44 cooperate with fixed member 36 to define pressurizable chamber 72 therebetween. Pressurizable chamber is in communication with secondary flow passage 48 through aperture 74, with free stream atmosphere through aperture 76 and with the exhaust gas stream through aperture 78. Blow-in doors 40 are pivotally attached to nacelle or fuselage 12 at pivot point 68 and are circumferentially positioned thereabout and extend between nacelle 12 and fixed member 36 to cooperate therewith and with engine or afterburner case 28 and primary exhaust nozzle flaps 52 in defining secondary flow passage 48 when exhaust nozzle 16 is in its FIG. 3 supersonic position. Blow-in doors 40 may be aerodynamically actuated to an open position when exhaust nozzle 16 is in its FIG. 2 subsonic position and cooperates with the inner member 56 of fixed member 36 to define a free stream ejector passage 70 therebetween.

Flaps 44 are shown in greater particularity in FIGS. 4-6. Referring to FIG. 4, we see flaps 44 located within fixed member or shroud 36 in their subsonic position

shown in cross section in FIG. 2. In the subsonic position, the forward extensions 80 of flaps 44 are recessed into fixed member 36, with adjacent edges 82 and 84 of forward extension 80 separated from one another by pie-shaped sectors 86 of fixed member 36. Pie-shaped sectors 36 are shaped to cooperate with flaps 44 in defining a smooth conical inner surface 64 when exhaust nozzle 16 is in its subsonic FIG. 2 and FIG. 4 positions. When in this position, FIG. 4 illustrates that the rearward extensions 88 of flaps 44 define secondary outlet 42 with the adjacent edges 90 and 92 of rearward flap extensions 88 substantially in contact. Interflap seals 94 extend between adjacent rearward extensions 88 of flaps 44 to seal therebetween. Seals 94 are preferably of triangular shape and are received in and carried by a triangular slot in flap rearward extension 88 and are received in sliding engagement in similar triangular slots in adjacent extensions 88. Alternatively, interflap seals 94 may be triangular extensions of one flap received in a triangular recess in the adjacent flap as shown in cross section in FIG. 7.

FIG. 5 shows flaps 44 in their supersonic positions wherein adjacent edges 82 and 84 of flap forward extensions 80 abut while adjacent edges 90 and 92 of flap rearward extensions 88 are separated with the separations therebetween filled by interflap seals 94 so that flaps 44 continue to present conical inner surface 64 when in their supersonic position, shown in cross section in FIG. 3.

FIG. 6 shows flaps 44 in cross section with respect to fixed member 36 when in their supersonic position. It will be noted by referring to FIG. 6 that flaps 44 include side leg portions 100 and 102, which slide in and out of recesses 104 in fixed member 36. Flaps 44 also include forward leg, shown in FIGS. 2 and 3.

Operation

During subsonic exhaust nozzle operation, exhaust nozzle 16 is in the position shown in FIG. 2. The primary nozzle 50 has been actuated by conventional mechanism (not shown) so that flaps 52 are in their inner position defining primary exhaust outlet 106 in its minimum area position. Flaps 44 are in their closed position with secondary outlet 42 being in its minimum area position as defined by flap trailing edges 108. The flap forward or leading edges 110, together with the flap forward extensions 80 are recessed into fixed member 36 so that flaps 44 and fixed member 36 cooperate to define an annular shroud member 112 of aerodynamic cross-sectional shape having a smooth and substantially cylindrical outer surface defined by fixed member outer wall 58 and flap outer surface 66 and further having a convergent-divergent inner surface with the convergent portion thereof defined by inner wall 56 of fixed member 36 and the divergent portion thereof defined by the conical interior surface 64 of flaps 44. It should be noted that gap 114 exists between fixed member inner surface 56 and flap inner surface 64 and that gap 116 exists between chambers 72a and 72b of compressible chamber 72. In the subsonic condition, as free stream air passes over the outer surface of nacelle 12 and blow-in doors 40, the pressure thereof is greater than the static pressure acting on the blow-in doors 40 within secondary flow passage 48 and, therefore, blow-in doors 40 are aerodynamically opened to establish free stream ejector passage 70 between blow-in doors 40 and the inner wall 56 of fixed member 36. While the engine exhaust gases which discharge through outlet 106 of primary exhaust nozzle 50 expand approximately along line 118, the free stream air which enters through annular passage 70 passes between primary exhaust nozzle 50 and fixed member inner wall 56 and then fills the annular passage 120 between the exhaust gases within line or cone 118 and inner surface 64 of flaps 44. The secondary gas from secondary flow passage 48 also follows this path in conjunction with the free stream air. In this fashion, since the free stream atmospheric air and the secondary gas fill annular passage

120, air at atmospheric pressure is not permitted access adjacent to surface 64 of flaps 44, thereby avoiding the creation of drag.

With exhaust nozzle 16 in its FIG. 2 subsonic position, the free stream air which flows over gap 114 reduces, due to an aspiration effect, the pressure within chamber 72a, which pressure passes through gap 116 into chamber 72b, where it is further reduced both due to the aspiration effect of free stream air passing over aperture 76 and ejector air passing over aperture 78. It will accordingly be seen that the pressure within chamber 72b will be less than pressure acting on inner surface 64 of flap forward extension 80, such that the force designated as F_4 tending to restrain flap 44 in its FIG. 2 subsonic position is greater than the force F_A within chamber 72b tending to pivot the leading edge 110 of flap 44 radially inwardly. This force differential, together with the fact that the pressure acting against outer surface 66 of flap 44 is higher than the pressure acting against rearward extension 88 of flap 44, will retain flap 44 in its subsonic position.

When vehicle 10 proceeds from subsonic to supersonic operation or motion, flaps 52 of the primary exhaust nozzle 50 are actuated to or toward the maximum area FIG. 3 position so that when in the FIG. 3 supersonic position, primary outlet 106 is in its maximum area condition. As flaps 52 move outwardly, their trailing edges 120 move closer to the leading edge 110 of flaps 44, thereby restricting the outlet 122 of secondary flow passage 48 to increase the pressure within secondary flow passage 48, thereby closing blow-in doors 40 and increasing the pressure within chamber 72 by placing chamber 72 into communication with the higher pressure within secondary flow passage 48 through aperture 74. This increased pressure within chamber 72, together with the increased pressure acting upon the rearward extension 88 of flap 44 is sufficient to overcome the force of the free stream flow acting upon outer surface 66 of flap 44 and the forward extension 80 of flap 64, thereby causing flaps 44 to pivot to or toward their supersonic position such that flap forward edge 110 eventually reaches its FIG. 3 minimum area position, whereupon secondary flow passage outlet 122 is in its minimum area condition, while flap trailing edge 108 of rearward extension 88 eventually reaches its FIG. 3 maximum area position to define secondary outlet 42 at its maximum area condition. In addition to the increased pressure within chamber 72, the supersonic operation in view of the fact that exhaust gas expansion surface 64 is conical in nature, the total area against which the exhaust gases and the secondary flow gas can expand forward of flap pivot point 62 gradually decreases as forward extension 80 reduces in diameter and the total area against which exhaust gases and secondary flow air can expand downstream of flap pivot point 62 increases. Accordingly, in the supersonic position flap 44 has the following force equation acting thereon:

$$F3d_3 + F4d_4 > F2d_2 + F4d_4$$

It will be noted that when exhaust nozzle 16 is in its FIG. 3 supersonic position due to the addition of flap forward extension 80, the exhaust gases flowing through primary outlet 106 have a longer expansion surface 64 to act against than would be the case if flap 44 comprised, as is conventional, its trailing extension 88 only. Further, because flap forward extension 80 and primary nozzle 50 cooperate to restrict the outlet of secondary flow passage 48, the gas passing therethrough and acting against surface 64 is greater and hence produces more thrust than would be the case if fixed member 36 were fabricated in conventional fashion with inner wall 56 thereof joined directly to the trailing edge 60 thereof.

Accordingly, my exhaust nozzle 16 due to the construction of flap 44 and fixed member 36 provides a two-fold benefit in the supersonic position, namely an increased exhaust gas and secondary flow passage expansion sur-

face 64 is provided, and an increase in secondary flow pressure is provided to both increase thrust by acting against expansion surface 64 and also to aid in flap actuation by pressurizing chamber 72.

When vehicle 10 decelerates from its supersonic to its sonic condition, primary exhaust nozzle 50 reduces in area to increase the area of secondary flow passage outlet 122, thereby decreasing the pressure within chamber 72, which pressure is further reduced as previously described by the aspiration effect at gap 114 and apertures 78 and 76. This reduced pressure within chamber 72, aided by the momentum effect of the free stream air impinging against the slightly divergent outer surface 66 of trailing edge flaps 44 cause flaps 44 to pivot from their FIG. 3 supersonic positions to their FIG. 2 subsonic positions when these flaps experience the following force equation acting thereagainst:

$$F_4 d_4 + F_2 d_2 > F_3 d_3 + F_A d_A$$

When exhaust nozzle 16 is proceeding from supersonic to subsonic operation, the free stream pressure external of blow-in doors 40 will eventually exceed the static pressure of secondary flow passage 48 to open blow-in doors 40 so that exhaust nozzle 16 eventually arrives at its FIG. 2 supersonic position.

It will, therefore, be seen that blow-in doors 40 and flaps 44 are aerodynamically actuated.

It will be obvious to those skilled in the art that pressure within chamber 72 may be controlled by calibrating apertures 74, 76 and 78, that is, by properly selecting the size and number thereof.

While my exhaust nozzle 16 has been described as a nozzle of circular cross section and concentric about axis 18, it should be borne in mind that it could as well have been of the two-dimensional type disclosed in U.S. Patent No. 3,057,150.

It is to be understood that the invention is not limited to the specific embodiment herein illustrated and described but may be used in other ways without departure from its spirit as defined by the following claims:

I claim:

1. In an ejector type exhaust nozzle, a variable area primary exhaust nozzle movable between minimum area and maximum area positions, a fixed member positioned externally of said primary nozzle and cooperating therewith to define a secondary flow passage, a plurality of flaps attached to said fixed member for pivot action with respect thereto, said flaps extending rearwardly from the area of attachment to said fixed member and also extending forwardly from the area of attachment to said fixed member to define a forward end adjacent and external of said primary nozzle and an after end rearward of said fixed member, said flaps being movable to a closed or subsonic position wherein said flaps cooperate with said fixed member to define a smooth aerodynamic surface constituting an extension of said secondary flow passage and to an open or supersonic position wherein said flaps cooperate with said primary nozzle to constrict the outlet of said secondary flow passage and further wherein said flaps present divergent expansion surfaces rearward of said primary nozzle and wherein said fixed member and said flap forward extension cooperate to define a pressurizable chamber to move said flaps.

2. Apparatus according to claim 1 wherein said pressurizable chamber communicates with said secondary flow passage.

3. Apparatus according to claim 2 wherein said pressurizable chamber also communicates with atmosphere.

4. In an ejector type exhaust nozzle of circular cross-section and concentric about an axis, a primary exhaust nozzle concentric about said axis and having a trailing edge defining a primary outlet and being movable between a minimum area or subsonic position and a maximum area or supersonic position, a fixed member enveloping said primary nozzle concentrically and cooperating

therewith to define a secondary flow passage therebetween, a plurality of circumferentially positioned flaps pivotally attached to said fixed member at a pivot point, said flaps having an extension forward of said pivot point with the leading edge of said flap forward extension positioned adjacent said primary nozzle trailing edge and cooperating therewith to define the outlet of said secondary flow passage, said flaps further having an extension rearward of said pivot point, and including a trailing edge defining a secondary outlet, said flaps being movable to a supersonic position wherein said flap leading edges are in their minimum area position and wherein said flap trailing edges are in their maximum area position and wherein said flaps present a conically convergent exhaust gas expansion surface and further wherein said flap leading edge cooperates with said primary nozzle trailing edge to restrict said secondary flow passage outlet, said flaps further being movable to a subsonic position and wherein said flaps cooperate with said fixed member to define an aerodynamically shaped annulus defining a continuation of said secondary flow passage wherein said flap leading edges are in their maximum area position and wherein said flap trailing edges are in their minimum area position and wherein said fixed member and said flaps cooperate to define a pressurizable chamber therebetween.

5. In an ejector type exhaust nozzle of circular cross-section and concentric about an axis, a primary exhaust nozzle concentric about said axis and having a trailing edge defining a primary outlet and being movable between a minimum area or subsonic position and a maximum area or supersonic position, a fixed member enveloping said primary nozzle concentrically and cooperating therewith to define a secondary flow passage therebetween, a plurality of circumferentially positioned flaps pivotally attached to said fixed member at a pivot point, said flaps having an extension forward of said pivot point with the leading edge of said flap forward extension positioned adjacent said primary nozzle trailing edge and cooperating therewith to define the outlet of said secondary flow passage, said flaps further having an extension rearward of said pivot point, and including a trailing edge defining a secondary outlet, said flaps being movable to a supersonic position wherein said flap leading edges are in their minimum area position and wherein said flap trailing edges are in their maximum area position and wherein said flaps present a conically convergent exhaust gas expansion surface and further wherein said flap leading edge cooperates with said primary nozzle trailing edge to restrict said secondary flow passage outlet, said flaps further being movable to a subsonic position and wherein said flaps cooperate with said fixed member to define an aerodynamically shaped annulus defining a continuation of said secondary flow passage wherein said flap leading edges are in their maximum area position and wherein said flap trailing edges are in their minimum area position and wherein said fixed member and said flaps cooperate to define a pressurizable chamber therebetween and including means to increase the pressure in said chamber when said flaps and said primary exhaust nozzle are in said supersonic positions and to decrease the pressure in said chamber when said flaps and said primary exhaust nozzle are in said subsonic positions.

6. In an ejector type exhaust nozzle of circular cross-section and concentric about an axis a primary exhaust nozzle concentric about said axis and having a trailing edge defining a primary outlet and being movable between a minimum area or subsonic position and a maximum area or supersonic position, a fixed member enveloping said primary nozzle concentrically and cooperating therewith to define a secondary flow passage therebetween a plurality of circumferentially positioned flaps pivotally attached to said fixed member at a pivot point, said flaps having an extension forward of said pivot point with the leading edge of said flap forward extension

positioned adjacent said primary nozzle trailing edge and cooperating therewith to define the outlet of said secondary flow passage, said flaps further having an extension rearward of said pivot point, and including a trailing edge defining a secondary outlet, said flaps being movable to a supersonic position wherein said flap leading edges are in their minimum area position and wherein said flap trailing edges are in their maximum area position and wherein said flaps present a conically convergent exhaust gas expansion surface and further wherein said flap leading edge cooperates with said primary nozzle trailing edge to restrict said secondary flow passage outlet, said flaps further being movable to a subsonic position and wherein said flaps cooperates with said fixed member to define an aerodynamically shaped annulus defining a continuation of said secondary flow passage wherein said flap leading edges are in their maximum area position and wherein said flap trailing edges are in their minimum area position and including an engine case forward of said primary exhaust nozzle and to which said primary exhaust nozzle attaches, a nacelle concentrically enveloping said engine case and positioned forwardly of said fixed member, a plurality of blow-in doors pivotally attached to said nacelle and extending between said nacelle and said fixed member and movable between a supersonic position wherein said nacelle, said blow-in doors and said fixed member present a continuous and smooth exterior surface and a subsonic position wherein said blow-in doors cooperates with said fixed member to define a passage for the admission of free stream air into said exhaust nozzle.

7. Apparatus according to claim 5 and including a vent between said chamber and said secondary flow passage whereby said pressure within said chamber is increased when said flaps and said primary exhaust nozzle are in said subsonic positions and including a vent between said chamber and free stream atmosphere whereby the pressure within said chamber is decreased when said flaps and said primary exhaust nozzle are in said subsonic positions.

8. In an ejector type exhaust nozzle of circular cross-section and concentric about an axis a primary exhaust nozzle concentric about said axis and having a trailing edge defining a primary outlet and being movable between a minimum area or subsonic position and a maximum area or supersonic position, a fixed member enveloping said primary nozzle concentrically and cooperating therewith to define a secondary flow passage therebetween, a plurality of circumferentially positioned flaps pivotally attached to said fixed member at a pivot point, said flaps having an extension forward of said pivot point with the leading edge of said flap forward extension positioned adjacent said primary nozzle trailing edge and cooperating therewith to define the outlet of said secondary flow passage, said flaps further having an extension rearward of said pivot point, and including a trailing edge defining a secondary outlet, said flaps being movable to a supersonic position wherein said flap leading edges are in their minimum area position and wherein said flap trailing edges are in their maximum area position and wherein said flaps present a conically convergent exhaust gas expansion surface and further wherein said

flap leading edge cooperates with said primary nozzle trailing edge to restrict said secondary flow passage outlet, said flaps further being movable to a subsonic position and wherein said flaps cooperate with said fixed member to define an aerodynamically shaped annulus defining a continuation of said secondary flow passage wherein said flap leading edges are in their maximum area position and wherein said flap trailing edges are in their minimum area position and including means to pass engine exhaust gas through said primary exhaust nozzle so that said exhaust gas will expand against said flap expansion surfaces when said flaps and said exhaust nozzle are in said supersonic positions and so that the exhaust gas will pass through the central portion of said secondary flow passage extension when said flaps and said primary exhaust nozzle are in said subsonic position, and means to pass secondary gas through said secondary flow passage so that the secondary gas will increase in pressure as said secondary gas passage outlet is restricted and thereby pressurize said chamber and also act against the expansion surfaces of said flaps when said flaps and said primary exhaust nozzle are in said subsonic positions.

9. In a supersonic exhaust nozzle having an axis, a primary exhaust nozzle actuatable between a minimum area, subsonic position and a maximum area, supersonic position, a fixed shroud positioned laterally outward of said primary exhaust nozzle and including an inner wall converging toward said axis and cooperating with said primary exhaust nozzle to define a secondary flow passage therebetween and an outer wall which is substantially parallel to said axis and which has a rearward end positioned rearwardly of said inner wall, and a plurality of flaps pivotally attached to said shroud outer wall rearward end, said flaps having inner and outer surfaces and further having a forward extension forward of said pivot attachment and a rearward extension rearward of said pivot attachment, said flaps and said shroud being shaped so that when said flaps are in a subsonic position, said flap inner surface forms a divergent continuation of said shroud inner wall and said flap outer surface and said shroud outer wall form a substantially continuous surface so that said flaps and said shroud form a fixed member of aerodynamic cross-section having a convergent-divergent inner surface and a substantially continuous outer surface and so that when said flaps are in a supersonic position, said flap forward extension cooperates with said primary exhaust nozzle to restrict the outlet of said secondary flow passage and so that said flap inner surfaces present a substantial, divergent expansion surface rearward of said primary exhaust nozzle.

10. Apparatus according to claim 9 wherein said primary exhaust nozzle, said shroud and said fixed member are of circular cross-section and concentric about an axis.

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