April 27, 1965 F. E. MICKEY 3,180,140

VARIABLE CONTOUR NOZZLE

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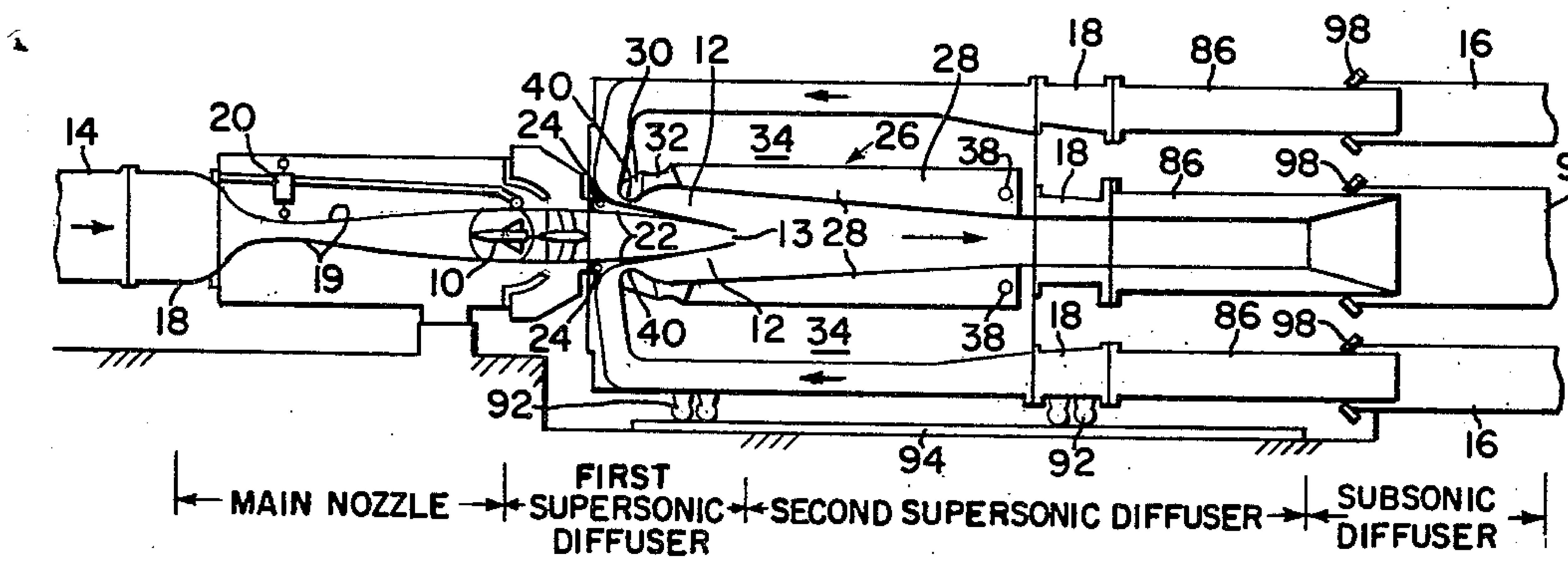

Fig. 1

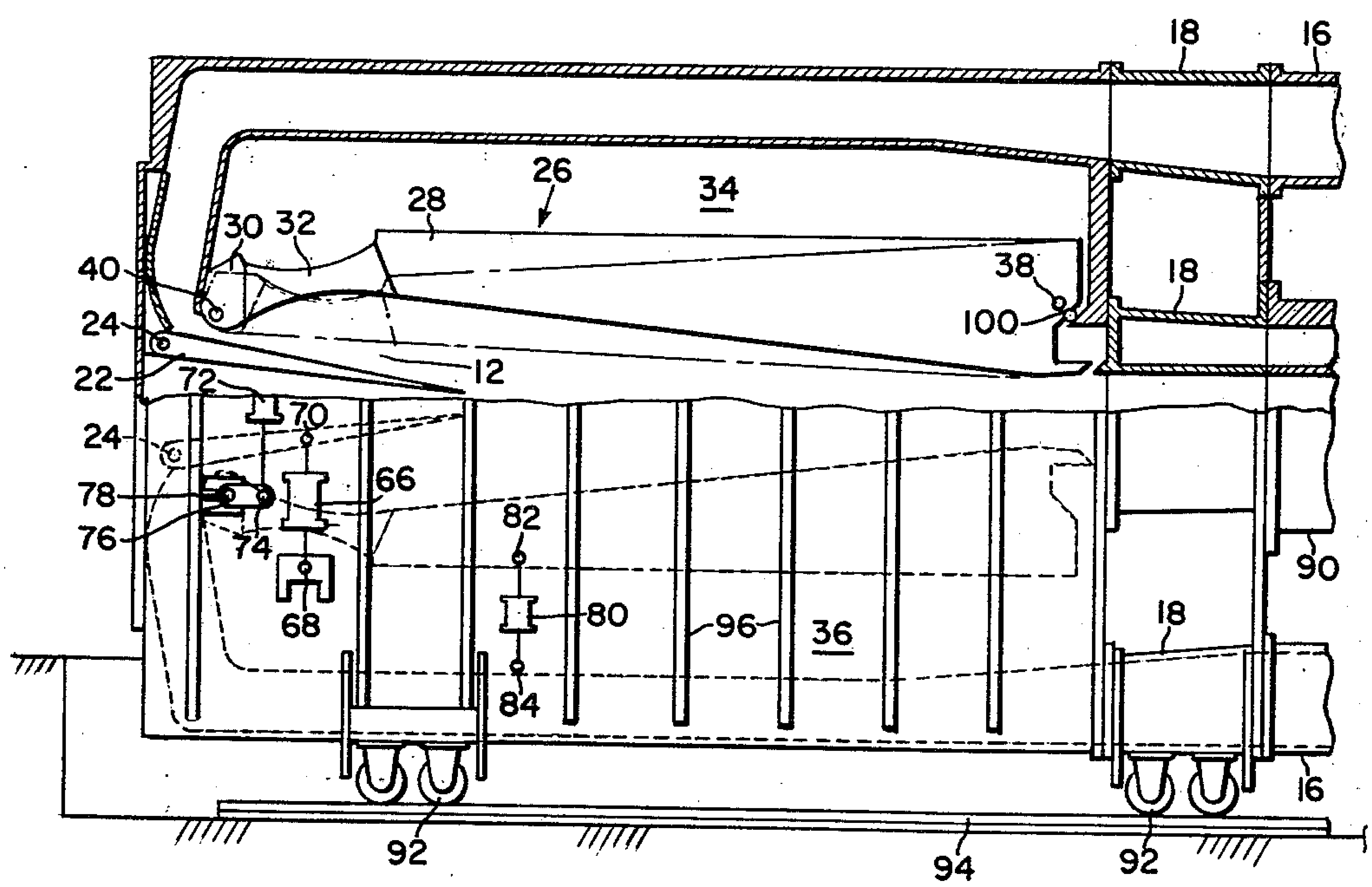

Fig. 2

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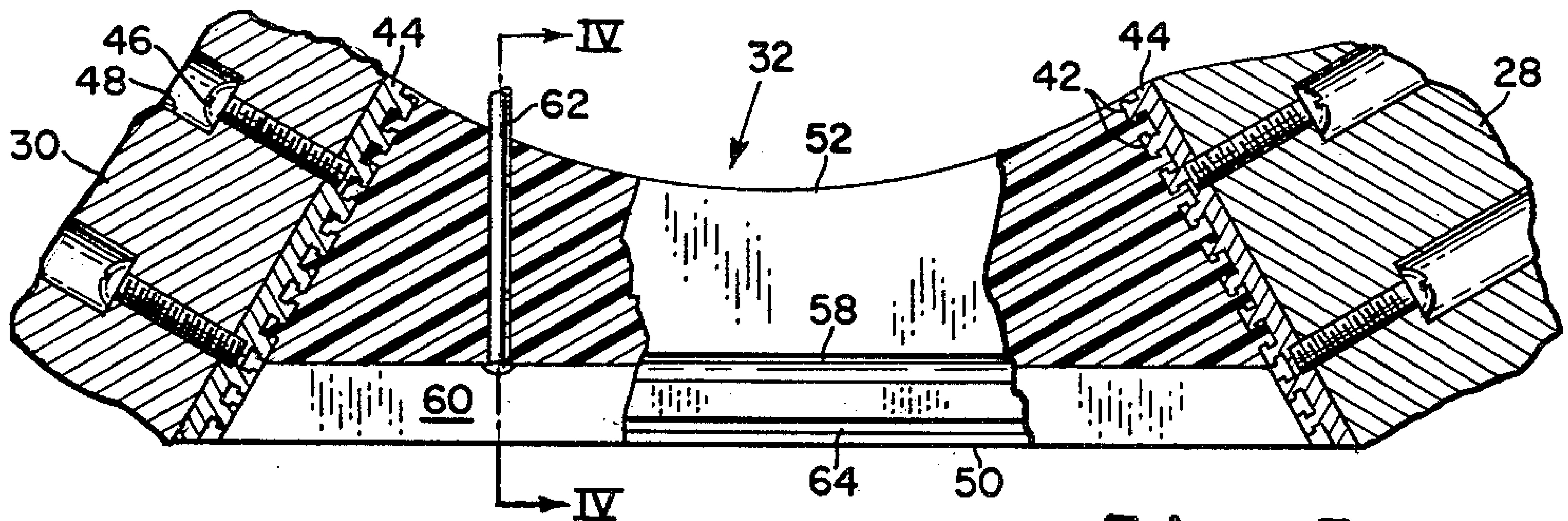

Fig. 3

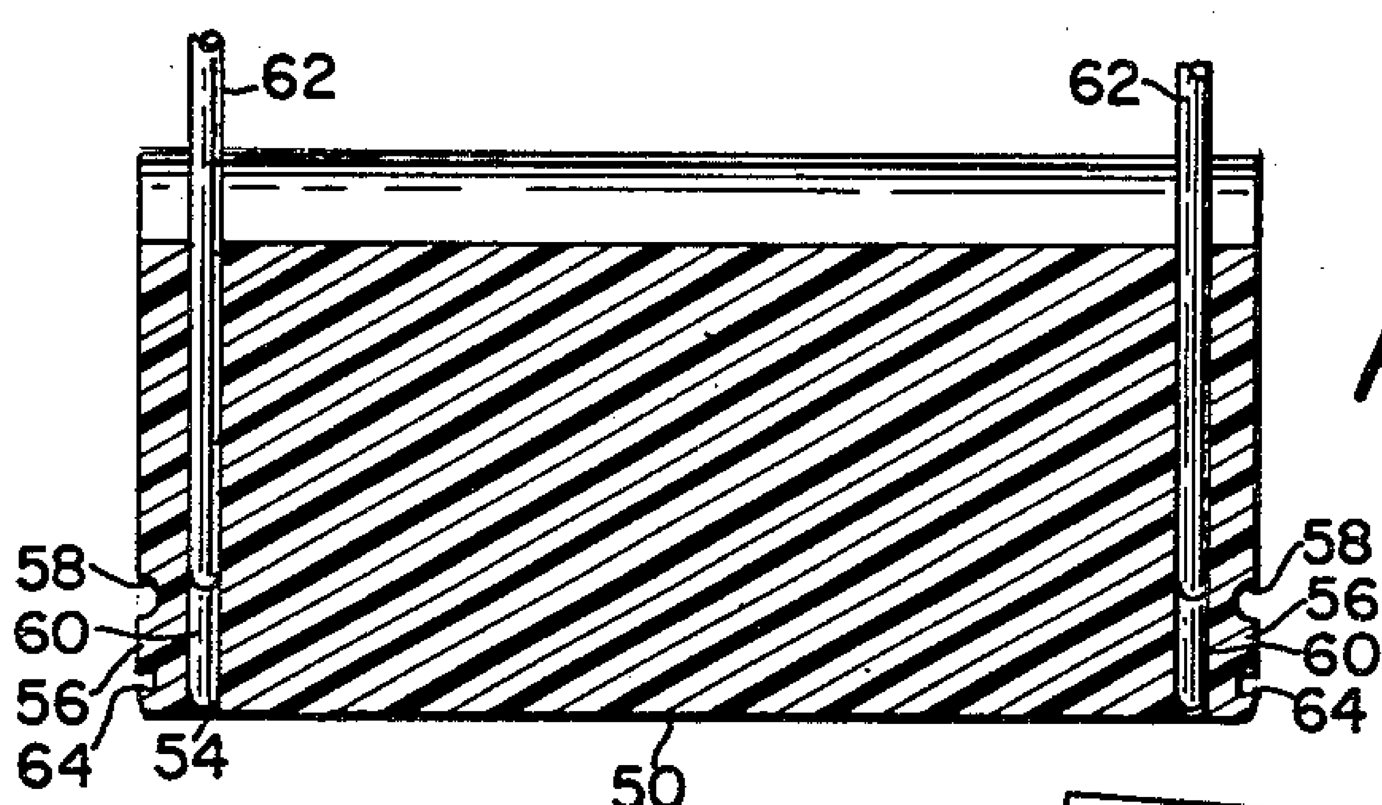

Fig. 4

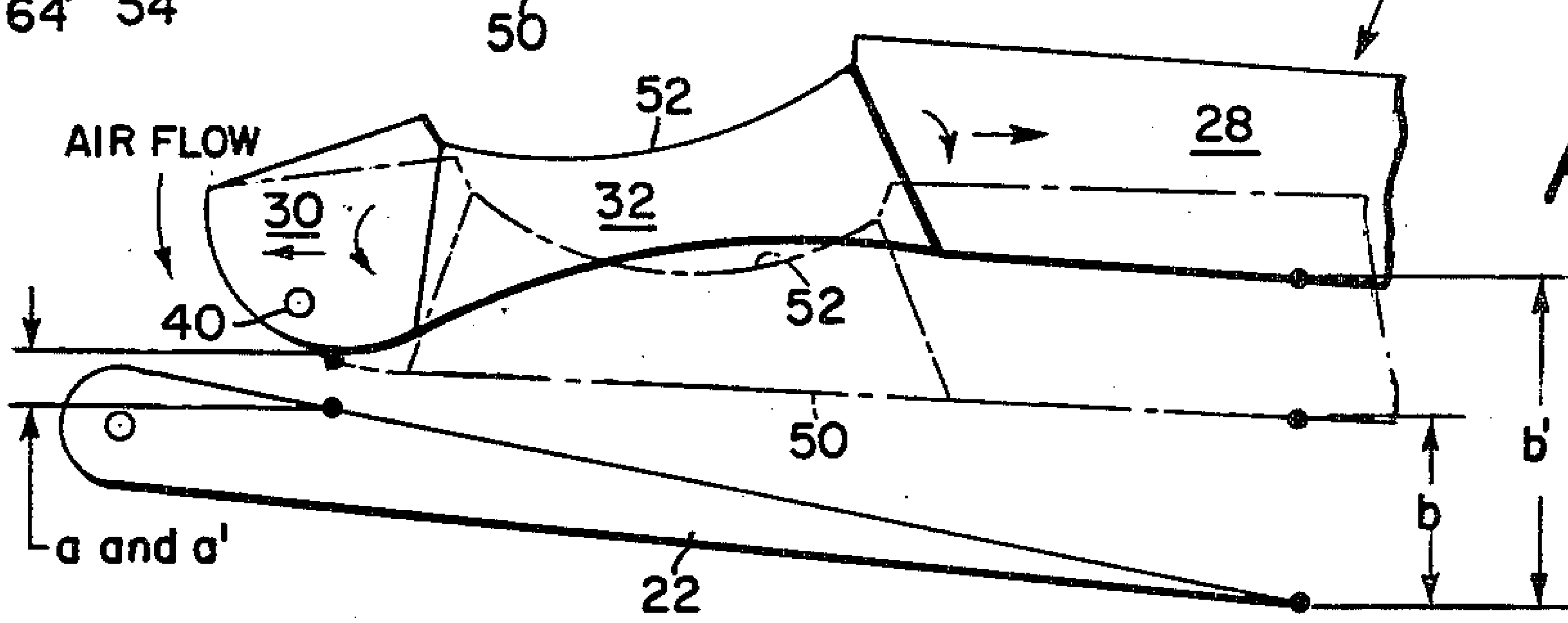

Fig. 6

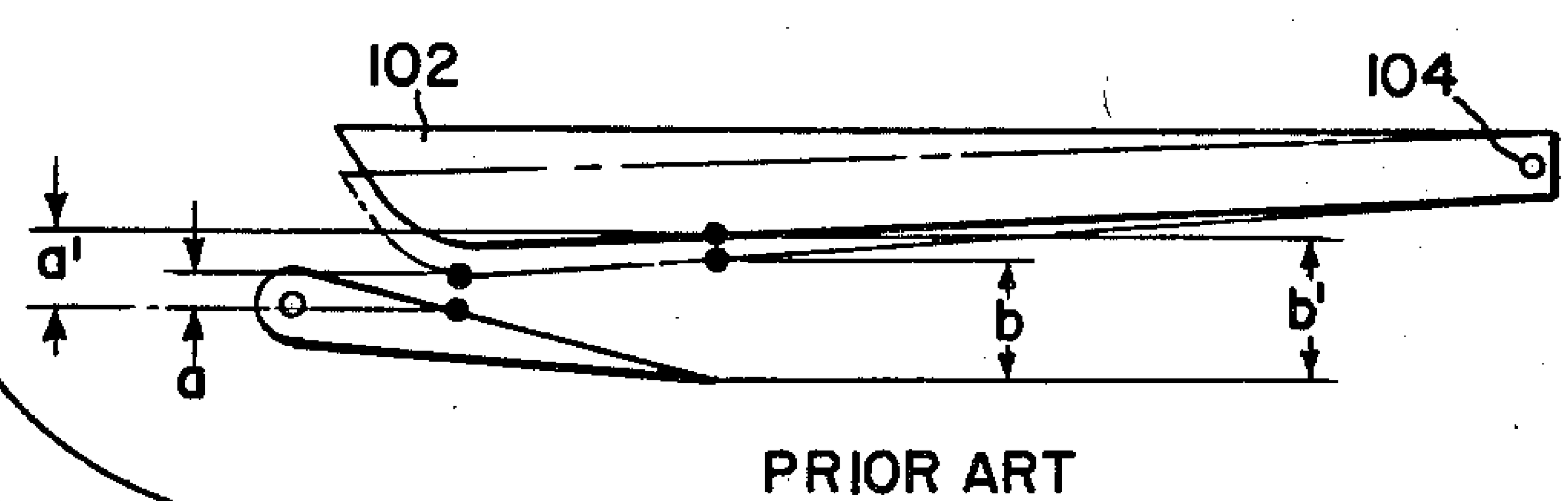

Fig. 7

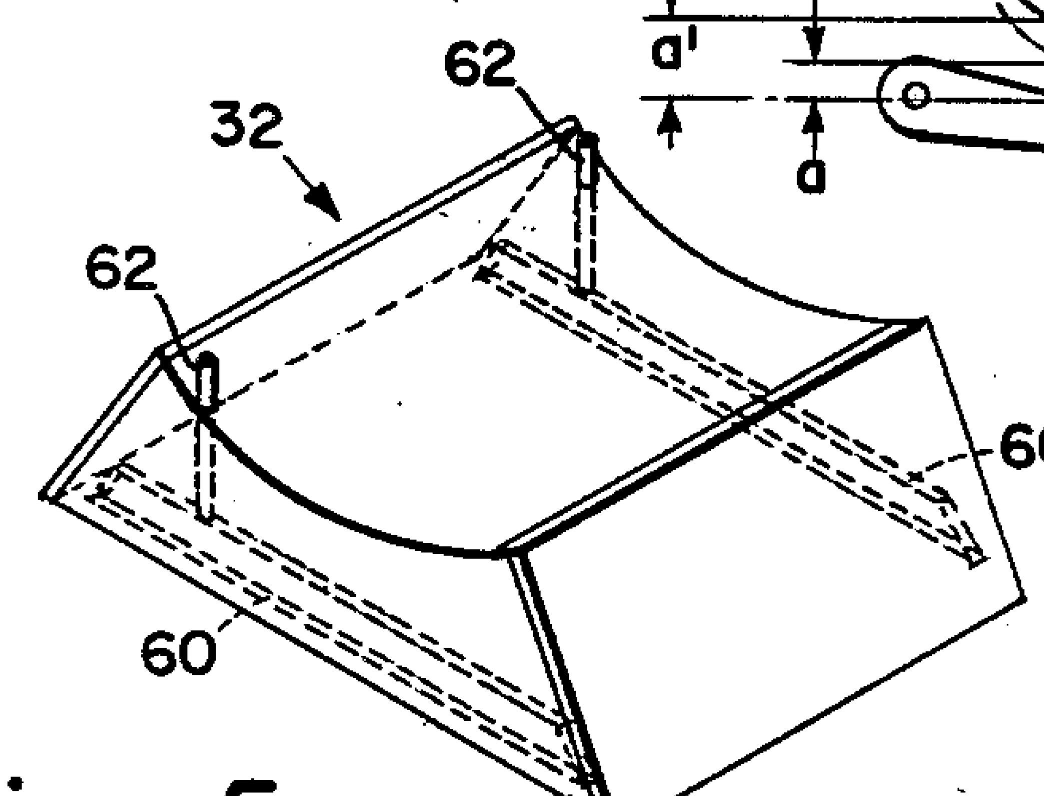

Fig. 5

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VARIABLE CONTOUR NOZZLE

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10 Claims. (Cl. 73—147)

The present invention relates to a variable contour nozzle and more particularly to a nozzle having an inner surface which can be shaped to contours which are aerodynamically more suitable for a supersonic air stream.

The primary use for the variable nozzle is for ejecting a secondary supersonic airflow at the throat of a supersonic diffuser in a wind tunnel so as to give support to a primary supersonic flow as it streams past a test model upstream from the diffuser. The ejection of a supersonic airflow by a pair of nozzles directed toward the throat of a first of two supersonic diffusers has been considered to be a significant prior art improvement in wind tunnel design. The effect has been to increase the Mach number in the test section of the tunnel without necessitating an increase either in the volume of air required or the pressure ratio available. In the past the ejector nozzles have been of a fixed contour as shown in FIG. 7. In this nozzle the ratio of the size of the throat opening to the exit opening thereof will increase upon the opening of the nozzle which is not favorable for increasing the Mach number of a supersonic airstream passing therethrough. The present invention overcomes this problem by increasing the exit opening at a faster rate than the throat opening upon opening the nozzle thereby allowing the supersonic airstream to attain a higher Mach number when it exits the nozzle. This is accomplished by pivoting an upper member for the ejector nozzle at both ends and providing a resilient beam along a portion of this member in the ejector nozzle so that when the beam is rotated to open the nozzle the ratio of the size of the throat opening to the exit opening decreases, thus allowing the airstream therethrough to attain a higher Mach number as it exits from the nozzle. The resilient beam is preferably constructed of urethane rubber and has a reduced central portion which enables the beam to assume a uniform curvature in a flexed condition. Because of the double pivoting of the member and the reduced cross section of the resilient beam, the inner side of the resilient beam is kept at a rather low stressed condition, thus preventing a drawing in of the sides of the beam which would leak the supersonic airstream from the nozzle. To insure at all times a good seal, the beam has a pair of slots spaced from its sides with an inflatable bag disposed therein which bags upon inflation bias the sides of the beam against other members of the nozzle.

An object of the present invention is to provide a variable contour nozzle which is aerodynamically more suitable for a supersonic airstream.

Another object is to provide a variable contour nozzle which upon opening the ratio of the size of the throat to the size of the exit thereof decreases so as to allow a supersonic airstream introduced therein to increase its Mach number as it passes therethrough.

A further object is to provide a resilient beam for a variable contour nozzle which will at all times maintain a good seal.

Yet another object is to provide a device which will produce a pair of more efficient secondary variable supersonic airstreams at the throat of a first supersonic diffuser within a wind tunnel under a given available pressure air source.

Yet another object is to provide a device for producing a more efficient downstream pressure environment for a main supersonic airstream flowing past a test model within a wind tunnel.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings in which like reference numerals designate like parts throughout the figures thereof and wherein:

FIG. 1 is a side schematic view of a wind tunnel, the wind tunnel being shown generally in cross-section.

FIG. 2 is a side view of a portion of the wind tunnel partly in cross-section with a portion of the outside of the wind tunnel cut away.

FIG. 3 is a side view of the resilient beam.

FIG. 4 is a cross-sectional view taken along line IV—IV of FIG. 3.

FIG. 5 is an isometric view of the resilient beam.

FIG. 6 is a diagrammatic side view of the present invention.

FIG. 7 is a diagrammatic side view of a prior art nozzle.

Referring now to the drawings, wherein like reference numerals designate like or corresponding parts throughout the several views, there is shown in FIG. 1 a wind tunnel having a main nozzle for directing a supersonic airstream on a test model **10**, a first supersonic diffuser downstream from the model, a second supersonic diffuser adjacent the first supersonic diffuser, a pair of variable contour nozzles **12** injecting supersonic air at the throat **13** of the first supersonic diffuser, and finally a sub-sonic diffuser adjacent the second supersonic diffuser. The wind tunnel receives primary air through a conduit **14** and secondary air through conduits **16**, this air being provided by any suitable high powered compressor (not shown). All of the air passages within the main nozzle, the first supersonic diffuser and an upstream portion of the second supersonic diffuser are generally rectangular in cross-section, the remainder of the air passages being circular in cross-section. The air streams are changed in their shape by various stream shapers **18**.

The main nozzle has a pair of plates **19** which are shaped at a throat section by a respective jack, one of these jacks being shown at **20**. After the primary air flows over the test model **10** it enters the first supersonic diffuser and is converged therein by a pair of wedge plates **22**, these wedge plates being pivoted about pins **24**.

Located in the second supersonic diffuser and the contour nozzles **12** are a pair of rotatable members **26**, each of these members having a tilt block **28**, a throat block **30** and a resilient beam **32**. Forming each side of the diffusers and the nozzles **12** are a pair of heavy side plates **34** and **36** which sealingly engage the wedge plates **22** and the movable members **26**, the inner wall of the side plate **34** and the outer wall of the side plate **36** being shown in FIG. 2.

The tilt block **28** is pivoted at one end about a pin **38** and the throat block **30** is pivoted about a pin **40**. The resilient beam **32** is constructed of an elastomeric material (preferably urethane of about 90 Shore durometer on the "A" scale), which is molded on to fingers **42** of end plates **44**. The resilient beams are then attached to the tilt block **28** and the throat block **30** by threading screws **46** in the blocks **28** and **30**.

The movable member **26** is shown closed in the phantom line position in FIG. 2 at which time the resilient beam **32** is in a relaxed condition, and open in the full line position at which time the resilient beam **32** is in a flexed condition. As shown in its relaxed position the resilient beam **32** is constructed to have a flat inner side **50** and a concave outer side **52**. This shape gives the resilient beam **32** a progressively reduced cross-section from its ends toward its center, thus causing the beam to assume along its inner side 50 a uniform curve between the throat block 30 and the tilt block 28 when the beam is in a flexed position as shown in FIG. 6. When the resilient beam 32 is in its flexed position rotational moments are applied to each end of the beam as shown by the small curved arrows in FIG. 6 which in the position shown would normally apply a considerable amount of tension to the top of the beam and a considerable amount of compression to the bottom of the beam. The compression that would normally occur at the inner side 50 of the flexed beam 32 is relieved by the rigidity of the tilt block 28 and the throat block 30, which blocks in the flexed position of the beam apply a tension force to the beam as shown by the straight arrows. Accordingly, with a proper design of the concave side 52 of the beam a uniform stressed condition can be maintained at the inner side 50 and a proper design of the movement of the blocks 28 and 30 a substantially zero stressed condition can be maintained at this inner side 50 throughout all positions of the beam 32.

Each resilient beam 32 has a pair of slots 54 running the full length of the beam and opening into the nozzle from the inner side 50, these slots being in the proximity of a respective side of the beam so as to provide fingers 56. Adjacent an inner end of each of the slots 54 is a groove 58 which allows the fingers to be more easily biased against the inner walls of the side plates 34 and 36 for sealing purposes. Disposed within each slot 54 is an inflatable bag 60 having an inlet tube 62 which receives air from a pressure air source (not shown). Running the full length of the each of the movable members 26 is an O-ring seal, the grooves of this seal for the resilient beam 32 being shown at 64. Accordingly, the degree of biasing of the fingers 56 against the walls of the side plates 34 and 36 for sealing purposes can be selectively controlled by the degree of pressure introduced into the inflatable bags 60. It is to be noted that the design of the movement of the blocks 28 and 30 with respect to the compression on the inner side 50 is to be corresponded with the design of the sealing means by the fingers 56 which are biased by the inflatable bag 60. Under certain circumstanes it may be desirable to design the movement of the blocks 28 and 30 so as to at all times introduce a predetermined amount of compression at the inner side 50, thus causing a continual biasing of the resilient beam against the walls of the side plates 34 and 36. With such a design it is conceivable that the sealing means obtained with the fingers 56 and inflatable bags 60 would not be required under these circumstances.

The means employed to move the movable members 26 and the wedge plates 22 may take many various forms. As shown in FIG. 2 one form for moving the lower wedge plate 22 is a jack 66, one end of the jack being pinned to the outer wall 36 at 68 and the other end of the jack being pinned to the lower wedge plate 22 at 70. The pin at 70 travels through the side plate 36 and is movable in a suitable sealed slot therein. The same arrangement would be used for the upper wedge plate 22 and if desired a jack can be provided for each side of the wedge plates 22. A jack 72 is provided for the pair of throat blocks 30, just half of this jack being shown in FIG. 2 since the other half of the jack is symmetrical. Each end of jack 72 is pinned at 74 to one end of an arm 76, the other end of the arm being fixedly attached to a pin 78 and the pin 78 being rigidly attached to the throat block 30 at the pivot point 40. Accordingly, when the jack 72 is actuated, the throat blocks 30 are moved in an identical manner. Again another jack 72 may be provided for the other side of the throat blocks 30. A jack 80 is provided for each tilt block 28 (only the one for the lower block 28 being shown in FIG. 2) and is pinned at 84 to the outer wall of the side plate 36 and at its other end is pinned at 82 to the lower tilt block 28. Once again a pair of jacks 80 may be provided for each tilt block 28, one on each side of the wind tunnel.

The second supersonic diffuser section is constructed to be movable with respect to the main nozzle. This is accomplished by telescoping conduits 86 into conduits 16 and 90 and providing wheels 92 which ride on a track 94. The side plates 34 and 36 may be reinforced by any suitable means such as ribs 96. Seals are provided between the telescoping sections at 98 and seals are provided for the movable members 26 at 100 by any suitable means such as O-rings.

FIGS. 6 and 7 illustrate the primary advantage of the invention over the prior art, the invention being shown in FIG. 6 and the prior art being shown in FIG. 7. The prior art shows a fixed contour member 102 which is pinned at 104. As the member 102 goes to a more open position from the phantom line to the full line the opening of the throat of the nozzle goes from *a* to *a'* which is a significant increase while the exit of the nozzle goes from *b* to *b'* which is not so significant an increase. Now referring to FIG. 6 as the member 26 goes to a more open position from the phantom line to the full line the throat of the nozzle remains substantially the same being designated as *a* and *a'* while the exit of the nozzle goes from *b* to *b'* which is a significant increase. Accordingly, it can be seen that as the nozzle is opened in the present invention the increase in the size of the exit of the nozzle with respect to the increase in the size of the throat of the nozzle is at a much greater rate than that found in the prior art. This results in a more favorable aerodynamic environment causing a greater increase in speed of a supersonic airstream passing through the nozzle in the present invention over that shown in the prior art.

In the operation of the device the nozzles 12 are closed and the flow is established in the main nozzle. The Mach number of this flow is increased by decreasing the throat area of the main nozzle and the throat of the first supersonic diffuser, the latter being accomplished by converging the wedge plates 22. As the main nozzle quantity of air flow decreases, the nozzles 12 are opened so as to pass excess air from a compressor into the second supersonic diffuser thus making it possible to increase the Mach number of the main nozzle air still further. Once the tunnel has been started, the diffuser components can be adjusted so as to provide a wide range of wind conditions. Mach numbers up to 6.5 at the test model can be attained with 4% of the flow from the compressor being introduced into the main nozzle and the remaining 96% of the flow from the compressor being introduced into the nozzle 12, the compression ratio between the outlet of the compressor and the pressure introduced back into the compressor from the wind tunnel being about 4 to 1. The increased Mach number of the secondary air exiting the nozzles 12 causes a low pressure area at the throat of the first supersonic diffuser thus causing a more favorable environment for higher velocities at the test model.

It is now readily apparent that the present invention provides an entirely new concept in supersonic nozzles; namely providing the nozzle with a movable side which can be made to assume various contours, these contours being aerodynamically more favorable for the stream of air passing through the nozzle. One important application of these nozzles is in a wind tunnel where wind velocities at the test model can be increased by using the nozzles to present a more favorable downstream pressure environment within the tunnel.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefor to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

I claim:

1. A supersonic nozzle having an inlet and an outlet and inner sides, comprising one side of the nozzle being formed by a member having a rigid upstream end portion and a rigid downstream end portion, each end portion being pivoted about a respective fixed axis, the axes being

parallel to one another and said member having a resilient middle portion between said end portions so that upon rotation of either of said end portions said member can be caused to assume various shapes for changing the contour of said nozzle.

2. An ejector nozzle for causing a low pressure supersonic fluid stream downstream from a diffuser comprising a pair of side plates opposing one another, a rigid block pivoted about an axis passing through said plates, a rigid arm spaced downstream from the block and pivoted about another axis passing through said plates, and parallel to said first mentioned axis, an elastomeric beam disposed in the space between the block and the arm having ends fixedly attached to the block and the arm, the block, arm and beam each having a pair of sides normal to the pivot axes which sealingly engage said plates, another plate mounted on the pair of plates so as to face the block and the beam whereby upon rotating the block and/or the arm about their respective pivots away from the latter plate the ratio of the size of the opening formed by the plates and the block with respect to the opening formed by the remainder of the nozzle decreases thereby causing the fluid stream to increase in velocity as it passes through said nozzle.

3. An ejector as claimed in claim 2 wherein the beam has a reduced cross section between its ends so as to even out stress upon the beam and minimize abrupt changes in the curve assumed by the beam upon rotation of the block or the arm.

4. An ejector as claimed in claim 2 wherein the plate facing the block and beam is pivoted about an axis upstream from the beam and has a side opposite the side facing the block and beam which forms a wall for said diffuser.

5. An ejector as claimed in claim 2 wherein the beam has a pair of slots opening into the fluid stream, each slot being spaced from a respective one of the beam's pair of sides and extending between the ends of the beam so as to form a portion of each of the latter sides into a finger and an inflatable bag disposed within each slot and extending therealong whereby upon inflation of the bags the fingers are biased against the side plates to maintain a seal between the beam and said side plates.

6. An ejector as claimed in claim 5 wherein the pair of sides of the beam each have a groove extending along an outer end of a respective finger with respect to the nozzle whereby the fingers can be more easily biased toward the side plates.

7. An ejector as claimed in claim 6 wherein the beam is made of a urethane rubber with a Shore hardness of about 90 durometer on the "A" scale.

8. In a wind tunnel having a first supersonic diffuser downstream from a test model, the first supersonic diffuser having pivoted wedge plates for converging air into a second supersonic diffuser, the wedge plates also each forming one wall for a respective injector nozzle, each injector nozzle merging a low pressure supersonic air stream with main air from the first supersonic diffuser after the main air exits the wedge plates; each injector nozzle having a movable member opposite a respective wall of the wedge plates and pivoted downstream from the wedge plates; the improvement comprising the movable member also being pivoted at an upstream end, a portion of the movable member opposite the wall of the wedge plate being an elastomeric beam whereby upon rotating the movable member about either of the pivots away from the wedge plate wall the ratio of the opening of an upstream end of the nozzle decreases thereby causing a more favorable environment for the air stream passing through the nozzles to increase its velocity as it travels downstream therein.

9. The improvement as claimed in claim 8 wherein each elastomeric beam in a relaxed state has a flat side facing the wedge plate wall and a side opposite the flat wall which is concave whereby upon flexing the beam by rotating the movable member about either pivot the beam will assume a smooth curve and undergo a more even stress condition throughout.

10. The improvement as claimed in claim 8 wherein each beam has a pair of sides engaging side plates of the nozzle and means within each beam for biasing each side thereof against opposite facing walls of the nozzle so as to provide sealing between the beams and the side plates of the nozzle.

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