137-13.
1-15-74 OR 3,785,390

United States Patent [19]

Taylor

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[45] **Jan. 15, 1974**

[54] **PURE FLUID AMPLIFIER**

[75] Inventor: **Wesley L. Taylor,** Glenview, Ill.

[73] Assignee: **The Powers Regulator Company,** Skokie, Ill.

[22] Filed: **July 27, 1970**

[21] Appl. No.: **64,885**

Related U.S. Application Data

[60] Division of Ser. No. 631,108, March 9, 1967, Pat. No. 3,545,675, which is a continuation-in-part of Ser. No. 571,829, Aug. 11, 1966, abandoned.

[52] **U.S. Cl.** **137/13,** 137/836, 137/840, 137/842

[51] **Int. Cl.** **F15c 1/14,** F15c 1/18

[58] **Field of Search** 137/81.5, 13, 837, 137/839, 841, 833, 842, 828

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Primary Examiner—William R. Cline

[57] **ABSTRACT**

A pure fluid amplifier which projects a laminar power stream and includes a control section for developing a pressure differential across the projected laminar power stream for a substantial portion of the length of the power stream (preferably a portion of the length of the power stream at least equal to four times the width of the power stream emission orifice) so as to angularly displace the power stream while maintaining the power stream laminar at all points in advance of the receiver aperture. Preferably, there is a venting region immediately in advance of the receiver aperture which is relieved in all directions in a plane perpendicular to the plane of angular displacement. A system for biasing the laminar deflector (or other pressure-operated pure fluid amplifier) by aspirating fluid from the control section in a quantity substantially equal to the quiescent input flow to the amplifier. A unit ventilator control using a laminar deflector is shown. A proportional controller using a biased laminar deflector is shown.

31 Claims, 22 Drawing Figures

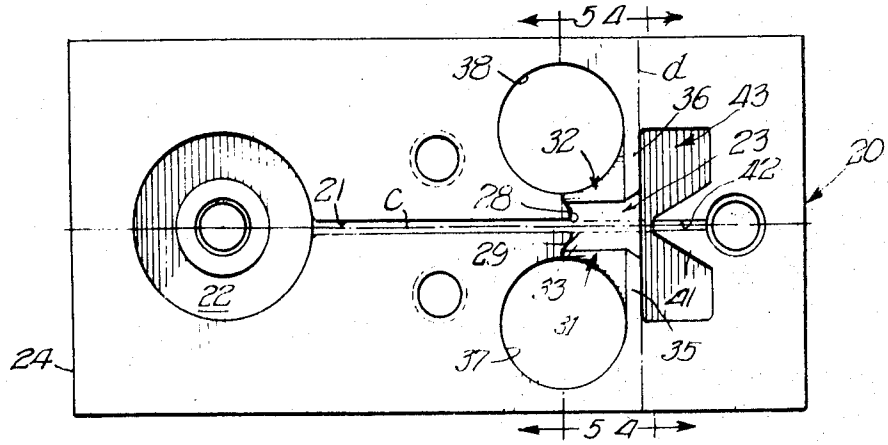


Fig. 1

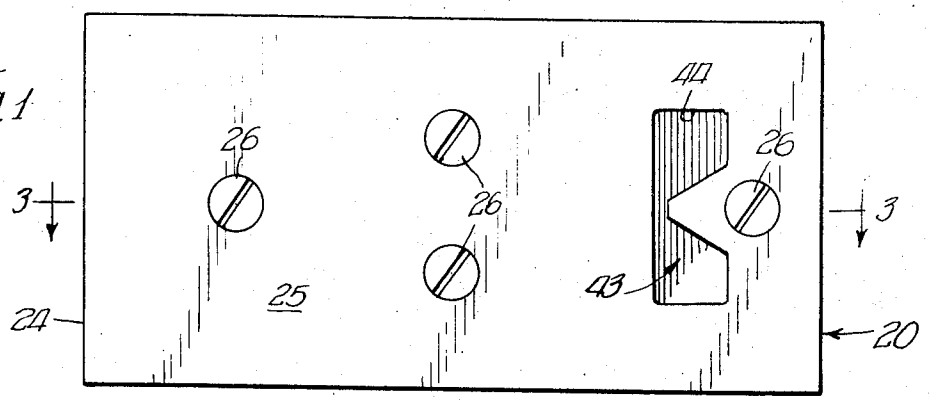


Fig. 2

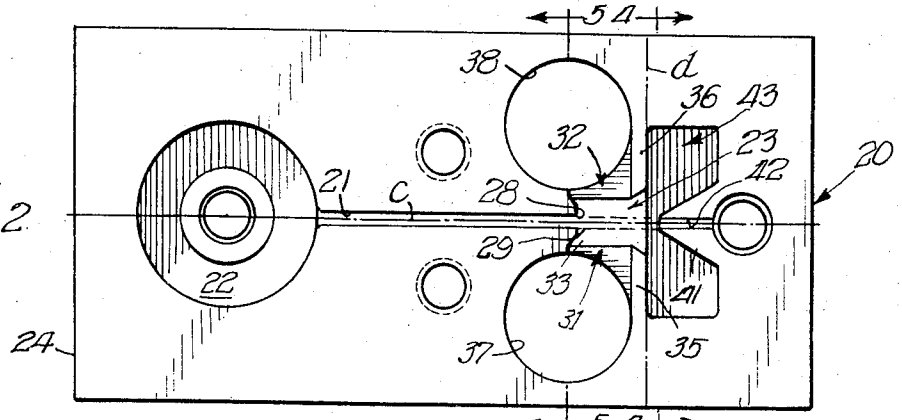


Fig. 3

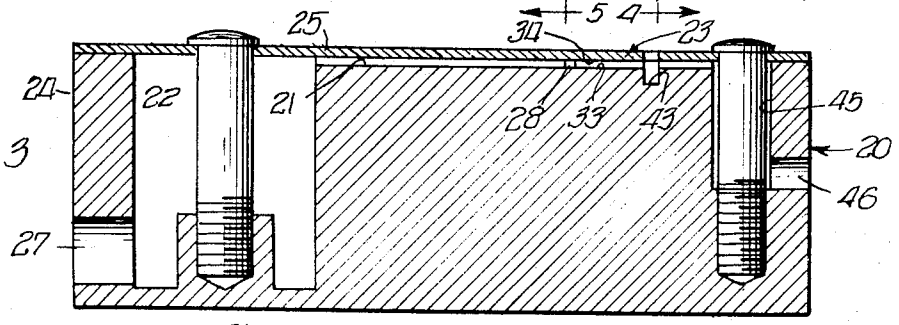


Fig. 4

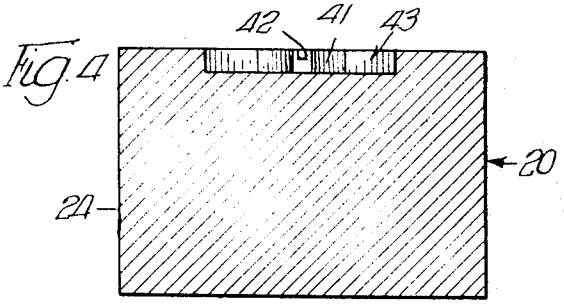


Fig. 5

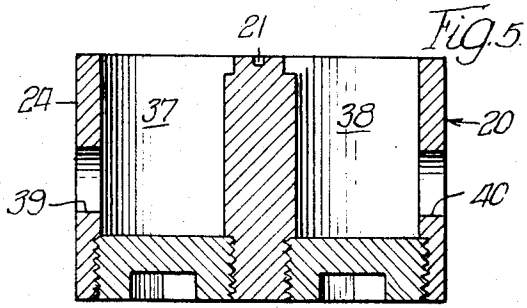


Fig. 10

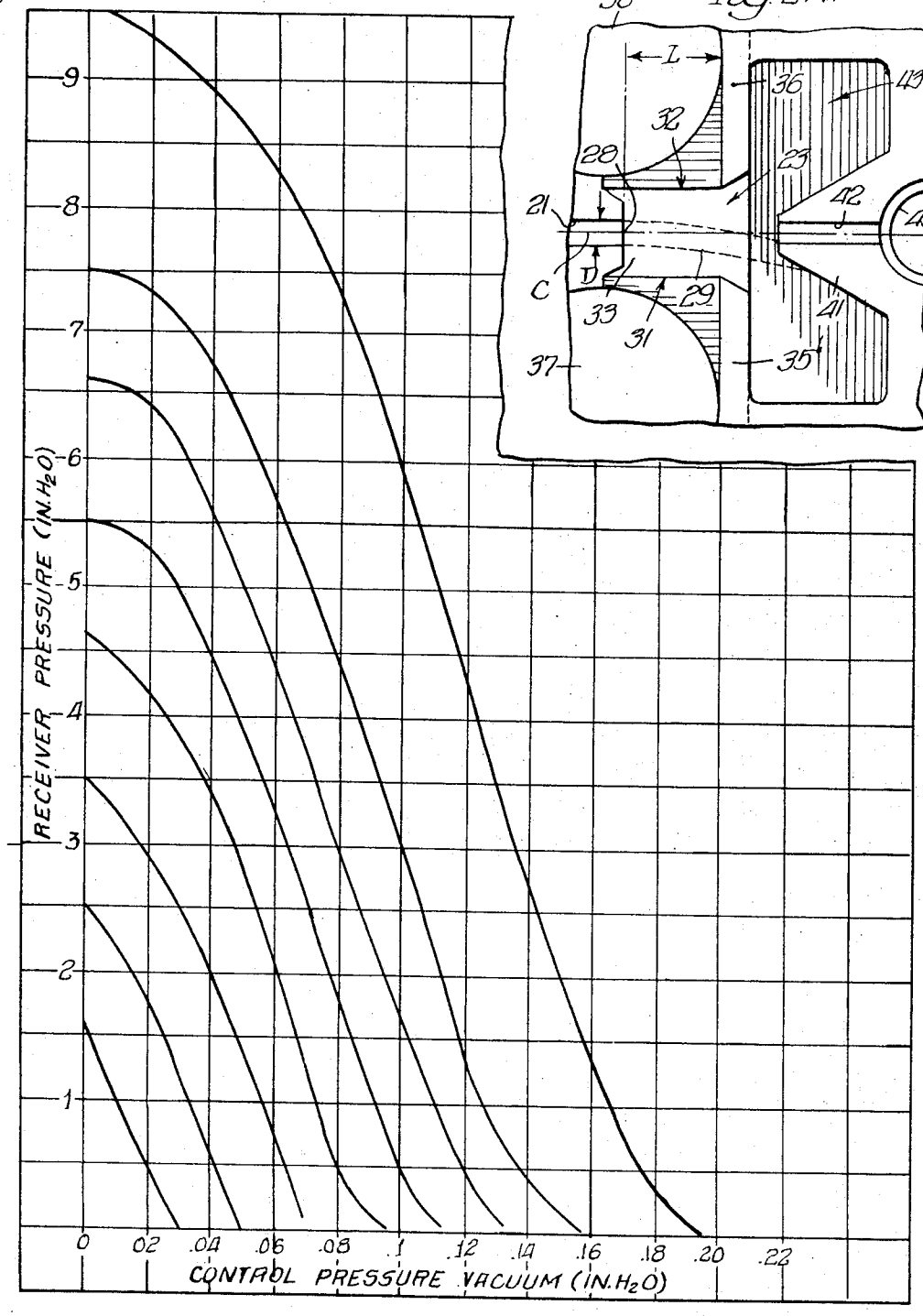

RECEIVER PRESSURE (IN. H_2O)
9
8
7
6
5
4
3
2
1
0
.02
.04
.06
.08
.1
.12
.14
.16
.18
.20
.22
CONTROL PRESSURE VACUUM (IN. H_2O)

Fig. 2A.

38
L
36
43
32
28
23
42
45
21
C
T
29
33
31
41
37
35

Fig. 6

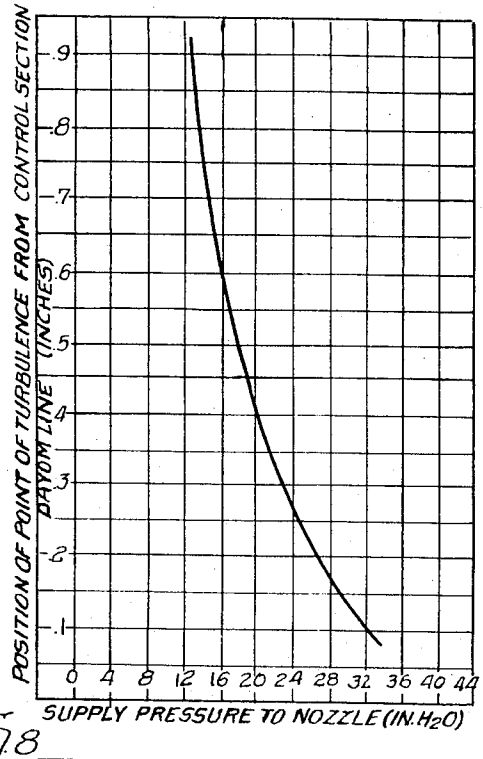


Fig. 7

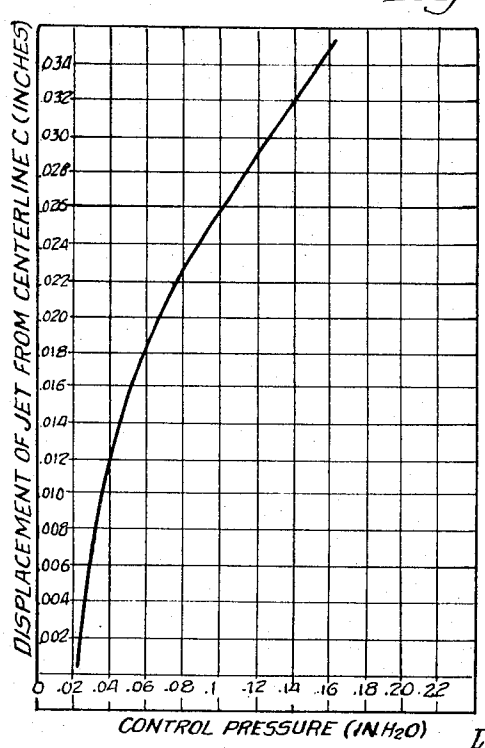


Fig. 8

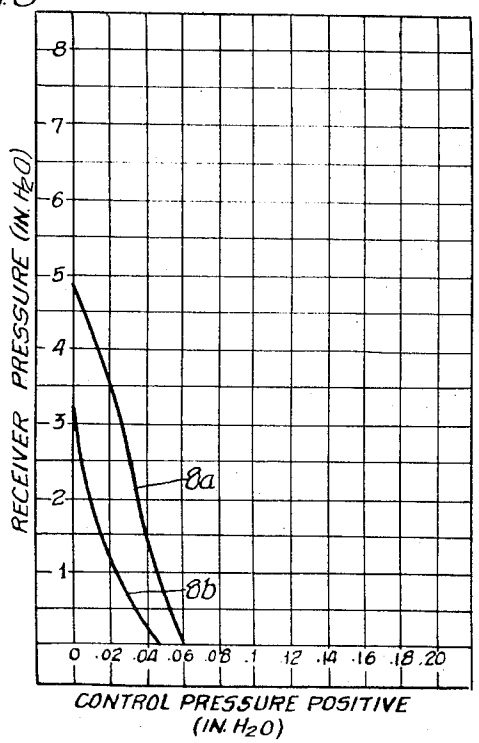


Fig. 9

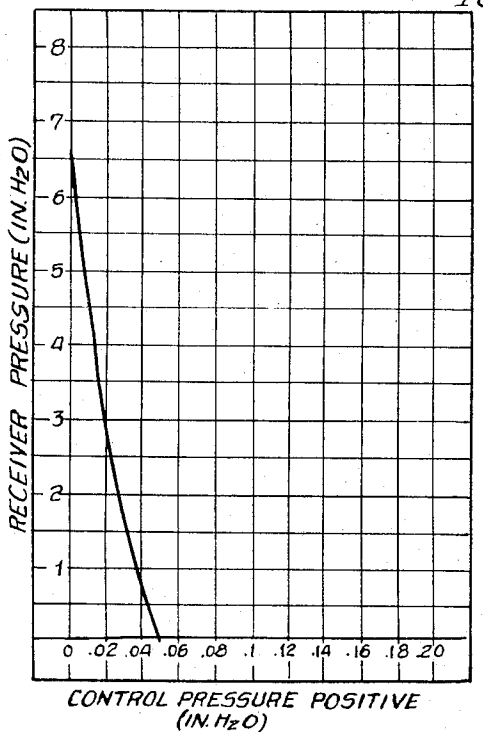


Fig. 11

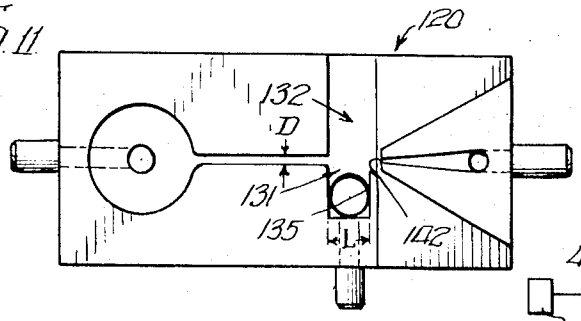


Fig. 12

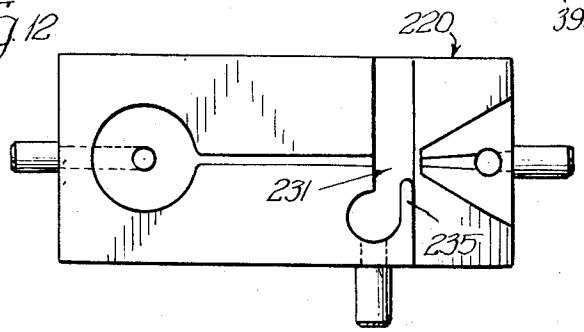


Fig. 13

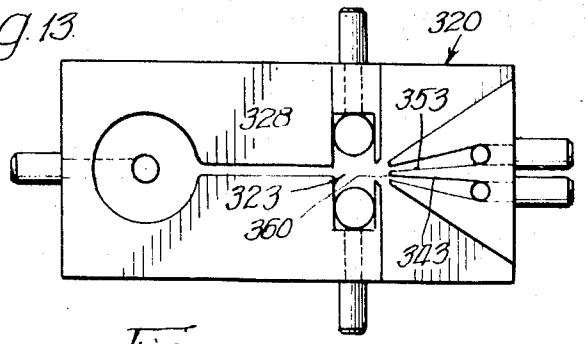


Fig. 14

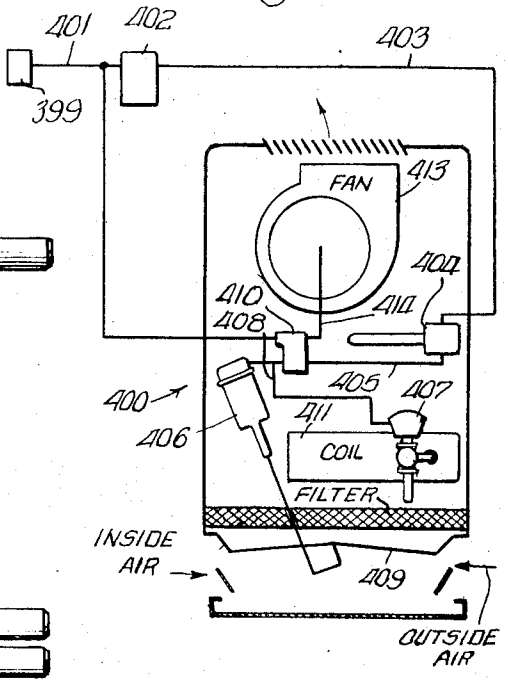


Fig. 15

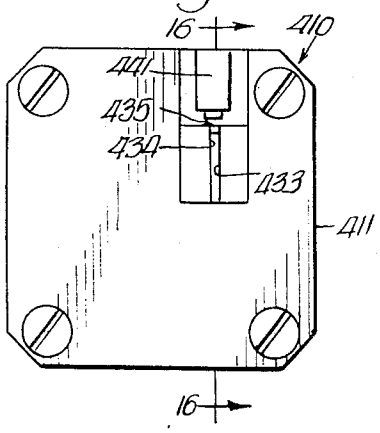


Fig. 16

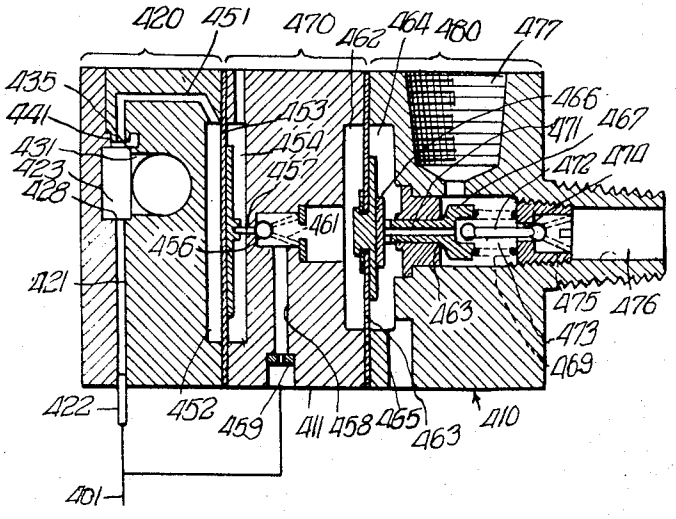


Fig. 17

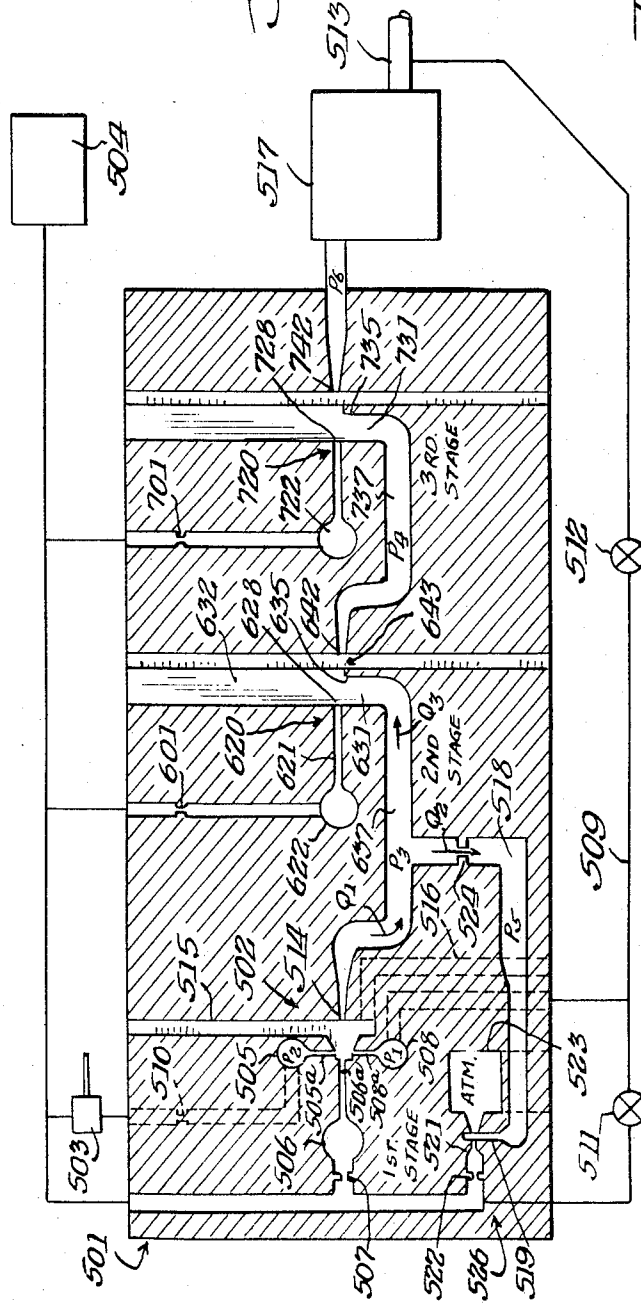
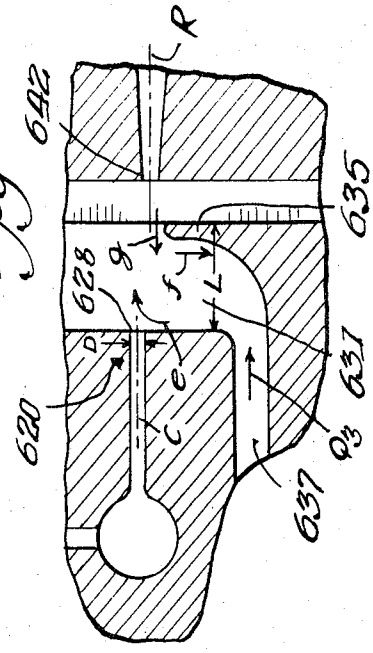


Fig. 19



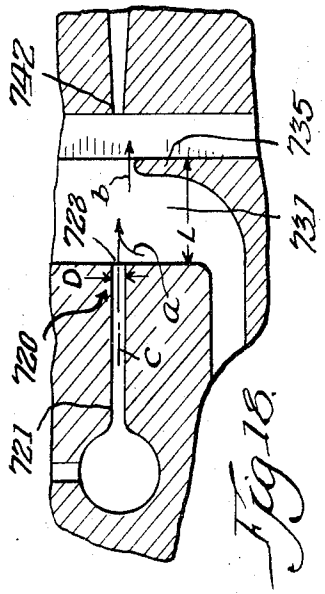


Fig. 18

Fig. 21.

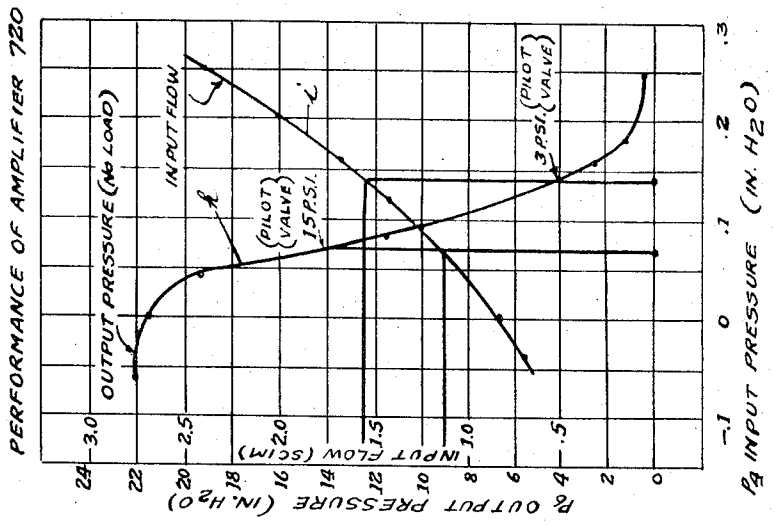


Fig. 20.B.

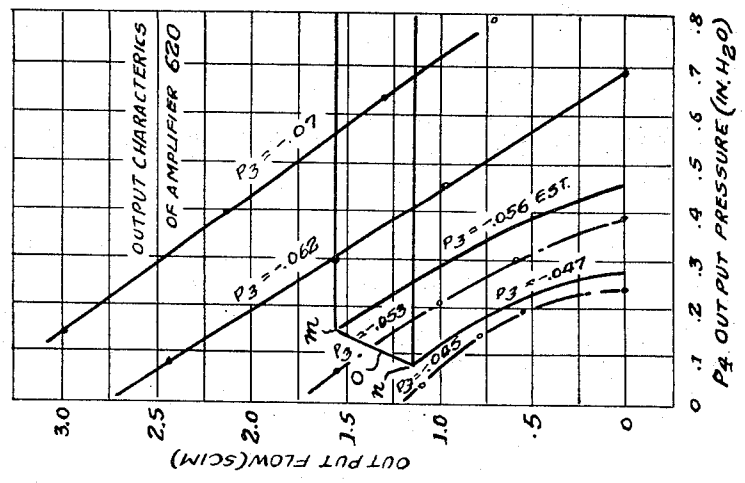
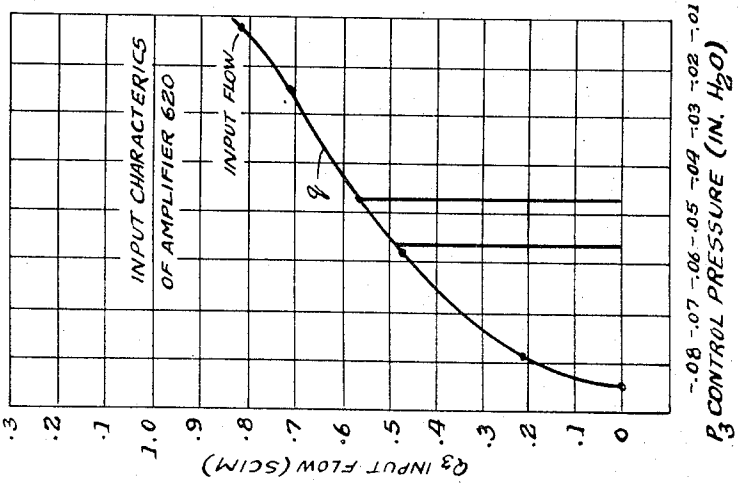


Fig. 20.A.



PURE FLUID AMPLIFIER

This application is a division of application, Ser. No. 631,108, filed Mar. 9, 1967, now U.S. Pat. No. 3,545,675, which, in turn, was a continuation -in- part of application, Ser. No. 571,829, filed Aug. 11, 1966, and now abandoned. This invention relates to fluid amplifiers, and more particularly, to pure fluid amplifiers of the type wherein amplification depends upon the influence exerted on a fluid power stream by a controlled fluid pressure gradient provided generally transversely of the direction of flow of the power stream. In practice, the present invention is characterized by a unique manner of providing and influencing a laminar power stream which results in unusually high pressure gain.

The advantages of low cost and increased reliability of pure fluid amplifiers in many applications has sparked considerable development activity in the field. As a result, a number of different types of pure fluid amplifiers have been produced. A general survey of various types of pure fluid amplifiers and their characteristics may be found in the June 24, 1965, issue of "Machine Design" at pages 153 through 180. Despite this development work, there is presently a need for pure fluid amplifiers capable of high pressure gain, yet smooth proportional action. The present invention responds to this need.

It is well known by those skilled in the art that a fluid power stream can be deflected by a fluid control stream directed against the power stream in a direction generally perpendicular thereto. The power stream deflects through an angle which is related to the energy and momentum of the control stream. In conventional practice, however, the deflected power stream is non-laminar turbulent for the reason that the interaction of the control stream with the power stream acts to produce or enhance turbulence in the power stream. Indeed, it is indicated in Auger U.S. Pat. No. 3,234,955 that a laminar power stream can be made turbulent by the control stream even though the control stream does not provide sufficient energy to substantially deflect the power stream.

In accordance with the present invention, it has now been found that a laminar power stream of considerable operational length (that is, a laminar power stream which extends a considerable distance from its emission orifice to a receiver port) can be angularly displaced by a pressure gradient acting transversely across the power stream for a substantial portion of length adjacent the emission nozzle — without causing turbulence to occur within the operational length of the power stream. The significance of this attainment is apparent. The deflection of a narrow power stream of considerable length affords greatly enhanced gain. Indeed, pressure gains in excess of 100 have been achieved in an amplifier according to the present invention with a dead-ended receiver and this with smooth proportional action.

It may be noted at this juncture that a pure fluid amplifier according to the present invention makes use of unusually large control ports, a condition which normally would lead one to expect that serious problems of low input impedance and large control pressure losses would ensue. However, while the input impedance does diminish as control port length increases, the no-load pressure gain increases rapidly, and the unexpected result is an amplifier with a very high pressure gain and power gains equal to or better than a typical momentum amplifier.

Accordingly, it is a principal object of the present invention to provide a novel pure fluid amplifier characterized by significantly high pressure gain, yet smooth proportional action. As used herein, the term "pressure gain" in reference to a single input amplifier means the ratio of change in output receiver pressure to the change in input control pressure. With reference to a dual input and dual output amplifier, this term means the ratio of the change in the difference between two output pressures to the change in the difference between two input control pressures.

It is another object of the present invention to provide a pure fluid amplifier wherein a laminar power stream of considerable length is angularly displaced without causing turbulence to occur within its operational length.

It is yet another object of the present invention to provide a system for biasing laminar deflectors and other pressure-operated pure fluid amplifiers. As will be seen, the biasing arrangement of the present invention enables the matching of the operating range of a pressure-operated amplifier stage with the operating range of a preceding amplifier stage. For example, it enables the matching of operating points of a pressure-operated amplifier stage with a preceding momentum-type amplifier stage. Moreover, biasing is accomplished in a manner which provides a compensating effect for variations in supply pressure and in a manner which does not work a degradation of gain.

Briefly described, the pure fluid amplifier of the present invention comprises a supply conduit of predetermined parameters and including an emission orifice such that the supply conduit is capable of producing and projecting a laminar stream, means for causing flow of fluid through the supply conduit under a predetermined pressure which is so related to the parameters of the supply conduit as to project a laminar power stream from the supply conduit emission orifice, at least one receiver aperture spaced a predetermined distance from the supply conduit outlet orifice and positioned to normally receive at least a portion of the projected laminar power stream, and control means for developing a biasing pressure differential across the projected laminar power stream for a substantial portion of the length of the projected power stream without causing a substantial fluid stream velocity component to impinge against the power stream so as to angularly displace the power stream while maintaining the power stream laminar at all points in advance of the receiver aperture. Preferably, the portion of the length of the projected power stream across which the pressure differential is applied is at least equal to four times the dimension of the supply outlet orifice in the plane of angular displacement of the power stream. Further, it is preferable to include means defining a venting region immediately in advance of the receiver aperture, the venting region being relieved in all directions in a plane perpendicular to the plane of angular displacement. A unique and advantageous biasing arrangement for matching the operating range of a laminar deflector or other pressure-operated pure fluid amplifier with the operating range of a source of control pressure signals is achieved by aspirating fluid from the control chamber of the pressure-operated amplifier in volume substantially equal to the quiescent point input flow vol-

ume from said source of control pressure signals so that deviations in said input fluid flow volume from said quiescent point volume effect a corresponding change in the control pressure applied to the power stream of the pressure-operated amplifier.

The foregoing and other features and objects of the present invention will become more apparent by reference to the following detailed description taken in conjunction with the appended drawings.

In the drawings:

FIG. 1 is a top plan view of one form of pure fluid amplifier according to the present invention.

FIG. 2 is a top plan view of the pure fluid amplifier of FIG. 1 with the cover plate removed.

FIG. 2A is an enlarged view of a portion of FIG. 2 to aid in explaining the present invention.

FIG. 3 is a cross-sectional view as taken along the line 3—3 in FIG. 1.

FIG. 4 is a cross-sectional view as taken along the line 4—4 in FIG. 2.

FIG. 5 is a cross-sectional view as taken along the line 5—5 in FIG. 2.

FIG. 6 is a graph illustrating the change in the position of the point of turbulence in a projected power stream in relation to the supply pressure in the supply conduit for the purpose of aiding the explanation of the present invention.

FIG. 7 is a graph illustrating the lateral displacement of the extreme end of the laminar power stream in relation to a change in the control pressure in accordance with the principles of the present invention.

FIGS. 8 and 9 are graphs illustrating receiver output pressure versus control pressure as obtained in accordance with the present invention.

FIG. 10 is a graph illustrating a family of curves of receiver output pressure versus control pressure as obtained in accordance with the present invention.

FIG. 11 is a top plan view of another form of a pure fluid amplifier according to the present invention.

FIG. 12 is a top plan view of still another form of pure fluid amplifier according to the present invention.

FIG. 13 is a top plan view of yet another form of pure fluid amplifier in accordance with the present invention.

FIG. 14 is a schematic representation of a unit ventilator system in which a pure fluid amplifier according to the present invention controls a switching action.

FIG. 15 is a top plan view of the pure fluid amplifier and associated valving elements as used in the unit ventilator system of FIG. 14.

FIG. 16 is a cross-sectional view as taken along the line 16—16 of FIG. 15.

FIG. 17 is a partially schematic, partially cross-sectional representation of a control circuit using a biased pure fluid amplifier according to the present invention.

FIG. 18 is an enlarged view of the third stage pure fluid amplifier in the FIG. 17 control circuit.

FIG. 19 is an enlarged view of the second stage pure fluid amplifier in the FIG. 17 control circuit.

FIGS. 20A, 20B, and 21 are three graphs of performance characteristics of the pressure-operated laminar deflector amplifiers of the control circuit of FIG. 17 arranged to aid in explaining the biasing system of the present invention.

ANGULAR DISPLACEMENT OF A LAMINAR POWER STREAM

Reference is made to the Auger U.S. Pat. No. 3,234,955. As pointed out therein, the distal end of a projected laminar stream is marked by a "point of turbulence" beyond which the stream flow is nonlaminar or turbulent and the position of the point of turbulence depends upon the size of the supply conduit outlet orifice from which the laminar stream is projected and upon the magnitude of the static pressure forcing the fluid through the supply conduit. The experimental work of the present inventor indicates that for a given size outlet orifice the position of the "point of turbulence" moves downstream very markedly as the static supply pressure is reduced. More specifically, it has been found that with a supply conduit such as shown in FIG. 2 comprising a 0.016 inch square passageway 21 of approximately one-half inch length preceded by a three-eighths inch diameter stagnation chamber 22, the distance from the datum line d following the control section 23 to the "point of turbulence" (not shown) increases rapidly as the static supply pressure decreases, as shown in FIG. 6. The graph of FIG. 6 is approximate and was based on the use of a 0.018 inch internal diameter, dead-ended probe in lieu of the receiver 41 shown in FIG. 2.

Significantly, it has been found that if one operates well within the region to the left of the curve in FIG. 6, a laminar power stream can be angularly displaced without causing the "point of turbulence" to advance to a position upstream of the receiver. The result, as will be seen, is greatly enhanced pressure gain.

Referring now more specifically to FIGS. 1 through 5, there is shown one preferred form of pure fluid amplifier 20 according to the present invention. As seen, the amplifier 20 includes a main body member 24 and a cover plate 25 which is secured to the main body member 24 by screws 26.

The main body member 24 is further fabricated to cooperate with the cover plate 25 to define a control section 23 which in the form of the invention shown in FIGS. 1 through 5 comprises a pair of control chambers 31 and 32 disposed on opposite sides of the laminar power stream 29 in opposing relationship. The wall 33 of the control chamber 23 and the parallel wall 34 cooperate to confine the laminar power stream 28 to its plan of angular displacement so that pressure differential between the control chambers 31 and 32 acts on the laminar power stream much in a manner as though the laminar power stream were a diaphragm separating the control chambers 31 and 32. In this regard, it may be noted that the walls 33 and 34 as shown in FIG. 2 have zero setback from the corresponding edges of the supply conduit outlet orifice 28. However, the walls 33 and 34 may also be in interference with the laminar power stream or be very slightly set back from the edges of the emission orifice 28.

The downstream sides of the control chambers 31 and 32 are formed by projecting wall elements 35 and 36, respectively, which approach the laminar power stream 29 in opposing directions, each preferably presenting a knife edge toward the laminar power stream 29. As will be discussed further on in this description, it has been found that the spacing between forward edge of the downstream projecting wall element associated with a particular control chamber determines

the input impedance of the particular control chamber.

The control chambers **31** and **32** are preferably provided with rather large diameter inlet ports **37** and **38** acting as stagnating chambers which tend to remove momentum from fluid introduced through the respective openings **39** and **40.**

The datum line d shown in FIG. **2** marks the downstream termination of the control section **33.** It falls along the downstream sides of the projecting wall elements **35** and **36.** From this datum line d to the upstream face of the receiver (a distance which will be referred to hereinafter as X distance), there is provided a venting region **43** which is relieved in all directions perpendicular to the plane of angular displacement of the power stream **28.** This venting region is important because it enables vented dispersion of the fluid particles which do not enter the reveiver port **42,** thereby preventing an undesired pressure build-up to occur in the vicinity of the receiver port. The venting provided is gross due to the enlarged wings of the venting region which extend outwardly and rearwardly on both sides of the receiver **41** and to the fact that the cover plate **25** is provided with a cutout **44** completely opening the venting region **43** to atmosphere.

As a matter of clarification, it should be understood that when the power stream is referred to as being laminar "at all points in advance of the receiver aperture," it is meant the power stream at all points before it enters the receiver aperture or impinges against the receiver face and does not include dispersion flow of fluid particles which have impinged against the receiver face. Also, in characterizing the power stream as "laminar," it is meant that the power stream in its essential integrity as a fluid stream is "laminar" as opposed to "turbulent." Obviously, this is not intended to exclude the possible presence in some applications of the invention of eddies or turbulence at the side edges of the power stream or interface regions between the power stream and the ambient fluid through which it passes.

The receiver port **42** in the form of the invention shown in FIGS. **1** through **5** is also a square passageway defined by the main body member **24** and the cover plate **25** and is concentrically aligned with the supply conduit outlet orifice **28** as indicated by the center line c. In this form of the invention, the cross-sectional area of the receiver port **42** is smaller than the cross-sectional area of the supply conduit emission orifice **28** so as to enhance the sensitivity of the amplifier. The outlet for the receiver in this form of the invention is through the bore **45** for one of the screws **26** and, thence, through the opening **46.** The screw bore **45** is sufficiently larger than the associated screw **26** to provide an adequate fluid path, and this arrangement reduces the cost of fabrication.

To effect operation of the amplifier shown in FIGS. **1** through **5,** the supply conduit opening **27** is connected to a suitable source of fluid under pressure (not shown). The control pressure inlet openings **39** and **40,** in turn, are connected respectively to sources of control pressure (not shown), the fluctuations of which relative to one another are to be amplified. In some cases, one or the other of the inlet openings may simply communicate with atmosphere, in which event atmospheric pressure serves as a reference with which pressure fluctuations communicated to the other control pressure inlet opening are compared. The control pressure sources may in some applications present positive pressure conditions (i.e. pressures above atmospheric pressure) and in other applications may present negative or vacuum pressure conditions. The point of importance is that separate pressure conditions are applied to the control sections **31** and **32** through the ports **37** and **38.** As previously indicated, the ports **37** and **38** act in the manner of stagnation chambers so that the pressure conditions applied to the control sections **31** and **32** are essentially static pressure conditions. Under these circumstances a pressure differential equal to the differences between the static pressures in the control chambers **31** and **32** is applied transversely across the laminar power stream. It is important to understand that the control chambers are relatively very large in width; in other words, the width dimension L shown in FIG. **2A** is appreciably larger than the dimension D, the dimension of the supply conduit emission orifice **28** in the plane of angular deflection of the laminar power stream. In fact, the ratio L/D should be four or greater. Accordingly, the pressure differential is applied to a substantial portion of the length of the laminar power stream. It will be noted that for the length L of the power stream (the portion of the power stream across which a pressure differential is applied), the power stream is confined by walls **33** and **34** causing the pressure differential to act on the power stream in the manner of a pressure differential acting on a diaphragm. The pressure differential causes an angular displacement of the laminar power stream as illustrated diagrammatically in FIG. **2A.** Importantly, this angular displacement occurs without causing the power stream to become nonlaminar or turbulent in the region in advance of the receiver port **42.** In other words, the point of turbulence referred to in the Auger U.S. Pat. No. 3,234,955 may be considered a virtual point located either within or downstream of the receiver port **42.** In the present invention, the pressure differential applied across the power stream does not cause this virtual point of turbulence to advance upstream of the receiver port. The angular displacement of the relatively long, narrow power stream without impairing its integrity as a laminar stream is indicated by the graph of FIG. **7.** The graph of FIG. **7** is based on tests using the same test structure previously referred to in relation to the graph of FIG. **6.** The probe was located an X distance of one-fourth inch from the datum line d, and the supply pressure to the supply conduit was 10 inches of water. As shown in FIG. **7,** the point of maximum pressure was laterally displaced as control pressure was increased on one side of the power stream, the opposite side of the power stream being exposed to atmosphere. The continued integrity of the power stream as a laminar stream during the displacement represented in FIG. **7** is shown by the fact that the output pressure from the probe decreased very little with power stream displacement. Specifically, the output pressure from the probe at zero relative control pressure was 4.9 inches of water; at a control pressure of 0.02 inches of water, the receiver probe output pressure was 4.8 inches of water; at a control pressure of 0.04 inches of water, the receiver probe output pressure was 4.7 inches of water; at a control pressure of 0.06 inches of water, the receiver probe output pressure was 4.6 inches of water; at a control pressure of 0.08 inches of water, the receiver probe output pressure was 4.5 inches of water; at a control pressure of 0.12 inches of water, the receiver probe output pressure was 4.2 inches of water;

and at a control pressure of 0.14 inches of water, the receiver probe output pressure was 3.8 inches of water.

Turning to FIG. **8**, there is presented a pair of curves of receiver output pressure versus control pressure. Again, a 0.018 inch internal diameter receiver probe was used. The supply pressure was 10 inches of water. Curve **8***a* was produced with an X distance spacing from the datum line *d* to the receiver probe of one-fourth inch. Curve **8**b was produced with an X distance spacing from the datum line d to the receiver probe of one-half inch. Significantly, curve **8***a* indicated an average gain of approximately **80** with curve **8***b* indicating an average gain of slightly less than **80.** By way of comparison with curve **8***b*, reference is made to FIG. **9** in which an average gain of approximately 135 is indicated for an X distance spacing of one-half inch with a supply pressure of 15 inches of water in liew of the supply pressure of 10 inches of water used to produce gain curve **8***b*.

A family of gain curves **10***a* through **10***h* obtained with vacuum control pressures is shown in FIG. **10.** By "vacuum control pressures" it is meant that one side of the laminar power jet was exposed to atmosphere while the other side was exposed to control pressure below atmospheric pressure. An X distance spacing of 0.031 inch was employed to produce the gain curves **10***a* through **10***h*. The supply pressures utilized were as follows:

15 inches of water for curve **10***a*
12.5 inches of water for curve **10***b*
11.2 inches of water for curve **10***c*
10 inches of water for curve **10***d*
8.5 inches of water for curve **10***e*
7.4 inches of water for curve **10***f*
5.7 inches of ewater for curve **10***g*
4.5 inches of water for curve **10***h*

Again, it is seen that the pressure gain is very high. For example, the pressure gain on the linear portion of curve **10***a* is approximately 100. Moreover, the proportional action is smooth.

Referring now to FIG. **11**, there is shown somewhat diagrammatically an additional form of pure fluid amplifiers according to the present invention with the cover plate removed. The amplifier **120** of FIG. **11** illustrated is arranged for single positive control pressure utilization. Control chamber **132** is designed to apply atmospheric pressure to one side of the laminar power stream while control chamber **131** is adapted to apply positive control pressure signals to the laminar power stream. As in the amplifier of FIGS. **1** through **5**, in the amplifier **120** the length of the control section is greater in magnitude than the width D of the power stream emission orifice **128** by at least a factor of four, and the region immediately in advance of the receiver port **142** is relieved in all directions in a plane perpendicular to the plane of angular displacement of the laminar power stream. This region, in turn, is grossly vented to the sides and by a cutout in the cover plate (not shown) like the cutout **44** shown in FIG. **1.** It should be noted in FIG. **11** that the forward edge of the wall element **135** is brought up to the quiescent or nonangularly displaced position of the laminar power stream and may in fact be slightly in interference with the laminar power stream. As previously noted, it has been found that in fluid amplifiers according to the present invention, input impedance and control pressure losses associated with a particular control chamber are a function of the spacing between the forward edge of the associated wall elements and the laminar power stream and the pressure condition in the control chamber relative to atmospheric pressure. Accordingly, FIG. **11** illustrates the arrangement for maximum input impedance and minimum control pressure losses for a positive-pressure-operated amplifier of the present invention having a given control port width. As the laminar power stream is moved away from the wall element **135** by an increase in positive control pressure in the chamber **131,** the input impedance declines somewhat.

Turning to FIG. **12,** there is shown another form of pure fluid amplifier **220** according to the present invention. The amplifier **220** is similar to the amplifier **120** of FIG. **11** except that it is designed for single vacuum-control-pressure operation. It will be noted that the wall element **235** associated with the control chamber **231** unlike the wall element **135** in FIG. **11** is spaced a finite distance from the nonangularly displaced position of the laminar power stream. The spacing is necessary in order to permit the laminar power stream to be moved toward the control chamber **231** as the magnitude of the control vacuum therein increases. In an application in which maximum possible input impedance is desired, this spacing will be made as small as possible consistent with the desired maximum angular displacement of the laminar power stream. In contrast with the amplifier **120** of FIG. **11,** in the amplifier **220** of FIG. **12** the input impedance will generally be at its highest level at the point of maximum angular displacement of laminar power stream and at its lowest level at the quiescent or nonangularly displaced position of the laminar power stream. However, the change in input impedance with angular displacement of the laminar power stream is not as pronounced under vacuum-control-pressure operation as under positive-pressure operation but rather tends to remain at a higher level.

FIG. **13** depicts an amplifier **320** according to the present invention which is adapted for dual input control signals and dual receivers. In other respects, the amplifier **320** is similar to those described above. The dual receiver ports **343** and **353** are separated by a splitter **360** which is aligned with the axis of the power stream outlet orifice **328** and which preferably presents a knife edge to the laminar power stream. A change in the pressure differential across the laminar power stream in the control section **323** is amplified as a proportional change in the difference in pressures in the dual receivers. As in the other amplifiers described, the input impedance of either of the control chambers is a function of the instantaneous spacing between the forward edge of the associated downstream wall element and the laminar power stream.

UNIT VENTILATOR CONTROL SYSTEM USING A LAMINAR DEFLECTOR

By way of illustration, there is shown in FIGS. **14** through **16** a utilization of a pure fluid amplifier according to the present invention to effect control of air dampers in a unit ventilator system. As will be seen, the amplifier in this arrangement serves to sense whether or not the unit ventilator fan is running, and, if it is not running, to cause closure of ths outside air dampers to prevent coil freeze-up.

Referring to FIG. **14,** it is seen that the unit ventilator **400** includes a supply line **401** for supplying air from a

conventional source 399 at a predetermined pressure level, 15 p.s.i. for example. The supply line 401 provides supply pressure to a pneumatic room thermostat 402 and to the pneumatic switch 410. A conduit 403 connects the output side of the room thermostat 402 to the input side of an internal pneumatic thermostat 404 disposed in the air stream. The output side of the air stream thermostat 404 is connected by a conduit 405 to the switch input port of the pneumatic switch 410. The outlet port of the switch 410 is connected to a pneumatic motor 406 and to a pressure-responsive coil flow control valve 407 via conduit 408. The motor 406 determines the position of the outside air damper 409 while the valve 407 determines the quantity of flow of heating fluid through the coil 411. The suction side of the fan 413 is connected via conduit 414 to an input control pressure port of the switch 410. With the exception of the pneumatic switch 410 and its interconnections, the structure of the unit ventilator 401 is conventional.

Referring to FIGS. 15 and 16, the switch 410 is depicted. It comprises an assembly 412 fabricated to include a sensing stage 420, a relay stage 470, and a switching stage 480.

The sensing stage 420 consists of a fluid amplifier according to the present invention. It includes a supply conduit comprising a straight line lead-in 422 of sufficient length to assure laminar flow and a passageway 421 which terminates at emission orifice 428. The control section 423 includes a control chamber 431 on one side. The opposite side of the control section 423 is open to atmosphere. The downstream end of the control chamber 431 is formed by the wall element 435. As in the previously described embodiments of the invention, the length of the control section 423 is larger than the width of the outlet orifice 428 by at least a factor of four, and the region immediately in advance of the face of the receiver 441 is relieved in all directions in a plane perpendicular to the plane of angular displacement of the laminar power stream and grossly vented to atmosphere. It will be also noted that the walls 433 and 434 confine the laminar power stream to its plane of angular displacement.

The output of the receiver 441 is communicated via conduit 451 to a chamber 452 on one side of the diaphragm 453. A chamber 454 on the opposite side of the diaphragm 453 cooperates with the diaphragm 453 to form a portion of the relay stage 470. The chamber 454 is vented to atmosphere by the outlet 455. The diaphragm 453 is connected to a ball member 456 which valves a port 457 adapted to connect the chamber 454 with a conduit 458. The conduit 458 is connected through a restriction 459 to the supply pressure line 401. The ball member 456 is normally biased by a spring 461 into seated position closing the port 457.

The conduit 458 is also connected to a chamber 462 on one side of another diaphragm 463. On the opposite side of the diaphragm 463 there is still another chamber 464 forming a portion of the switching stage 480. The chamber 464 is vented to atmosphere by outlet 465. The diaphragm 464 carries a plate 466 which is adapted to abut against a valving member 467. At one end, the conduit 471 continuously communicates with the chamber 464. At its opposite end, the conduit 471 is in valved communication with a chamber 473. Valving of the conduit 471 is provided by one end of a dumbbell valve member 472. The opposite end of the valve member 472 valves the exterior end of a bore 474. A bias spring 475 urges the valve member 472 into a seated position such that communication between the chamber 473 and the switch inlet port 476 is normally closed. A port 477 connected directly to chamber 473 serves as the switch outlet port which is connected to conduit 408. The inlet port 476 is connected to conduit 405.

In normal operation with the fan 413 operating, a vacuum condition is presented to control chamber 431 of the fluid amplifier comprising sensing stage 420 via conduit 414. In accordance with the principles of the present invention, the laminar power stream projected from the emission orifice 428 is angularly displaced with the result that the pressure level in the receiver 441 and thus in the chamber 452 is substantially atmospheric pressure. With no effective pressure differential across the diaphragm 453, the bias spring 461 maintains the valve member 456 in the relay stage 470 closed so that the chamber 462 is maintained at supply pressure. The diaphragm 463 responds to supply pressure in the chamber 462 by moving the valve member 467 to the right in FIG. 16. This action closes off the path through which chamber 473 and port 477 are otherwise vented and connects port 477 to port 476. In short, the switching stage 480 is caused to function in the manner of a three-way valve, disconnecting outlet port 477 from communication with atmospheric and connecting it instead to switch inlet port. Under these conditions, the room thermostat functions in conventional manner to position the coil control valve 407 and the damper motor 406 to maintain the desired temperature. The air stream thermostat 404 functions in conventional manner to prevent air from being discharged at a temperature below a predetermined minimum temperature (for example, 60°F) by venting pressure from the control valve 407 and damper motor 406 to gradually open the control valve and gradually close the outside air damper 409.

When the fan 413 is off, a vacuum is no longer presented to the control chamber 431 of the fluid amplifier section 420. As a result, the laminar power stream is received by the receiver 441 without angular displacement. A pressure equal to several inches of water is thus produced in the receiver 441 and communicated to the chamber 452. This causes deflection of the diaphragm 453 which opens the bore 457. The chamber 462 is thereby vented with the result that in the switch stage 480, the inlet port 476 is closed, and the switch outlet port 477 is vented to atmosphere. Accordingly, the damper motor 406 and the control valve 407 are relieved, causing the air damper 409 to be closed and the control valve 407 to be fully opened for maximum flow of heating fluid. Thus, the coil 411 is protected from freeze-up.

BIASING SYSTEM AND ITS APPLICATION IN A CONTROLLER

Turning now to FIG. 17, there is shown a control circuit 501 in which two single-sided-type laminar deflectors 620 and 720 of the present invention are employed as the second and third stages. By "single-sided-type," it is meant that the amplifier has a single control signal input and a single output receiver like the amplifiers shown in FIGS. 12 and 13 and previously described. One advantage of "single-sided-type " amplifiers is that with only a single receiver, the need for a splitter is

eliminated thereby increasing the ease of manufacture.

The control circuit **501** is arranged as a proportional controller for maintaining a variable such as temperature at a preselected level or "setpoint." A conventional pneumatic thermostat **503** is provided with supply pressure from a conventional regulated source **504** which may, for example, provide pneumatic fluid at 20 p.s.i. The thermostat **503** provides an input signal via restrictor **510** to one control jet chamber **505** of the amplifier **502** which is a differential momentum-type amplifier as distinguished from the pressure-operated laminar deflectors of the present invention. The input variable signal pressure P_2 in chamber **505** varies with sensed temperature within a range, for example, of 1 to 4 inches of water, to project a control jet from nozzle **505***a* which varies accordingly. The chamber **506** of the amplifier **502** is connected to the regulated source through a restrictor **507** for providing a power stream from nozzle **506***a*. The other control jet chamber **508** provides a reference signal pressure P_1 for projecting a corresponding control jet from nozzle **506***a*. The chamber **508** is connected to a conduit **509** which, in turn, is connected through variable restrictor **511** to the regulated source **504** and through variable restrictor **512** to the controller output conduit **513.** The variable restrictor **511** serves as the setpoint adjustment, and the variable restrictor **512** serves as the sensitivity adjustment. The amplifier **502** is vented in front of its receiver **514** by venting conduits **515** and **516.** The receiver **514** is connected to the control pressure chamber **631** of the second stage amplifier **620** via conduit **637.** In order to provide suitable output characteristics from the amplifier **502,** the receiver **514** may be laterally offset with respect to the power stream nozzle.

The second stage amplifier **620** is a single-sided laminar deflector similar to the amplifiers of FIGS. **11** and **12**; the control chamber **632** is vented to atmosphere. Like the laminar deflectors previously described, the amplifier **620** includes a supply conduit including a stagnation chamber **622** followed by a passageway **621** which terminates in an emission orifice **628** for projecting a laminar power stream. The region **643** immediately in advance of the receiver **642** is relieved in all directions in a plane perpendicular to the axis of the receiver **642** and vented. The amplifier **620** differs from the amplifiers of FIGS. **11** and **12** in that the receiver **642** is laterally offset toward the control chamber **631.** As will be specifically referred to further on, the width of the control chamber **631** is much larger than the width of the emission orifice **628,** and the control chamber downstream wall element **635** is set back from the center line of the emission orifice. It will be noted that the stagnation chamber **622** is connected to the supply source **504** through a restrictor **601.** The receiver **642** is connected via conduit **737** to the control pressure chamber **731** of the third stage amplifier **710.**

The third stage amplifier **720** differs from the second stage amplifier **620** in that the receiver **742** is aligned with the emission orifice **728,** the wall element **735** is spaced a lesser distance from the center line of the emission orifice than is the wall element **635,** and the width of the emission orifice **728** is slightly smaller than the width of the emission orifice **628.** As a general proposition, in a laminar device, it is desirable to make the emission orifice as small as possible consistent with manufacturing capabilities. The reason for making the emission nozzle small is to lower the Reynolds number which is the best available index of a laminar power stream. For example, with a 0.016 inch by 0.016 inch emission orifice and a 10D or 0.16 inch control chamber width, the maximum working output pressure obtained from the laminar power stream may be 10 inches of water, but if the emission orifice is reduced to 0.010 inch by 0.010 inch, a working output pressure from the laminar power stream of 20 inches of water may be obtained. In the controller **501,** the amplifier **720** is provided with a 0.010 inch by 0.010 inch emission orifice in order to provide the relatively high input pressure required by the pilot valve **517.** The supply conduit stagnation chamber **722** of the amplifier **720** is connected via restrictor **701** to the supply source **504.** The receiver **742** is connected directly to the pilot valve **517.**

The pilot valve **517** preferably has a 30 to 1 pressure ratio. This relative high pressure ratio may be obtained in a small size by using the valving structure described in U.S. Pat. No. 3,244,190 of the present inventor which issued on Apr. 5, 1966. The output conduit **513** from the pilot valve **517** would normally be connected to utilization means such as a motor valve in a hot water heating conduit.

The biasing portion of the control circuit **501** is formed by a bias conduit **518** which terminates in an outlet orifice **519.** A Venturi section **521** is connected to the supply source **504** via a restrictor **522** and conducts a high velocity flow transversely across the orifice **519** into the chamber **523** which is well vented to remain at atmospheric pressure. In the well known manner of aspirator operation, the high velocity flow through the Venturi section **521** creates a low pressure condition at the outlet of the orifice **519,** drawing off fluid from the conduit **518** through the orifice **519.** This aspirator arrangement **526** effectively acts as a pressure sink, maintaining a predetermined pressure level in the conduit **518.** It is important to note that the conduit **637,** and hence the control chamber **631** of the second stage amplifier, are connected to the bias conduit **518** via a restrictor **524.**

Referring to FIG. **18,** there is shown an enlarged view of the third stage amplifier **720** in FIG. **17** which is a positive pressure-operated laminar deflector. The width of the emission orifice **728** is indicated by the reference character D. The width L of the control section **731** is preferably 10D. The outer edge of the wall element **735** is preferably spaced 1D from the center line C of the emission orifice **728.** The receiver **742** is coaxial with the emission orifice **728.** With the receiver from the preceding fluid amplifier connected to the control chamber **731,** the control port pressure is always essentially positive. Accordingly, the input flow comprises a component *a* which is entrained by the power stream plus a component *b* which passes between the tip of the wall element **735** and the laminar power stream. As previously noted in reference to FIG. **11,** the input impedance of this type of device decreases as the laminar power stream is angularly displaced by increasing control pressure. The input flow will rise appreciably with increasing control pressure in chamber **731.**

FIG. **19** is an enlarged view of the second stage amplifier **620** in the control circuit of FIG. **17** which is a negative pressure-operated laminar deflector. In normal operation, the pressure in the control chamber **631** is less than atmospheric. The spacing of the tip of the

wall element **635** from the emission orifice **628** center line is 2 ½D and L is 10D. The receiver **642** center line R is offset 1 ½D from the emission orifice center line C. With a negative control pressure input to the control chamber **631**, the input control signal flow Q_3 into the chamber **631** is determined by the composite of entrainment flow *e*, return flow *f*, and reverse flow *g* between the tip of the wall element **635** and the laminar power stream. In normal operation, the Q_3 flow will be positive, that is, air will be flowing from the conduit **637** into the chamber **631** because the entrainment flow component *e* will be larger than the sum of the return flow component *f* and the reverse flow component *g*. A discussion of the components of flow in a pressure control port generally can be found at pages 50 through 64 of "Basic Applied Research in Fluid Power Control" by S. -Y. Lee et al., Massachusetts Institute of Technology, Technical Report AFFDL–TR–65–79, dated May, 1965, and distributed by the Clearinghouse for Federal Scientific and Technical Information, Department of Commerce. The negative pressure mode of operation of amplifier **620** is characterized by a generally higher and more stable input impedance than found in positive pressure operation. The input flow magnitude varies much less than in the case of the positive control mode. There is a slight decrease in input flow as the control pressure becomes more negative.

One phenomenon with respect to the negative pressure mode of operation may be noted at this point. If the conduit **637** were obstructed or for other reasons could not supply sufficient fluid into the control chamber **631** to equal the output entrainment flow *e*, the entrainment flow component *e* will cause an increasingly negative pressure condition to occur in the control port **631.** As the pressure becomes more negative, the laminar power stream is drawn toward the wall element **635** which further restricts the flow component *g*, increasing the tendency toward a vacuum in the control port **631.** In this manner it would be possible for the partial vacuum in the control port **631** to draw the power stream partially into the control port **631** to a point where return flow *f* equals entrainment flow *e*. To provide desirable input flow and pressure characteristics in negative pressure operation, the tip of the wall element **635** is spaced farther away from the center line of the emission orifice **628** than in the case of the positive pressure operated amplifier **720.** The preferred spacing from the emission orifice **628** center line where the control chamber width is 10D is from 2D to 3 ½ D, or, in reference to the control chamber width, the preferred spacing is from 0.2L to 0.35L. Having determined the proper spacing of the tip of wall element **635** from the center line C of the emission orifice **628,** the offset of the center line R of the receiver **642** from the center line of the emission orifice **628** is selected to provide desired output flow and pressure performance characteristics.

Referring now to FIGS. **20A**, **20B**, and **21**, the relationship between the performance characteristics of the second stage amplifier **620** and the third stage amplifier **720** is illustrated. In FIG. **21** relating to amplifier **720**, a curve *h* of output pressure in inches of water versus input pressure in inches of water, and a curve *i* of input flow in standard cubic inches per minute (s.c.i.m.) versus input pressure in inches of water are provided. The curves *h* and *i* were derived with an amplifier like the amplifier **720** operating with a supply pressure of 1.6 p.s.i. In order for the pilot valve **517** to provide an output pressure range of 3 to 15 p.s.i., the output pressure P_6 range provided by the amplifier **720** in the particular case represented by FIG. **21** was 4 inches of water to 14 inches of water which, in turn, represented an input control pressure P_4 range of approximately 0.07 inches of water to 0.14 inches of water. For this range of input control pressures, it is seen from FIG. **21** that the input flow to amplifier **720** is from approximately 1.15 to 1.52 s.c.i.m. Since the input flow to the amplifier **720** is approximately equal to the output flow from the amplifier **620,** and the input control pressure to the amplifier **720** is approximately equal to the output pressure from the amplifier **620,** two points *m* and *n* can be located on FIG. **20B** which is a graph of amplifier **620** output flow versus amplifier **620** output pressure. The graph of FIG. **20B** was derived from an amplifier like amplifier **620** operating at a supply pressure of 10 inches of water.

The points *m* and *n* in FIG. **20B** determine the control pressure P_3 range for the amplifier **620** to provide the proper flow and pressure to the amplifier **720,** and the line *o* extending between points *m* and *n* can be considered an output load line for amplifier **620.** In the present example, it is seen that the control pressure range must be approximately minus 0.047 inches of water to minus 0.056 inches of water. Having determined the control pressure P_3 range from FIG. **20B**, the range of input flow Q_3 to the amplifier **620** control section **631** can be determined from FIG. **20A**, which is a graph of input flow Q_3 versus control pressure P_3. The curve *q* in FIG. **20A** was derived from an amplifier like amplifier **620** operating at a supply pressure of 10 inches of water.

From the input flow curve *q* in FIG. **20A**, it can be seen that the given control pressure P_3 range, the input flow Q_3 will vary between approximately 0.31 and 0.49 s.c.i.m. The amplifier **502,** the aspirator **526,** and the restrictor **524** are designed to provide the requisite control pressure range P_3 and attendant input flow Q_3 to the amplifier **620.** In particular, the aspirator **526** and restrictor **524** provide the biasing means for matching the output operating range of the momentum-type amplifier **502** with the negative pressure operation of the laminar deflector amplifier **620.**

In the control circuit of FIG. **17,** the opposing control jets from the respective nozzles **505***a* and **506***a* determine the angular deflection of the power stream so that a summing point function $(P_2 - P_1)$ is performed by the momentum-type amplifier **502.** In actual operation it would be advantageous to operate about the point where $P_2 = P_1$, but the no-load output pressure of the amplifier **520** at this point may typically be 10 inches of water, and the control pressure input to the second stage must be much less than this pressure or the amplifier **620** will be over-driven into saturation. As noted above, it is the function of the aspirator **526** and the restrictor **524** to suppress the output of the first stage to bring it within the working range of the second stage. This function may be understood by investigating flow of pneumatic fluid in the conduit **637.**

Essentially the flow in conduit **637** is a summation of three possible components. The first component is the output flow Q_1 from the first stage receiver **514.** The second component is the aspirated outflow Q_2 through the restrictor **524,** which outflow in general is a function of the difference between the pressure P_3 in the

conduit **637**, the pressure P_5 in the bias conduit **518**, and the value of the restrictor **524**. The third component of flow is Q_3, the flow into the control chamber **631** of the amplifier **620** from the conduit **637**.

As seen from FIG. **20B**, the aspirator-biased amplifier **620** produces very small load change in the output from the preceding amplifier stage throughout the operating range since the pressure P_3 in the conduit **637** and the control chamber **631** is very close to zero, the operating range being from minus 0.056 inches of water to minus 0.047 inches of water. Hence, the instantaneous value of the flow Q_1 into the conduit **637** from the receiver **514** is substantially independent of fluctuations in the pressure P_3 and may be approximated as

$$Q_1 = Q_1 \text{ quiescent} + K_1 (P_1 - P_2)$$

where Q_1 quiescent is the known no-load flow from the receiver **514** when $P_1 = P_2$, and K_1 is a proportionality constant. By "no-load flow," it is meant the volume of flow to a pressure region in which the pressure is effectively atmospheric pressure in terms of its effect on the flow Q_1. The flow Q_3, as previously noted, is a composite of entrainment flow *e*, return flow *f*, and reverse flow *g* shown in FIG. **19**. It will be appreciated that the Q_3 flow varies with the angular displacement of the power stream caused by variations in the control pressure P_3 as shown in FIG. **20A**. Assuming operation along a linear segment of the curve *q* in FIG. **20A**, the instantaneous value of the flow Q_3 may be approximated as

$$Q_3 = Q_v + K_3 P_3$$

where K_3 is a proportionality constant and where Q_v is the value of Q_3 when P_3 is zero (or, for more exact approximation, the value of Q_3 at the point $P_3 = 0$ on a straight line projected from coincidence with the linear operating range). The flow Q_2 through the restrictor **524** to the aspirator **526** may be expressed as

$$Q_2 = (P_3 - P_5/R_{524})$$

The flow Q_1 into the chamber **637** is equal to the output flows Q_2 and Q_3. Hence, summing the flows,

$$Q_1 = Q_2 + Q_3$$

$$Q_1 \text{ quiescent} + K_1 (P_1 - P_2) = (P_3 - P_5/R_{524}) + Q_v + K_3 P_3$$

At this point it is important to understand that $(P_3 - P_5/R_{524})$ can be made virtually a constant by making P_5 very large in comparison with P_3. In practice that is what is done. P_5 is given a magnitude on the order of 1 or 2 p.s.i. while P_3, as seen, is in the range of about 0.05 inches of water. Also, R_{524} is made large as possible in practice. Now to set the correct bias for the amplifier **620**, R_{524} is adjusted to a value at which $(P_3 - P_5/R_{524})$ is approximately equal to Q_1 quiescent, i. e. the flow into the aspirator is made approximately equal to the known "no-load" quiescent flow from the receiver **514**. Hence, the quantity can be subtracted from both sides of the flow summing equation above with the result that

$$K_1 (P_1 - P_2) = Q_v + K_3 P_3 \text{ or}$$

$$P_3 = [-Q_v + K_1 (P_1 - P_2)]/K_2$$

Thus, it is seen that the control pressure P_3, and hence, the angular displacement of the power stream in amplifier **620** is a function of the deviations $K_1 (P_1 - P_2)$ in input flow Q_1 and, therefore, a function of the summation $(P_1 - P_2)$ performed by the amplifier **502**. By use of the aspirator **526**, the operating range of the amplifier **620** has been matched to the operating range of the amplifier **502**.

Under certain circumstances such as a radical change in set point, a condition could occur in which the power stream of the first stage amplifier **501** is virtually completely removed from the receiver **514**. If this condition lowers P_3 to an extent that the power stream of the amplifier **620** is effectively drawn into the control chamber **631**, a control inversion would be produced, resulting in a total controller runaway condition. The possibility of a runaway situation is prevented by properly spacing the tip of the wall element **635** from the center line of the emission orifice **628** as previously described and by correlating the design of the input characteristics of the amplifier **620** so that P_3 will not reach a negative level sufficient to pull the power stream into the control chamber **631**.

In typical operation of the controller **501**, a temperature ste point such as 72°F is set by adjustment of the variable restrictor **511**. A drop in temperature below 72°F will result in error signal in the form of a change in output pressure from the first stage amplifier **502**. This error signal is amplified by the second stage amplifier **620** and by the third stage amplifier **720** and is submitted to the pilot valve **517** to effect an increase in heat output by the heating apparatus. A negative feedback signal from the pilot valve **517** is transmitted to the chamber **508** of the first stage amplifier **502** via the conduit **509** to provide a throttling effect. Adjustment of the variable restrictor **512** enables adjustment of the throttling effect and, hence, sensitivity of the controller. It should be noted that since the effect of the aspirator **526** is determined by supply pressure, the aspirator **526** provides a compensating effect for variations in the pressure level at the supply source **504**.

The foregoing description discloses a unique pure fluid amplifier system in which angular displacement of a laminar power stream is achieved providing unusually high pressure gain together with smooth proportional action and versatile impedance matching characteristics. In FIGS. **14** through **16**, one form of application of the pure fluid amplifier has been shown. Many other applications will occur to those skilled in the art. The foregoing description also discloses a biasing system for a laminar deflector and other pressure-operated pure fluid amplifiers and the use of the biasing system in a proportional controller.

While specific forms of the present invention have been illustrated and described herein, it is to be understood that this is by way of example only and is not to be construed in any manner as a limitation. It is contemplated that modifications may be made within the scope of the claims without departing from the spirit of the invention.

What is claimed is:

1. A pure fluid amplifier comprising:

a. a supply conduit of predetermined parameters and including an emission orifice, said conduit being adapted to produce a laminar fluid stream;

b. means for effecting flow of fluid through said supply conduit under a predetermined pressure relative to said parameters so as to project a laminar fluid power stream from said supply conduit emission orifice;

c. at least one receiver aperture spaced a predetermined distance from said supply conduit emission orifice and positioned to normally receive at least a portion of said projected laminar power stream;

d. control means for applying a biasing pressure differential across said power stream for a predetermined portion of its length for angularly displacing said power stream an amount dependent upon the magnitude of said pressure differential while maintaining said power stream laminar at all points in advance of said receiver aperture, said control means including means confining said power stream to its plane of angular displacement for said predetermined portion of its length, means defining a control chamber extending along one side of said power stream from said supply conduit emission orifice for a distance equal at least to four times the dimension of said supply conduit emission orifice in said plane of angular displacement and including a downstream wall which approaches the non-angularly displaced location of said power stream, means for applying a fluid pressure condition to said control chamber without causing a substantial fluid stream velocity component to impinge against said power stream, means disposed on the opposite side of said power stream from said control chamber for applying a second fluid pressure condition to said predetermined portion of the length of said power stream, said second fluid pressure condition being applied to said power stream without causing a substantial fluid stream velocity component to impinge against said power stream, said biasing pressure differential being the difference in magnitude between the first mentioned fluid pressure condition and said seocnd fluid pressure condition; and

e. means defining a venting region immediately in advance of said receiver aperture, said venting region being relieved in all directions in a plane perpendicular to the plane of angular displacement of said power stream.

2. A pure fluid amplifier as defined in claim **1** wherein said confining means confines said power stream to a dimension perpendicular to said plane of angular displacement and substantially equal to the dimension of said supply conduit emission orifice which is perpendicular to said plane of angular deflection.

3. A pure fluid amplifier as defined in claim **1** wherein said downstream wall approaches the non-angularly displaced position of said laminar power stream to a preselected spacing determining the input impedance characteristics of said control chamber.

4. A pure fluid amplifier comprising:

a. a supply conduit of predetermined parameters and including an emission orifice, said conduit being adapted to produce a laminar fluid stream;

b. means for supplying to said supply conduit under a predetermined pressure relative to said parameters so as to project a laminar fluid power stream from said supply conduit emission orifice;

c. at least one receiver aperture spaced a predetermined distance downstream from said supply conduit emission orifice and positioned to normally receive at least a portion of said projected laminar power stream;

d. control means for applying a biasing pressure differential across said power stream for a predetermined portion of its length for angularly displacing said power stream an amount dependent upon the magnitude of said pressure differential while maintaining said power stream laminar at all points in advance of said receiver aperture, said control means including means confining said power stream to the plane of its angular displacement for said predetermined portion of its length, means defining a control chamber extending along one side of said power stream from said supply conduit emission orifice for a distance equal to at least four times the dimension of said supply conduit emission orifice in said plane of angular displacement and including a downstream wall which approaches the non-angularly displaced loaction of said power stream, means for applying a fluid pressure condition to said control chamber without causing a substantial fluid stream velocity component to impinge against said power stream; and

e. means defining a venting region immediately in advance of said receiver aperture, said venting region being relieved in all directions in a plane perpendicular to the plane of angular displacement of said power stream.

5. A pure fluid amplifier comprising:

a. a supply conduit of predetermined parameters and including an emission orifice, said conduit being adapted to produce a laminar fluid stream;

b. means for effecting flow of fluid through said supply conduit under a predetermined pressure relative to said parameters so as to project a laminar fluid power stream from said supply conduit emission orifice;

c. at least one receiver aperture spaced a predetermined distance from said supply conduit emission orifice and positioned to normally receive at least a portion of said projected laminar power stream; and

d. control means for applying a biasing pressure differential across said power stream for a predetermined portion of its length at least in excess of the width of said supply conduit emission orifice for angularly displacing said power stream, as a proportional function of said biasing pressure differential, while maintaining said power stream laminar at all points in advance of said receiver aperture, whereby an output signal is received at said receiver which is a proportional function of said biasing pressure differential.

6. A pure fluid amplifier as defined in claim **5** wherein said control means applies said biasing pressure differential across said power stream for a portion of its length in excess of four times the dimension of said supply conduit emission orifice in the plane of angular deflection of said power stream.

7. A pure fluid amplifier as defined in claim **5** wherein said control means includes means for confining said power stream in the plane of its angular displacement for said predetermined portion of its length.

8. A pure fluid amplifier as defined in claim **7** wherein the last mentioned means confines said power stream to a dimension perpendicular to said plane of angular displacement substantially equal to the dimension of said supply conduit emission orifice which is perpendicular to said plane of angular deflection.

9. A pure fluid amplifier according to claim **5** further comprising means defining a venting region immedi-

ately in advance of said receiver aperture, said venting region being relieved in all directions in a plane perpendicular to the plane of angular displacement of said power stream.

10. A pure fluid amplifier as defined in claim **5** wherein said control means includes: means confining said power stream in the plane of its angular displacement for said predetermined portion of its length; means further defining a control chamber on at least one side of said power stream, open to said power stream, and extending said predetermined portion of the length of said power stream in a direction parallel to said power stream, said means defining said control chamber including a downstream wall which approaches the non-angularly displaced location of said power stream; and means for applying a fluid pressure condition to said control chamber without causing a substantial fluid stream velocity component to impinge against said power stream whereby said fluid pressure condition is applied to said predetermined portion of the length of said power stream.

11. A pure fluid amplifier as defined in claim **10** wherein said control means further includes means disposed on the opposite side of said power stream for applying a second fluid pressure condition to said predetermined portion of the length of said power stream, said second fluid pressure condition being applied to said power stream without causing a substantial fluid stream velocity component to impinge against said power stream, said biasing pressure differential being the difference in magnitude between the first mentioned fluid pressure condition and said second fluid pressure condition.

12. A pure fluid amplifier as defined in claim **11** wherein said control means applies said biasing pressure differential across said power stream for a portion of its length in excess of four times the dimension of said supply conduit emission orifice in said plane of angular displacement.

13. A pure fluid amplifier as defined in claim **11** wherein said downstream wall approaches the non-angularly displaced position of said laminar power stream to a preselected spacing therefrom for determining the input impedance characteristics of said control chamber.

14. A pure fluid amplifier comprising:

a. a supply conduit of predetermined parameters and including an emission orifice, said conduit being adapted to produce a laminar fluid stream;

b. means for effecting flow of fluid through said supply conduit under a predetermined pressure relative to said parameters so as to project a laminar fluid power stream from said supply conduit emission orifice;

c. at least one receiver aperture spaced a predetermined distance from said supply conduit emission orifice and positioned to normally receive at least a portion of said projected laminar power stream; and

d. control means for applying a biasing pressure differential across said power stream for a predetermined portion of its length at least in excess of the width of said supply conduit emission orifice for angularly displacing said power stream, as a proportional function of said biasing pressure differential, while maintaining said power stream laminar at all points in advance of said receiver aperture, said control means including means defining a control chamber including a downstream wall element which approaches the center line of said supply conduit emission orifice to a preselected spacing therefrom which determines the input impedance characteristics of said control chamber, whereby an output signal is received at said receiver which is a proportional function of said biasing pressure differential.

15. A pure fluid amplifier as defined in claim **14** wherein said preselected spacing is substantially equal to one half the width of said supply conduit emission orifice such that said power stream is angularly displaced away from said wall element by a positive pressure condition in said control chamber and said preselected spacing determines the input impedance of said control chamber.

16. A pure fluid amplifier as defined in claim **14** wherein said preselected spacing defines the limit of usable angular displacement of said power stream toward said control chamber and determines the input impedance presented by said control chamber as said power stream is angularly displaced toward said control chamber by a negative pressure condition in said control chamber.

17. A pure fluid amplifier as defined in claim **16** wherein said preselected spacing is within the range of from 0.2 to 0.35 times the length of said control chamber.

18. A pure fluid amplifier as defined in claim **16** wherein there is not more than one receiver aperture and the center line of said receiver aperture is laterally offset toward said control chamber from the center line of said emission orifice a predetermined amount.

19. In a pure fluid amplifier which includes a supply conduit of predetermined parameters with an emission orifice, means for effecting flow of fluid through said supply conduit so as to project a laminar fluid power stream from said emission orifice, and at least one receiver aperture spaced from said emission orifice and positioned to normally receive at least a portion of said projected power stream, a method for influencing said power stream comprising: applying a biasing pressure differential across said power stream for a predetermined portion of its length at least in excess of the width of said supply conduit emission orifice to angularly displace, as a proportional function of said biasing pressure differential, said power stream while maintaining said power stream laminar at all points in advance of said receiver aperture.

20. The method defined in claim **19** further comprising: grossly venting a region immediately in advance of said receiver aperture in all directions in a plane perpendicular to the plane of angular displacement of said power stream.

21. The method defined in claim **19** wherein said biasing pressure differential is applied across said power stream for a distance at least equal to four times the dimension of said supply conduit emission orifice in the plane of angular displacement of said power stream.

22. The method defined in claim **19** wherein said biasing pressure differential is applied across said power stream by confining said power stream to its plane of angular displacement and imposing a first substantially static pressure condition on one side of said power stream for said predetermined portion of its length while imposing a second substantially static pressure

condition to the opposite side of said power stream for said predetermined portion of its length, whereby said power stream is not subjected to impingement by a substantial fluid stream velocity component.

23. A pure fluid amplifier comprising:

a. a supply conduit including an emission orifice for projecting a power stream;

b. means for effecting flow of fluid through said supply conduit under a predetermined pressure so as to project said power stream from said supply conduit emission orifice;

c. at least one receiver aperture spaced a predetermined distance downstream from said supply conduit emission orifice;

d. control means for applying control pressure to said power stream for angularly displacing said power stream in accordance with said control pressure, said control means including means defining a control chamber on at least one side of said power stream and conduit means connecting said control chamber to a source of control pressure signals having a known no-load quiescent output flow volume; and

e. means for drawing off fluid from said control chamber in volume substantially equal to said quiescent output fluid flow volume from said source of control pressure signals to match the input operating range of said pure fluid amplifier with the output operating range of said source of control pressure signal so that deviations in said output fluid flow volume from said quiescent volume effect a corresponding change in the control pressure applied to said power stream.

24. The pure fluid amplifier as defined in claim 23 wherein the side of said power stream opposite from said control chamber is open to atmosphere.

25. The pure fluid amplifier as defined in claim 23 wherein said source of control pressure signals comprises a momentum-type fluidic device.

26. The pure fluid amplifier as defined in claim 23 wherein said means for drawing off fluid from said control chamber comprises aspirating means connected to said control chamber through a restriction.

27. The pure fluid amplifier as defined in claim 26 wherein said aspirating means includes a supply nozzle connected to said source of supply pressure.

28. The pure fluid amplifier as defined in claim 22 wherein said supply conduit is of predetermined parameters and adapted to produce a laminar fluid stream; said means for effecting flow of fluid through said conduit effects said flow under a predetermined pressure relative to said parameters so as to project a laminar fluid power stream from said emission orifice; and said control means applies said control pressure to said laminar power stream for a predetermined portion of the length of said power stream at least in excess of the width of said emission orifice for angularly displacing said power stream while maintaining said power stream laminar at all points in advance of said receiver aperture.

29. The pure fluid amplifier as defined in claim 28 wherein there is not more than one receiver aperture and the center line of said receiver aperture is laterally offset toward said control chamber from the center line of said emission orifice a predetermined amount.

30. The pure fluid amplifier as defined in claim 29 wherein said receiver aperture is laterally offset within the range of from 2 to 3 ½ times the dimension of said emission orifice in the plane of angular displacement of said power stream.

31. In a fluid signal amplifying system including a pure fluid amplifier having a control chamber for applying control pressure to a power stream for angularly displacing the power stream, a source of control pressure signals having a known no-load quiescent output flow volume, and conduit means connecting the control chamber of the pure fluid amplifier to the source of control pressure signals, the method for matching the input operating range of the pure fluid amplifier with the output operating range of the source of control pressure signals comprising: drawing off fluid from said control chamber of said pure fluid amplifier in volume substantially equal to said quiescent output flow volume from said source of control pressure signals so that deviations in said output fluid flow volume from said quiescent volume effect a corresponding change in the control pressure applied to said power stream.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,785,390 Dated January 15, 1974

Inventor(s) WESLEY L. TAYLOR

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the first page of printed patent the Assignee should read	-- Powers Regulator Company --

In the Specification:

Column 8, line 65 of printed patent Page 21, line 9 of application	"ths" should read -- the --
Column 11, line 56 of printed patent Page 27, line 20 of application	"710" should read -- 720 --
Column 16, line 22 of printed patent Page 38, line 2 of application	"ste" should read -- set --

In the Claims:

Column 17, line 35 of printed patent Claim 1(d), line 37 of application	"seocnd" should read -- second --
Column 18, line 15 of printed patent Claim 4(d), line 26 of application	"loaction" should read -- location --

Signed and sealed this 3rd day of December 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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