Feb. 4, 1969 B. M. HORTON 3,425,430

FLUID-OPERATED SYSTEM

Filed Aug. 24, 1960 Sheet 1 of 10

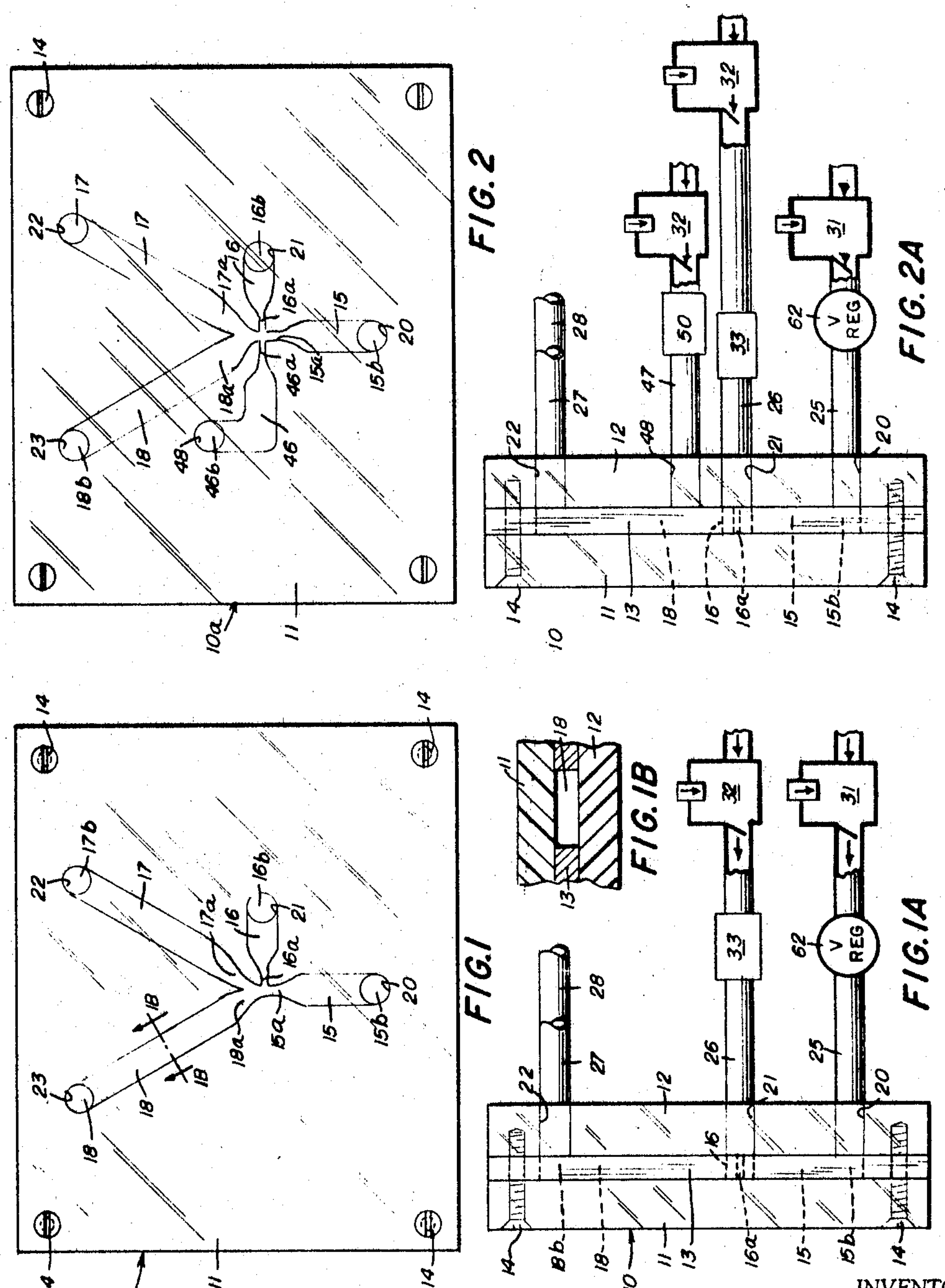

FIG. 2

FIG. 2A

FIG. 1

FIG. 1A

FIG. 1B

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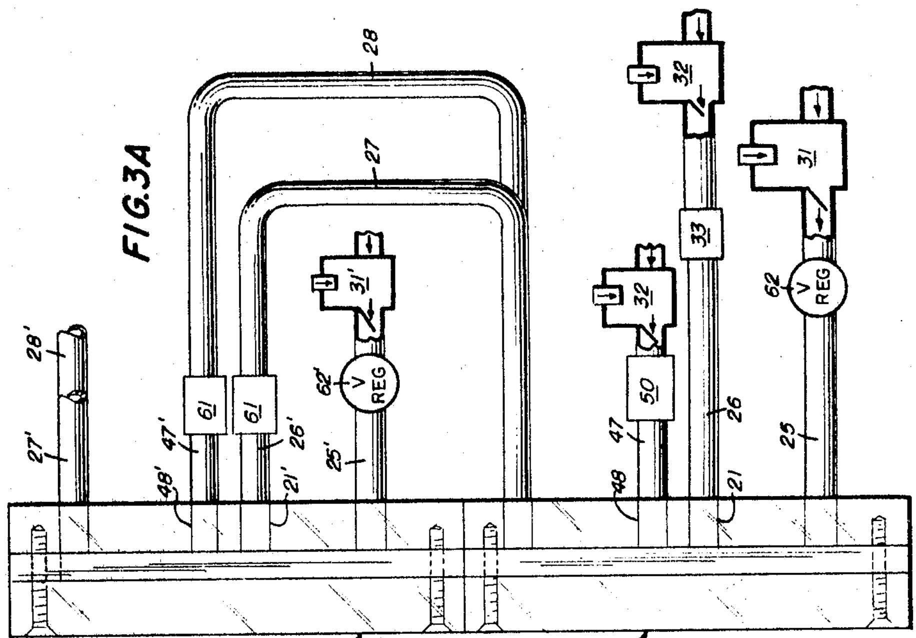
FIG.3A



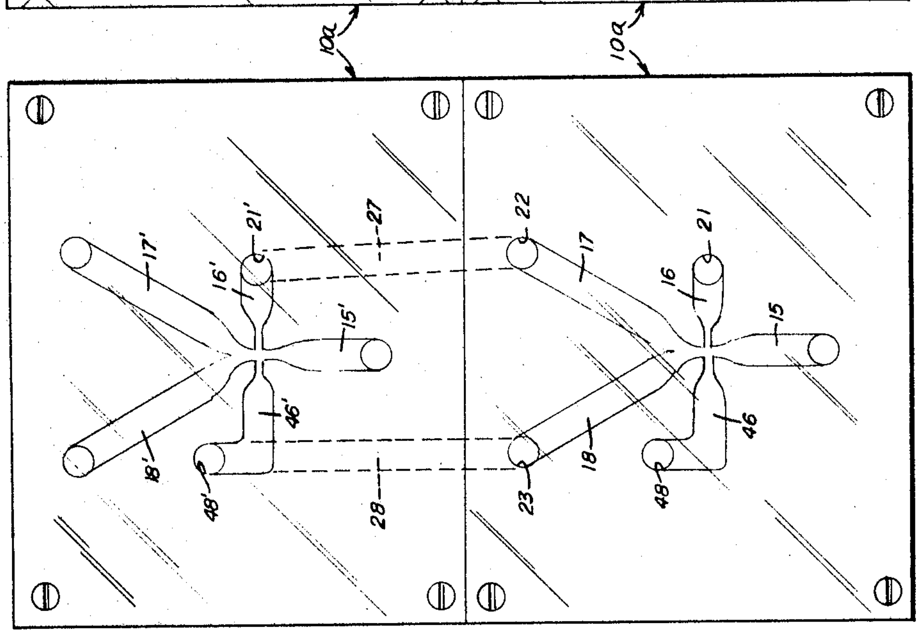


FIG.3

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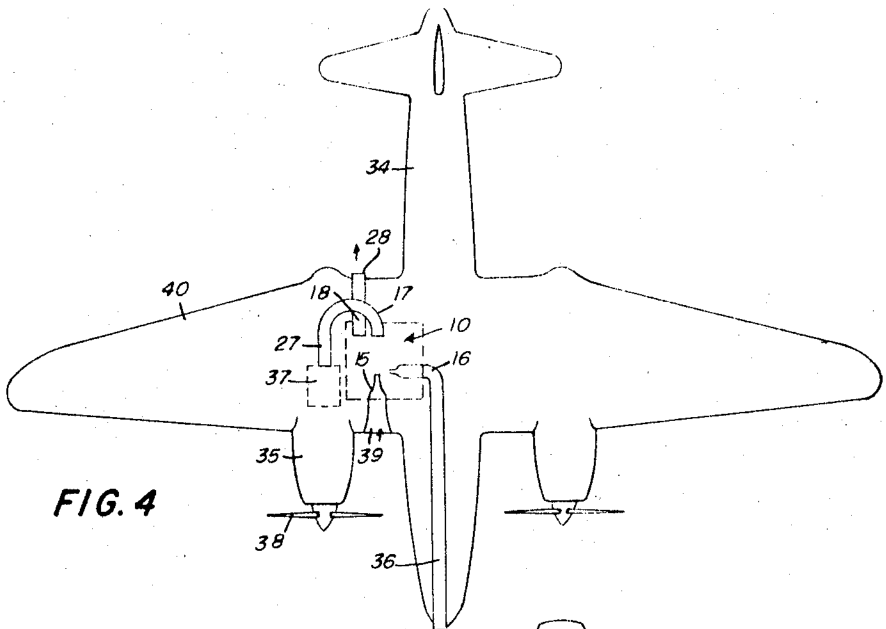
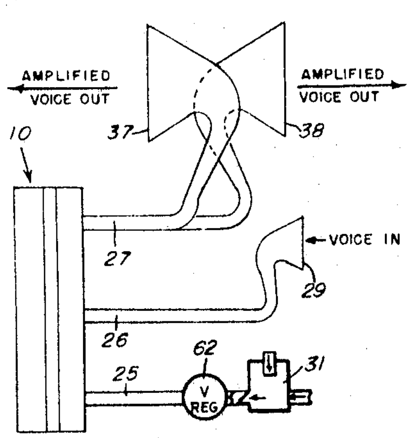


FIG. 4

FIG. 5



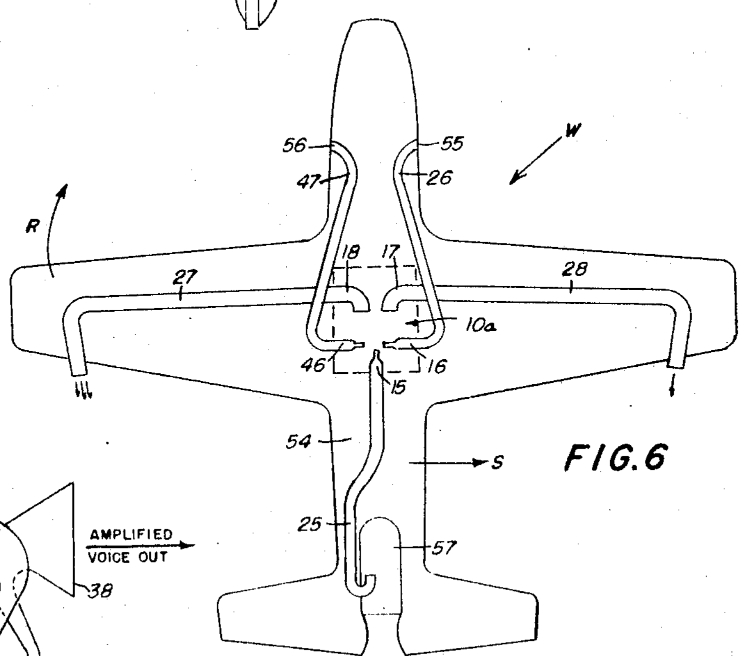


FIG. 6

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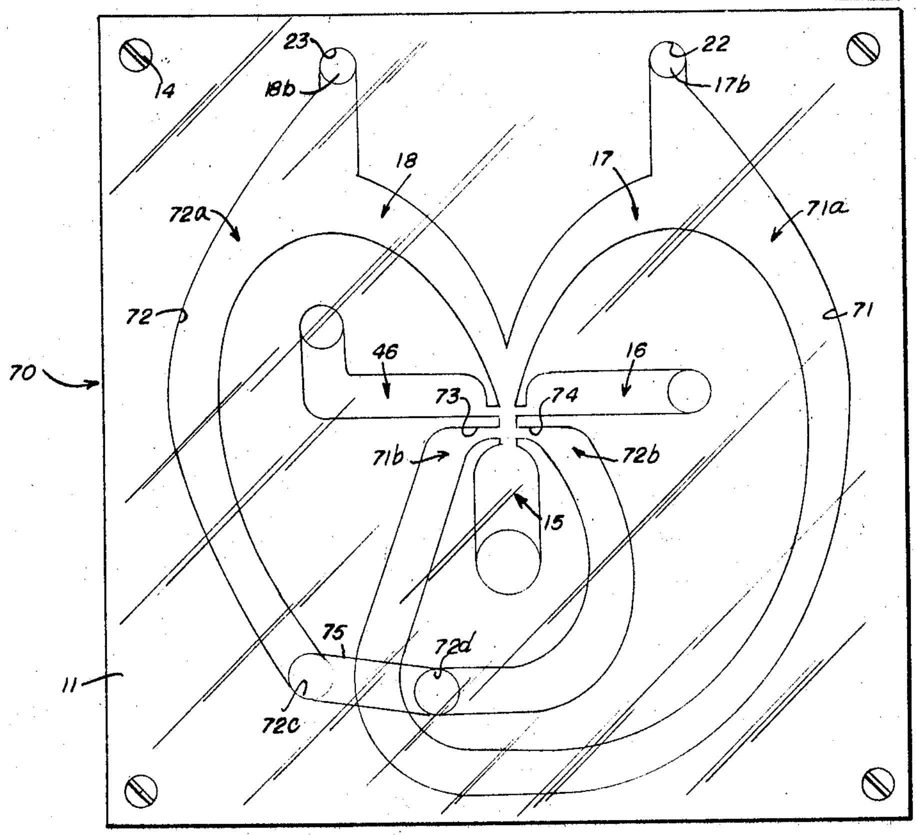

FIG. 7

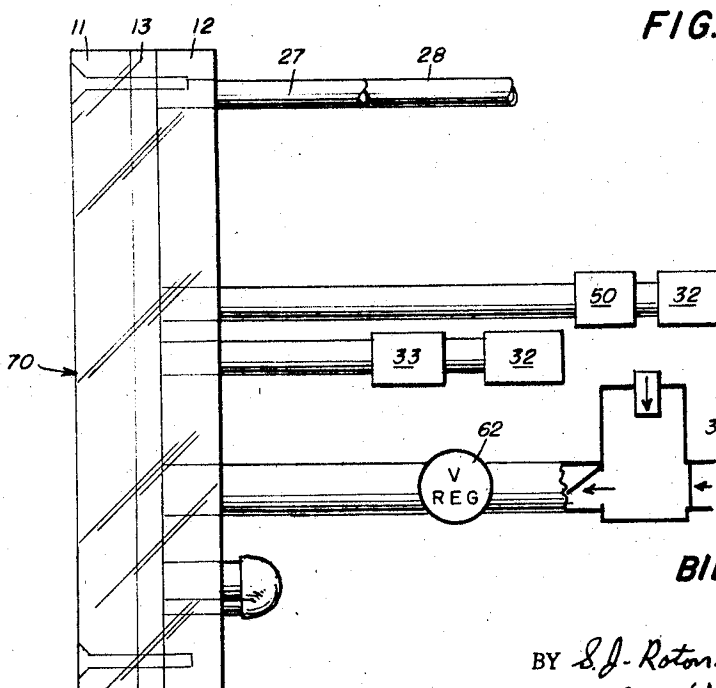

FIG. 7A

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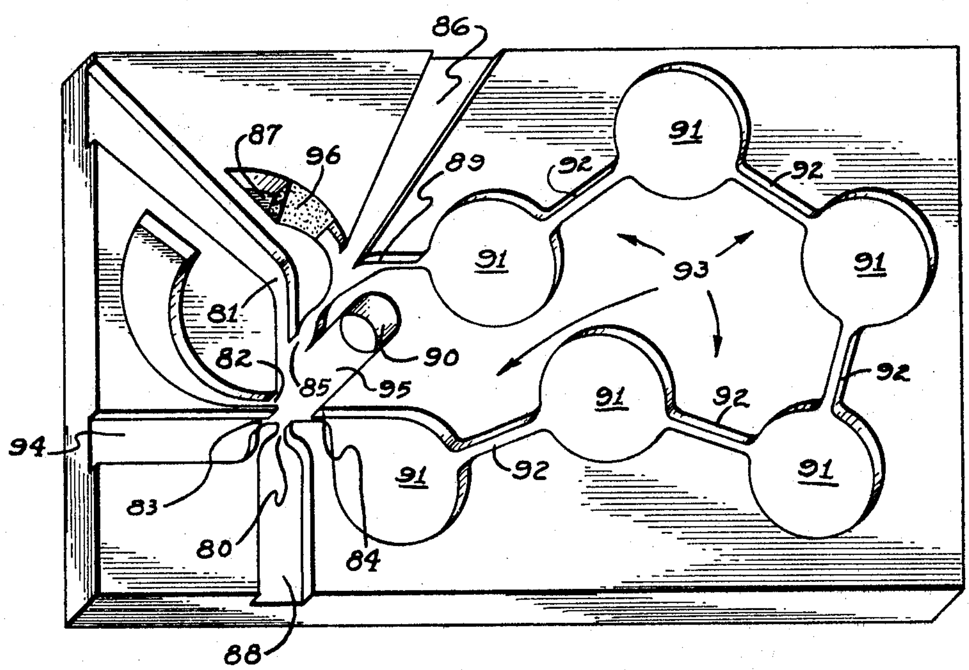

Fig. 8

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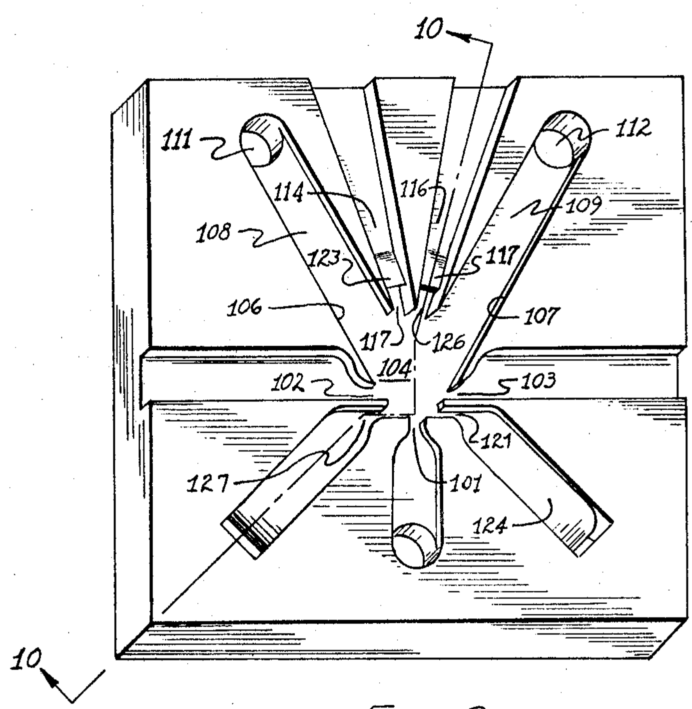

Fig. 9

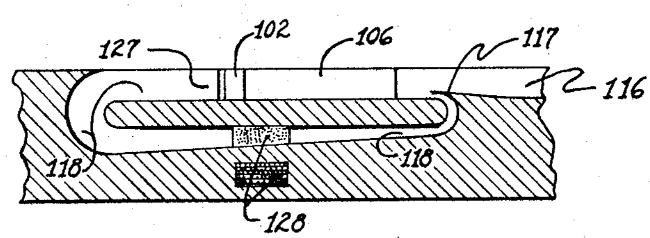

Fig. 10

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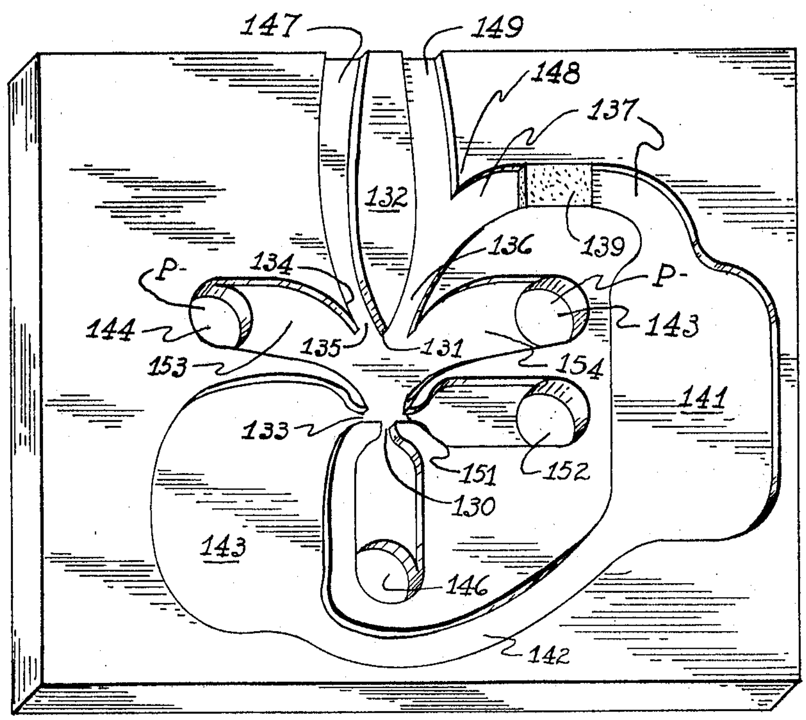

Fig. 11

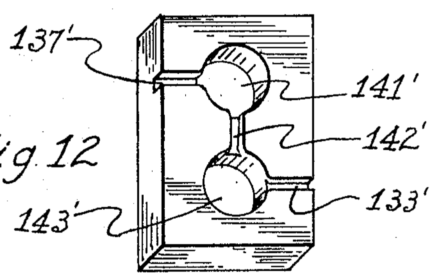

Fig. 12

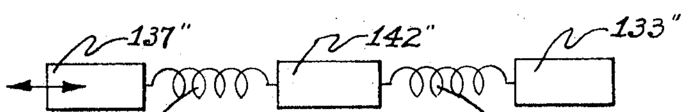

Fig. 13

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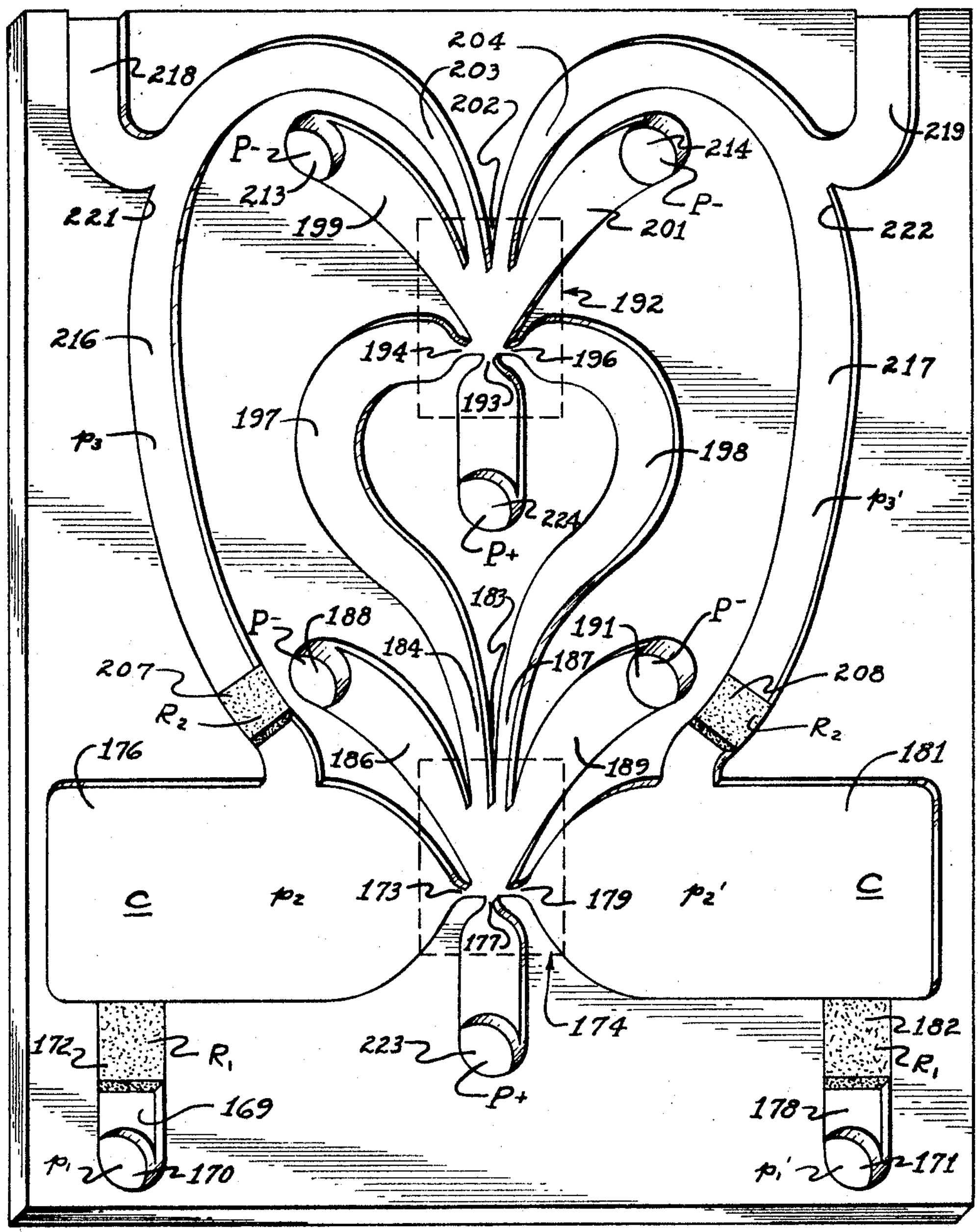

Fig. 14

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FLUID-OPERATED SYSTEM

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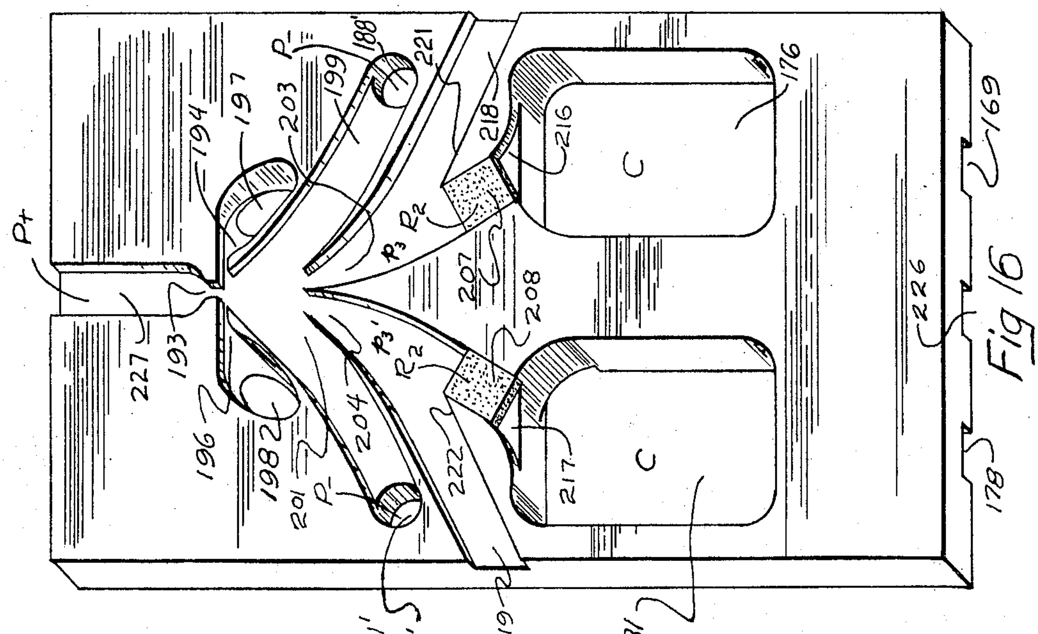

Fig 16

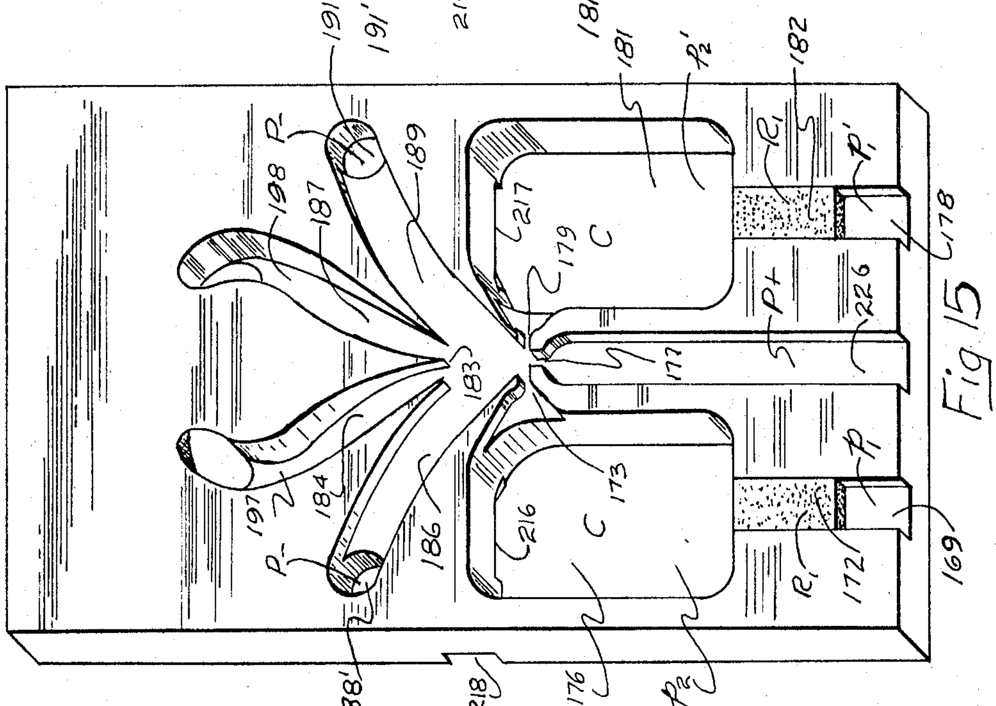

Fig 15

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FLUID-OPERATED SYSTEM

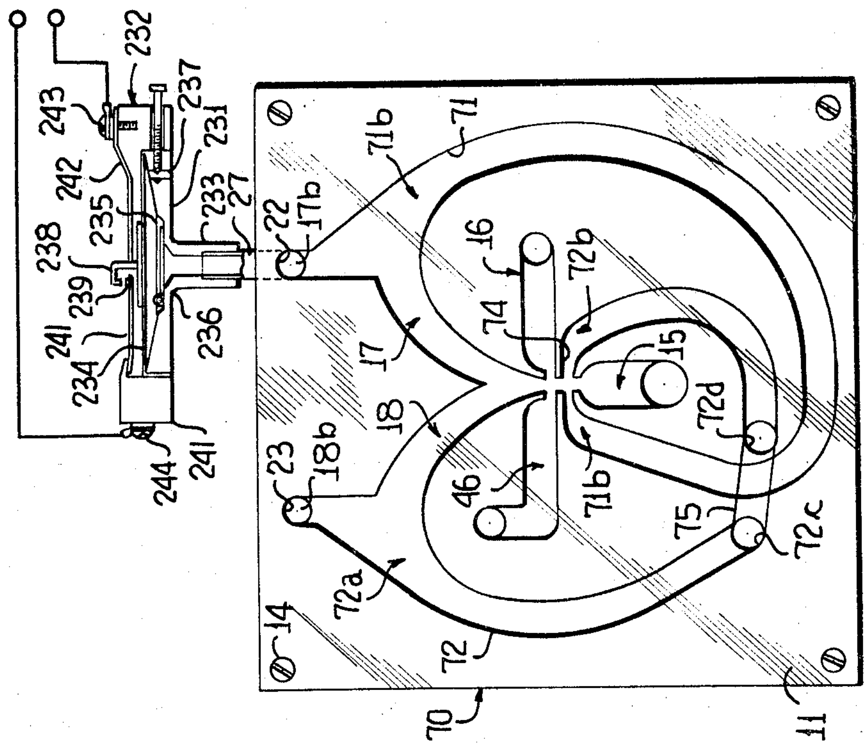

FIG.17

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United States Patent Office

3,425,430

Patented Feb. 4, 1969

3,425,430
FLUID-OPERATED SYSTEM

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Continuation-in-part of application Ser. No. 848,878, Oct. 26, 1959, which is a continuation-in-part of application Ser. No. 855,477, Nov. 25, 1959. This application Aug. 24, 1960, Ser. No. 51,754
U.S. Cl. 137—81.5 66 Claims
Int. Cl. F15c *1/10;* F15d *1/12;* G06m *1/12*

The invention described herein may be manufactured and used by or for the Government for governmental purposes without payment to me of any royalty thereon.

The present invention relates generally to fluid amplifier systems in which amplification is a function of the magnitude of deflection of a main fluid jet by a transversely operating source of fluid pressure, and more particularly to a fluid amplifier employing positive feedback to accomplish amplification and switching functions now conventionally performed only by electronic circuits. This application is a continuation-in-part of application Ser. No. 848,878 filed Oct. 26, 1959, for Fluid Operated System, by Billy M. Horton, now abandoned and refiled as application Ser. No. 51,896 on Sept. 19, 1960, now issued as Patent No. 3,122,165, and is also a continuation-in-part of application Ser. No. 855,477 filed Nov. 25, 1959 for Fluid Amplifier Computer with Feed-Back, by Billy M. Horton, now abandoned.

In fluid amplifier systems of the type with which the present invention is concerned, a power jet of fluid, which is well defined in space, is deflected by means of a pressure differential established approximately transverse to the normal direction of movement of the power jet. The differential in pressure established across the power jet may be employed to deflect the jet to one of various positions at which load mechanisms may be situated. These may convert the energy of the fluid stream to useful work. Alternatively, the energy, pressure or mass flow of the deflected stream may be employed as an input signal to a further device, fluid amplifier, to increase the over-all amplification of the system or to perform switching functions. Amplification is achieved by the fluid amplifier as a result of the fact that a relatively small fluid pressure gradient is required to deflect a high energy fluid stream so as to produce a large variation in energy, pressure or mass flow, delivered to an output location. A fluid jet may initially be directed away from a load device or output channel so that the energy of the fluid stream is not utilized. Only a small amount of energy in the control jet is required to alter the course of the power jet so that some or all of the jet becomes intercepted by the load device or output channel. The gain of the system can be considered equal to the ratio of the energy supplied to the load device, etc. by the power jet to the amount of energy required to deflect the jet to this location. Gains of the order of magnitude of 100 are obtainable with an amplifier stage of the type described above.

A typical single stage amplifier may comprise a main fluid nozzle extending through an end wall of a chamber defined in a typical case by the end wall and two outwardly diverging side walls, hereinafter referred to as the left and right walls. A V-shaped divider is disposed at a predetermined distance from the end wall with the apex of the divider disposed along the center line of the orifice and its sides generally parallel to the left and right side walls of the chamber. The regions between the divider and the left and right side walls define left and right output passages, respectively. Left and right control nozzles extend through the left and right side walls, respectively with one wall of each nozzle forming an extension of the end wall of the chamber.

In operation, fluid under pressure is supplied to the main nozzle and a well defined fluid stream issues into the chamber. Control signals in the form of changes of pressure are developed at the control nozzles and produce deflection of the main stream in one direction or the other depending upon whether the signal is in the form of increased or decreased pressures, respectively.

There are several broad classes of fluid amplifier units. Two of these classes are:

(I) Those in which there are two or more streams which interact in such a way that one or more of these streams deflect another stream with little or no interaction between the side walls of the chamber in which the streams interact and the streams themselves. In an amplifier or computer fluid element, the detailed contours of the side walls of the chamber in which the streams interact is of secondary importance to the interacting forces between the streams themselves. Although the side walls can be used to contain fluid in the interacting chamber, and thus make it possible to have the streams interact in a region at some desired pressure, the side walls are placed in such a position that they are somewhat remote from the high velocity portions of the interacting streams. Under these conditions the flow pattern within the interacting chamber depends primarily upon the size, speed and the direction of the streams and upon the density, viscosity, compressibility and other properties of the fluids in the streams. In the case of interacting free jets, i.e., those in which streams of fluid impinge upon one another with no interaction between the streams and the side walls, and with no forces from fluids around the streams, momentum must be conserved. This condition of momentum conservation can be approximated by interacting streams of water in air, since the viscosity of air is much lower than the viscosity of water, and since air is much less dense than water. An even better approximation to the condition of momentum conservation by interacting free jets is provided by the case of interacting jets of liquid mercury in vacuum.

(II) The second broad class of fluid amplifier and computer elements comprises those amplifier or computer elements in which two or more streams interact in such a way that the resulting flow patterns and pressure distribution within the chamber are greatly affected by the details of the design of the chamber walls. The effect of side wall configuration on the flow patterns and pressure distribution which can be achieved with single or multiple streams depends on: the relation between width of the interacting chamber near the power nozzle; the angle that the side walls make with respect to the center line of the power stream; the length of the side wall (when a divider is not used); the spacing between the power nozzle and the flow divider (if used); and the density, viscosity, compressibility and uniformity of the fluid. It also depends to some extent on the thickness of the amplifying or computing element. Amplifying and computing devices utilizing boundary layer effects, i.e., effects which depend upon details of side walls configuration can be further subdivided into three categories:

(a) Boundary layer elements in which there is no appreciable "lock on" effect. Such a unit has a power gain which can be increased by boundary layer effects, but these effects are not dominant;

(b) Boundary layer units in which "lock on" effects are dominant and are sufficient to maintain the power stream in a particular flow pattern thru the action of the pressure distribution arising from boundary layer effects, and requiring no additional streams other than the power stream to maintain that flow pattern, but having a flow pattern which can be changed to a new stable flow pattern either by the supplying or removal of fluid thru one or more of the control nozzles, or by altering the pressures at one or more of the output apertures;

(c) Boundary layer units in which the flow pattern can be maintained thru the action of the power stream along without the use of any other stream, which flow pattern can be modified by the supplying or removal of fluid thru the control nozzles, but which units maintain certain parts of the power stream flow pattern, including "lock on" to the side wall, even though the pressure distribution at the output apertures is modified.

In order to understand more fully the reasons for the lock-on phenomena, attention is called to the copending patent applications of Bowles and Warren, Ser. Nos. 855,478 and 4,830 filed Nov. 25, 1959 and Jan. 26, 1960, respectively, portions of the discussions of which are reproduced herewith for the purposes of clarity of the present discussion only. The lock-on phenomena is due to a boundary layer effect existing between the stream and a side wall. Assume initially that the fluid stream is issuing from the main nozzle and is directed toward the apex of the divider. The fluid issuing from the orifice, in passing through the chamber, entrains fluid in the chamber and removes this fluid therefrom. If the fluid stream is slightly closer to, for instance, the left wall than the right wall, it is more effective in removing the fluid in the region between the stream and the left wall than it is in removing fluid between the stream and the right wall since the former region is smaller. Therefore, the pressure in the left region between the left wall and the stream is lower than the pressure in the right region of the chamber and a differential pressure is set up across the jet tending to deflect it towards the left wall. As the stream is deflected further toward the left wall, it becomes even more efficient in entraining air in the left region and the pressure in this region is further reduced. This action is self-reinforcing and results in the fluid stream becoming deflected toward the left wall and entering the left outlet passage. The stream intersects the left wall at a predetermined distance downstream from the outlet of the main orifice; this point being normally referred to as the point of attachment. This phenomena is referred to as boundary layer lock-on. The operation of this type of apparatus may be completely symmetrical in that if the stream had initially been slightly deflected toward the right wall rather than the left wall, boundary layer lock-on would have occurred against the right wall.

Continuing the discussion of the three categories of the second class of fluid amplifying elements, the boundary layer unit type (a) above utilizes a combination of boundary layer effects and momentum interaction between streams in order to achieve a power gain which is enhanced by the boundary layer effects, but since boundary layer effects in type (a) are not dominant, the power stream does not of itself remain locked to the side wall. The power stream remains diverted from its initial direction only if there is a continuing flow out of, or into, one or more of the control nozzles. Boundary layer unit type (b) has a sufficient "lock on" effect that the power stream continues to flow entirely out one aperture in the absence of any inflow or outflow signal from the control nozzles. A boundary layer unit type (b) can be made as a bistable, tristable, or multistable unit, but it can be dislodged from one of its stable states by fluid flowing out of or into a control nozzle or by blocking the output passage connected to the aperture receiving the major portion of the power stream. Boundary layer units type (c) have a very strong tendency to maintain the direction of flow of the power stream through the interacting chamber, this tendency being so strong that complete blockage of the passage connected to one of the output apertures toward which the power stream is directed does not dislodge the power stream from its "locked on" condition. Boundary layer units type (c) are therefore memory units which are virtually insensitive to loading conditions at their output passages.

To give a specific example: boundary layer effects have been found to influence the performance of a fluid amplifier element if it is made as follows: the width of the interacting chamber at the point where the power nozzle issues its stream is two to three times the width, W, of the power nozzle, i.e., the chamber width at this point is 3W; and the side walls of the chamber diverge so that each side wall makes a 12° angle with the center line of the power stream. In a unit made in this way, a spacing between the power nozzle and the center divider equal to two power nozzle widths 2W will exhibit increased gain because of boundary layer effects, but the stream will not remain locked on either side. This unit with a divider spacing of 2W is a boundary layer unit type (a) which if the spacing is less than 2W an amplifier of the first class, i.e., a proportional amplifier results. If the divider is spaced more than three power nozzle widths, 3W, but less than eight power nozzle widths, 8W, from the power nozzle, then the power stream remains locked onto one of the chamber walls and is a boundary layer type (b). Complete blockage of the output passage of such a unit causes the power stream to lock to a new flow pattern. A boundary layer unit having a divider which is spaced more than twelve power nozzle widths, 12W, from the power nozzle remains "locked on" to a chamber wall even though there is complete blockage of the passage connected to the aperture toward which the power stream is directed, and thus it is a boundary layer unit type (c). Another factor affecting the type of operation achieved by these units is the pressure of the fluid applied to the power nozzle relative to the width of the chamber. In the above examples, the types of operation described are achieved if the pressure of the fluid is less than 60 p.s.i. If, however, the pressure exceeds 80 p.s.i. the expansion of the fluid stream upon emerging from the main nozzle is sufficiently great to cause the stream to contact both side walls of the chamber and lock on is prevented. Lock-on can be achieved at the higher pressures by increasing the widths of the chamber.

The boundary layer effects which produce lock-on provide a feedback action in a fluid amplifying element and thus have an important bearing on its gain, sensitivity to input signals, sensitivity to pressure at its output apertures, response time, frequency response and memory. This feedback action can be used to provide digital operation, logical operations and memory.

In some instances it is desired to introduce feedback into a fluid amplifying element in a manner which cannot be conveniently provided by boundary layer effects. For example, it is sometimes desirable to introduce a time delay or a phase shift in the feedback path, and it may be very difficult to achieve the required fluid inertances, fluid capacitances, and fluid resistances in a boundary layer feedback path. In those cases in which boundary layer feedback effects are not adequate to provide the desired feedback action, it is possible to employ an external feedback path, in conjunction with an amplifier of the first class; that is, a proportional amplifier, to provide the desired feedback. In such cases, and in order to achieve a fluid amplifier circuit which has stable gain, and which is substantially free of distortion and nonlinearities, it is often desirable to eliminate all feedback paths other than the external feedback path. Elimination of the boundary layer feedback paths in a fluid amplifying element can be accomplished by having fluid streams interact in a manner such that the flow pattern is virtually unaffected by the contours of the side walls of the chamber in which the streams interact. This can be accomplished as indicated above by employing a sufficiently high pressure to the power nozzle or by having the interaction chamber side walls placed at a remote location from the power stream. This latter effect can be accomplished either by setting the side walls back from the output end of the power nozzle so that the set back is many times greater than the width of the power nozzle and the stream cannot deflect sufficiently to "attach" to the side wall, or by having the side walls of the chamber diverge sharply so that only a small portion of each wall is in close proximity to the power stream. This latter method of avoiding boundary layer effects has the advantage that the control nozzle can be located very close to the power stream, thus the control stream is not appreciably degraded by viscous effects prior to its interaction with the power stream. The angle of divergence of the side walls has a definite effect on the operation of the apparatus since those units having the lesser divergence angles are not as completely free of side wall effects as are those having more sharply divergent side walls.

The present invention is concerned with fluid amplifier systems employing external feedback circuits and consequently amplifiers of Class I; that is, proportional amplifiers are employed. In the proportional amplifier, in the absence of a signal or application of pressure to a control nozzle, the power jet or stream divides equally between two output apertures. An increase or decrease in pressure in one of the control nozzles may deflect the fluid stream away from or toward this control nozzle thereby decreasing the fluid flow to one of the outlet passages and increasing the flow to the other passage. The proportional fluid amplifier may amplify various quantities, relating to fluid flow, depending upon the design of the unit. Specifically, gain may relate to pressure, power or mass flow. In considering the different types of amplifiers, it is necessary to determine whether the amplifier employs a free jet or a submerged jet. In the case of a free jet, such as water-in-air, the viscous drag of the surrounding medium on the stream has little effect on the system and both the total and pitot pressures across the jet are substantially uniform. In consequence, the characteristics of the jet are uniform with cross-section and all factors in the system, pressure, power and mass flow are amplified by the system. In a submerged jet, such as air-in-air, the viscous drag of the surrounding medium on the jet has an appreciable effect and produces a non-uniform pressure gradient across the jet. Maximum pressure of the jet is usually found along the axis thereof and in consequence, if a pressure amplifier is desired, the output apertures are constructed to sense only a small region at the center of the jet when the jet is deflected its maximum desired extent. A mass flow amplifier is constructed by accumulating all of the fluid in the jet while a power amplifier employs outlet apertures intermediate in size between the two aforesaid outlet apertures. The size of the outlet apertures for the power unit is such that the product of pressure and volume flow are maximized.

Each of the different types of amplifiers obtainable with a submerged jet system have specific areas of application and a pressure amplifier is normally employed in systems where it is undesirable to transport large quantities of fluid. Mass flow amplifiers are utilized where the system discharges into a low pressure and large masses of fluid may be moved with little pressure. Power amplification is normally employed to drive a load device, such as a piston, and in such cases the product of pressure times volume flow must be maximized.

Fluid amplifiers may be operated with or without feedback of energy from the outlet passages to the control passages regardless of the type of amplification required by the system in which the units are operating. If feedback is employed the gain of the amplifier is controlled by the standard equation

$$p_3 = p_1 \frac{G}{1-GB} \tag{1}$$

where p_3 is the output signal, p_1 is the input signal, G is the gain of the amplifier and B is the gain of the feedback path to the input of the system. In this equation, if the magnitude of the quantity $1-GB$ is greater than 1, negative feedback results. Fluid amplifier systems utilizing negative feedback are covered by my co-pending application Ser. No. 30,691 filed May 20, 1960, now U.S. Patent No. 3,024,805, Mar. 13, 1962.

If, however, the magnitude of the quantity $1-GB$ is less than 1, positive feedback results and two different types of systems may be devised. If the aforesaid quantity $(1-GB)$ is equal to 0, the output signal becomes infinite (see Equation 1 above) and the system oscillates. Fluid amplifier oscillators are covered in co-pending patent application Ser. No. 21,062 filed Apr. 8, 1960 by Billy M. Horton and Romald E. Bowles, now Pat. No. 3,185,166, May 25, 1965.

The third possible arrangement of amplifiers employing feedback, and the arrangement with which the present invention is concerned, results when the parameters of the amplifier are such that the magnitude of the quantity $1-GB$ of Equation 1 is less than 1 but greater than 0. In the conventional positive feedback amplifier system, gain enhancement results; that is, the gain of the amplifier is greater with positive feedback than it is without, but is not sufficiently great to send the system into oscillation. Feedback for gain enhancement may be of the broad band type in which the gain of the system is substantially the same for all frequency components of the input signal in the band. On the other hand, positive feedback may be at a single frequency or more correctly over only a narrow range of frequencies so that the amplifier becomes, in effect, a tuned narrow-band amplifier having a large gain at a specific frequency. Further, the feedback signal may be derived as a non-linear function of the jet deflection, using specially shaped apertures, and a function generator may thus be produced. This principle could be used to provide a logarithmic or exponential amplifier. Various other feedback systems may be employed and in a specific example a bootstrap integrator is provided.

The positive feedback systems described above relate primarily to systems for amplifying time varying continuous signals. Another class of positive feedback systems relate to switching systems, such as, flip-flops and monostable multivibrators. When employed in such systems, the positive feedback amplifier employing a basic unit of the first type of amplifier described above can be made to operate in the manner of a type three or a type four device. The positive feedback switching device employs D.C. feedback to insure that upon the application of a signal to a control nozzle, the power jet is deflected completely from one output aperture to another and, in the case of the flip-flop, is held there until the next input signal. In the case of the monostable multivibrator, the power jet is deflected from a first to a second output aperture and held in the latter position for a predetermined time after which it is returned to the first aperture.

In the various systems requiring timing or tuning, it is necessary to employ fluid elements capable of storing fluid energy as either potential or kinetic energy. Potential energy is stored by a fluid capacitance, which includes any element capable of storing fluid potential energy. In general, the energy stored in a fluid capacitance increases as a result of introduction of additional fluid therein. Fluid capacitance may take one or more of the following forms: compression of the fluid to a greater density, change of thermodynamic state of the fluid, change of elevation of the fluid, change of fluid internal energy level, compression of a second fluid separated from the first fluid by a flexible wall, compression of a second fluid in contact with the first fluid, deformation of elastic walls which restrain the fluid, change of elevation of a weight supported by the fluid, and compression of bubbles or droplets of one fluid entrained in another. Fluids in motion have a kinetic energy which represents a second form of stored energy. The method of storing energy in this form is to accelerate the fluid to a higher speed, the energy being stored in the kinetic energy of translation of the fluid. Fluid devices for storing kinetic energy are referred to as inertances and such device may take the form of a pipe filled with a fluid.

It is a broad object of the present invention to provide fluid amplification systems employing positive feedback of signals in order to provide switching systems, high gain, linear or non-linear amplification systems, and operational amplifiers.

It is another object of the present invention to employ positive fluid feedback in a fluid amplification system having no moving parts in order to provde fluid amplification systems capable of performing as switches, and high gain and operational amplifiers.

It is yet another object of the present invention to employ positive fluid feedback in fluid amplification systems having no moving parts in order to provide fluid amplification systems capable of performing as a bi-stable switching element.

It is still another object of the present invention to employ positive feedback in a pure fluid amplifier to provide a mono-stable switching element.

Yet another object of the present invention is to employ positive feedback in a pure fluid amplification system to provide a high gain proportional amplifier.

It is another object of the present invention to employ positive fluid feedback in a pure fluid amplification system to provide a high gain amplifier for mass flow, power or pressure.

Still another object of the present invention is to employ positive fluid feedback at specific signal frequencies in a fluid amplification system in order to provide a narrow band high gain amplifier.

It is yet another object of the present invention to employ positive fluid feedback in fluid amplifiers employing no moving parts so as to provide operational amplification systems.

Yet another object of the present invention is to employ positive fluid feedback in fluid amplification systems employing no moving parts in order to provide a signal integrator.

Another object of the present invention is to provide a fluid-operated system which utilizes feedback principles to produce a definite switching effect.

It is a further object of this invention to provide fluid-operated systems in accordance with the above objects which require no moving parts.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of various specific embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a plan view of the fluid-operated system in accordance with the principles of this invention.

FIGURE 1A is an end view of the system shown in FIGURE 1 with means for applying fluid to the system.

FIGURE 1B is a partial sectional view taken through section lines 1B—1B in FIGURE 1.

FIGURE 2 is a plan view of another embodiment of the system shown in FIGURE 1.

FIGURE 2A is an end view of the embodiment of FIGURE 2 with means for applying fluid to the system.

FIGURE 3 and 3A show a stacking arrangement for a pair of fluid-operated systems shown in FIGURES 2 and 2A.

FIGURES 4 and 4A schematically illustrate an arrangement for utilizing the systems shown in FIGURES 1 and 1A.

FIGURE 5 shows another arangement for utilizing the system shown in FIGURES 1 and 1A.

FIGURE 6 schematically illustrates another arrangement for utilizing the system shown in FIGURES 2 and 2A.

FIGURE 7 is a plan view of another fluid-operated system which effects a switching action of the fluid stream by utilizing feedback principles.

FIGURE 7A is an end view of FIGURE 7 with means for applying fluid to the system.

FIGURE 8 is a front view of a monostable switching element.

FIGURE 9 is a front view of a fluid amplifier employing positive feedback to provide a high gain amplifier.

FIGURE 10 is a cross-sectional view taken along section line **10**—**10** of FIGURE 9.

FIGURE 11 is a front view of a tuned or band-pass fluid amplifier.

FIGURE 12 is a front view of a structure providing the fluid capacitances and inertance required in the amplifier of FIGURE 11.

FIGURE 13 is a physical structure employed to explain the operation of the apparatus of FIGURE 11 by analogy.

FIGURE 14 is a front view of an amplification system employed as integrator of fluid signals.

FIGURES 15 and 16 are views in elevation of fluid amplification systems which when combined provide a preferred form of fluid integrator illustrated in FIGURE 14, and

FIGURE 17 is a view in elevation and in partial cross-section of an amplifier **70** controlling the opening and closing of contacts of an electric switch.

The fluid-operated system **10** of this invention consists basically of a power nozzle through which a fluid, for example, compressed air from a suitable source, passes; a control nozzle through which fluid under pressure can flow and impinge upon the fluid issuing from the power nozzle; and two or more apertures for receiving the fluid from the power nozzle. The apertures, power nozzle and control nozzle are positioned such that when the fluid from the control nozzle impinges upon the fluid issuing from the power nozzle, the apertures will receive varying amounts or proportions of fluid depending upon the quantity and velocity of the fluid issuing from the control nozzle. Suitable means are connected to the apertures and the functioning of these means is based upon variations in proportions of fluid flow into the apertures.

FIGURES 1 and 1A illustrate one embodiment of the fluid-operated system of this invention. The fluid operated system referred to by numeral **10** is formed by three flat plates **11**, **12**, and **13** respectively. Plate **13** is positioned between plates **11** and **12** and is tightly sealed between these two plates by machine screws **14**. Plates **11**, **12** and **13** may be composed of any metallic, plastic, ceramic or other suitable material. For purposes of illustration, plates **11**, **12** and **13** are shown composed of a clear plastic material.

The substantially Y-shaped configuration cut from plate **13** provides a fluid supply nozzle **15**, a control nozzle **16**, and apertures **17** and **18**. Nozzle **15** and nozzle **16** are adjacent to each other and are at substantially right angles. Nozzles **15** and **16** form constricted orifices or throats **15***a* and **16***a*, respectively, for issuing fluid. The exact shape of the throats is not critical as long as they form a jet of fluid issuing from the nozzles. The input ends **15***b* and **16***b* of nozzles **15** and **16** communicate with bores **20** and **21**, respectively, formed in plate **12**. The output ends of **17***b* and **18***b* of apertures **17** and **18**, respectively, communicate with bores **22** and **23**, respectively, in plate **12**. Orifices **17***a* and **18***a* form openings for apertures **17** and **18**, respectively, and are symmetrically spaced relative to nozzle **15**. Both orifices **17***a* and **18***a* have identical cross-sectional areas in this embodiment.

Bores **20**, **21**, **22** and **23** are internally threaded so that tubes **25**, **26**, **27** and **28** which are externally threaded can be tightly held in their respective bores. The end of tube **25** extending from plate **12** is attached to a source of fluid under pressure. This source is designated by numeral **31**. The fluid under pressure can be air or other gas, or water or other liquid. Gas such as air, with or without solid or liquid particles, has been found to work very satisfactorily in system **10**. Also the liquid may have solid particles or gas bubbles therein. A fluid-regulating valve **62** may also be used in conjunction with source **31** to insure continuous flow of fluid at a constant pressure. Combinations of liquid and gas may also be used. Such fluid-regulating valves are, of course, conventional.

Since the fluid stream flowing from nozzle **15** is reduced in cross-sectional area by the nozzle throat **15***a*, the velocity of the fluid increases. Relatively small fluid pressures applied to nozzle **16** causes a jet to form which impinges at right angles to the jet exiting from nozzle **15.** This impingement will cause considerable displacement of the jet stream from the latter nozzle as it passes nozzle throat **16***a* and the principle can be termed "momentum exchange," since the control jet from nozzle **16** imparts momentum to the jet from nozzle **15.** When nozzle **16** does not apply fluid pressure against the jet issuing from nozzle **15,** orifices **17***a* and **18***a* will receive equal proportions or quantities of fluid. Thus the proportions of fluid flow from tubes **27** and **28** will be equal and constant. A relatively small fluid pressure applied to the stream issuing from nozzle **15** by the jet from nozzle **16** will cause aperture **18** to receive a much larger proportion or quantity of fluid. This is because the jet from nozzle **15** can be substantially deviated as it passes nozzle throat **16***a*.

This momentum exchange principle is utilized by the present invention so that system **10** is capable of performing the functions of multiplication and amplification. It can be seen that small variations in fluid pressure applied to nozzle **16** cause large variations in fluid pressure in tubes **27** and **28.** Thus the system **10** is capable of amplifying small pressure variations in tube **26.**

One illustration of how the system **10** can be used to regulate the air speed of a plane is illustrated in FIGURE 4. Airplane **34** has the usual gasoline engine **35** for driving propeller **38.** Engine **35** has a carburetor **37** attached which feeds air and gasoline into the engine. Pitot tube **36** is connected to nozzle **16** while nozzle **15** is connected to an airscoop **39.** Tube **27** is connected to the carburetor **37** while tube **28** exhausts through the trailing edge of wing **40.** While only one system **10** and associated tubes are shown in airplane **34,** it will be evident that the number of systems used will depend upon the number of carburetors **37.**

When the airspeed of airplane **34** increases, pitot tube **36** senses an increase in air pressure which causes the jet from nozzle **16** to deflect the air forced into nozzle **15** by airscoop **39** so that a larger proportion of air is deflected into tube **28.** Less air will thus be fed into carburetor **37** automatically reducing the speed of airplane **34.** A decrease in air speed of airplane **34** will cause less deflection of the air stream from nozzle **15** so that more air is fed into carburetor **37,** thereby increasing the speed of engine **35** and airplane **34.** The effect is thus to maintain essentialy constant air speed.

Another illustration of a system which will utilize the amplifying feature of system **10** is shown in FIGURE 5. In this figure exponentially curved horn **29** is attached to tube **26.** Source **31** provides a constant, continuous source of air to nozzle **15.** Anyone speaking into the enlarged end of this horn will cause pressure pulsation to occur in tube **26.** These pulsations will be amplified by system **10.** The amplified pulsations pass through tubes **27** and **28** and into horns **37** and **38** respectively. Amplified voice issues from horns **37** and **38.**

FIGURES 2 and 2A illustrate a modification of the fluid-operated system shown by FIGURES 1 and 1A. This modification is designated by numeral **10***a*. In system **10***a* a second control nozzle **46** is positioned opposite the control nozzle **16.** Throats **16***a* and **46***a* are substantially of the same size and shape. Input end **46***b* of nozzle **46** communicates with tube **47** threadedly fixed in bore **48.** Numeral **50,** like numeral **33,** represents any means which would cause a fluctuating fluid pressure. Fluid-regulating valve **62** insures that the system **10***a* receives constant quantities of fluid.

Since throats **16***a* and **46***a* are in opposed relationship, variation in fluid pressure in either nozzle will cause amplified movement of the jet issuing from nozzle **15** in

accordance with the "momentum exchange" principle. If both nozzles **16** and **46** simultaneously receive fluid pressure, the resultant movement of the jet from nozzle **15** will depend upon the difference between the magnitude of the two opposing fluid streams from nozzles **16** and **46.** Also, should one control nozzle be under a vacuum, the resultant effect upon the jet from power nozzle **15** will be the difference between the two pressures. Thus, it can be seen that the resultant fluid pressure difference causes movement of the stream from nozzle **15.**

The above-described feature which amplifies the difference of two pressures from any two sources is utilized as shown in FIGURE 6 as a yaw control for a jet airplane. FIGURE 6 shows jet airplane **54** the tail end of which is beginning to yaw or sideslip in the direction of arrow S so that the oncoming air approaches the airplane in the direction of arrow W. Tubes **26** and **47** extend from ports **55** and **56,** respectively, adjacent the nose of the plane, as shown. Movement of plane **54** through the air produces air pressure in tubes **26** and **47.** Tube **25** communicates with jet chamber **57** so that nozzle **15** will issue a continuous stream of gas under pressure. Wind pressure acting in the direction of arrow W will cause an increase in air pressure in tube **26** with the result that the pressure in tube **26** is greater than the pressure in tube **47.** Nozzle **16** will thereupon issue a jet at higher pressure than that jet issuing from nozzle **46.** As a result, the fluid from nozzle **15** will be moved a larger proportional amount into aperture **18.** The greater air pressure issuing from tube **27** will cause a greater reactive force than that produced by tube **28** causing jet airplane **54** to turn about its center of gravity in the direction of arrow R thereby aligning airplane **54** so that it heads directly into the wind.

FIGURES 3 and 3A illustrate another embodiment of the present invention wherein like numerals refer to like parts in FIGURES 2 and 2A. In these figures, two identical fluid-operated systems **10***a* shown in FIGURES 2 and 2A are stacked on top of one another so that differential air pressures in tubes **27** and **28** can be amplified again.

This can be easily effected by merely connecting tubes **27** and **28** by means of suitable sleeves **61** to control nozzles **16′** and **46′.** Source **31′** is identical to source **31** so that the power nozzle **15′** can receive continuous air pressure. Air introduced into nozzles **16′** and **46′** will be amplified again and will issue from tubes **27′** and **28′**, respectively. The amplified variations in air pressure in tubes **27′** and **28′** can be utilized to move expansible bellows, diaphragms, pistons or other fluid responsive mechanisms, as will be evident to those skilled in the art. If so desired, further amplification can be effected by adding additional systems to the stacking arrangement shown in FIGURE 3.

The fluid-operated system **10***a* described above gradually moves the air stream from one aperture to another upon the application of air from the control nozzles. Fluid-operated system **70** shown in FIGURES 7 and 7A effects a definite switching movement of the fluid so that either substantially all the fluid enters one aperture, or substantially all the fluid enters the other aperture. Also, since system **70** utilizes a feedback principle, the sensitivity of the system **70** to fluid issuing from nozzles **16** and **46** is considerably greater than the sensitivity of system **10***a*.

Fluid-operated system **70** comprises fluid-operated system **10***a* which is modified by adding two substantially semi-circular feedback channels or tubes **71** and **72.** These channels are cut from plate **13.** Input ends **71***a* and **72***a* of channels **71** and **72** communicate with apertures **17** and **18,** respectively, as shown. Channels **71** and **72** form a continuous channel for air passing from apertures **17** and **18** into feedback nozzles **71***b* and **72***b*, respectively. In the embodiment shown, opposed nozzles **71***b* and **72***b* are identical in size to nozzles **16** and **46** and are positioned between nozzles **16** and **46** and nozzle **15.** Throats **73** and **74** are formed at the ends of nozzles **71***b* and **72***b*, respectively. Bores **72***c* and **72***d* in plate **12** are connected by tube **74** (FIGURE 7A), so that feedback channel **72** does not intersect feedback channel **71**. Jets of fluid issuing from nozzles **71***b* and **72***b* will impinge at substantially right angles against the fluid jet issuing from power nozzle **15**.

Since channels **71** and **72** feed back proportional quantities of fluid received by apertures **17** and **18**, respectively, when one control nozzle **16** or **46** receives a greater quantity of fluid than the other, its associated feedback channel **72** or **71**, respectively, will initially bias or deflect the jet as it passes from nozzle **15**. Only relatively small quantities of fluid from that control nozzle, **16** or **46** are then required to keep substantially all of the fluid flowing into channel **72** or **71**, respectively. Thus all or substantially all, of the fluid will be passing either through tube **27** or tube **28**.

As a result of feedback channels **71** and **72** initially biasing the air stream in the same direction as that control jet which issues the greatest quantity of fluid, a definite switching action occurs in apertures **17** and **18** and in tubes **27** and **28**. Fluid-operated system **70** is sensitive to small variations in air pressure in control nozzles **16** and **46**, and because of the definite deflection of substantially all the fluid from one aperture to another the operation of system **70** can be analogized to the operation of a conventional bistable electronic switch.

If feedback channels **71** and **72** are sufficiently large, the fluid issuing from nozzle **71***b* or **72***b* will be sufficient to maintain substantially all of the flow from nozzle **15** into either aperture **17** or **18**, respectively, even though the fluid flow from nozzles **46** or **16**, respectively, is stopped. Thus the system stays "locked" into one aperture flow.

The system **70** shown in FIGURES 7 and 7A can be used as system **10***a* shown in FIGURES 2 and 2A. For example, the system **70** can be used to compensate for yaw of a plane by replacing system **10***a* in FIGURE 6 with system **70**. Other possible applications, as for example, flipping a switch will be apparent to those skilled in the art.

The amplifying elements of FIGURES 1 through 7A of the accompanying drawings are all of the first type of element described in the introduction to the specification; that is, the elements are proportional amplifying devices in which the fluid issuing from the power nozzle is centrally located in the receiving chamber and divides equally between two output nozzles in the absence of an input signal. However, it is seen that by employing the positive feedback of the circuit of FIGURE 7 it is possible to establish a flip-flop action which is essentially the same as the flip-flop action achievable with the third and fourth type of amplifying elements described in the introduction; that is, the positive lock-on and positive lock-on with memory elements.

In the field of switching, the bistable flip-flop of the type illustrated in FIGURE 7 represents only one specific type of switch of several types which may be provided by the present invention. A second example of a positive feedback switch is illustrated in FIGURE 8 of the accompanying drawings.

Referring now specifically to FIGURE 8 of the accompanying drawings, there is illustrated a monostable multivibrator comprising an input or main power nozzle **80** directing a power fluid jet directly at an output channel **81** axially aligned with the nozzle **80**. A first control jet **83** is connected via an aperture **94** with the source of pressure pulses. A second control jet **84** is provided on an opposite side of the main power jet from the control nozzle **82** and is intended to return the system to its quiescent condition when supplied with a fluid pulse. The apparatus is provided with a second outlet passage **86** which is adapted to supply fluid to a utilization or load device. A positive feedback path **87** is connected between the output passage **86** and control nozzle **82**. A fluid resistor **96** which may be a porous plug, is connected at the junction of the passages **86** and **87** so as to limit the amount of fluid fed back through the passage **87**. The passage **86** is also intersected by a passage **89** connected via a plurality of alternate chambers **91**, acting as fluid capacitors, and lengths of straight passages **92**, acting as inertances, to the control nozzle **84**. The elements **89**, **91** and **92** constitute a negative feedback path **93** having a time delay determined by the size and number of elements **91** and **92**.

In operation it is assumed that initially a positive pressure pulse is applied through passage **94** to the control nozzle **83** and the main power stream is deflected into the output pasage **86**. A predetermined portion of the energy of the stream is fed back via the feedback path **87** to the orifice **82** and the stream is maintained directed to the output passage **86** even after termination of the input pressure pulse. However, a pressure pulse is also developed in the feedback path **93** and after an interval determined by the value of fluid capacitors **91** and fluid inertance **92** the pulse appears at the control nozzle **84**. By appropriately designing the feedback path **93** to have a relatively small attenuation, the pressure appearing at the nozzle **84** is sufficiently greater than the feedback pressure developed in the feedback path **87**, this presure being reduced by the resistor **96**, to deflect the main stream issuing from the nozzle **80** to the output passage **81** and the unstable state is terminated. The stream continues to flow to the passage **81** until another pressure pulse arrives via the passage **94** to nozzle **83** at which time the stream is again deflected to the passage **86** and again remains deflected to this path for the time interval required for a pressure pulse to proceed through the feedback path or delay line **93** to the control nozzle **84**. In the apparatus of FIGURE 8, the preferential state, that is, the state in which the fluid stream enters the passage **81** is determined by aligning the passage **81** with the nozzle **80**. Lobe **95** is connected to orifice **90** which is connected to the atmosphere or to a source of pressure P–, which is lower than the pressure supplied to power nozzle **80** through orifice **88**. Control of pressure P– may also be used as a means of biasing the flow pattern of the power stream so that initially substantially all of the power stream flows out through passage **81**. Other techniques may be employed to effect this preference, and specifically a pressure leak between the supply to the nozzle **80** and the control nozzle **84** may be employed so that a small bias pressure is always available at the nozzle **84**. In this latter case, the more conventional symmetrical or Y configuration, as illustrated in FIGURE 7 may be employed. Boundary layer lock on may also be used to bias the power stream to flow initially along the left wall of the interacting chamber.

The lower side of lobe **95**, is viewed in FIGURE 8 of the accompanying drawings, diverges sharply from the center line of the power stream issuing from nozzle **80**. This sharp divergence prevents boundary layer effects of the right wall from influencing the flow of the power stream.

The positive feedback configurations illustrated in FIGURES 7 and 8 relate only to switching actions. As previously indicated a large field of application exists for fluid amplifier systems employing positive feedback in proportional amplifier systems as opposed to stable state systems. Referring specifically to FIGURE 9 of the accompanying drawings, there is illustrated a positive feedback amplifier which enhances the gain of the amplifying system by a predetermined amount which depends upon the resistance of the feedback path. Specifically, there is provided a main power nozzle **101**, a first control nozzle **102** and a second control nozzle **103**. A stream from the nozzle **101** issues into a chamber **104** defined by side wall **106** on the left and **107** on the right. It will be noted that the ratio of the distance between the walls **106** and **107** with respect to the width of the nozzle **101** is such that the positive lock-on would normally result, except for the fact that the angle of divergence of the walls **106** and **107** in the immediate region of the nozzle **101** is so great that lock-on cannot be effected.

In this case lock on of the power stream to one of the side walls is prevented by a combination of set back of the side walls at the lower portion of the chamber and the angle of divergence of the side walls with respect to the center line of the power stream. The angle of divergence can be less in this case than if the set back of the side walls were less.

The wall **106** forms the lower portion of a lobe-shaped passage **108** there being a corresponding pasage **109** on the right side of the orifice **101** which is partially defined by the wall **107**. The lobe-shaped passages **108** and **109** are provided with outlet orifices **111** and **112** respectively which may be vented to the atmosphere or a suitable source of pressure P– for purposes to be defined subsequently. The apparatus is also provided with outlet passages **114** and **116**, the interior walls of which are defined by the divider **113** and the exterior walls of which extend into contact with the upper walls of the lobes **108** and **109** respectively. The outlet passage **116** has positioned therein a U-shaped catcher structure **117** which samples a portion of the fluid directed to the outlet orifice **114** and communicates via pasage **118** with the first feedback nozzle **127**. The feedback passage **118** is provided with a porous plug **128** constituting a fluid resistance so as to reduce the amount of feedback obtainable with the system. The outlet passage **114** is also provided with a U-shaped fluid catcher **123** which communicates with a second feedback passage **124** to a second feedback nozzle **121**. FIGURE 10 is a cross sectional view along the line **10—10** of FIGURE 9. FIGURE 10 shows the canfiguration of the feedback passage of the feedback amplifier shown in FIGURE 9. Passage **124** is also provided with a fluid resistor or porous plug **129**, also to limit the amount of feedback pressure.

In operation, fluid from the nozzle **101** is normally directed at the apex of the divider **113** and divides equally between the passages **114** and **116**. Substantially equal portions of this fluid are captured by the catchers **117** and **123** so that equal proportions of the fluid are fed back to the feedback nozzles **127** and **121** so that the system is stabilized in its intermediate position. Upon the application of an input signal, which in the apparatus of FIGURE 9 should be a push pull signal, the fluid stream is diverted from its central position so that a greater proportion of the fluid enters one of the output channels, for instance, the channel **116**. Consequently, the catcher **117** intercepts a greater proportion of fluid than the catcher **123** associated with the passage **114** and a larger feedback signal is developed in the feedback passage **118** than in the feedback passage **124**. This results in an even greater proportion of the stream being directed to the channel **114** thereby increasing the gain of the system. The function of such a system is governed by Equation 1. So long as the magnitude of the quantity $1-GB$ is less than 1 but greater than 0, the system does not become unstable and switch the flow completely to one output aperture as opposed to the other. However, the amount of fluid directed to the one output aperture is greater than would be thus directed in the absence of a feedback signal and therefore the gain of the system is greater than without feedback.

The lobes **108** and **109** are employed only in those instances when it is desired to produce a pressure gain or a power gain, and are not employed when a mass flow gain is desired. As previously indicated, if mass flow gain is desired, then all of the fluid issuing from the jet **101** is directed to the output passages and there is therefore no residual moving fluid that does not appear in the output passages. In the case of pressure gain, the output passages **114** and **116** are quite narrow and sample only a small portion of the total fluid available in the stream. If power gain is desired, the passages **114** and **116** are wider than if a pressure gain is desired.

The amplifier of FIGURE 9 is a wide band amplifier in that all frequencies are amplified equally within the range of operation of the system.

Referring now specifically to FIGURE 11 of the accompaning drawings, there is illustrated an amplifier which may be employed to amplify a single frequency rather than a broad range of frequencies. This system employs a single ended input. The feedback signal is supplied to a single feedback nozzle which is located on the side of the power nozzle opposite to the side on which the input control nozzle is located. Specifically, the amplifier is provided with a power nozzle **130** for providing a power stream directed at an apex **131** of a divider **132**. The lower sides of lobes **153** and **154** diverge sharply from the centerline of the power stream so as to prevent lock on of the stream which would otherwise occur. The apparatus is provided with a first outlet passage **134** and a second outlet passage **136**. The outlet passage **136** is connected to a tuned feedback path which supplies a fluid feedback signal to nozzle **133**. A porous plug fluid resistor **139** is positioned in passage **137** so as to limit the amount of the signal fed back to the control nozzle **133**. The passage **137** communicates with a fluid capacitance **141** which is connected via a fluid inertance **142** to a second fluid capacitance **143** connected to the control nozzle **133**. Input signals to the control nozzle **151** are supplied through an orifice **152** connected to a suitable source of fluid signals. The feedback network is tuned to a specific frequency and therefore the system has maximum gain at a specific frequency.

In order to explain the operation of the system and more specifically the design considerations relating to the feedback network, reference is made to FIGURE 12 of the accompanying drawings. Passages **137′**, **142′** and **133′** of FIGURE 12 constitute fluid inertances corresponding to the fluid inertances of passages **137**, **142** and nozzle **133** respectively of FIGURE 11. Chambers **141′** and **143′** of FIGURE 12 constitute fluid capacitors corresponding to fluid capacitors **141** and **143** respectively of FIGURE 11. The functioning of the physical arrangement shown in FIGURE 12 is as follows: The inertance **137′** will tend to resonate with a fluid capacitor at some particular frequency. A portion of fluid capacitor **141′** serves to resonate with fluid inertance **137′** at that frequency. Similarly, a portion of fluid capacitor **143′** can be made to resonate with fluid inertance **133′** at that same frequency f. Thus, considering the input to the physical arrangement of FIGURE 12 through passage **137′** and the output through passage **133′** the network can be made to resonate at some frequency f. The combination of fluid inertance **142′** with the remaining portions of capacitor **141′** and **143′** serve as a matching network also tuned to this same frequency f. Such a matching network can be used to provide a matching of impedances between the input and the output resonate flow structures. Fluid inertance **137′** includes the inertance of the fluid in passage **137** of FIGURE 11 plus additional inertance caused by the mass of fluid in passages **136** and **149**. Fluid inertance **133′** is a fluid inertance corresponding to the effective inertance of the fluid in nozzle **133** of FIGURE 11. The fluid capacitors required to resonate at some particular frequency with fluid inertance **137′** can be combined with the fluid capacitors necessary to accomplish the impedance matching between the input to FIGURE 12 and the output. Hence, a single fluid capacitor **141′** is used to accomplish these two functions. The total fluid capacitors of fluid capacitor **141′** is equal to the sum of these two capacitors. Similarly, fluid capacitor **143′** can serve both to resonate with the output inertance **133′** and to match the output impedance level of FIGURE 12 to the input impedance level.

Referring now to FIGURE 13, a mechanical resonant system similar to the resonant fluid arrangement shown in FIGURE 12 is provided by masses **137″**, **142″** and **133″** and springs **141″** and **143″**. This mechanical arrangement of masses and springs can by appropriate choice of mass and spring constants be made to resonate at any desired frequency. Mass 137'' represents fluid inertance **137'** and mass **133''** corresponds to fluid inertance **133''** of FIGURE 12. Springs **141''** and **143''** of FIGURE 13 corresponds to fluid capacitors **141'** and **143'** of FIGURE 12.

The specific frequency to which the apparatus shown in FIGURE 12 is tuned is a function of the physical dimensions of the elements **141'**, **142'** and **143'** and therefore, by properly choosing these elements one may tune the amplifier shown in FIGURE 11 to pass a specific frequency or more correctly a specific narrow band of frequencies while rejecting all other frequencies applied to the input of the system through orifice **152**.

In operation of the system of FIGURE 11, an input signal applied via the orifice **152** to control nozzle **151** produces alternating deflections of the main or power stream issuing from the nozzle **130**. This alternating deflection produces pressure fluctuation in outlet passages **134** and **136**. A portion of this signal is fed back via the feedback path and only those signals having a frequency within the pass band of the feedback path produce positive feedback; that is, reinforce the deflection of the power stream from power nozzle **130**. All other signals are fed back by the feedback path either with such a small magnitude that they have little effect on the path of the power stream, or they arrive at nozzle **133** with such a phase angle that they actually diminish the deflection of the power stream by nozzle **151**.

The amplifiers thus far described have related specifically to amplification functions but the apparatus may be employed as a computational or operational element and in one embodiment of the present invention it is employed in an integration circuit. The integrating circuit which is illustrated in FIGURE 14 of the accompanying drawings is a push-pull circuit having a first signal input orifice **170** and a second signal input orifice **171**. The orifice **170** is connected via a channel **169** having a fluid resistor **172** connected therein to a fluid capacitor **176** which is in turn connected to first control nozzle **173** of a fluid amplifier generally designated by the reference numeral **174**. The fluid resistor **172** and capacitor **176** connected in series constitute an integration network the output of which is developed at the control nozzle **173**. The integration circuit is symmetrical to provide push-pull output signals and therefore on the right side of a main power nozzle **177** there is provided a fluid passage **178** connected between fluid input nozzle **171** and a second fluid capacitor **181**. Capacitor **181** is connected to a second control nozzle **179** of the amplifier **174**. Between the nozzle **171** and the capacitor **181** is a fluid resistance **182**. The resistor **182** and capacitor **181** constitutes an integrating circuit, the output of which is connected to the control nozzle **179**. Fluid is supplied to the power nozzle **177** via orifice **223** and passage **226** and the fluid issuing from the nozzle **177** is normally directed at a divider **183** having output channels **184** and **187** disposed to the left and right thereof respectively. Interposed between the control nozzle **173** and the output channel **184** is a lobe **186** serving the same purpose as the lobe **109** in FIGURE 9 of the accompanying drawings; that is, the portion of the fluid stream not captured by the output channel **184** is disposed of to the atmosphere or to a source of pressure P–, which is lower than pressure $p+$, through an orifice **188** communicating with the lobe **186**. Utilization of the lobe **186** permits the divider **183** to be set back a considerable distance from the nozzle **177** without "lock-on," referred to earlier, resulting. Disposed between the control nozzle **179** and output channel **187** is another lobe **189** communicating through a passage **191** with the atmosphere or other pressure source P– to which the excess fluid may be discharged.

The apparatus of FIGURE 14 comprises a second amplifying element **192** which receives the output signal from amplifying element **174** and returns a portion of

its output to fluid capacitors **176** and **181**. The amplifier **192** includes a power nozzle **193** and a pair of control nozzles **194** and **196**. The control nozzles **194** and **196** communicate with the outlet passages **184** and **187** of the amplifier **174**, respectively, via passages **197** and **198**. The amplifier **192** is provided with lobes **199** and **201** which communicate with the channels **213** and **214** which are connected to the atmosphere or to a source of pressure P–. The amplifier **192** is provided with a divider **202**, a first output passage **203** and a second output passage **204**. Output passage **203** of the amplifying element **192** supplies fluid to feedback passage **216** and integrator output passage **218**. Divider **221** insures that the total pressure, including dynamic pressure plus static pressure, is fed to passages **216** and **218**. Similarly output passage **204** of the amplifying element **192** supplies fluid to feedback passage **217** and integrator output passage **219**. Divider **222** insures that total pressure, including dynamic pressure plus static pressure, is fed to passages **217** and **219**. Fluid in passage **216** flows through fluid resistor **207** into fluid capacitor **176**. Similarly fluid in passage **217** flows through fluid resistor **208** into capacitor **181**.

It is apparent from the arrangement of the two amplifiers that push-pull output signals developed by the amplifier **174** are fed in push-pull relation to the input channels of the amplifier **192**. Further the output signals developed by the amplifier **192** after passing through appropriate fluid resistors are applied in push-pull to the input orifices **173** and **179** of the amplifier **174**.

In analyzing the operation of the fluid integrator shown in FIGURE 14 the following postulates will be assumed: (1) The total fluid flowing to a junction must be zero. This is exactly true for an incompressible fluid contained in passages which have rigid walls. It is approximately true for compressible fluids if the volume of the junction is small in relation to the volume of adjacent parts of the system, or if only steady state or slowly varying fluctuations are considered. This postulate is a consequence of the continuity equation of fluid mechanics. (2) The volume current of fluid through a fluid resistor depends only upon the difference in pressure at its two ends and the resistance of the fluid resistor. Compressibility effects or expansion of the side walls of the passage in which the resistor is located can cause thereby a fluid capacitance in addition to the fluid resistance. But if the volume of the resistor is small in relation to the volume of adjacent parts of the system, the effect of this capacitance can be made small. The mass of the fluid in a fluid resistor causes it to have, in addition to its resistance, an inertance; but, again, if the mass of fluid in the fluid resistor can be kept small and if in addition the fluid resistor is broad so that the local velocity of the fluid is kept small, then the total kinetic energy stored in the resistor can be made small and the fluid resistor will have low inertance. Thus, the inertance will be negligible for steady flow or slowly varying flow conditions. When the above conditions are met, a fluid resistor will have an instantaneous flow rate which is substantially equal to the difference in pressure across its ends divided by the fluid resistance. (3) The volume current of a varying fluid current into a fluid capacitor is directly proportional to the variation of pressure in that capacitor and inversely proportional to the reactance of the fluid capacitor, where that reactance depends upon the fluid capacitance C and the frequency of the fluctuating pressure. The generalized expression for the reactance of a fluid capacitor is given by Equation 2

$$X_c = 1/sC \qquad (2)$$

where s is the generalized frequency used in Laplace transform analysis as described in "Transients in Linear Systems" by Gardiner and Barnes, vol. I. If the signal being considered is a pure sinusoidal signal, then s has the value $j2\pi f$. In this case, the fluid reactance of the capacitor is

$$X_c = 1/2\pi fC \qquad (3)$$

Utilizing the above postulates and terminology, we are now about to analyze the operation of the fluid integrator shown in FIGURE 14. We first consider the fluid flow in the left side of the integrator. Let p_1 represent the input pressure supplied through orifice **170** and passage **169** to fluid resistor **172** and let fluid resistor **172** have the value R_1. Let p_2 represent the pressure in fluid capacitor **176**. Let the value of the capacitance of fluid capacitor **176** be represented by C. Let p_3 be the pressure in passage **216**. Let fluid resistor **207** have the value R_2. Let the fluid resistance of nozzle **173** be represented by R_n. Let the pressure in the region into which nozzle **173** discharges be represented by p_4, where p_4 is essentially the chamber pressure in the vicinity of nozzle **177** of amplifying element **174**.

Considering only the left half of the fluid integrator, we have

$$\frac{p_1-p_2}{R_1}+\frac{p_3-p_2}{R_2}-\frac{p_2}{1/sC}-\frac{p_2-p_4}{R_n}=0 \qquad (4)$$

Similarly, let p_1' represent the fluid pressure supplied through orifice **171** and passage **178** to fluid resistor R_1'. Let p_2' represent the fluid pressure in capacitor **181**. Let the value of fluid capacitor **181** be C. Let the pressure in passage **217** be represented by p_3'. Let fluid resistor **208** have the value R_2. Let the fluid resistance of nozzle **179** have the value R_n. Then for the right half of the fluid integrator, we have

$$\frac{p_1'-p_2'}{R_1}+\frac{p_3'-p_2'}{R_2}-\frac{p_2'}{1/sC}-\frac{p_2'-p_4}{R_n}=0 \qquad (5)$$

Subtracting expression (5) from expression (4) gives

$$\frac{p_1-p_1'}{R_1}-\frac{p_2-p_2'}{R_1}+\frac{p_3-p_3'}{R_2}-\frac{p_2-p_2'}{R_2}-(p_2-p_2')sC-\frac{p_2-p_2'}{R_n}=0 \qquad (6)$$

We now define pressure differences between corresponding points in the left and the right halves of fluid integrator of FIGURE 14 as follows:

$$\Delta p_1=p_1-p_1' \qquad (7)$$

$$\Delta p_2=p_2-p_2' \qquad (8)$$

$$\Delta p_3=p_3-p_3' \qquad (9)$$

Using these definitions, we have

$$\frac{\Delta p_1}{R_1}-\frac{\Delta p_2}{R_2}+\frac{\Delta p_3}{R_2}-\frac{\Delta p_2}{R_2}-\Delta p_2 sC-\frac{\Delta p_2}{R_n}=0 \qquad (10)$$

Now let

$$\Delta p_3=G\Delta p_2 \qquad (11)$$

Or

$$\Delta p_2=\frac{\Delta p_3}{G} \qquad (12)$$

Substituting expression (12) into expression (10) yields

$$\frac{\Delta p_1}{R_1}-\frac{\Delta p_3}{R_1G}+\frac{\Delta p_3}{R_2}-\frac{\Delta p_3}{R_2G}-\frac{\Delta p_3 sC}{G}-\frac{\Delta p_3}{R_nG}=0 \qquad (13)$$

Or

$$\frac{\Delta p_1}{R_1}=\Delta p_3\left(\frac{1}{R_1G}-\frac{1}{R_2}+\frac{1}{R_2G}+\frac{sC}{G}+\frac{1}{R_nG}\right) \qquad (14)$$

Solving for the ratio of output pressure difference for the entire integrator Δp_3 divided by the input pressure difference Δp_1 gives

$$\frac{\Delta p_3}{\Delta p_1}=\left(\frac{R_2R_nG}{R_2R_n-R_1R_nG+R_1R_n+sCR_1R_2R_n+R_1R_2}\right) \qquad (15)$$

Or

$$\frac{\Delta p_3}{\Delta p_1}=\frac{G}{1-\frac{R_1}{R_2}(G-1)+sCR_1+\frac{R_1}{R_n}} \qquad (16)$$

Now if

$$1-\frac{R_1}{R_2}(G-1)+\frac{R_1}{R_n}=0 \qquad (17)$$

Or

$$G=1+\frac{R_2}{R_1}\left(\frac{R_1}{R_n}+1\right) \qquad (18)$$

Then the fluid integrator has an overall gain given by

$$\Delta p_3/\Delta p_1=G/sCR_1 \qquad (19)$$

This final expression (19) shows that if the gain of fluid amplifier elements **174** and **192** in cascade have a gain satisfying expression (18) then the over all integrator will operate as an ideal fluid integrator. Equation 18 can be satisfied by adjusting the pressure supplied to nozzles **177** and **193** through orifices **223** and **224** respectively.

The fluid integrator shown in FIGURES 15 and 16 is substantially equivalent to the integrator of FIGURE 14, except that fluid amplifying element **192** has been, in effect, folded behind fluid amplifying element **174**. The reference numerals in FIGURE 14 are also employed in FIGURES 15 and 16. The configuration of FIGURES 15 and 16 has the advantage that passages **216** and **217** can be made appreciably shorter than corresponding passages in FIGURE 14. In addition the orifices **188** and **191** of FIGURE 14 can be connected to orifices **213** and **214** of FIGURE 14 respectively. These are replaced in FIGURES 15 and 16 with orifices **188'** and **191'** respectively. Except for these changes, the structures are the same and the explanation previously given to describe the operation of fluid integrator **14** can now be applied to describe the operation of the fluid integrator **174'** shown in FIGURES 15 and 16.

The structures illustrated in FIGURES 8, 9, 10, 11, 12, 14, 15 and 16 are incomplete in that no means is illustrated for confining the fluid to the passages of the amplifier systems. It is apparent, however, that front and where necessary back plates may be provided, as in FIGURES 1, 1A, 2, 2A, 7 and 7A, to confine the fluid and provide apertures for access to external fluid power and signal sources.

As has been previously indicated, a system **70** as illustrated in FIGURES 7 and 7*a* can be used as the system **10***a* shown in FIGURES 2 and 2*a*. Thus, in FIGURE 3, one or both of the cascaded amplifiers **10***a* may be replaced by the system **70** of FIGURE 7. Such an arrangement where one of the amplifiers **10***a* is replaced by the system **70** is illustrated in FIGURE 17 of the accompanying drawings. Referring specifically to FIGURE 17 wherein reference numerals corresponding to the numerals of FIGURES 2 and 7 are employed on corresponding elements, the system or bi-stable switch **70** includes control nozzles **16**, **46**, **71***b* and **72***b* and further includes output channels **17** and **18**. The output channel **17** is connected via feedback path **71** to the nozzle **71***b* and the output channel **18** is connected via feedback path **72** to the nozzles **72***b*. Outlet passages **17***b* and **18***b* are connected to the feedback paths **71** and **72**, respectively, at the general region of their juncture with the channels **17** and **18**, respectively.

Pipes **27** and **28** are connected to the channels **17***b* and **18***b*, respectively, and extend into communication with nozzles **16'** and **46'** of the amplifier **10***a* arranged above the amplifier or flip-flop **70** as illustrated in FIGURE 3. The amplifier **10***a* is provided with a power nozzle **15'** and outlet passages **17'** and **18'**.

In operation, upon an input signal being applied to, for instance, the input nozzle **16**, more fluid is applied to channel **18** than channel **17** and, due to the feedback action through the feedback channel **72**, the power stream issuing from the nozzle **15** is switched completely to the output channel **18**. The flow from the output channel **18** proceeds through the output passage **18***b* and the pipe **28** to the control nozzle 46′ of the amplifier 10*a*. This causes the power stream issued by the nozzle 15′ of the amplifier 10*a* to be switched to the output channel 17′. If, on the other hand, an input signal had originally been applied to the input nozzle 46, the power stream issuing from the nozzle 15′ of the amplifier 10*a* would be directed to the output channel 18′.

As mentioned immediately above, both of the amplifiers 10*a* to be switched to the output channel 17′. If, on the desired so that as previously indicated in the discussion of the FIGURE 7, the system of that figure may also drive a switch; that is, a fluid switch.

The switch driven by the system 70 of FIGURE 7 may also be an electrical switch and reference is now made to FIGURE 18 of the accompanying drawings to illustrate such an arrangement. In this arrangement, the pipe 27, which is connected to the output passage 17*b*, is connected to a further centrally apertured base member 231 of an electric switch generally designated by the reference numeral 232. The member 231 is basically a circular disc having a downwardly extending centrally apertured pipe 233 into which the tube 27 extends so that the interior of the pipe 27 communicates with the hollow interior of the pipe 233. The upper surface of the member 231 is generally concave and a flexible diaphragm 234 is secured to the periphery of the member 231 so as to define a sealed fluid region 235 between the diaphragm 234 and the concave upper surface of the member 231. The interior of the pipe 233 is in communication with the region between the diaphragm and the upper surface of the member 231 so that fluid directed to the pipe 237 causes upward movement as viewed in FIGURE 18 of the diaphragm. A flapper valve 236 is provided which permits air to be admitted through the pipe 27 to the region 235 but which prevents fluid from egressing from the region 235 back into the tube 227. A bleed passage 237 is provided for communication between the chamber 235 and the ambient atmosphere. The diaphragm 234 carries a first switch contact 238 and a second switch contact 239 is carried on an arm 240 secured to an annular member 241 which extends about the periphery of the member 231. A lead 242 is connected between a first electrical terminal 243 and the contact 238. The arm 240 is made of conductive material so as to connect the contact 239 to a second terminal 244. The terminals 243 and 244 may be connected in some external circuit which is responsive to closure of the contacts 238 and 239.

In operation, when fluid is directed to the channel 17, the flexible diaphragm 234 is raised and breaks the connection between the contacts 238 and 239. When the fluid from the nozzle 15 of the system 70 is directed to the channel 18, the flapper valve 236 closes, the pressure in the chamber 235 is reduced due to bleed-out of fluid through the passage 237 and the diaphragm returns to its unextended position and causes the contact 238 to engage the contact 239. This latter condition therefore indicates that the fluid from the nozzle 15 is directed to the passage 18.

As previously indicated, the switch 70 of FIGURE 7 may be employed to operate an electrical switch and reference is now made to FIGURE 7 of the accompanying drawings to illustrate such an arrangement. In this arrangement, the pipe 27, which is connected to the output passage 17*b*, is connected to a further centrally apertured base member 231 of an electric switch generally designated by the reference numeral 232. The member 231 is basically a circular disc having a downwardly extending centrally apertured pipe 233 into which the tube 27 extends so that the interior of the pipe 27 communicates with the hollow interior of the pipe 233. The upper surface of the member 231 is generally concave and a flexible diaphragm 234 is secured to the periphery of the member 231 so as to define a sealed fluid region 235 between the diaphragm 234 and the concave upper surface of the member 231. The interior of the pipe 233 is in communication with the region between the diaphragm and the upper surface of the member 231 so that fluid directed to the pipe 237 causes upward movement as viewed in FIGURE 7 of the diaphragm. A flapper valve 236 is provided which permits air to be admitted through the pipe 27 to the region 235 but which prevents fluid from egressing from the region 235 back into the tube 227. A bleed passage 237 is provided for communication between the chamber 235 and the ambient atmosphere. The diaphragm 234 carries a first switch contact 238 and a second switch contact 239 is carried on an arm 240 secured to an annular member 241 which extends about the periphery of the member 231. A lead 242 is connected between a first electrical terminal 243 and the contact 238. The arm 240 is made of conductive material so as to connect the contact 239 to a second terminal 244. The terminals 243 and 244 may be connected in some external circuit which is responsive to closure of the contacts 238 and 239.

In operation, when fluid is directed to the channel 17, the flexible diaphragm 234 is raised and breaks the connection between the contacts 238 and 239. When the fluid from the nozzle 15 of the system 70 is directed to the channel 18, the flapper valve 236 closes, the pressure in the chamber 235 is reduced due to bleed-out of fluid through the passage 237 and the diaphragm returns to its unexpected position and causes the contact 238 to engage the contact 239. This latter condition therefore indicates that the fluid from the nozzle 15 is directed to the passage 18.

While I have described and illustrated one specific embodiment of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

I claim:

1. A fluid-operated system comprising: means adapted to issue a continuous fluid stream under pressure, apertures positioned to receive fluid issuing from said means, and control means positioned to deflect said stream, said control means adapted to issue a stream of fluid against said continuous fluid stream thereby varying the quantity of fluid received by each aperture, means connected to said apertures responsive to variations in the quantity of fluid received by said apertures, and means communicating with at least one aperture adapted to feed back a stream of fluid against said continuous stream of fluid.

2. A pure fluid system comprising at least one output aperture, an interaction region, means for issuing a stream of fluid through said interaction region to said output aperture, at least one fluid control means for developing a pressure gradient across said stream to deflect said stream and vary a parameter of the fluid received by said aperture, and feedback means for diverting a portion of the fluid directed to said aperture to said interaction region to vary said pressure gradient and modify deflection of said stream.

3. The combination according to claim 2 wherein said at least one aperture is a pair of apertures arranged to accept fluid from said stream differentially.

4. The combination according to claim 3 further comprising, a second fluid control means arranged to develop a fluid pressure gradient across said stream to deflect said fluid stream in a sense opposite to the sense in which it is deflected by a first mentioned control means, and a second feedback means communicating with said second aperture and arranged to increase the fluid pressure gradient produced by said second control means.

5. The combination according to claim 4 wherein each of said feedback means increases the fluid pressure gradients of the same sense sufficiently to deflect the fluid stream completely to one of said apertures upon pressure gradients of one sense becoming larger than the pressure gradients of the other sense.

6. The combination according to claim 5 further comprising means to apply a pressure to said control means to deflect said fluid stream sufficiently to cause the majority of fluid to enter the other of said apertures.

7. The combination according to claim 4 wherein said feedback means include fluid resistances and capacitances, and means for supplying input signals through said fluid capacitances to said control means to provide a fluid signal integrator.

8. The combination according to claim 3 wherein said feedback means comprises two positive feedback means each connected to a different one of said output apertures and each supplying sufficient fluid to said interaction region to completely deflect said stream to the aperture which receives more fluid from said stream than the other of said apertures.

9. The combination according to claim 8 further comprising means for selectively biasing the stream to one of said apertures.

10. The combination according to claim 3 further comprising a second control means providing a fluid pressure gradient across said fluid stream in a sense opposite to the sense of said first mentioned pressure gradient, a second feedback means communicating with said at least one aperture and arranged to increase said pressure gradient established by said second control means, a second feedback means having a predeterminable fluid time delay, means for normally biasing said fluid stream to enter said second aperture and means for applying a pressure to said first mentioned control means to deflect said fluid stream to said at least one aperture, said second feedback means developing a larger pressure gradient than said first mentioned feedback means.

11. The combination according to claim 10 wherein said second feedback means comprises a plurality of alternately arranged fluid capacitances and inertances.

12. The combination according to claim 2 wherein said feedback means increases said pressure gradient sufficiently to deflect said stream completely to said at least one aperture.

13. The combination according to claim 2 wherein said feedback means comprises a fluid flow path between said at least one aperture and said control means and wherein the pressure developed in said flow path increases said fluid pressure gradient.

14. The combination according to claim 2 further comprising a second control means providing a fluid pressure gradient across said fluid stream in the same sense as said first mentioned control means, said feedback means comprising a flow path between said at least one aperture and said second control means.

15. The combination according to claim 2 wherein said feedback means includes further means tuned to present a low, substantially resistive impedance to fluid signals lying in a predetermined narrow band of frequencies.

16. The combination according to claim 15 wherein said means included in said feedback means comprise fluid capacitances and inertances tuned to a frequency at the center of said narrow band.

17. The combination according to claim 15 wherein said means tuned to a low substantially resistive impedance includes fluid capacitance and inertance in series with a fluid resistance.

18. The combination according to claim 2 wherein said feedback means includes means resonant over a narrow band of fluid signal frequencies.

19. The combination according to claim 2 further comprising a first fluid resistance, a flow path for applying input fluid signals through said first fluid resistance to said control means, a fluid capacitance connected to said flow path between said first fluid resistance and said control means, a second fluid resistance connected in said feedback means, and said fluid operated system being such that the ratio of the magnitude of the fluid signal developed at said at least one aperture to the magnitude of the fluid signal applied to said control means is equal to

$$1+\frac{R_2}{R_1}\left(\frac{R_1}{R_n}+1\right)$$

where R_1 and R_2 are the fluid resistances respectively of said first and second fluid resistances and R_n is the fluid resistance of said fluid control means.

20. The combination according to claim 2 further comprising a load device connected to receive fluid from said at least one aperture.

21. The combination according to claim 20 wherein said load device comprises a deflectable diaphragm.

22. The combination according to claim 20 wherein said load device comprises a member deformable in response to variations in pressures on one side of said member.

23. The combination according to claim 20 wherein said load device comprises a chamber having a movable member defining at least a wall of said chamber and means connecting said load device such that fluid from said aperture is applied to said chamber.

24. The combination according to claim 2 wherein said fluid in said stream is liquid and wherein said pressure gradient is developed by means for varying gas pressure on at least one side of said stream.

25. The combination according to claim 2 wherein said feedback means diverts a quantity of fluid such that said feedback means alters said pressure gradient by an amount proportional to said pressure gradient.

26. The combination according to claim 2 further comprising a pure fluid amplifier having an outlet passage, a fluid control means, and means for issuing a stream of fluid towards said outlet passage; said control means of said amplifier connected to receive fluid signals from said aperture; and said output passage of said amplifier being connected to said feedback means.

27. The combination according to claim 2 wherein said control means includes a wall defining one side of said interaction region such that a boundary layer region may be developed between said stream and said wall and wherein said feedback means controls the supply of fluid to said boundary layer region to vary the differential pressure across said stream.

28. The combination according to claim 27 further comprising a second sidewall defining another side of said boundary layer region, said second sidewall being remote from said stream so as to prevent boundary layer effects, said feedback means including means for issuing fluid against said stream from the side of said interaction region defined by said second sidewall.

29. The combination according to claim 27 further comprising a second sidewall defining another side of said interaction region, said feedback means including means extending through said second sidewall for varying the differential pressure across said stream.

30. The combination according to claim 2 wherein said feedback means develops a fluid flow relative to said interaction region such that said pressure gradient is varied in proportion to said pressure gradient.

31. The combination according to claim 30 wherein said feedback is positive feedback.

32. A fluid-operated system comprising means adapted to issue a stream of fluid, apertures positioned to intercept said stream of fluid, control means for establishing a pressure gradient across said stream of fluid to vary its direction and the quantity of fluid intercepted by said apertures, means connected to at least one of said apertures responsive to variatons in a flow parameter of said fluid stream, and means for feeding back a part of the fluid intercepted by at least one of said apertures to said control means.

33. The combination according to claim 32 wherein said feedback means includes means for storing the potential energy of said stream.

34. The combination according to claim 32 wherein said feedback means includes means for storing the kinetic energy of said stream.

35. A fluid-operated system comprising means for issuing a directed stream of fluid, control means adapted to establish a pressure gradient across said stream so as to vary the direction of said stream from an initial direction, feedback means for receiving varying quantities of the energy of said stream as a function of the deflection of said stream, said feedback means receiving a maximum of energy of said stream when said stream is deflected from its initial direction, and means for varying the pressure gradient across said stream as a function of the energy received by said feedback means.

36. A fluid operated system comprising means for establishing a first fluid stream, means for deflecting said stream, and means for increasing the deflection of said first stream in the same sense including a second fluid stream produced by said first fluid stream.

37. A fluid operated system comprising means for establishing a first fluid stream, means for deflecting said stream, and means for altering the deflection of said first stream including a second fluid stream produced by said first fluid stream.

38. A data storage device comprising: a fluid amplifier having first and second control signal inputs and a data signal output; signal delay means connected between said data signal output and said first control signal input; means to apply input data signals to said second control signal input; and means connected to said signal delay means for reading out data signals.

39. A data storage device comprising: a fluid amplifier having first, second and third control signal inputs and a data signal output; signal delay means connected between said data signal output and said first control signal input; means for applying signal pulses to said second and said third control signal inputs; and readout means responsive to signals from said signal delay means for producing data output signals.

40. A circulating data storage device comprising: fluid amplifier means and fluid delay line means connected in a data pulse circulating loop; means for applying a signal to said fluid amplifier means; and means connected to said data pulse circulating loop for reading out said data pulse.

41. A fluid operated system comprising power means adapted to issue a continuous fluid stream, receiving means positioned to receive fluid issuing from said power means, control means positioned to deflect said stream, said control means adapted to issue a control stream against said continuous stream thereby varying the quantity of fluid received by said receiving means by momentum exchange, means communicating with said receiving means adapted to feed back a stream of fluid against said continuous stream of fluid through said control means, an input flow path connected to said control means for applying input control signals to said system, a first resistance along said flow path, a fluid capacitance connected to said flow path between said first fluid resistance and said control means, and a second fluid resistance along said feedback means, said feedback means being connected to said fluid capacitance downstream of said second resistance, the values of said resistances and said capacitance and the gain of said fluid system being such as to render said fluid system operable to perform ideal calculus mathematical functions.

42. An analog fluid amplifier circuit for obtaining calculus mathematical functions comprising first means for generating a main fluid jet to be controlled, fluid receiver means downstream from said first means for receiving the main jet, second means for establishing a control fluid flow and generating a control fluid jet to controllably deflect said main jet, said second means including a first plurality of circuit components, third means in communication with said receiver means for establishing a feedback flow and generating a feedback fluid jet to further controllably deflect said main jet, said third means including a second plurality of circuit components establishing fluid flow characteristics essential to the generation of said calculus mathematical functions, said first and second pluralities of circuit components including resistive and reactive elements defining in each of said second and third means transfer impedance functions containing equivalent time constant factors, and means combining said control and feedback fluid flows for rendering said analog fluid amplifier circuit operable to produce calculus mathematical functions.

43. A fluid amplifier comprising a first passage for issuing a stream of fluid, an output passage axially aligned with and downstream of said first passage, a straight wall extending generally from said first passage to said output passage and forming a wall of said output passage, a control nozzle for issuing fluid into the region between said passages generally perpendicular to said stream of fluid to deflect said stream of fluid away from said wall and said output passage, and a second passage positioned to receive said stream of fluid upon deflection of said stream away from said wall.

44. A fluid amplifier comprising a first passage for issuing a stream of fluid, an output passage axially aligned with and downstream of said first passage, a straight wall extending generally from said first passage to said output passage and forming a wall of said output passage, said stream of fluid forming a boundary layer along said wall to maintain said stream attached to said wall and thus into said output passage, a control nozzle for issuing fluid into the region between said passages generally perpendicular to said stream of fluid to defeat said boundary layer and deflect said stream of fluid away from said wall and said output passage, and a second passage positioned to receive said stream of fluid upon deflection of said stream away from said wall.

45. A fluid amplifier comprising a first passage for issuing a stream of fluid, an output passage axially aligned with and downstream of said first passage, a straight wall extending generally from said first passage to said output passage, a control nozzle for issuing fluid into the region between said passages generally perpendicular to said stream of fluid to deflect said stream of fluid away from said wall and said output passage, and a second passage positioned to receive fluid of said stream upon deflection of said stream away from said wall.

46. A fluid-operated system, comprising means for directing a fluid stream in a predetermined direction, means for applying pressure deflecting said stream from said direction, and means responsive to said stream when deflected from said direction for modifying said pressure, said last means including a passage for flow of at least a portion of said fluid stream, said portion increasing with deflection of said fluid stream.

47. A fluid-operated system comprising means directing a fluid stream in a predetermined direction, means operative to impart a deflection of said stream from said predetermined direction, and fluid feedback means applying a deflecting stream of fluid against said fluid stream, said fluid feedback means carrying at least a portion of said fluid stream.

48. A fluid-operated system, comprising means for issuing a deflectable fluid stream, further means arranged to increasingly intercept fluid from said stream when said stream is increasingly deflected in one of two directions, fluid flow control means arranged to provide a fluid pressure gradient transversely of said fluid stream, and a flow passage interconnecting said fluid flow control means with said further means.

49. A fluid-operated system, comprising means directing a fluid stream in a predetermined direction, positive feedback means applying a deflecting stream of fluid against said fluid stream, said positive feedback means including means for increasingly collecting said fluid when

said fluid stream is increasingly deflected in one of said predetermined directions.

50. A fluid-operated system, comprising means for establishing a fluid stream, means for deflecting said stream, and means responsive to deflection of said stream to further deflect said stream in the same sense.

51. A fluid-operated system comprising means for directing a fluid stream in a predetermined direction, a control nozzle disposed on one side of said stream for developing stream deflecting pressure gradients across said fluid stream, further means for deflecting said fluid stream, pure fluid means responsive to deflection of said fluid stream for developing a fluid signal indicative of said deflection, and feedback means directing said fluid signal to said control nozzle for developing a deflecting pressure across said fluid stream.

52. In combination, a fluid amplifier having first and second control signal inputs and a signal output; signal delay means connected between said signal output and said first control signal input; means to apply input signals to said second control signal input; and means connected to said signal delay means for reading out signals.

53. The combination according to claim **52** wherein said signal delay means comprises a fluid conducting means and said readout means comprises a fluid flow responsive device connected to said fluid conducting means.

54. In combination, fluid amplifier means and fluid delay line means connected in a data pulse circulating loop; means for applying a signal to said fluid amplifier means; and means connected to said data pulse circulating loop for reading out said data pulse.

55. A bistable fluidic switch, comprising means issuing a deflectable power stream of fluid, at least two receptor ports located to differentially receive said stream of fluid and feedback channels for stably deflecting said stream of fluid toward that one of said receptor ports which is in process of receiving the major part of the fluid of said power stream.

56. A pure fluid integrator comprising a fluid amplifier having an output passage for receiving a main fluid flow and a control flow path for issuing fluid to control the recovery of the main fluid flow at said output passage, a fluid input restrictor connected in said control flow path, a feedback path including a feedback restrictor means connected between said input and said output passage, a signal source restrictor connected to said input restrictor and a fluid capacitance connected to said input restrictor.

57. A fluid amplifier system comprising a fluid amplifier having means for issuing a stream of fluid, at least one output aperture positioned to receive fluid issuing from said means, and a pair of control means for developing stream deflecting pressure gradients of opposite senses across the stream of fluid, first and second fluid flow paths having different fluid flow time delays therethrough, a fluid conducting means, each of said fluid flow paths connected to control flow to a different one of said pair of control means and to have flow thereto controlled by flow in said fluid conducting means.

58. The combination according to claim **57** wherein said fluid conducting means is a passage connected between one end of each said fluid flow paths and said output aperture.

59. The combination according to claim **57** wherein said fluid flow paths each have a first end connected directly to a different one of said pair of control means.

60. A fluid amplifier having an interaction region, at least two fluid receiving means and means for issuing a stream of fluid through said interaction region toward said fluid receiving means, a pair of sidewalls defining said interaction region, one of said sidewalls being located sufficiently close to said means for issuing said stream of fluid to develop a boundary layer between said wall and said stream to maintain said stream directed to one of said fluid receiving means, another of said sidewalls being sufficiently remote from said means for issuing to develop less boundary layer effect than said one sidewall, means for developing a differential pressure in said interaction region to deflect said stream from said one to another of said fluid receiving means and feedback means for diverting a portion of the fluid directed toward said another fluid receiving means to vary the differential pressure in said interaction region.

61. In combination, first and second fluid amplifiers having signal input means, signal output means and means for producing at said signal output means an amplified function of an input signal, means connecting an output means of said first amplifier to an input means of said second amplifier and feedback means constituting a flow path between one of said output means and one of said input means.

62. A pure fluid system comprising an output aperture, an interaction region having a wall extending generally toward said aperture, means for issuing a stream of fluid through said interaction region toward said aperture sufficiently close to said wall to develop a region of reduced pressure between said wall and said stream of fluid due to fluid entrainment in said region, means for varying the pressure in said region and feedback means for controlling fluid flow to said means for varying to vary the pressure in said region as a function of fluid flow to said aperture.

63. A fluid amplifier system comprising at least a first and a second plate, each plate having formed in a surface thereof channels defining in each plate elements of at least one fluid amplifier including at least one output passage, an interaction region, means for issuing a stream of fluid across said interaction region toward said output passage and first control means for developing a variable differential pressure across said stream of fluid to vary the quantities of fluid directed to said aperture; means for covering the channels formed in each said surface to define fluid amplifiers, stacking said plates one above the other and means interconnecting a channel of one of said amplifiers with a channel of another of said amplifiers.

64. The combination according to claim **63** wherein the interconnected channels constitute an output passage of one of said amplifiers and said first control means of another of said amplifiers.

65. The combination according to claim **64** wherein said means interconnecting channels of said amplifier comprises an impedance means.

66. The combination according to claim **64** wherein said means interconnecting channels of said amplifier comprises a capacitor, said capacitor including enlarged regions in said surfaces of both said plates, said enlarged regions being positioned to define a single large region in said means interconnecting said amplifiers.

References Cited

UNITED STATES PATENTS

3,016,063	1/1962	Hausmann	137—81.5
3,016,066	1/1962	Warren	137—81.5

SAMUEL SCOTT, *Primary Examiner.*

U.S. Cl. X.R.

235—201

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REEXAMINATION CERTIFICATE (1739th)

United States Patent [19]

[11] **B1 3,425,430**

Horton

[45] Certificate Issued **Jul. 14, 1992**

[54] **FLUID-OPERATED SYSTEM**

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[73] Assignees: **Ronald E. Bowles; Raymond W. Warren; Billy M. Horton**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 848,878, Oct. 26, 1959, Pat. No. 3,425,430, which is a continuation-in-part of Ser. No. 855,477, Nov. 25, 1959, abandoned.

[51] **Int. Cl.**^{5} **F15C 1/12**
[52] **U.S. Cl.** .... **137/806;** 137/820; 137/835; 235/201 PF
[58] **Field of Search** 137/806, 820, 835

[56] **References Cited**

U.S. PATENT DOCUMENTS

325,459	9/1885	Taylor	137/823
1,329,559	2/1920	Tesla	137/842
1,984,707	12/1934	Sommer	181/275
2,052,869	9/1936	Coanda	137/83
2,111,741	5/1935	Buckland	352/221
2,167,303	7/1939	Kadenacy	60/324
2,247,301	6/1941	Lesser	137/83
2,262,940	11/1941	Samu-el-ish-Shalom	366/101
2,397,448	3/1946	Todd	137/83
2,408,603	10/1946	Braithwaite	137/829
2,408,705	10/1946	Todd	137/823
2,692,800	10/1954	Nichols et al.	137/14
2,702,986	3/1955	Kadosch	366/101
2,725,040	11/1955	Harris	137/83
2,727,525	12/1955	Harris	137/83
2,727,535	12/1955	Linderoth	137/803
2,755,767	7/1956	Levavasseur	116/137 A
2,770,501	11/1956	Coanda	239/429
2,793,493	5/1957	Kadosch	239/265.17
2,812,636	11/1957	Kadosch	415/914
2,812,980	11/1957	Kadosch	60/230
2,825,204	3/1958	Kadosch	239/265.17
2,875,578	3/1959	Kadosch	239/265.27
2,889,856	6/1959	Magnuson	137/823
2,907,337	10/1959	Bemporad	137/83
2,916,873	12/1959	Walker	137/803
2,943,821	7/1960	Wetherbee, Jr.	244/52
2,948,148	8/1960	De La Salle D'Anfreville	60/231
3,004,547	10/1961	Hurvitz	137/83
3,005,533	10/1961	Wadey	239/265.23
3,016,066	10/1961	Warren	137/835
3,024,805	3/1962	Horton	137/835
3,034,628	5/1962	Wadey	137/832
3,036,430	5/1962	Eggers et al.	239/265.23
3,071,145	12/1962	Blanchard	116/137 A
3,111,931	1/1963	Bodine	137/835

FOREIGN PATENT DOCUMENTS

154674	1/1954	Australia .
493723	6/1953	Canada .
573961	4/1959	Canada .
217365	11/1906	Fed. Rep. of Germany .
567913	1/1933	Fed. Rep. of Germany .
660258	4/1938	Fed. Rep. of Germany .
676304	6/1939	Fed. Rep. of Germany .
677803	7/1939	Fed. Rep. of Germany .
933896	10/1955	Fed. Rep. of Germany .
971025	11/1958	Fed. Rep. of Germany .
973315	1/1960	Fed. Rep. of Germany .
563579	11/1982	Fed. Rep. of Germany .
1030483	6/1953	France .
1039511	10/1953	France .
1109415	1/1956	France .
1131551	2/1957	France .
1206616	of 1960	France .
5497	12/1951	German Democratic Rep. .
6111	12/1953	German Democratic Rep. .
242314	11/1925	United Kingdom .

OTHER PUBLICATIONS

"Dietechnik", vol. 9, Issue No. 6, Jun. 1954, V. Ferner.
"Electronic Measuring Instruments", 1958, pp. 70–72, Banner.
"Pulse and Digital Circuits", 1956, pp. 4–9 Millman et al.

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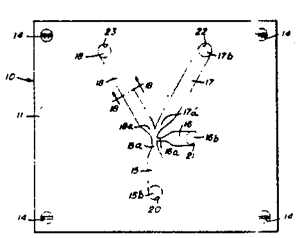
EXEMPLARY CLAIM

1. A fluid-operated system comprising: means, adapted to issue a continuous fluid stream under pressure, apertures positioned to receive fluid issuing from said means, and control means positioned to deflect said stream, said control means adapted to issue a stream of fluid-against said continuous fluid stream thereby varying the quantity of fluid received by each aperture, means connected to said apertures responsive to variations in the quantity of fluid received by said apertures, and means communicating with at least one aperture adapted to feed back a stream of fluid against said continuous stream of fluid.



REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **1–36**, **38–46**, and **48–66** is confirmed.

Claims **37** and **47** are cancelled.

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