Langley

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: GP

NOV 28 1973

TO: KSI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,770,021

Government or Corporate Employee : Government

Supplementary Corporate Source (if applicable) : —

NASA Patent Case No. : LAR-10,868-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes [ ] No [X]
Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Elizabeth A. Carter
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Enclosure
Copy of Patent cited above

(NASA-Case-LAR-10868-1) FLUID PRESSURE AMPLIFIER AND SYSTEM Patent (NASA) 9 p CSCL 09E 00/09 N74-11050 Unclas 22296

United States Patent [19]

Garner et al.

[11] **3,770,021**

[45] **Nov. 6, 1973**

[54] **FLUID PRESSURE AMPLIFIER AND SYSTEM**

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[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, D.C.

[22] Filed: **May 15, 1972**

[21] Appl. No.: **253,249**

[52] **U.S. Cl.** **137/819**, 137/833, 137/840

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

[58] **Field of Search** 137/81.5, 819, 833, 137/837, 840

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Attorney—Howard J. Osborn et al.

[57] **ABSTRACT**

A flueric beam-deflection amplifier and a method of controlling the same wherein either a single or a series of cascaded fluid amplifier units are provided and each one of which may include the usual power nozzle, control nozzles, outlet passages and vent passages. In the present disclosure, all vent passages of each fluid amplifier unit lead to an enclosed vent outlet chamber which is connected to the ambient environment or to a return manifold through a variably restricted passage. To control the fluid amplifier unit, power and control stream pressures are first established, after which the restricted passage is reduced to regulate the input bias, the gain and the input impedance of the fluid amplifier unit. As examples, the vent outlet chamber may be a container completely enclosing the fluid amplifier unit or an enclosed chamber formed integrally within the fluid amplifier unit and communicating with the vent passages.

2 Claims, 9 Drawing Figures

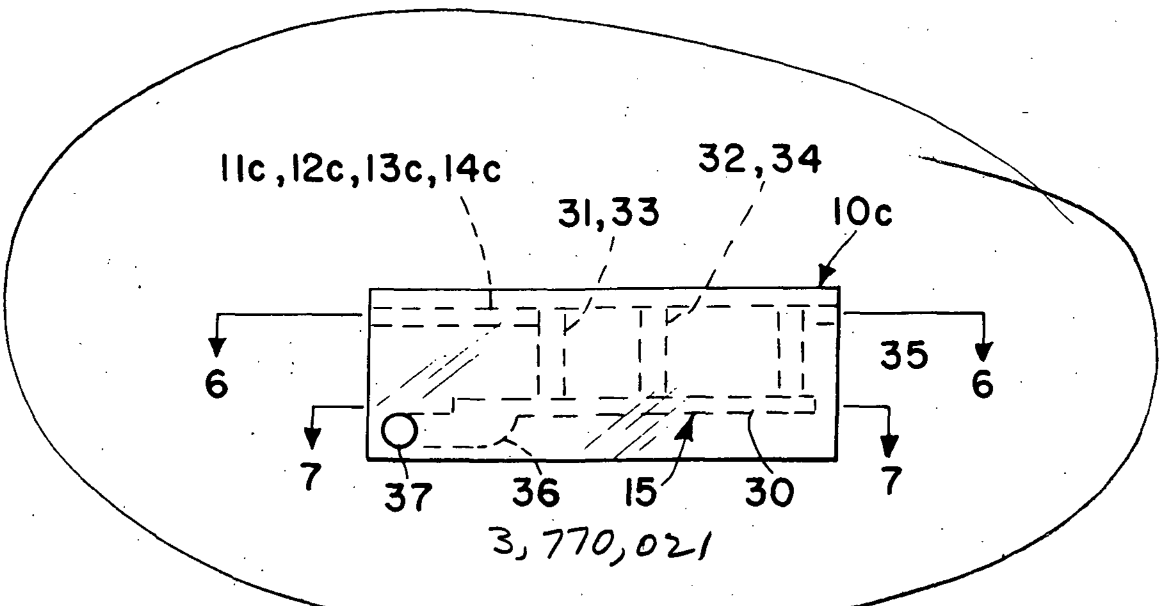


FIG. 1

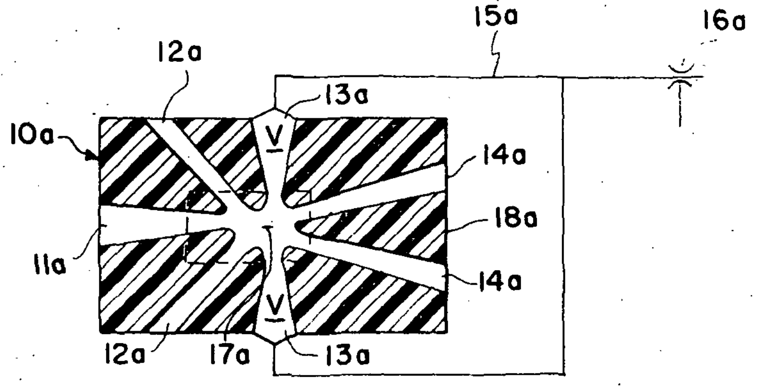


FIG. 2

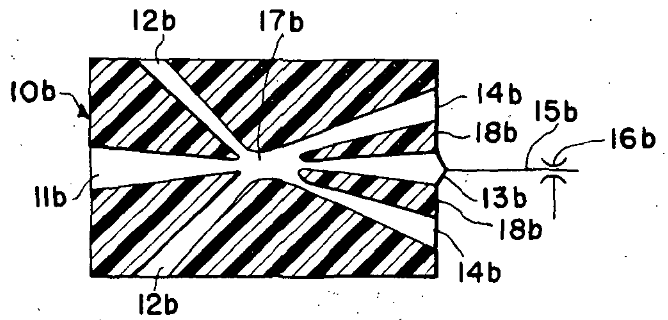


FIG. 3

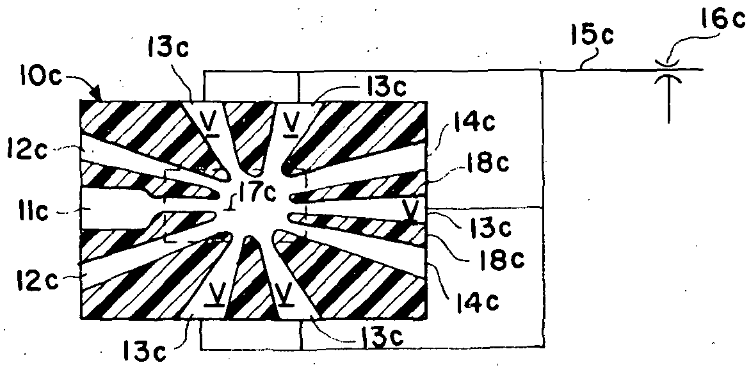
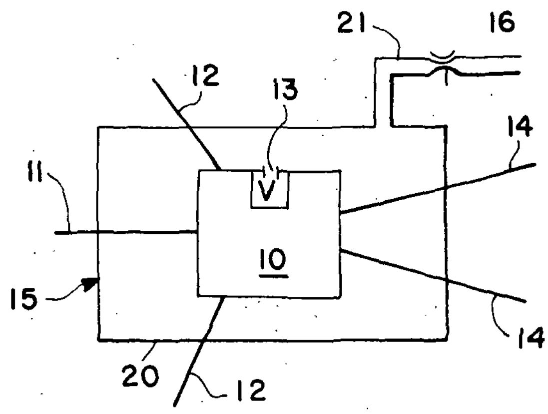


FIG. 4



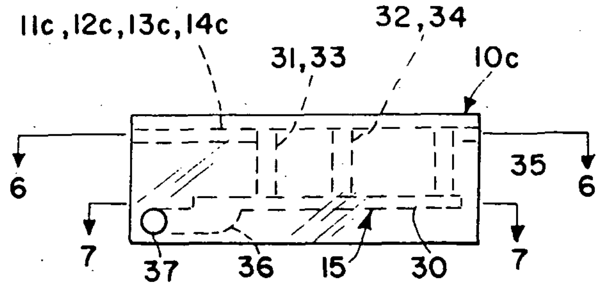


FIG. 5

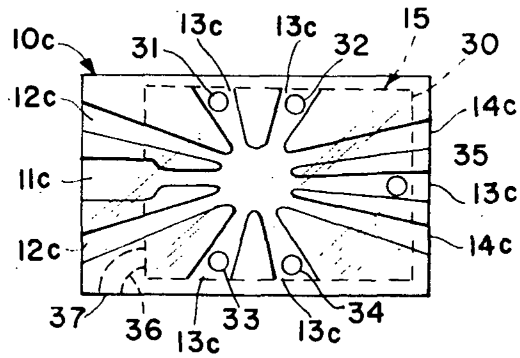


FIG. 6

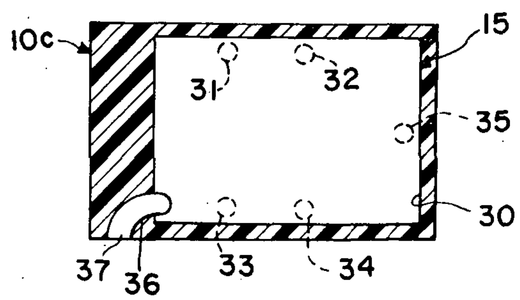


FIG. 7

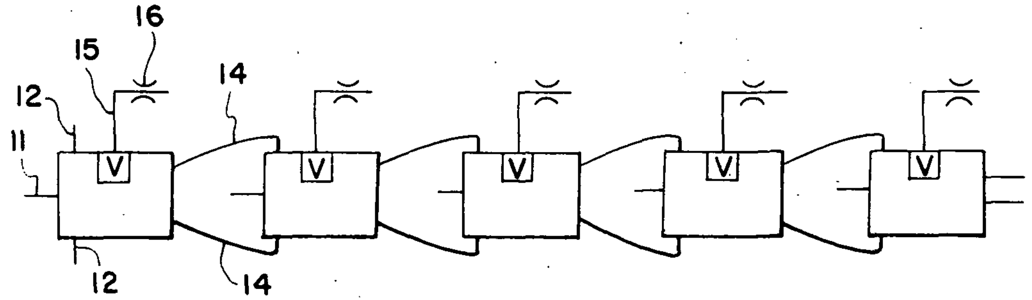


FIG. 8

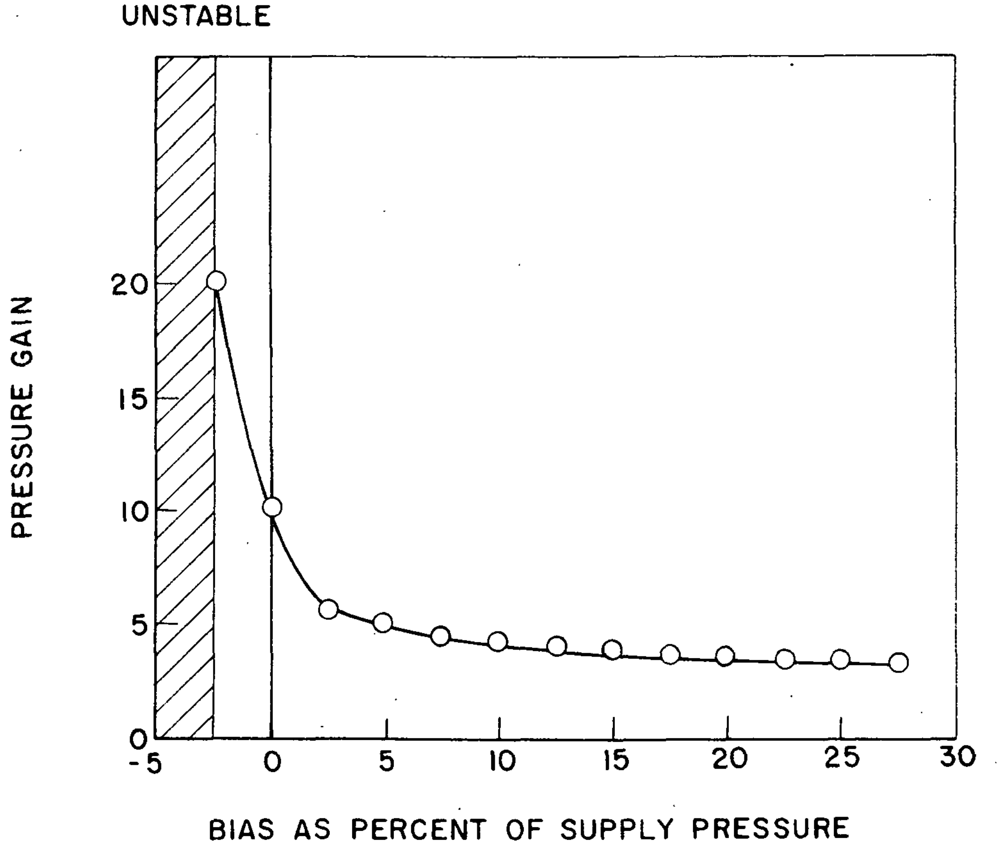

UNSTABLE
PRESSURE GAIN
20
15
10
5
0
-5
0
5
10
15
20
25
30
BIAS AS PERCENT OF SUPPLY PRESSURE

FIG. 9

FLUID PRESSURE AMPLIFIER AND SYSTEM

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to flueric beam-deflection amplifiers, and in particular it relates to a new and improved flueric beam-deflection amplifier and a method of controlling the same.

A flueric beam-deflection proportional amplifier, also known as a fluidic beam-deflection proportional amplifier, increases the magnitude of a fluid signal. The term "flueric" as used herein refers to fluidic components or systems having no moving parts. In the conventional arrangement, a power stream is introduced through a power nozzle and passes between a set of control nozzles through which control streams are introduced to determine the direction of the power stream through a pair of outlet passages. The interaction region between the outlet passages and the point at which the control streams engage the power stream is normally connected through vent passages to the ambient environment. The term "ambient" or "ambient environment" as used herein refers to the low pressure side of the system and may be a vacuum, atmospheric pressure or high pressurized area. There are normally a pair of control streams, one entering from each side of the power stream, and the control signal is the resultant of the differential between these two signals. When no control signal is present, the power stream is divided equally between the two outlet passages by a splitter. When a control signal is introduced in the form of an increase or decrease in one or both of the control streams relative to the other, this deflects the power stream by an amount proportional to the differential and produces a differential recovery pressure between the two outlet passages.

To be useful, fluid amplifiers must be compatable with other fluidic components since a mismatch can cause serious degradation of the signal. Of particular interest is the matching of amplifiers to one another in a series of cascaded fluid amplifiers in order to obtain the very high gains required to amplify the minute differential pressure signals received from some sensors. Such matching is accomplished by matching the input and output characteristics of the individual stages of the cascaded series. Usually, characteristic input-output curves for each device are used. However, on some occasions, sufficient test data cannot be obtained and on other occasions, even with sufficient test data, the range of such a series is very limited.

Normally beam-deflection amplifiers include a power jet or stream directed toward a pair of downstream receiver ducts or outlet passages. If the power stream is not deflected, an equal pressure is recovered in each outlet passage. Two control streams are introduced, each through a separate control nozzle, to deflect the power stream near its point of origin. The signal control stream may come from either or both control nozzles. The deflected power stream flow will result in one outlet passage collecting more pressure than the other. This outlet passage differential pressure is generally greater than the differential control stream pressure, also referred to as the differential input pressure, used to deflect the power stream flow. The ratio of outlet or receiver differential pressure to input or control differential pressure is defined as the pressure gain. Similarly, flow gain is defined as the ratio of differential receiver or outlet passage flow to differential input or control stream flow. The average pressure of the two control streams relative to the vent pressure, which of course is normally at ambient pressure, is called the control bias pressure or simply the bias at which the amplifier is operating.

Deflection of the power stream is achieved by other momentum deflection or pressure deflection. Most amplifiers make use of both of these types of deflection, but usually one deflection principle will dominate.

Vents are frequently incorporated into fluid amplifiers to carry off excess fluid and stabilize the fluid flow. These may include side vents leading from the interaction region out to each side of the unit or they may include a center vent passage located between the two outlet passages. The purpose of a center vent passage is to dump the center high velocity portion of the power stream. Thus, recovery pressure in the receiver or outlet passages is at a lower average pressure in a center vent fluid amplifier than in one with a solid wedged shaped splitter.

To understand the features of the present invention, it is necessary to understand the operating characteristics of a fluid amplifier. The power stream pressure is measured with respect to vent pressure. Typical power stream pressures are several pounds per square inch. But for quiet operation, it is desirable to use laminar flow pressures. Maximum laminar flow power stream pressures are normally from 3 to 6 mm Hg for an amplifier having a rectangular passage depth of 0.040 inches. Typically 0.8 mm Hg. is the minimum power stream pressure rendering good pressure gain in this size amplifier. Control bias pressure is the average of the two control stream pressures measured with respect to vent pressure. Control bias pressure greatly influences the stability and gain of the fluid amplifier. Usable control bias pressures are typically in the range of −10 to 30 percent of supply pressure depending upon the design of the particular amplifier employed. Recovery pressure, which is another important characteristic of beam-deflection amplifiers, is determined by the power stream pressure and the load impedance on the outlet passages of the amplifier. Typically, recovery pressures range from 10 to 30 percent of power stream pressure for amplifiers with wedge type splitters operating into infinite impedance (a blocked load) while in a center vented splitter amplifier the block load recovery pressure may be reduced to about 5 to 15 percent of supply pressure.

It will be seen that vent pressure is therefore an important amplifier characteristic since it is a reference for measuring both power stream and control bias pressures. At present, vent pressure simply means ambient pressure. Pressure gain is defined as the ratio of output differential pressure to control differential pressure. Pressure gain is affected by control bias pressure and the load on the outputs. For blocked load conditions, gain typically ranges from 2 to 20 in a given fluid amplifier unit.

A major problem with existing fluid amplifiers is the task of designing a cascaded series of fluid amplifiers to obtain very high overall pressure gains. Typical procedures for cascading beam-deflection proportional amplifiers utilize the input-output characteristic curves of the amplifiers. After the characteristic curves have been determined, the input curve from one amplifier is superimposed on the output curve from the preceding stage of the cascade. The point of intersection of the curves represents the operating point for the amplifier. The operating point defines the control bias as a percent of power stream pressure. The power stream pressure of each succeeding amplifier is raised sufficiently to bring the bias pressure to the desired percent of power stream pressure. Typically, a power stream pressure might double from one amplifier to the next.

Clearly, this approach to cascading amplifiers is feasible but it may severely limit the range of application of an amplifier system. As noted above, when it is deisred to have all stages operate at laminar flow, power stream pressures should range from 0.8 to about 3 to 6 mm Hg. Therefore, the power stream pressure in the first stage could be no less than about 0.8 mm Hg to obtain laminar flow in that stage. The power stream pressure in the second stage would then have to be twice that amount, that is 1.6 mm Hg and the third stage double that, at about 3.2 mm Hg, etc. But since in some cases the upper limit of laminar flow may be as little as 3 mm Hg, it will be seen that to retain laminar flow throughout the entire system of cascaded fluid amplifiers, it may be possible to use no more than two, and perhaps three stages. It is apparent that such standard staging techniques could not be used to provide four or more stages at laminar flow. But four or more stages may be required in many applications in order to achieve the necessary overall gain. Thus, there exists a need for improvement which will permit high gain multi-stage laminar cascaded fluid amplifier units.

SUMMARY OF THE INVENTION

It is therefore a purpose of this invention to provide improvements in flueric beam-deflection amplifiers which will solve the disadvantages and problems of the prior art. More specifically, it is a general purpose of the invention to provide improvements in beam-deflection amplifiers which will permit adjustment of the control, or input bias of a single fluid amplifier unit or of each stage of a multi-stage amplifier independently of input and output conditions, thereby optimizing gain and/or input impedance matching.

It is another purpose of this invention to provide a fluid amplifier with variable operating characteristics.

These purposes of the present invention are achieved by a design and method of opertion in which the vent passages, instead of simply being open to the ambient, are controlled, preferably variably controlled. According to this feature of the invention, the vent passages associated with a given fluid amplifier unit or a given stage of a multi-stage cascaded fluid amplifier unit are placed in sole communication with an enclosed vent outlet chamber which is in turn connected to the ambient through a variable restricted passage. Thus, the pressure in this vent outlet chamber, and hence also the pressure in the vent passages themselves can be raised to create an artificial ambient pressure or vent chamber pressure within the fluid amplifier. By varying the bleed to ambient through the variable restricted passage, it is possible to vary the operating characteristics of the fluid amplifier.

The ambient pressure in which the amplifier operates is usually taken as the reference level for measuring power stream pressure and control bias pressure. If the absolute pressure of the power stream and the control bias are held constant and the artificial ambient or vent chamber pressure is changed, the effective or gauge values of the power stream pressure and the control bias pressure are changed proportionately to the change in vent chamber pressure. It will be recalled that the control stream pressures are normally much less than the power stream pressures. If the difference between each of these two pressures and the reference ambient or vent chamber pressure is then reduced, the ratio of the control bias to the power stream pressure is greatly reduced. Stated differently, an increase in the vent pressure will then increase the gain without changing the absolute values of the power stream or control stream pressures for the specific example described herein.

Applying this principle to a cascaded series of fluid amplifiers, one can then control the vent chamber pressure of each stage in the cascaded amplifier series to vary the effective control bias and also the control input impedance without varying the absolute power stream or control stream pressures thereof. Such individual adjustment of the control bias pressure for each stage of a cascaded amplifier is extremely important since control bias essentially determines the gain and stability of the amplifier. This adjustment now makes it possible to design a series of cascaded fluid amplifiers having a large number of stages, for example four, five or more, thereby achieving the desired high gain, for example 1,000 to 5,000 in a series of five amplifiers, while achieving laminar flow through all stages.

In its simplest form, the concept of controlling the vent outlet pressures as described above simply entails leading all vent outlets of each stage into a common pipe or manifold from which the pressures are bled to ambient through a variably restricted passage. In one embodiment, a single flueric amplifier unit for one or more stages of a cascaded flueric amplifier system can be enclosed in a container with passages leading through the walls of the container to the power stream, the control stream and the outlet passages while the vent passages are opened to the interior of the enclosed container, which enclosed container is then connected to ambient through a restricted opening in a wall thereof. In a more sophisticated embodiment, the enclosed chamber may simply be formed as a totally enclosed portion formed integrally within the block which forms the various nozzles and passages of the fluid amplifier. Holes would then be drilled from the vent passages to this enclosed chamber, which chamber would then be connected to the ambient through a variably restricted passage.

Thus, it is an object of this invention to provide a new and improved flueric beam-deflection amplifier, and it is another object of this invention to provide a new and improved means for controlling a fluid amplifier.

It is another object of this invention to provide a new and improved fluid amplifier, the operating characteristics of which can be varied, and a method for operating such characteristics.

It is another object of this invention to provide a new and improved fluid amplifier in which the pressure of the vent passages may be controlled to in turn control the operating characteristics of the fluid amplifier.

It is another object of this invention to control the operating characteristics of each of a series of cascaded fluid amplifier units.

It is another object of this invention to provide a cascaded fluid amplifier system in which high gain may be achieved while maintaining laminar flow through the system.

It is another object of this invention to provide a new and improved fluid amplifier unit comprising a solid block with the fluid amplifier passages therein and with a vent outlet chamber also formed therein and communicating on the one hand with the vent passages and on the other hand through a variably restricted passage to ambient.

Other objects and the advantages of the invention will become apparent from the detailed description to follow together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

There follows a detailed description of preferred embodiments of the invention to be read together with the accompanying drawings.

FIGS. **1, 2** and **3** are schematic views of three different fluid amplifier circuits, each employing the features of the present invention.

FIG. **4** is a schematic view of a fluid amlifier showing one arrangement for confining the flow from the vent passages to ambient.

FIGS. **5, 6** and **7** illustrate an embodiment of a fluid amplifier unit showing a preferred arrangemnt for the enclosed chamber between the vent passages of the fluid amplifier unit and the ambient, this embodiment utilizing the fluid circuit of FIG. **3.** FIG. **5** is an elevational view while FIGS. **6** and **7** are horizontal sectional views taken along line **6—6** and **7—7** of FIG. **5,** respectively.

FIG. **8** is a schematic view of a cascaded fluid amplifier system in which the individual stages of the cascaded system employ features of the present invention.

FIG. **9** is a graph illustrating the relationship of gain to control bias for a specific amplifier, the latter represented as control bias pressure as a percent of power stream pressure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the figures wherein like numerals represent like elements throughout the several views, FIGS. **1, 2** and **3** illustrate schematically three typical flueric circuits, each modified to include features of the present invention.

FIG. **1** illustrates a typical fluid amplifier **10*a*** having a small power nozzle **11*a*** through which issues a power stream, a pair of control nozzles **12*a*** through which flow a pair of control streams impinging upon the power stream in the vicinity of interaction region **17*a*.** Depending upon the differential pressure of the control streams through nozzle **12*a*,** the power stream is directed through outlet passages **14*a*** which are divided by a flow splitter **18*a*.** A pair of vent passages **13*a*** communicate with the fluid stream but downstream from the interaction region **17*a*.** In accordance with a main feature of the present invention, these vent passages **13*a*** do not communicate directly with the ambient but communicate with a common vent outlet chamber shown schematically in FIG. **1** as lines **15*a*,** this chamber in turn communicating with the ambient through restricted passage **16*a*.** For convenience, the vent passages **13*a*** are further labeled V.

FIGS. **2** and **3** illustrate other fluid circuits **10*b*** and **10*c*.** In these figures, like elements are represented by like numerals but with the subscripts *b* and *c* for circuits **10*b*** and **10*c*,** respectively. The circuit **10*b*** of FIG. **2** varies from FIG. **1** in that it includes only a center vent passage **13*b*** located between the two outlet passages **14*b*** as formed by beam splitter structure designated by reference numeral **18*b*.** This central outlet passage is connected to the vent outlet chamber **15*b*** which is in turn connected with the atmosphere through variably restricted passage **16*b*.**

Of course the principle of the present invention is applicable to virtually any type of fluid circuit having vent passages. For example, one can employ a fluid amplifier employing both the side vent passages **13*a*** and the central vent passage **13*b*.** In fact, FIG. **3** shows a fluid amplifier having side vent passages like **13*a*,** a central vent passage like **13*b*** and an additional set of side vent passages, all of these passages being labeled **13*c*** in FIG. **3.** In accordance with the present invention, all of these vent passages are in communication with an enclosed vent outlet chamber **15*c*** which is connected to the atmosphere through variably restricted passage **16*c*.**

FIG. **4** illustrates one possible arrangement for forming the enclosed vent outlet chamber **15.** In this embodiment, the vent outlet chamber takes the form of a completely enclosed container **20** with the fluid amplifier **10** mounted therein. Lines **11, 12** and **14** pass through the wall of the container in fluid sealed relationship therewith to communicate with the power nozzle, the control nozzles and the outlet passages, respectively. However, the vent passages **13** are opened into the interior of container **20.** The enclosed container **20** is then in fluid communication with the atmosphere through variably restricted passage **16** which takes the form of a conduit **21** having a variable orifice therein.

FIGS. **5** through **7** illustrate a specific fluid amplifier unit utilizing the circuit of FIG. **3** and illustrating a preferred embodiment of the present invention. Since these figures show the circuit of FIG. **3,** the fluid amplifier shown in FIGS. **5** through **7** is labeled **10*c*.** The various nozzles and passages **11*c*, 12*c*, 13*c*,** and **14*c*** are substantially the same as shown in FIG. **3.** In this case, however, the vent outlet chamber **15** is formed as a plenum chamber **30** formed integrally with the solid block which forms the body of fluid amplifier **10*c*.** All of the passages **11*c*** through **14*c*** are located generally between a pair of common planes, the edges of which are visible in FIG. **5.** The nozzles **11*c*** and **12*c*** and the outlet passages **14*c*** are opened at the exterior of the blck **10*c*** in the conventional manner. However, the ends of vent passages **13*c*** do not reach the exterior of the block **10*c*.** Instead, they communicate through openings **31, 32, 33, 34,** and **35** which are vertical as viewed in FIG. **5** to the plenum chamber **30.** The only communication of this plenum chamber **30** with the ambient is through a passage **36** to the exterior opening **37.** This opening **37** would in turn be connected to a fluid line having a variable restricted passage therein between the opening **37** and ambient.

FIG. **8** illustrates schematically a fluid amplifier system in which a plurality of fluid amplifiers **10** are cascaded in series. The numerals **11** through **16** represent the same elements as described for FIGS. **1** through **7.** This system is the same as a conventional cascaded system with the exception that the vent passages from each stage of the cascaded series are led not directly to ambient but to an enclosed vent outlet chamber **15** which communicates through a variably restricted passage **16** with ambient. Although in a preferred arrangement each stage will have its own vent outlet chamber **15** and variably restricted passage **16**, it is clearly within the scope of the invention that one or more stages share the same vent outlet chamber **15** and restricted passage **16**. For example, two or more stages could be grouped within the same container of the type shown in FIG. **4**. Alternately, two or more stages can be built within the same solid block, the vent passages from both stages communicating through suitable openings such as **31** through **35** (of FIG. **5**) with a suitable plenum chamber **30** located in this enlarged block.

FIG. **9** illustrates the gain for a single specific fluid amplifier unit **10***c* of the type as shown in FIGS. **5** through **7** plotted against the control bias pressure as a percentage of power stream pressure. To maximize the gain, it is clearly desirable to reduce the bias pressure relative to the power stream pressure as much as possible. However, if the bias pressure is reduced too much, the flow is unstable and hence the high gain indicated on the chart for the lowest levels is not really attainable in practice.

In one test conducted with the present invention, as applied to a cascaded fluid amplifier circuit, four amplifier stages were cascaded, each stage being similar to the circuit of FIG. **3**. In this case, the first two amplifiers were placed in one container like the container **20** of FIG. **4** and hence subjected to the same outlet vent chamber pressure and the other two stages were placed in a second container and hence subjected to a second vent outlet chamber pressure. In all stages, tubing from the nozzles **11** and **12** and the passages **14** were passed through fluid tight openings in the containers. It was observed that an overall proportional pressure gain of 6,000 could be obtained with a signal to noise ratio at the output being ten times greater than at the input. It was not conclusively determined why the S.N ratio improved, but it is believed that it was due to damping in the vent outlet chambers or to attentuation because the amplifier system was not dynamically capable of amplifying the high frequency noise at the input.

In a second test, a vortex rate sensor was used to supply the input signal for a fluid amplifier system comprising five cascaded proportional beam-deflection amplifiers of the type as shown in FIGS. **5** through **7**, the circuit being that shown in FIG. **8**. The power stream pressure for the vortex rate sensor and for the first stage was 1 mm Hg to give quiet laminar flow. The system was first operated with the vent passages open to ambient in a conventional manner. The differential output sensitivity of the rate sensor was measured at 1.0×10^{-5} mm Hg/Deg/Sec. This low output sensitivity was attributed to poorly matched impedance characteristics of the vortex rate sensor in the amplifier. The system was then modified to replace each stage with a fluid amplifier unit according to the present invention as shown in FIGS. **5** through **7**. The size of the vent outlet chamber was approximately $1 \times 1\frac{1}{4} \times \frac{1}{8}$ inch thick. The addition of vent outlet chambers allowed the input impedance of the first stage amplifier to be raised to give an indicated rate sensor sensitivity of 1.5×10^{-4} mm Hg/Deg./Sec. Thus the output differential sensitivity of the vortex rate sensor was increased by a factor of 15.

The five stages were operated at laminar flow power stream pressures. The total gain of the system was adjustable from below 1,000 to about 5,000 by varying the vent outlet chamber pressures by varying the opening through variably restricted passages **16**.

The method for adjusting the stages of the cascaded amplifier system to obtain the desired characteristics is as follows. Optimum control bias levels are first determined for each stage. Power stream pressures are then chosen for each amplifier and such pressures are maintained at a desired value above the vent outlet chamber pressure. The vent outlet chamber pressure of each stage is then adjusted until the recovered pressure from the preceding stage is at the desired control bias pressure with respect to the stage it is controlling.

Some difficulty has been encountered in making the final adjustment due to feedback from the vent outlet chambers which occurs as a result of changing the input characteristics and the recovery pressures of each amplifier. The adjustment procedure can be simplified by making minute adjustments simultaneously such that all stages are brought into their respective operating points at the same time.

It should be noted that the situation where the control bias pressure equals zero is well suited for an application of the principles of the present invention. With control bias pressure equal to zero, for all stages in a cascaded system, the receiver output of a given amplifier stage is effectively blocked by the vent outlet chamber pressure of the succeeding stage which results in an increased pressure gain for each amplifier stage.

Although the invention has been described in considerable detail with respect to preferred embodiments thereof, it will be apparent that the invention is capable of numerous modifications and variations apparent to those skilled in the art without departing from the spirit and scope of the invention.

We claim:

1. A flueric beam deflection amplifier comprising a solid block having recesses therein forming a power nozzle, control nozzles, an interaction region, outlet passages and at least one vent passage, said power nozzle arranged to issue a power stream into the interaction region of the fluid amplifier, said control nozzle communicating with the power stream for issuing control streams into the power stream to control the direction of the power stream within the fluid amplifier, said outlet passages communicating with the power and control nozzles for receiving the power stream, the portion of the power stream received in each outlet passage being dependent upon the characteristics of the control streams, said at least one vent passage communicating with said interaction region, and including an enclosed vent outlet chamber formed totally within the block and an opening from the vent outlet chamber to the exterior of the block, said opening being adapted to be connected to a means for variably restricting the communication of this opening with the ambient pressure wherein said power nozzle, said control nozzles, said interaction region, said outlet passages and said at least one vent passage all being positioned in a common plane within the block, said enclosed vent outlet chamber being spaced from this plane and including passageways within the block extending at an angle to the said plane and connecting all vent passages of the amplifier to said enclosed chamber.

2. A fluеric beam deflection amplifier system compising a plurality of individual flueric amplifier stages, each amplifier stage comprising:

a power nozzle for issuing a power stream into an interaction region, control nozzles communicating with the power nozzle for issuing control streams into the power stream to control the direction of the power stream, outlet passages communicating with the power and control nozzles for receiving the power stream, the portion of the power stream received in each outlet passage being dependent upon the characteristics of the control streams, and at least one vent passage communicating with the said interaction region and leading to the exterior of the stage; in each stage, said power nozzle, said control nozzles, said interaction region, said outlet passages and said at least one vent passage are all positioned in a common plane within the stage, said enclosed vent outlet chamber being spaced from this plane, and including passageways extending at an angle to this plane and connecting all vent passages of the fluid amplifier stage to said enclosed chamber;

said amplifier stages arranged in cascade with the outlet passages of each stage in fluid communication with the control passages of the succeeding stage in the cascade;

and wherein all vent passages of all stages are in fluid communication with at least one vent outlet chamber, such said vent outlet chamber having a variably restricted passage leading therefrom to ambient pressure.

* * * * *