The Fluid Amplifier and its Application in Medical Devices

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FOR SEVERAL years a physician-engineer team from the Walter Reed Army Institute of Research and the Harry Diamond Laboratories has been exploring the application of the fluid amplifier in medical equipment.

The word "amplifier" suggests to most persons an electronic component used in the control or switching of a flow of electrons. Fluid amplification is analogous; however, rather than a flow of electrons, a stream of fluid, either a liquid or a gas, is controlled or switched. This fluid is forced to flow through channels of certain geometric configuration cut in a block of solid material. The fluid amplifier controls and switches the fluid stream without electronics and with no moving parts. This latter feature, with its ability to function in extremes of temperature, vibration, and shock, makes fluid amplification systems highly reliable and maintenance free.

The principles underlying the fluid amplifier have been known for many years. The "Coanda effect," named for a Roumanian engineer working in fluids in the 1930s,[1] Bernoulli's principle, and the venturi effect are all utilized. It is only since 1961, however, that the concept of fluid amplification as it is known today has been developed.

There are two basic types of fluid amplifier—the proportional and the boundary fluid amplifier. In the proportional unit (fig. 1), a power stream of fluid (we shall confine it to a gas in this discussion) is forced to emerge from an area of constriction. Immediately past this constriction are two small channels at right angles to the direction of this power stream. The power stream is directed into one of two or three openings, called "receivers," by much smaller streams known as control jets emerging from these side channels. The degree of deflection of the power stream determines the

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Read at the 42nd Congress of the International Anesthesia Research Society, March 17-21, 1968, San Francisco, California.

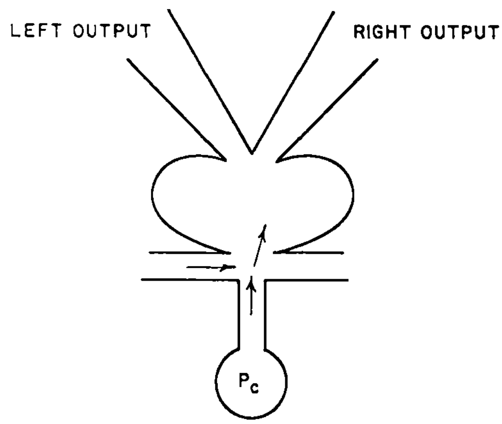

FIG. 1. Diagram of proportional fluid amplifier.

amount of gas directed into a given receiver, and this is proportional to the much smaller amount of "signal" gas directed into a control jet. The gain is found by determining the ratio of the momenta of the two gas streams or the ratio of their pressures.

In the boundary fluid amplifier (fig. 2), the Coanda effect is seen. To describe this effect we must note that the turbulence in a stream of gas as it leaves an area of constriction causes entrainment of gas at its sides. This causes an area of negative pressure to exist along the sides of the stream. The power stream is then slightly deflected toward the nearest side wall by this negative pressure. As it approaches the wall, the negative pressure rapidly drops, and the stream quickly locks onto this wall, hence is directed entirely out through the receiver opening on the same side.

Either a short pulse or a small, steady flow of gas through the control jet on this side will release the stream from this wall, and the entire stream will shift to the other side and flow out of the opposite receiver. This switching in the case of small fluid amplifiers may be accomplished within a few milliseconds, a fact which facilitates the use of these units in computer logic circuits. A boundary fluid amplifier where the configuration is such that the power stream will stay on either side without a continuous flow at one of the control jets is called a "bistable boundary fluid amplifier."

First Application in Medicine—The first application of the fluid amplifier in medical devices came with the development of a pulsatile blood pump[2] (figs. 3 and 4), which has a pulsatile output with a waveform similar to that of the human heart. It has not been shown that pulsatile flow is necessary in extracorporeal circulation during the periods of time needed for heart surgery.

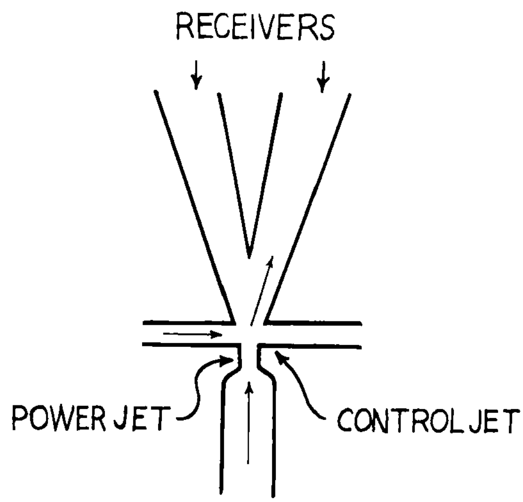

FIG. 2. Diagram of bistable boundary layer fluid amplifier.

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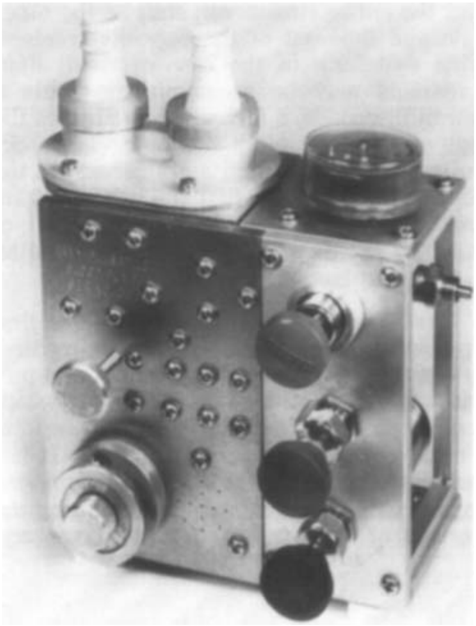

FIG. 3. Army pulsatile blood pump.

There is evidence, however, that pulsatile flow may be of more importance during prolonged periods of assisted circulation (low hemolysis,[3] less renal damage,[4] lower peripheral resistance[5]).

This pump was developed for use as a circulatory assistance device and is to be coupled with a small disposable membrane oxygenator for field use. It is intended for use in cases where circulatory collapse or pulmonary insufficiency exists, and where there are indications that repair and survival would be possible if temporary support could be given. The pump is capable of meeting complete or partial bypass requirements in adult humans. It uses a disposable presterilized valve ventricle assembly; it is low in hemolysis production;[3] the output responds to changes in filling pressure; it has simple controls; it is small and lightweight (6 lbs.).

Further studies concerning pulsatile flow with the pump, including blood gases, pH, lymph production, hemolysis, fibrinogen

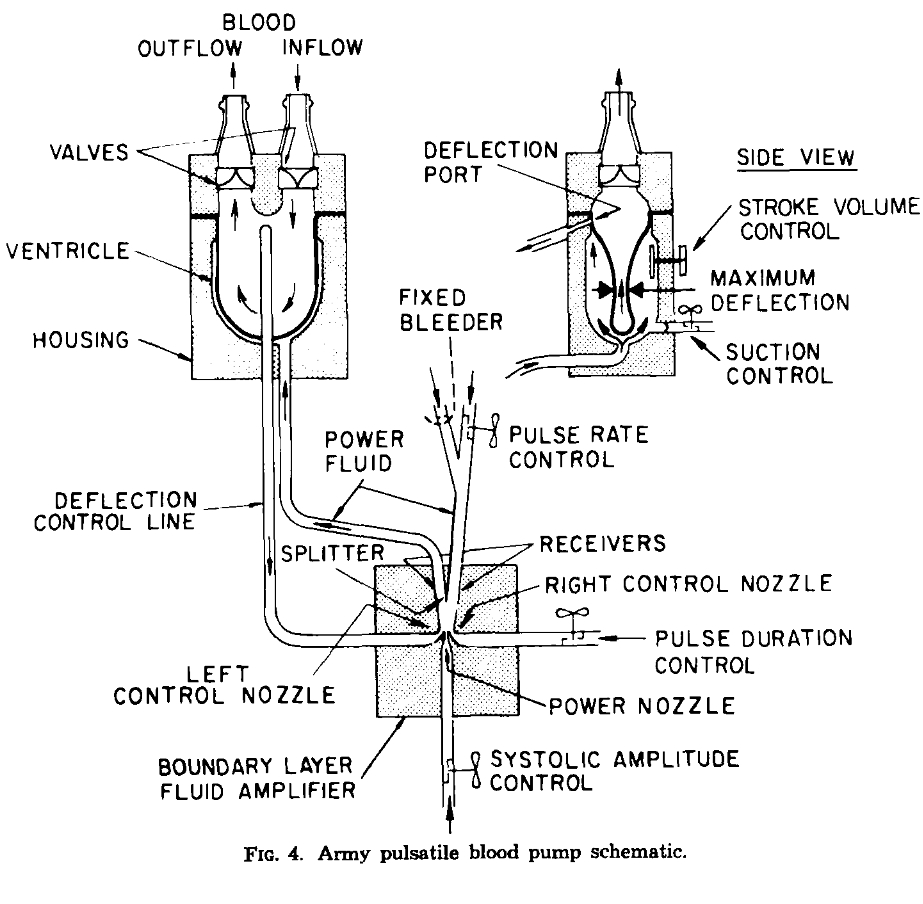

FIG. 4. Army pulsatile blood pump schematic.

FIG. 5. Army emergency respirator.

level, and platelets, are in progress in the laboratory. Clinical studies, using this pump for left heart bypass in severe cardiac patients unable to survive anesthesia and surgery for noncirculatory conditions, such as in the acute abdomen, are also underway.

Development of Ventilators — The fluid amplifier is also being applied in the development of two ventilators. The first is designed primarily as a resuscitator[6] (fig. 5). It is a fluid amplifier molded in the center of a block of plastic, 2 x 3½ x ¾ inch. There are no moving parts other than a plastic disc in an exhalation valve (fig. 6). This device will ventilate a patient in either

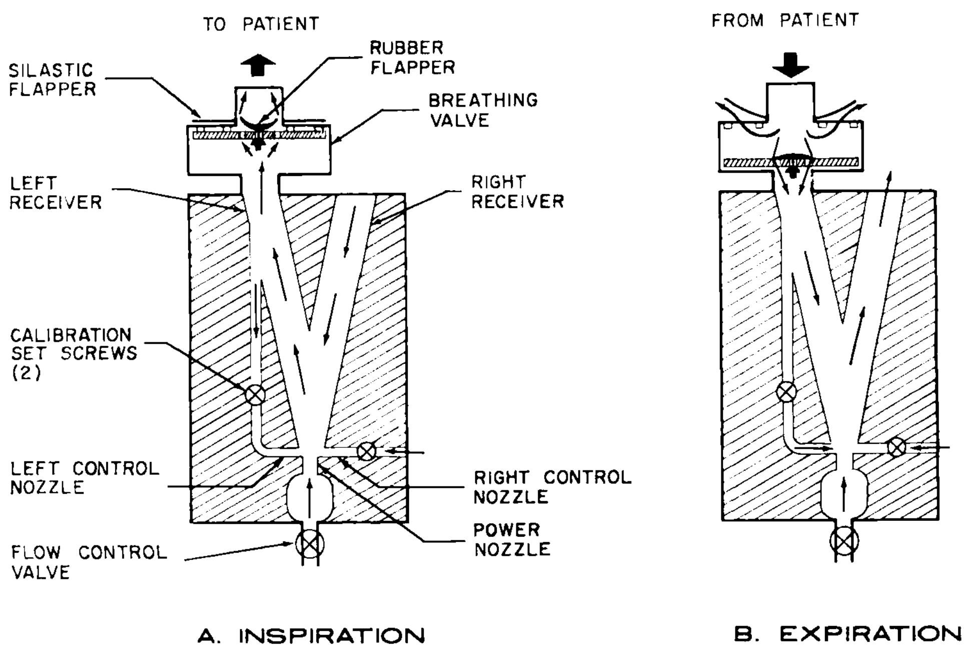

FIG. 6. Army emergency respirator schematic.

an assist or control mode. The unit automatically controls ventilation when there is no patient effort. An on-off valve controls the flow rate as well as the cycling pressures, which range from 12 cm. of water with an input pressure of 2 psig to 33 cm. of water at 5 pounds per square inch gauge.

The second unit is a volume-cycled ventilator (fig. 7) which also has the capability for pressure limit cycling. Two fluid amplifiers are utilized for the powering and control (fig. 8). A piston and bellows separate the driving gas from the breathing gas. This allows powering the respirator by an air supply not suitable for breathing. Oxygen from a demand valve or a bag reservoir, room air, or anesthetic gases can be delivered. The present model is for nonrebreathing only. Testing, both in animals and in humans, has proved the versatility of this design.

Another volume ventilator containing a small digital control circuit using only fluid amplifiers is under development. This unit will have only one moving part other than the exhalation valve. Subminiature flueric components will provide efficient operation from oxygen supplies.

A fluid amplifier oscillator has been used to control an external cardiac compressor (fig. 9). This bistable boundary fluid amplifier drives an oscillating valve which results in variable time cycling (fig. 10). The force applied to the chest is adjustable from

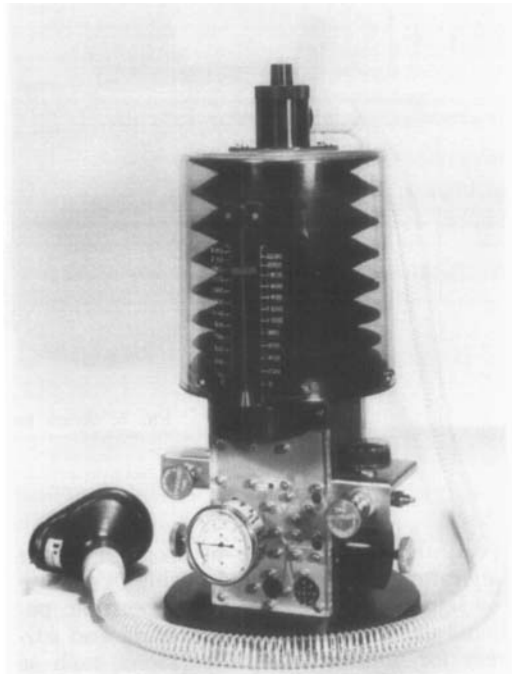

FIG. 7. Volume cycled ventilator.

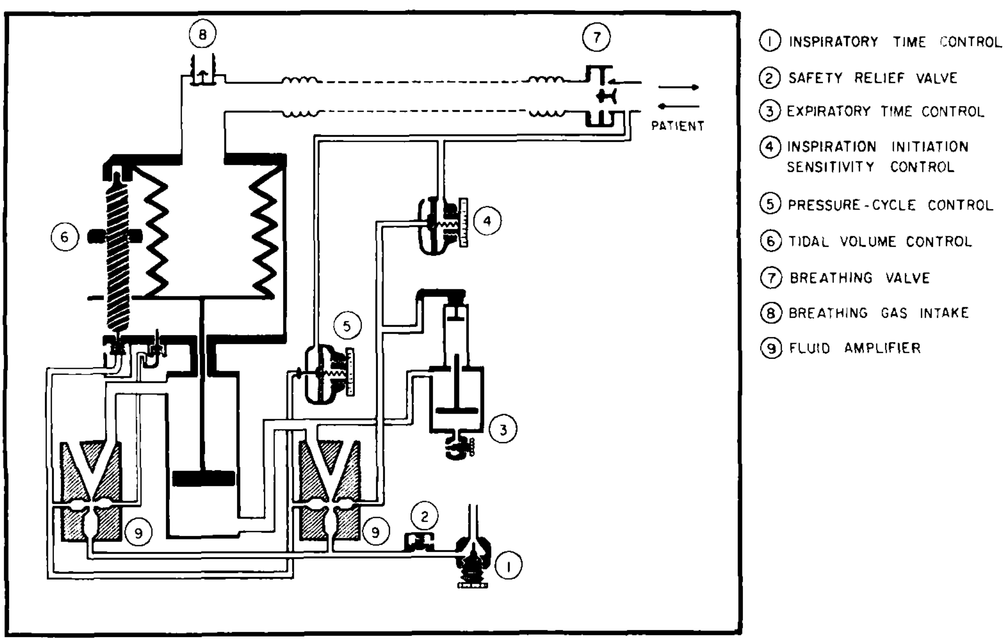

FIG. 8. Volume cycled ventilator schematic.

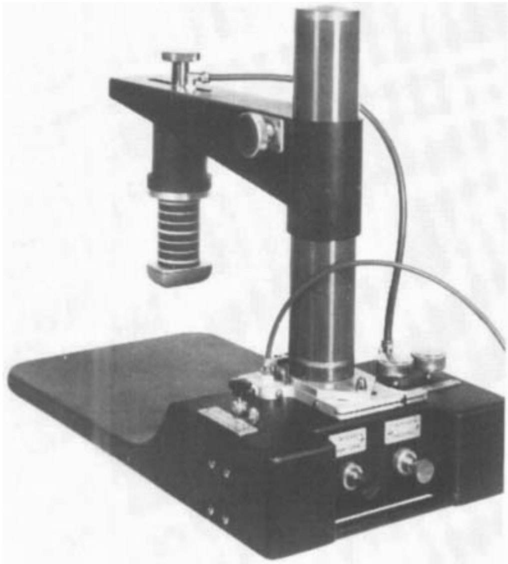

FIG. 9. External cardiac compressor.

0 to 150 lb. and is independent of the cycling control. Once the patient has been positioned on the base, the ram can be positioned in three planes, which allows exact placement without further moving of the patient. Tests have proved this unit helpful in the saving of human life.

These prototype medical devices, though not yet ready for routine use, have shown that fluid amplifiers can perform sophisticated operations with high reliability. They have undergone extensive life testing. One fluid amplifier pulsatile blood pump, pumping 4½ L./min. against a 500-mm. Hg load, has run continuously 24 hours a day without failure for over 2 years.

Disadvantages—There are some disadvantages to fluid amplification. A fluid amplifier is a continuous-flow device. Since the power stream is flowing at the same rate during all phases of operation, it wastes, in most

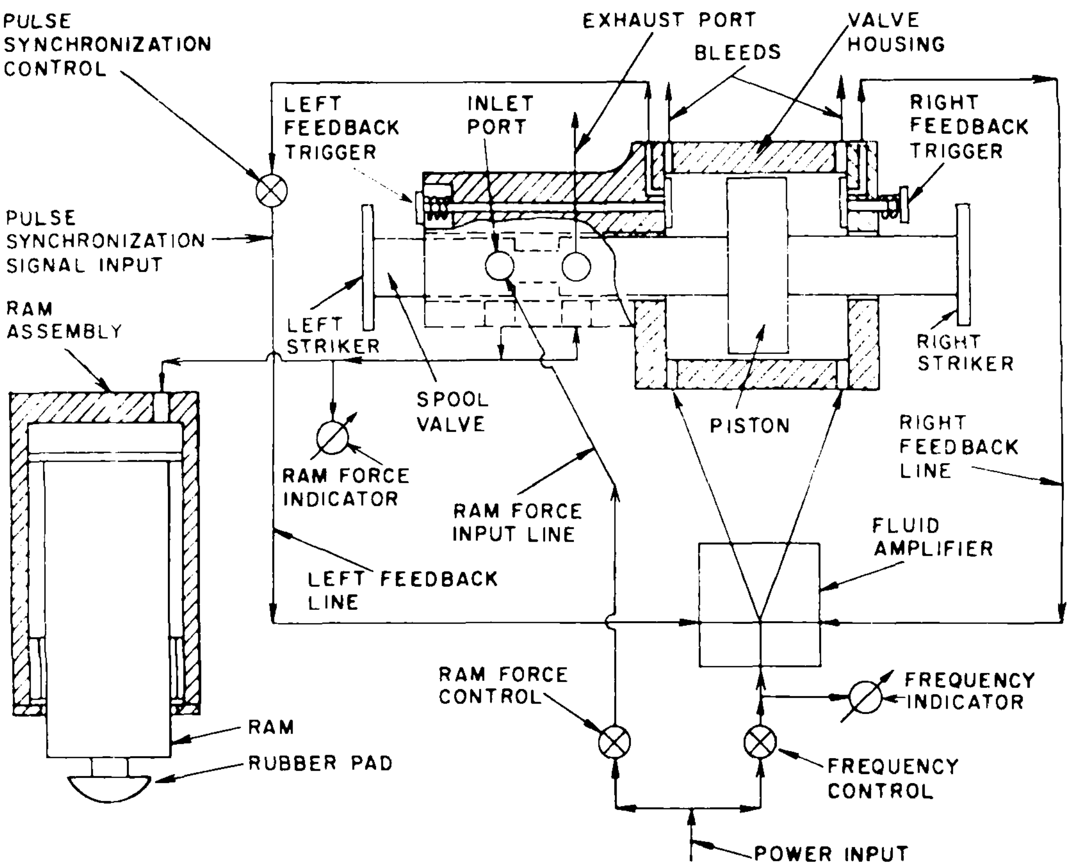

FIG. 10. External cardiac compressor schematic.

instances, at least one-half of the power. This fact alone becomes a problem for military field operation. When these devices are used with liquid oxygen wall systems, however, they represent no significant economic burden. Efforts are being made to reduce the size of fluid amplifiers and use them only for control and logic functions rather than to convey the working power.

SUMMARY

A group of medical devices is under development using the principle of fluid amplification.

A pulsatile blood pump, two types of ventilators, and a closed-chest cardiac compressor are all in various stages of development. Testing and evaluation indicate that where power is readily available, the fluid amplifier adds simplicity and reliability to medical devices. The pulsatile blood pump adds several desirable features to the technics of assisted circulation; however, the value of these benefits depends on the future of long-term bypass and the still not completely defined need for pulsatile flow.

REFERENCES

1. Angrist, S. W.: Fluid Control Devices. Sci. Amer. 211:81-88 (December) 1964.

2. Barila, T. G., Nunn, D. B. and Woodward, K. E.: A Blood Pump Powered and Controlled by a Fluid Amplification System. Trans. Amer. Soc. Artif. Intern. Organs 8:30-42, 1962.

3. Castaneda, A., Bernstein, E. F., Gleason, L., Hagfors, N. and Varco, R. L.: Further In Vitro Evaluation of the Army Heart Pump. Trans. Amer. Soc. Artif. Intern. Organs 10:57-62, 1964.

4. Dalton, M. L., Jr., Mosley, E. C., Barila, T. G., Wagner, S. C. and Woodward, K. E.: Renal Blood Flow During Left Heart Bypass. Vasc. Dis. 2:316-321 (November) 1965.

5. Mandelbaum, I. and Burns, W. H.: Pulsatile and Nonpulsatile Blood Flow. JAMA 191:657-660, 1965.

6. Straub, H. and Meyer, J. A.: An Evaluation of a Fluid Amplifier, Face Mask Respirator. Proc. Third Fluid Amplification Symposium 3:309-315, 1965.

Put a grain of boldness in everything you do.
— **Baltasar Gracian**

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Courage, considered in itself or without references to its causes, is no virtue, and deserves no esteem. It is found in the best and worst, and is to be judged according to the qualities from which it springs and with which it is conjoined. — **William Ellery Channing**

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He that fails in his endeavors after wealth or power will not long retain either honesty or courage. — **Samuel Johnson**