AD-A049 256 HARRY DIAMOND LABS ADELPHI MD F/G 13/7

FLUIDICS--BASIC COMPONENTS AND APPLICATIONS.(U)

OCT 77 J W JOYCE, R N GOTTRON

UNCLASSIFIED HDL-SR-77-6 NL

| OF |

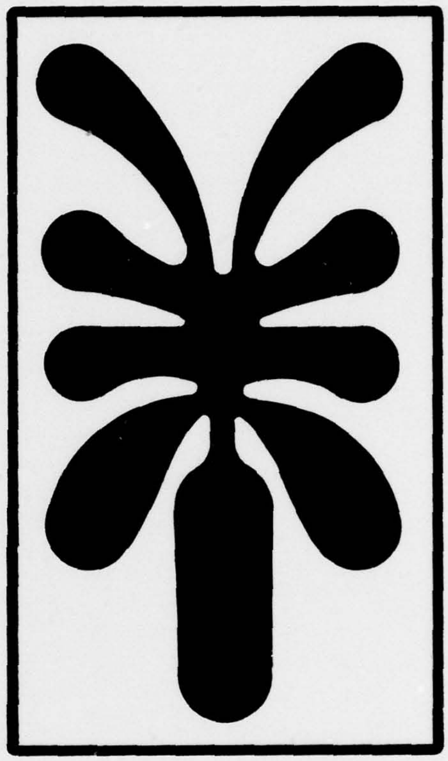
AD
A049256

END
DATE
FILMED
2-78
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6

HDL-SR-77-6
October 1977

FLUIDICS



Basic Components and Applications

HDL-SR-77-6, *Fluidics—Basic Components and Applications*,
by James W. Joyce and Richard N. Gottron

U.S. Army Materiel Development
and Readiness Command

HARRY DIAMOND LABORATORIES
ADELPHI, MARYLAND 20783

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER HDL-SR-77-6	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Fluidics--Basic Components and Applications		5. TYPE OF REPORT & PERIOD COVERED Special Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James W. Joyce Richard N. Gottron		8. CONTRACT OR GRANT NUMBER(s) Pron: A17R000302A1A9
9. PERFORMING ORGANIZATION NAME AND ADDRESS Harry Diamond Laboratories 2800 Powder Mill Road Adelphi, MD 20783		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Ele: 62114A
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Materiel Development and Readiness Command Alexandria, VA 22333		12. REPORT DATE October 1977
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

HDL Project: 304734 DRCMS Code: 612114.H730011

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fluidics
Fluerics
Bistable devices
Proportional amplifiers
Sensors
Laminar flow
Fluid control

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Since its discovery at Harry Diamond Laboratories in 1959, fluidics has gradually been developed into a viable technology. This report provides a description of fluidic components and systems now in use or ready for use in many applications. The fluidic technology provides sensing, computing, and controlling functions with fluid power through the interactions of fluid streams. Since fluidics can perform these functions without mechanical moving parts that will wear out, it has the advantages of simplicity and reliability. Other advantages discussed are the low cost, environmental insensitivity, and safety of fluidic systems.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Commercial applications of fluidics are found in the aerospace industry, industrial control, medicine, and personal-use items. The first aerospace application in production in the United States was for the thrust-reverser controls for a DC-10 airplane. In industry, fluidics has been applied to air-conditioning controls, machine controls, process controls, and production-line controls. More than 100 different applications have been identified in these areas.

One of the first commercial applications of fluidics was for life-support medical equipment. Several medical devices now on the market incorporate some degree of fluidic control. Personal-use fluidic products include pulsating showerheads, lawn sprinklers, and oral irrigators.

For military use, fluidics has been successfully applied to a fluidic generator to convert pneumatic energy into electrical energy, a fluidic stability augmentation system for helicopters, and a pressure-regulating system for aircraft. Currently under development is a fluidic fuel control for a gas-turbine engine.

ORIGINAL CONTAINS COLOR PLATES: ALL DDC REPRODUCTIONS WILL BE IN BLACK AND WHITE.

Contents

Figures

Figures (cont'd)

Tables

1. INTRODUCTION

The technology known as fluidics provides sensing, computing, and controlling functions with fluid power through the interaction of fluid (liquid or gas) streams. Consequently, fluidics can perform these functions without mechanical moving parts. The inherent advantages of fluidics are, therefore, simplicity and reliability, since there are no moving parts to wear out.

Fluidics—originally called fluid amplification—was discovered in 1959 by a group of scientists at the U.S. Army Harry Diamond Laboratories (HDL). During the first 10 years of its existence, there was a tendency to try to use fluidics in anything and everything, without giving adequate attention to whether it offered any true advantages over existing technologies. This period of trying to over-employ fluidics reached its peak in the mid-1960's. Those days have now passed. Fluidics is no longer a novelty; it can stand on its own merits.

Since 1970, a number of truly valid applications of fluidics have been realized. The areas of use include the aerospace industry, medicine, personal-use items, and factory automation. Fluidics for military systems has also progressed to the point where several systems are in advanced development stages. In most cases, the reason for selecting fluidics has been a combination of low cost, high reliability, inherent safety, and the ability to operate in severe environments.

In the sections that follow, the basic concepts and components of fluidic technology will be presented. The inherent advantages of fluidics will also be discussed. Finally, the applications of fluidics will be highlighted with some specific examples.

2. FLUIDIC COMPONENTS

A wide variety of fluidic components is now available "off the shelf." As might be expected, the components of today are vastly improved over their counterparts of the early 1960's. Figure 1 illustrates the giant strides made in component packaging by comparing an early 1960's prototype unit to a current equivalent off-the-shelf component. Manufacturing techniques have improved, size has been reduced, and unit cost has been lowered. In addition, integrated subsystems have replaced breadboard circuits.

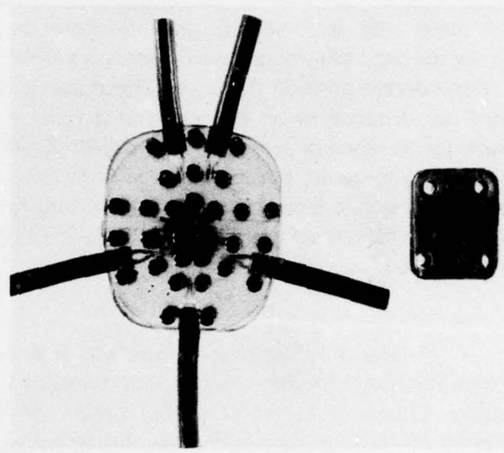


Figure 1. Early prototype (a) and current (b) fluidic hardware.

Fluidic components are generally classified as sensors, amplifiers, or interface devices. Sensors translate a parameter of interest (for example, angular rate, distance, or temperature) into a pressure/flow signal that can then be processed in a control circuit. Amplifiers perform the logic and control functions. The interface devices transform the signals from the control section of the circuit to an appropriate output (for example, electrical display, mechanical motion). Each of the categories of components may be either active or passive. An active fluidic component is one that requires a separate power source in addition to whatever input signals are applied to it. Passive components, on the other hand, operate on the signal power alone. With the exception of passive circuit components, such as fluid resistors and capacitors, almost all fluidic components are active.

2.1 *Fluidic Sensors and Interface Devices*

Many types of sensors and interface devices are available off the shelf. Because of the wide variety of functions offered by these components, they will not be discussed in detail here.

L. M. Sieracki[1] presents thorough cataloging of fluidic sensors—both off-the-shelf items and those still in research and development. Among the most commonly used sensors is a family of non-contact-position sensors. These devices sense the distance to an object (analog type) or simply the absence or presence of an object (digital type). Angular speed, temperature, gas concentration, fluid flow rate, and acceleration are among the parameters for which fluidic sensors have been built and used.

The most often used interface devices include those that produce mechanical or electrical outputs. Others yield pressure/flow outputs in a different medium or at a significantly different (usually higher) level than that of the control circuit. Examples of the latter type of interface device are low-pressure piloted spool or diaphragm valves in which the pilot signals are supplied by the fluidic control circuit. The high pressures controlled by the spool or diaphragm valve may be used to actuate a cylinder or other mechanical device.

2.2 *Fluidic Amplifiers*

Most fluidic amplifiers have at least four basic functional parts. These include (1) a supply port, (2) one or more control ports, (3) one or more output ports, and (4) an interaction region. These are illustrated in figure 2. These sections may be compared, respectively, to the cathode, control grid, plate, and interelectrode region of a vacuum tube. Many amplifiers also contain vents to isolate the effects of output loading from control flow characteristics. The sound of air escaping from such vents gives many fluidic amplifiers their characteristic hiss or whistle.

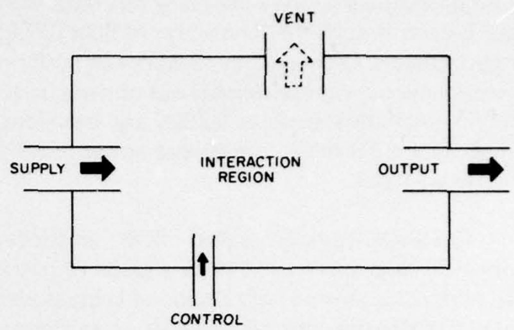


Figure 2. Schematic diagram of basic fluidic amplifier device.

The supply jet in the fluidic amplifier passes into the interaction region where it is directed toward the output port(s) or receiver(s). Control flow injected into the interaction region determines the direction and distribution of the supply flow which in turn affects the flow reaching the receiver(s). The amount of pressure or flow recovery available in a receiver is determined by the internal shape of the device. Useful amplification occurs inasmuch as change in output energies can be achieved with smaller changes in control energies.

In general, a fluidic amplifier may be categorized in either of two ways—by the function it performs or by the fluid phenomenon that is the basis for its operation. Categorized by function, amplifiers are either analog (proportional) or digital (bistable). Identifying amplifiers by fluid phenomena produces the following major categories:

(a) Jet deflection

(b) Wall attachment

(c) Impact modulation

(d) Flow mode control

(e) Vortex flow

---
[1]L. M. Sieracki, *Handbook of Fluidic Sensors,* Harry Diamond Laboratories CR-77-787-1 (May 1977).

2.2.1 *Jet-Deflection Amplifiers*

In jet-deflection (or beam-deflection) amplifiers, one or more control ports are constructed perpendicular to the supply jet (fig. 3). The direction of the supply jet is thus altered by flow issuing from the control port. This type of control results in proportional or analog performance, since the jet deflection is continuously varied (over a limited range) from one output receiver to the other.

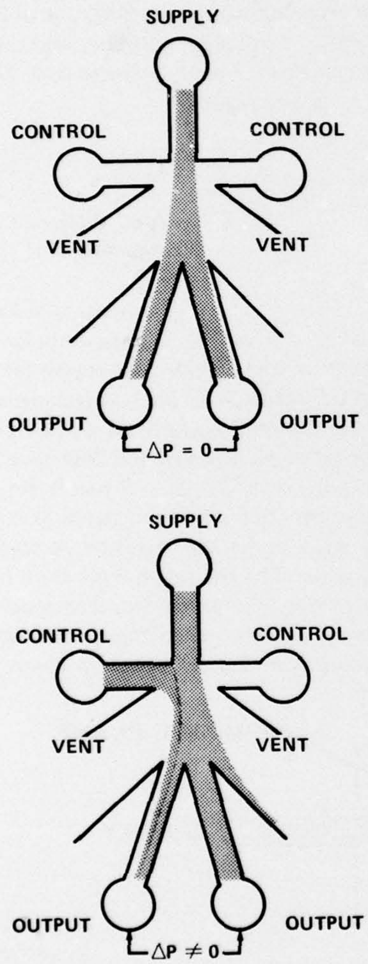


Figure 3. Jet-deflection fluidic proportional amplifier.

In all early forms of the analog jet-interaction amplifier, the flow was turbulent. This condition imposed limitations on the signal-to-noise levels and dynamic ranges available with such amplifiers. More recent research work at HDL has produced the laminar proportional amplifier (LPA).[2] Typically, an LPA exhibits a pressure gain of greater than 15, a dynamic range of over 1000, and a bandwidth ranging from 100 to 1000 Hz, depending on the supply pressure. The addition of the LPA to the inventory of available fluidic components has increased the potential uses for fluidic systems where analog control is required.

2.2.2 *Wall-Attachment Amplifiers*

A typical two-dimensional wall-attachment amplifier is depicted in figure 4. This device has a supply nozzle, control

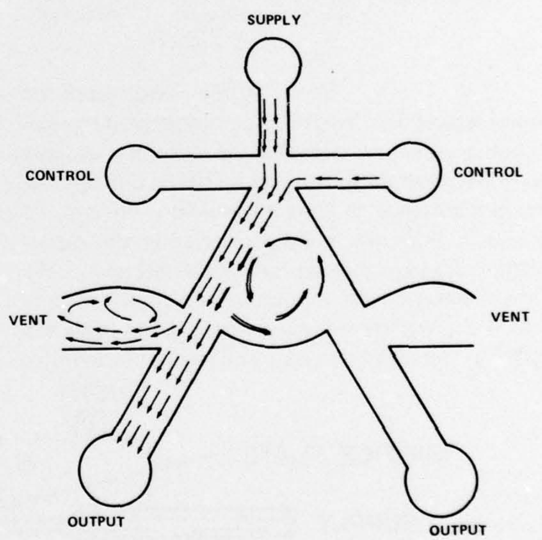


Figure 4. Wall-attachment fluidic bistable amplifier.

[2]F. M. Manion and G. Mon, *Fluerics 33: Design and Staging of Laminar Proportional Amplifiers,* Harry Diamond Laboratories TR-1608 (September 1972).

ports, two walls set back from the supply nozzle, and output receivers. The Coanda effect—a turbulent jet's property of attaching itself to a wall—causes this device to be bistable. The issuing turbulent jet attaches to one of the walls downstream of the control ports and subsequently flows into the corresponding output receiver. The jet will remain attached to this wall until a sufficient pressure signal is applied to the control port on that side. This signal will inject enough fluid into the low-pressure bubble formed by the attached jet to raise the pressure at that point and switch the jet to the opposite wall. In this manner of operation, digital performance is achieved. When one output receiver is "on," the other is "off." Variations in the geometrical configurations of this basic device yield elements that can produce most of the common digital logic functions—flip flop, AND, OR/NOR, etc. In addition, an oscillator can be made by providing a feedback loop from each output receiver to its corresponding control port.

2.2.3 *Impact Modulation Amplifiers*

When two opposed round supply nozzles direct jets along the same axis at one another, an impact plane is formed at some point between the two nozzles. This is the basis for the performance of impact modulator devices. As one jet is weakened relative to the other, the impact plane will move toward the weakened jet nozzle. One resulting configuration that uses this phenomenon is the transverse impact modulator shown in figure 5. Here, the two opposed jets have an orifice plate located between them. If the impact plane is initially to the right of the orifice plate, it tends to seal off the orifice, and a positive pressure at the output is realized. However, as control flow is injected, the jet on the left is weakened, the impact plane moves to the left side of the orifice plate, and the pressure at the output drops to ambient or slightly below. Thus, a digital logic function is achieved at the output.

Another configuration of this type of device is known as the summing impact modulator (SIM). In the SIM, one of the two opposed jets is maintained constant, and the other is varied to cause the impact plane to shift. The SIM produces an analog output.

2.2.4 *Flow Mode Control Amplifiers*

This class of fluidic amplifiers makes use of the laminar-turbulent flow phenomenon. In such devices, the supply jet will be laminar in the absence of any control signal, and flow will be directed toward an output port, as depicted in figure 6a. Because the flow is laminar, a significant portion of the jet will reach the output receiver and produce an output signal. If this jet is disturbed, such as by the injection of transverse control flow (fig. 6b), the jet changes from laminar to turbulent flow, and virtually no flow reaches the output receiver. Thus, when the control signal is applied, there is no output signal. In essence, this

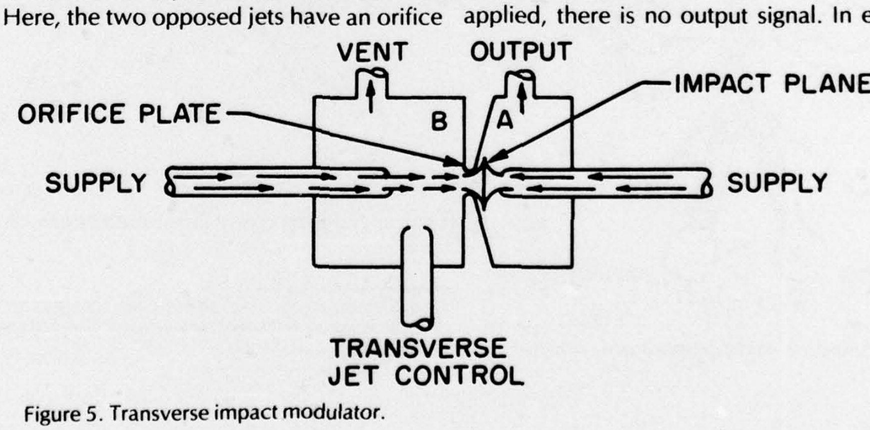


Figure 5. Transverse impact modulator.

device—known as a turbulence amplifier—is an OR/NOR gate. In addition to pressure/flow, the control signal may be acoustic; this phenomenon is the basis for a class of fluidic acoustic sensors.

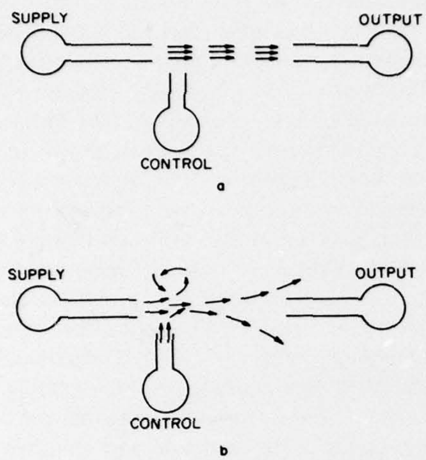


Figure 6. Flow mode control amplifier.
(a) Without control signal
(b) With control signal applied

2.2.5 *Vortex Flow Amplifiers*

In the vortex flow device, flow from the power nozzle is directed radially inward in a shallow cylindrical chamber, as shown in figure 7. In the absence of any control flow, the supply flow continues radially inward toward the outlet, or drain, located at the center of the chamber. If control flow is injected tangentially, the supply flow and control flow combine to produce a swirl-type flow pattern which becomes a forced vortex field. The pressure gradient across the

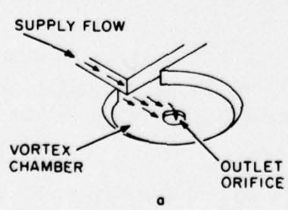


Figure 7. Vortex flow amplifier.
(a) Without control flow

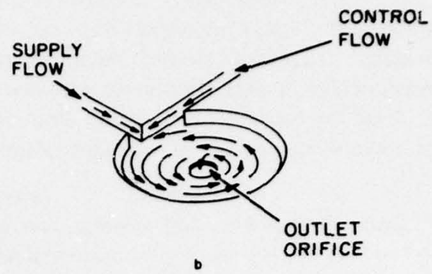


Figure 7 (cont'd). Vortex flow amplifier.
(b) With control flow

chamber produced by this forced vortex field alters the magnitude and the pattern of the supply flow. Specifically, as control flow is increased, the supply flow is decreased, so that the device acts as a throttling valve. This same principle is the basis for the operation of the vortex angular rate sensor. Here, no control flow is introduced; instead, the swirl is imparted by the angular rotation (about the axis of the drain) of the chamber itself. Differential pressure signals from an angle-of-attack detector located in the drain (or in the chamber near the drain) correspond to the angular velocity of the sensor.

3. ADVANTAGES OF FLUIDICS

The fact that the basic elements of fluidics, as described in section 2, contain no moving mechanical parts and require no electricity leads to numerous inherent advantages of this technology for controls applications. Among these advantages are the following.

(a) High reliability: Since there are no moving parts to wear out, the normal wear-out types of failures are essentially nonexistent. Some specific examples of proven high reliability of fluidic systems will be discussed later in this report.

(b) Low cost: In most uses, fluidic systems have a lower initial cost than competitive equivalents. In addition, the high reliability and low maintenance of fluidics, combined with low initial cost, result in total life-cycle costs that are extremely low when compared with alternatives.

(c) Environmental insensitivity: Fluidic components and systems can be designed so that the effects of environmental stresses (shock, vibration, acceleration, temperature, altitude, etc.) are minimal. Fluidics also has superior tolerance to the effects of nuclear or electromagnetic radiation.

(d) Safety: Fluidic systems require no special explosion proofing, since they are inherently safe. This advantage makes fluidic systems particularly desirable for applications such as munitions loading or process controllers involving corrosive or explosive chemicals.

In addition to the four major advantages cited above, fluidics offers a wide variety of sensing functions, some of which are unique. Fluidics systems are generally small and lightweight compared to most other competitive control systems. And the speed of operation, while nowhere near as fast as electronics, is nevertheless considerably faster than mechanical or conventional moving-part pneumatic/hydraulic systems.

4. COMMERCIAL APPLICATIONS OF FLUIDICS

The applications of fluidics are too numerous to list completely. Consequently, this report will address several representative applications, both civilian and military, from different fields.

In general, fluidic applications have been realized in machine controls, process controls, production-line controls, air-conditioning controls, aerospace systems, medical equipment, and personal-use items. Although only a limited number of military fluidic systems are "in the field," several systems are in advanced development stages and offer high promise for eventual field use.

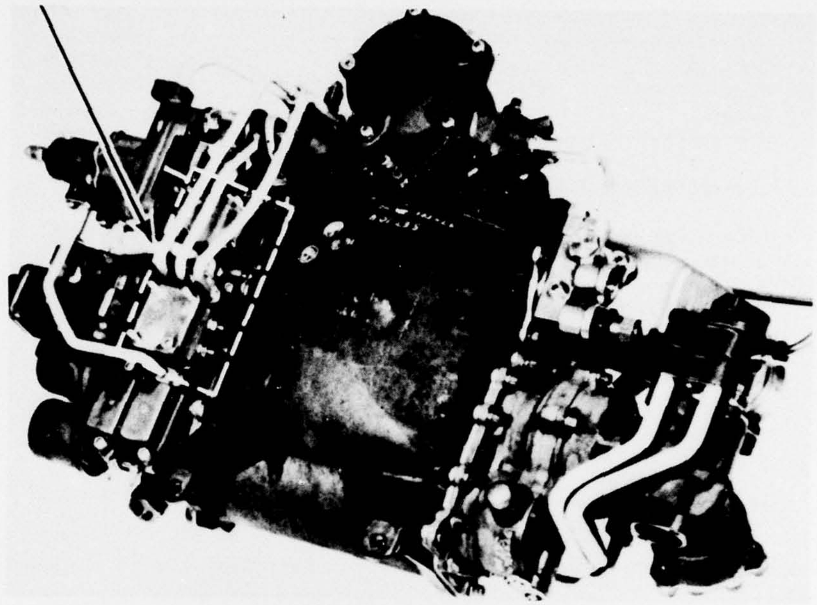
4.1 *Aerospace Applications*

The first production aerospace fluidic application in the U.S. was for the thrust-reverser actuator controls for the General Electric CF-6 engine for the McDonnell Douglas DC-10 aircraft. This system was placed in revenue service in August 1971. (The same control system on the same engine is also used on the European A300B Airbus.) The fluidic thrust-reverser hardware is shown in figure 8. The fluidic system controls the thrust-reverser actuator air motor speed after 90 percent of the actuation stroke and also limits the torque at the end of the stroke. To achieve these functions, a fluidic operational amplifier, providing lag-lead compensation, accepts the appropriate speed or torque-limiting signal and drives a mechanical servovalve that, in turn, actuates the snubbing valve and brake on the air motor as required to maintain proper control. The actuator and controls must operate in a temperature range from −40 to 177°C (-40 to 350°F). The supply gas for the fluidic circuitry is engine-compressor bleed air at a maximum temperature of 315°C (600°F).

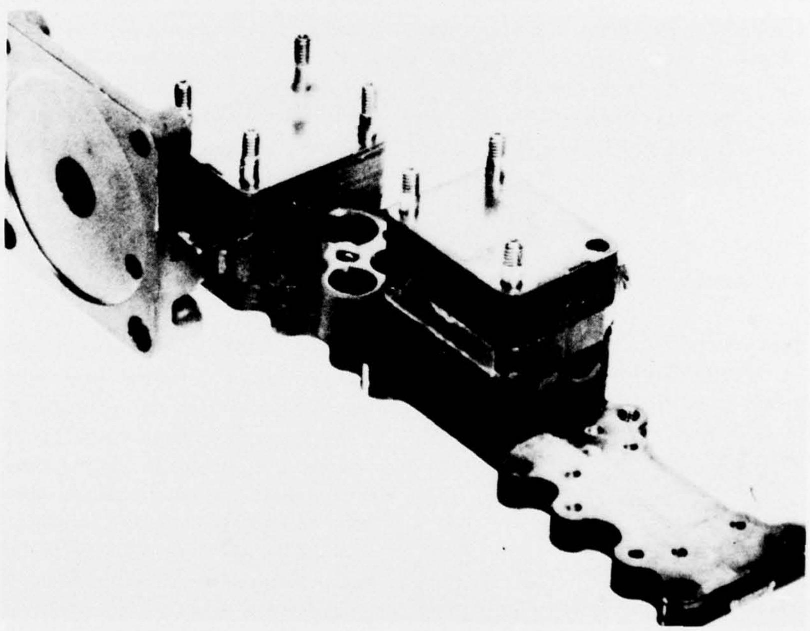
Actual performance data for this system have demonstrated a mean time to failure (MTTF) in excess of 600,000 hr.[3] This value is based on about 5,500,000 hr of component operating time. As of 30 June 1976, a total of 221 DC-10 aircraft with the fluidic thrust-reverser controls (3 per aircraft) were in operation.

An indication of the impact of the reliability of the fluidic controls on the overall thrust-reverser system is illustrated by the following data. From maintenance data on the DC-10, the Boeing 747, and the Lockheed L-1011 thrust reversers, the values for mean time between unscheduled removals (MTBUR) and total component flight hours are presented in table I.[3] These values show that the MTBUR for the thrust-reverser system using fluidics

[3] W. T. Fleming and H. R. Gamble, *Reliability Data for Fluidic Systems,* Harry Diamond Laboratories CR-76-092-1 (December 1976).



a. PNEUMATIC ACTUATOR FOR THRUST REVERSER



b. FLUIDIC CONTROL MODULE

Figure 8. Fluidic thrust-reverser control system.

TABLE I. CONVENTIONAL VERSUS FLUIDIC RELIABILITY COMPARISON

Complete thrust-reverser system	MTBUR	Component Total flight hours
Conventional pneumatic		
Boeing-747 fan thrust reverser	4035	16,028,680
Lockheed L-1011 thrust reverser	3742	2,252,589
Fluidic		
McDonnell Douglas DC-10 thrust reverser	9510	6,114,618

on the DC-10 is more than double that of the other two systems that use conventional pneumatic-controlled actuators.

Other fluidic commercial applications in aerospace include the thrust-reverser and secondary nozzle actuator control systems on the Concorde SST and pressure ratio and variable inlet guide vane controls for the Rolls-Royce RB211 engine on the Lockheed L-1011 aircraft.

4.2 *Industrial Control Applications*

Included in this category of fluidic applications are air-conditioning controls, machine controls, process controls, and production-line controls. Over 100 different applications have been identified from these areas of use in the U.S. and abroad.

Fluidic controllers for large-scale air-conditioning systems (for example, in office buildings) have been in service since the late 1960's. These units control the flow of air through the complex ducting circuit of the air-conditioning system. One such controller is shown in figure 9. This particular unit uses three summing impact modulators to achieve proportional control.[4] Inputs to the controller are pressure signals that represent parameters such as temperature and relative humidity. Another type of controller uses a three-stage jet-interaction fluidic proportional amplifier in a unit that gives positive assurance of fan operation in the forced-air system and, at the same time, eliminates the need for any pneumatic-electric interface. Over 100,000 fluidic controllers for air-conditioning systems have been sold and installed by several manufacturers, making this the most widely used application of a fluidic system.

Machine-control applications include the control of industrial sewing-machine attachments (fig. 10). In one such attachment, a fluidic control system senses the leading and trailing edges of a garment moving through a sewing station.[5] The system then controls the attachment to cut a continuous thread chain and/or binding flush with the edge of the garment. The fluidic circuitry includes interruptible jet sensors that detect the edges of the

[4] J. A. Enright, *The Impact Modulator Meets the Market,* Fluidics Quarterly, *3,* 3 (1971).
[5] Corning Glass Works, Fluidic Product Department, *Fluidics Case History,* Data Sheet FCH-2B (1971).

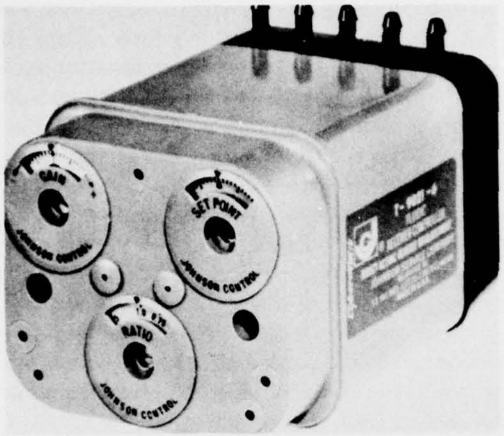


Figure 9. Fluidic air-conditioning controller.

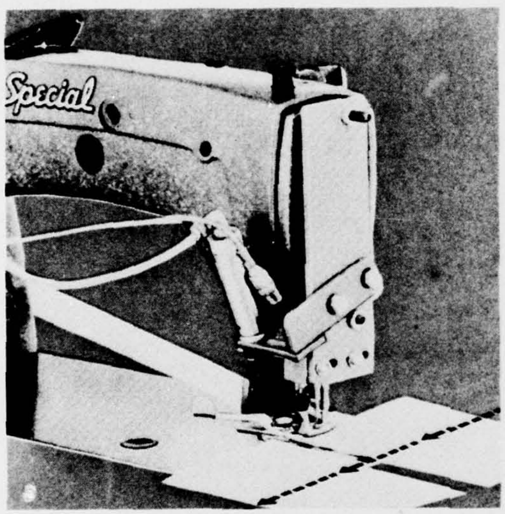


Figure 10. Fluidically controlled industrial sewing-machine attachment.

garment and 12 logic elements to perform the control function. Fluidics was selected for this use because it could perform the required operation more accurately and reliably than competitive approaches. Other machine-control applications include sequencing controls for turret lathes and sensing/control systems for die protection.

An example of the use of fluidics in process controls is the application of a fluidic diverter valve (*fig. 11*) to control liquid level. These diverter valves are wall-attachment devices with a single control port. Flow normally issues out of one output leg of the valve; when a control signal is applied, the flow is diverted to the opposite leg. This type of valve was installed in a paper and pulp plant in 1964 to control the level in a white water (paper stock with a 0.5-percent consistency) chest.[6] The valve, which is still in operation, maintains the proper level by adding waste condensate water whenever the chest level is low. The only maintenance required on this valve has been an occasional cleaning of the control tube to remove pulp deposits.

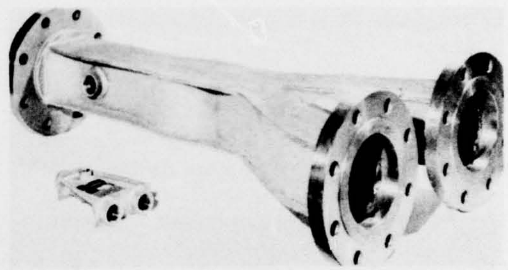


Figure 11. Fluidic diverter valves (¾- and 4-in. pipe sizes).

A good example of fluidics in production-line controls is a system that counts and orients cartons for palletizing. In one specific application, a 28-year-old palletizer had its electro-mechanical parts replaced with a fluidic circuit because of prohibitive maintenance costs associated with the electro-mechanical parts.[7] The fluidic system consists of fluidic acoustic sensors and logic gates. More than 3,000 logic gates are used; integrated circuitry reduces the size and complexity of the control system. The acoustic sensors replaced photo-electric cells to detect open carton flaps, sense carton height and position, and count cartons. The control system sequences the palle-

---

[6] R. B. Adams, *Some Industrial Process Applications of Fluidics*, Fluidic State-of-the-Art Symposium, *V* (30 September to 3 October 1974), 91–117.

[7] *Fluidic System Counts and Orients Cartons for Palletizing*, Hydraulics and Pneumatics, *26*, 10 (October 1973), 82–83.

tizer in response to one of three programmed stacking patterns designed to handle several carton sizes. In numerous other instances, fluidics has been applied to controlling the movement of objects along conveyor systems.

4.3 *Medical Applications*

Investigating the feasibility of using fluidics in life-support medical equipment was one of the first research and development efforts undertaken at HDL in the early 1960's. Because of the high reliability of fluidics, the technology was considered a strong contender for items such as pulsatile extracorporeal blood pumps and respirators, both of which involve controlling the movement of fluids. Today, several medical devices on the market incorporate some degree of fluidic control.

One such item is a pressure-cycled respirator (fig. 12) designed for home therapy use by patients with chronic respiratory problems. In this system, the fluidic control element provides the flow of breathing gases directly to the patient, thus eliminating the need for any interface valves. The respirator senses the patient's inspiratory effort (which appears as a slight negative pressure) and switches flow to him. At a predetermined pressure at the mouthpiece (or breathing mask), the inspiratory phase is terminated, and the exhalation phase begins and continues until the next inspiratory effort by the patient. The fluidic control module is made of glass ceramic material and may be sterilized by standard autoclaving methods. In addition to this unit, there are several other commercial respirators that contain fluidic controls. These latter respirators are generally more complex in function and are intended primarily for hospital use.

The chief advantages of fluidics in this and other respirators are increased reliability over conventional pneumatic controls and inherent safety. Respirators are, of course, normally used in areas where high oxygen levels require explosion-proofing of any electrical equipment. Conse-

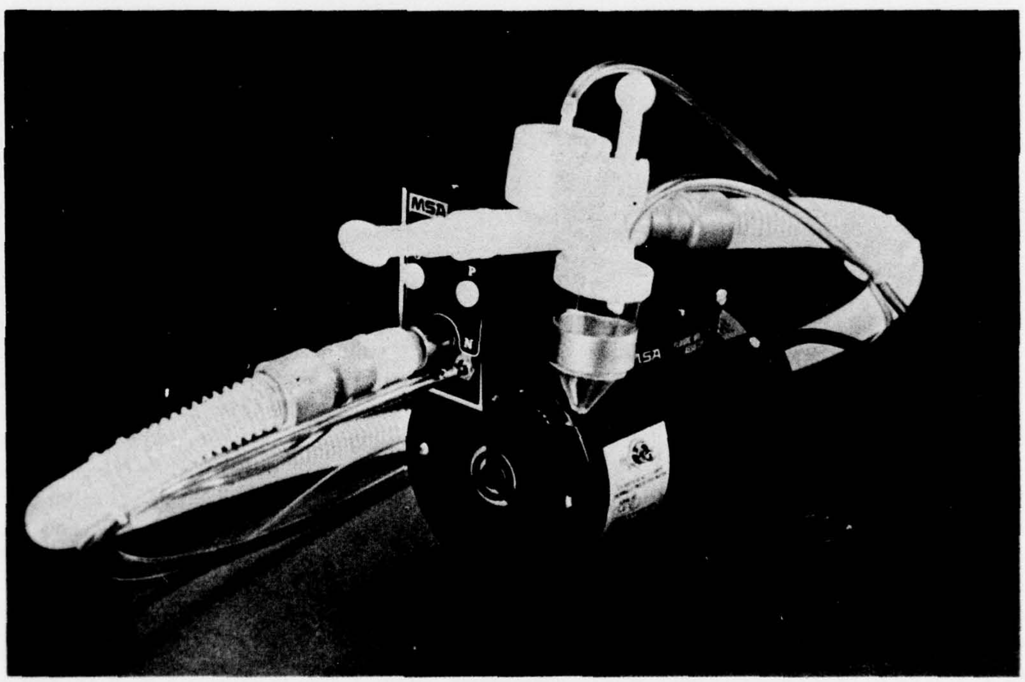


Figure 12. Fluidic respirator.

quently, many respirators have been designed to operate directly from either oxygen or air supplies that are commonly available in hospitals. Such respirators thus become natural candidates for fluidic controls.

4.4 *Personal-Use Applications*

One of the first fluidic personal-use items to appear on the market was a pulsating showerhead (fig. 13). A manually controlled valve, operated by twisting the barrel of the showerhead, provides two modes of operation. One mode is a continuous steady stream, as in any conventional showerhead. In the other mode, a fluidic oscillator produces a pulsating flow out of each of two rectangular slots in the face of the showerhead. This pulsating flow yields a massaging action.

Other personal-use fluidic products include a family of fluidic lawn sprinklers and oral irrigators. In the former, the back and forth action of the sprinkler to sweep an area of the lawn is achieved without mechanical moving parts. The oral irrigator is similar to the showerhead in that it provides a pulsating flow to massage the gums and enhance the rinsing action.

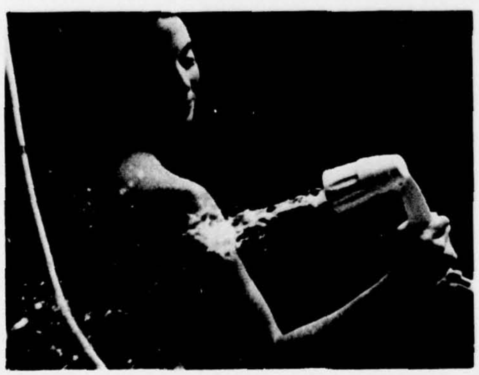


Figure 13. Fluidic pulsating showerhead.

5. MILITARY APPLICATIONS OF FLUIDICS

Maintenance and logistics costs are extremely high in a military system's life cycle, and almost all such systems must operate through environmental extremes; hence, a military system *has* to be rugged. As a result, the military is interested in fluidics because of its reliability and environmental insensitivity. Low initial cost, another military concern, can be realized by use of fluidic systems.

The fluidic generator (fig. 14), an interface device that converts pneumatic energy into electrical energy, has been type classified in a Navy system. In this application, the fluidic generator ingests ram air and converts it to electrical energy to supply the total electrical power requirements of a bomblet dispenser system. The aircraft must be flying above a specified velocity in order for the generator to operate; therefore, no electrical power is available below the specified velocity. Hence, fluidics is used as an environmental safety system by allowing the pilot to activate the dispenser only if the aircraft is flying at or above the specified velocity range. The Army recognized the potential of using the fluidic generator as an inexpensive means of furnishing the total power requirements of an electronic fuze. In addition, safety is enhanced, since no power is generated unless the projectile is in flight. These advantages have led to the selection of the fluidic generator for the Army's new General Support Rocket System.

Within the military, the Army and Navy have cosponsored a development program for a fluidic stability augmentation system (SAS) for helicopters. The SAS assists the pilot by providing rotational damping about one or more axes. A single-axis fluidic SAS is shown in figure 15. The SAS uses a vortex angular-rate sensor that senses the rate of turn of the aircraft in a particular axis. The fluidic signal from the rate sensor is amplified by several jet-interaction fluidic proportional amplifiers, shaped dynamically by passive fluidic RC-networks and then converted into mechanical motion by

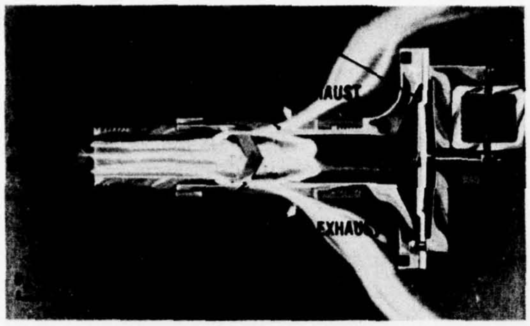


Figure 14. Fluidic generator.

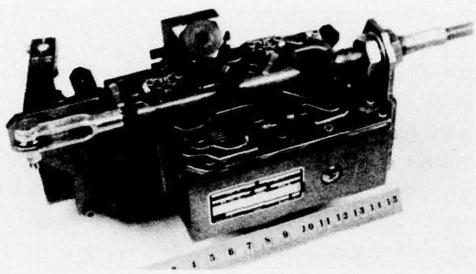


Figure 15. Fluidic single-axis stability augmentation system.

means of conventional hydraulic servoactuators. The SAS uses the on-board hydraulic power supply to operate the fluidic circuitry. This system is low-cost, easy to maintain, and more reliable than electro-hydraulic or electromechanical equivalents.

A recent series of flight tests for the fluidic SAS on the Army's OH-58 helicopter (using a two-axis SAS) and the Navy's TH-57 helicopter (using a single-axis SAS) produced over 12,000 hr of total aircraft flight time. From these tests, the measured mean time between failure (MTBF) for the fluidic SAS was 4,557 flight hours. Since the failures experienced during these tests of prototype SAS's are considered to be about 90 percent correctable, the estimated MTBF for final production units is about 25,000 to 50,000 flight hours. Investigations have shown that the electromechanical flight-control equipment on the Army's Huey Cobra helicopter has exhibited MTBF of about 140 flight hours. By comparison, the fluidic SAS *prototype* MTBF is more than 30 times greater than that of the Huey Cobra system, which is considered to be a mature one. These data, together with those from the DC-10, clearly demonstrate that fluidic systems are extremely reliable.

Another fluidic application that has demonstrated high reliability is the pressure-regulating system for the Navy's S-3A aircraft. The system, shown in figure 16, controls the coolant air for the aircraft avionics. A similar regulating system will also be used on the Navy's F-18.

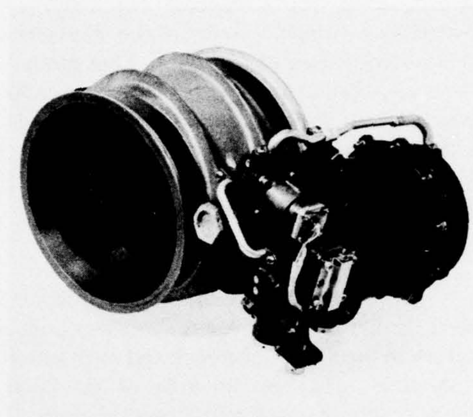


Figure 16. Fluidic pressure-regulating system.

A joint-service development project for fluidic fuel control of a gas-turbine engine has shown significant progress and should be in the field in the near future. The prototype system, shown in figure 17, measures temperature and rotational speed, schedules start up, and controls turbine speed to $\pm 1/4$ percent. The system will cost approximately 20 percent less than present turbine fuel-control systems. More important, however, is that the predicted reliability will be six to ten times greater than current systems.

Other military development efforts that use fluidics and that will soon reach maturity include gun stabilization for armored vehicles, fuel fill and shut-off control for the Huey helicopter, gun firing-rate control for 20- and 30-mm guns, missile actua-

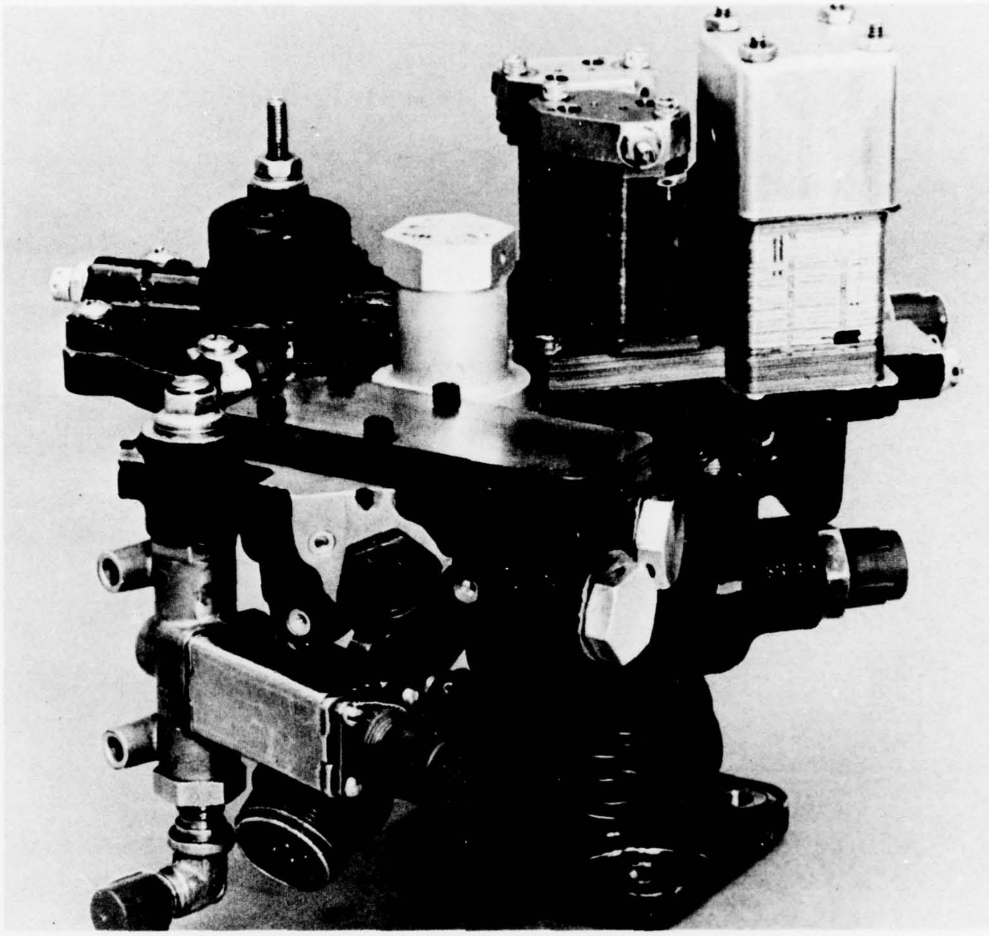


Figure 17. Fluidic fuel control for gas turbine engine.

tor control, and angular-rate sensors for controlling gun and missile projectiles.

6. CONCLUSIONS

The technology known as fluidics is quietly advancing into commercial and military use. The advantage of this technology's high reliability has been conclusively demonstrated from data on the air-driven system on the DC-10 and the hydraulic-driven system on helicopters. The advent of the laminar proportional amplifier has resulted in fluidic systems with more precision control—resulting in an increase of potential use for this technology.

Fluidics has now been accepted as a viable technology for military applications and for commercial use. It is expected that the next decade will find more widespread use of this advancing technology.

Literature Cited

1. L. M. Sieracki, *Handbook of Fluidic Sensors,* Harry Diamond Laboratories CR-77-78-1 (May 1977).

2. F. M. Manion and G. Mon, *Fluerics 33: Design and Staging of Laminar Proportional Amplifiers,* Harry Diamond Laboratories TR-1608 (September 1972).

3. W. T. Fleming and H. R. Gamble, *Reliability Data for Fluidic Systems,* Harry Diamond Laboratories CR-76-092-1 (December 1976).

4. J. A. Enright, *The Impact Modulator Meets the Market,* Fluidics Quarterly, *3,* 3 (1971).

5. Corning Glass Works, Fluidic Product Department, *Fluidics Case History,* Data Sheet FCH-2B (1971).

6. R. B. Adams, *Some Industrial Process Applications of Fluidics,* Fluidic State-of-the-Art Symposium, *V* (30 September to 3 October 1974), 91-117.

7. *Fluidic System Counts and Orients Cartons for Palletizing,* Hydraulics and Pneumatics, *26,* 10 (October 1973), 82-83.

Bibliography

Technical Reports

Carter, V. and D. Marsh, *Fluerics 23. A Bibliography. Supplement 1,* Harry Diamond Laboratories TR-1597, April 1972.

Deadwyler, R., *Theory of Temperature and Pressure-Insensitive Fluid Oscillators,* Harry Diamond Laboratories TR-1422, March 1969.

Drzewiecki, T. M., *A Computer Aided Design Analysis for the Static and Dynamic Port Characteristics of Laminar Proportional Amplifiers,* Harry Diamond Laboratories TR-1758, June 1976.

Drzewiecki, T. M., *The Fluid Mechanics of Fluidics,* Harry Diamond Laboratories TR-1798, February 1977.

Drzewiecki, T. M., *A General Planar Nozzle Discharge Coefficient Representation,* Harry Diamond Laboratories TM-74-5, August 1974.

Drzewiecki, T. M., *Planar-Nozzle Discharge Coefficients,* Harry Diamond Laboratories TM-72-33, September 1973.

Fluidics State-of-the-Art Symposium, Proceedings, Harry Diamond Laboratories, 30 September to 3 October 1974.

Gaylord, W. and V. Carter, *Flueric Temperature-Sensing Oscillator Design,* Harry Diamond Laboratories TR-1428, April 1969.

Goto, J. and T. M. Drzewiecki, *An Analytical Model for the Response of Flueric Wall-Attachment Amplifiers,* Harry Diamond Laboratories TR-1598, June 1972.

Gottron, R. N. and S. D. Weinger, *Parameters Affecting the Noise in No-Moving-Parts Fluid Devices,* Harry Diamond Laboratories TR-1283, April 1965.

Katz, S. and E. Hastie, *The Transition from Isothermal to Adiabatic Capacitance in Cylindrical Enclosures,* Harry Diamond laboratories TM-71–35, December 1971.

Keto, J. R., *Transient Response of Some Flueric Components to Step Waves and Application to Matching,* Harry Diamond Laboratories TR-1531, September 1970.

Kirshner, J. M., *Fluerics 1: Basic Principles,* Harry Diamond Laboratories TR-1418, November 1968.

Kirshner, J. M., *Jet Dynamics and Its Application to the Beam Deflection Amplifier,* Harry Diamond Laboratories TR-1630, July 1973.

Kirshner, J. M. and R. N. Gottron, *Fluerics 28: State of the Art 1969,* Harry Diamond Laboratories TR-1478, December 1969.

Manion, F. M. and G. Mon, *Design and Staging of Laminar Proportional Amplifiers,* Harry Diamond Laboratories TR-1608, September 1972.

Roffman, G. L. and S. Katz, *Experimental Fluidic Analog Computation,* Harry Diamond Laboratories TR-1292, June 1965.

Spyropoulos, C. E., *Large-Scale Modeling of Laminar Flueric Devices,* Harry Diamond Laboratories TM-73–28, February 1974.

Toda, K. et al, *The Matched Acoustic Generator,* Harry Diamond Laboratories TR-1574, December 1971.

Military Standards

MIL-STD-1306A, *Fluerics: Terminology and Symbols,* 8 December 1972.

MIL-STD-1361A, *Fluidics: Test Methods and Instrumentation,* 28 September 1973.