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Fluidic Technology

RATIONALE

The A-6A3 Technical Committee approved the stabilization of this document during the Spring 2009 A-6 meeting in Valley Forge. See minutes paragraph A3.7.

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FOREWORD

Fluidics is the control technology that relies on fluid interactions to perform functions of sensing, logic, amplification, signal transmission, signal conditioning and control. Fluidics, therefore, parallels many of the functions traditionally associated with electronics. Pure fluidics, sometimes called fluerics, employs no moving part mechanical devices at all, but most operational fluidic systems employ mechanical peripheral components, such as valves, actuators, push buttons, switches commonly associated with fluid power control.

Since the original release of this document, significant changes have occurred in the fluidic technology. A number of successful applications have been in operation for many years. They have proven that the current state of the technology offers significant advantages over other methods of performing the same functions when requirements call for:

a. High reliability
b. Operation in harsh environments such as high temperature, EMI/EMP, vibration
c. Protection from, or immunity to nuclear, electromagnetic, or directed beam weapons
d. Deadband free amplification and switching
e. Operating frequencies beyond the capability of hydromechanical control elements

Fluidics may be implemented in either pneumatic or oil based systems. Pneumatic applications frequently use available energy, such as engine compressor discharge, as power. Hydraulic fluidics employ standard aircraft hydraulic fluids, but frequently operate at much lower pressures than the main/ power hydraulic system. In the most sensitive sensing and control applications, such as rate sensing, the use of laminar flow nozzles offers very high signal/noise ratio systems.

Fluidics are usually integrated with fluid power control systems and require appropriate interface devices with these systems. Reference should be made to the appropriate fluid power systems specification. The power fluid conditioning for fluidic devices is described in AIR1245.

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FOREWORD (Continued)

The content of this document is not necessarily complete and may be revised on a continuing basis as the field demands. No attempt has been made to be all inclusive in the listing of types of devices or elements, nor could the suggested specification parameters be considered more than a guideline to the types of parameters which have so far been found of importance. Similarly, it is difficult to establish test procedures in a field where wide variations in devices exist and where new devices of a highly proprietary nature may be added.

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1. SCOPE:

The scope of this document is limited to encompass terminology, symbols, performance criteria and methods reflecting the current status of the technology.

1.1 Purpose:

The purpose of this document is to promote the use of a common terminology and useful symbols and to encourage users and manufacturers of fluidic devices and systems to conform to meaningful standards of performance.

This document is intended for use as the basis for a procurement specification for fluidic devices and systems when the need for such a specification arises.

This document shall be the starting point for future SAE documents, either through revision or addition, in the field of fluidics as such documents become necessary.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this specification and references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

AIR1245	Power Sources for Fluidic Control
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation, and Control Technologies

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2.2 Definitions:

2.2.1 General:

FLUIDICS: The general field of fluid devices and systems performing sensing, logic, amplification and control functions employing primarily no-moving-part (flueric) devices.

FLUERIC: An adjective which can be applied to fluidic devices and systems performing sensing, logic, amplification, and control functions if no moving mechanical elements whatsoever are used.

ELEMENTS: The general class of devices in their simplest form used to make up fluidic components and circuits; for example, fluidic restrictors and capacitors, a proportional amplifier or an OR-NOR logic gate. Elements are the least "common denominators" of the fluidics technology.

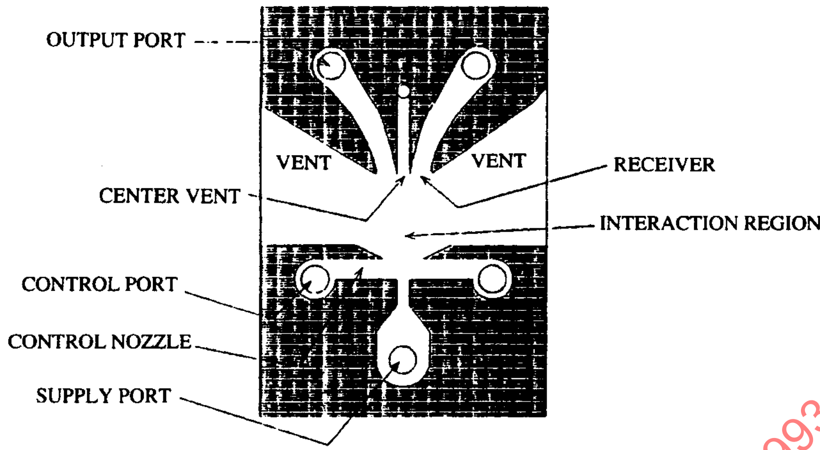

FIGURE 1 - Jet Interaction Amplifier

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2.2.1 (Continued):

ANALOG: The general class of devices or circuits whose output is a continuous function of its input; for example, a proportional amplifier.

DIGITAL: The general class of devices or circuits whose output is a discontinuous function of its input; for example, a bistable amplifier.

ACTIVE: The general class of devices which respond to a signal or signals separate from the fluid stream which powers the output.

PASSIVE: The general class of devices which operate on the signal inputs without the use of a separate power supply.

2.2.2 Amplifiers:

AMPLIFIER: An active fluidic component which provides a variation in output power greater than the impressed control signal variation. The polarity of the output may be either positive or negative relative to the control signal. The level (pressure or flow) of the control signal may be greater or less than the respective output levels.

PRESSURE AMPLIFIER: A component designed specifically for amplifying pressure signals, usually with high impedance output.

FLOW AMPLIFIER: A component designed specifically for amplifying flow signals, usually with low impedance output.

POWER AMPLIFIER: A component designed specifically for increasing signal power.

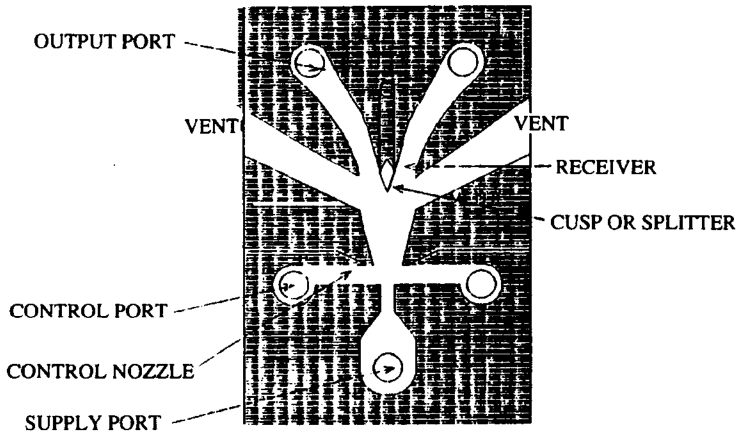

FIGURE 2 - Wall Attachment Amplifier

2.2.2 (Continued):

VENTS: Auxiliary ports used to establish a reference pressure in a particular region of the amplifier; analogous to an electrical ground potential.

JET INTERACTION AMPLIFIER: An amplifier which utilizes control jets to deflect a power jet and modulate the output, usually employed as an analog amplifier. Terminology usage for the geometry is illustrated in Figure 1.

WALL ATTACHMENT AMPLIFIER: An amplifier which utilizes control of the attachment of a free jet to a wall (Coanda effect) to modulate the output, usually employed as a digital amplifier. Terminology usage for the geometry is illustrated in Figure 2.

VORTEX AMPLIFIER: An amplifier which utilizes the pressure drop across a controlled vortex for modulating the output. Terminology usage for the geometry is illustrated in Figure 3.

TURBULENCE AMPLIFIER: An amplifier which utilizes control of the laminar-to-turbulent transition of a power jet to modulate the output. Terminology usage for the geometry is illustrated in Figure 4.

AXISYMMETRIC FOCUSED-JET AMPLIFIER: An amplifier which utilizes control of the attachment of an angular jet to an axisymmetric flow separator, (that is, control of the focus of the jet) to modulate the output. Usually employed as a digital amplifier. Terminology usage is illustrated in Figure 5.

IMPACT MODULATOR: An amplifier which utilizes the control of the intensity of two opposed, impacting power jets thereby controlling the position of the impact plane to modulate the output. Terminology usage is illustrated in Figure 6.

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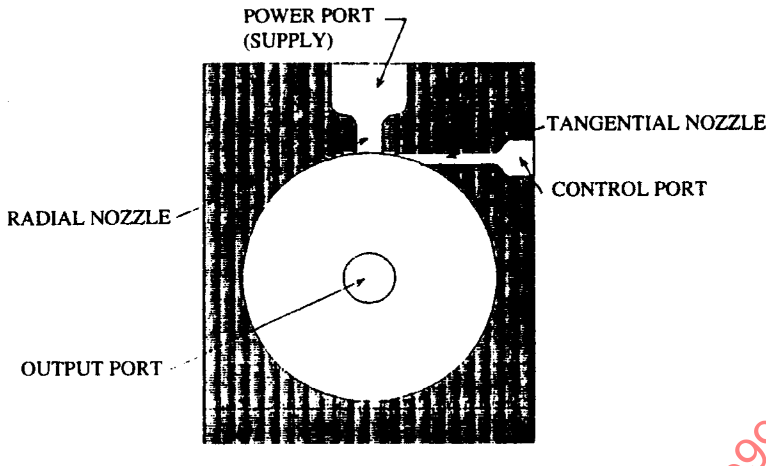

FIGURE 3 - Vortex Amplifier

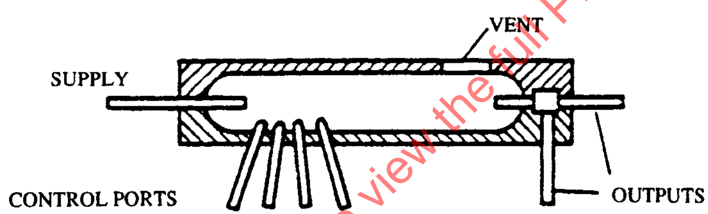

FIGURE 4 - Turbulence Amplifier

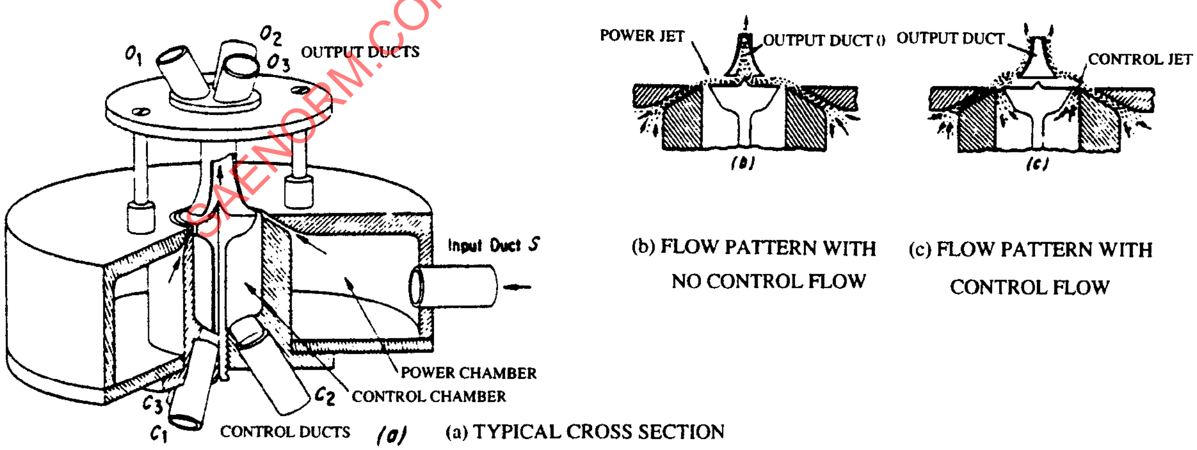

FIGURE 5 - Focused - Jet Amplifier

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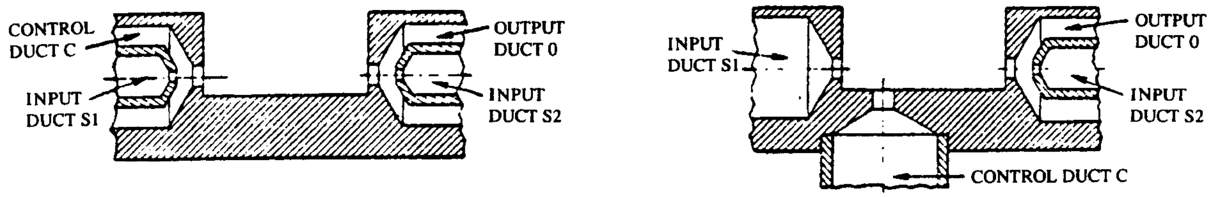

(a) DIRECT IMPACT MODULATOR (b) TRANSVERSE IMPACT MODULATOR

FIGURE 6 - Impact Modulators

2.2.2 (Continued):

THROAT-INJECTION AMPLIFIER: An amplifier which utilizes auxiliary flow at a nozzle throat for a control signal to modulate the output flow. Pressure level of the control signal may either be above or below local throat pressure to result in a positive of negative (suction) quiescent control flow.

LAMINAR FLOW AMPLIFIER: In this jet amplifier the nozzle Reynolds number is maintained at such a level that laminar flow conditions exist in the device.

FANOUT, HYSTERESIS LINEARITY, RESPONSE, SATURATION, SIGNAL/NOISE RATIO: Note: This terminology when related to fluidics has the same meaning as the generally accepted usage in other control fields. See Section 4 for definitions.

2.2.3 Transducers:

TRANSDUCER: A component which converts a signal from one medium to an equivalent signal in a second medium, one of which is compatible with fluidic devices, e.g., a pressure transducer generates an electrical output equivalent to pressure in a fluidic circuit.

2.2.4 Sensors:

SENSOR: A component which senses variables and produces a signal in a medium compatible with fluidic devices; for example, a temperature or angular rate sensor. Sensors are input transducers.

2.2.5 Actuators:

ACTUATOR: A component which converts fluid energy into an equivalent mechanical output. Displays are visual output transducers.

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2.2.6 Displays:

DISPLAY: A component which converts a fluid signal into an equivalent visual output. A type of output transducer.

2.2.7 Logic Devices:

LOGIC DEVICE: The general category of digital fluidic components which perform logic functions; for example AND, NOT, OR, NOR, and NAND. They can gate or inhibit signal transmission with the application, removal, or other combinations of control signals.

FLIP-FLOP: A digital component or circuit with two stable states and sufficient hysteresis so that it has "memory". Its state is changed with a control pulse; a continuous control signal is not necessary for it to remain in a given state.

2.2.8 Circuit Elements:

RESISTOR: Passive fluidic element which because of viscous losses or turbulent losses or both produces a pressure drop as a function of the flow through it and has a transfer function of essentially real components (i.e., negligible phase shift) over the frequency range of interest. See Section 4 for definition of fluidic resistance.

CAPACITOR: A passive fluidic element which, because of its own compliance or fluid compressibility, produces a pressure in the device which lags net flow into it by essentially 90°. See Section 4 for definition of fluidic capacitance. Note that fluidic capacitor cannot block steady flow in the way its electrical counterpart blocks DC.

INERTANCE: A passive fluidic element which, because of fluid inertia, has a pressure drop across it, which leads flow through it by essentially 90°. See Section 4 for definition of fluidic inertance.

FANOUT, HYSTERESIS, LINEARITY, RESPONSE, SATURATION, SIGNAL/NOISE RATIO: Note: This terminology when related to fluidics has the same meaning as the generally accepted usage in other control fields. See Section 4 for definitions.

2.2.9 Nomenclature and Units:

BASIC QUANTITIES: The quantities listed in Table 1 refer to the general parameters of a system or component. Wherever specific or detailed parameters are used, such as the pressure at point 2 subscripts should be used, e.g., P_2. In many instances, "customary" units have been listed alongside the pure units of the SI system. Frequently used conversion factors are provided in 2.2.9.2.

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TABLE 1 - Basic Quantities

TABLE 1A

Quantity	Symbol	SI Units	FLT (lb-in-s)
acceleration			
angular	α	rad/s	rad/s (°/s)
linear	a	m/s	in/s
angle	optional	rad(ian)	rad (°)
area	A	m^2	in^2
bulk-modulus	B	Pa $\frac{N}{m^2}$	$\frac{lb}{in^2}$
capacitance	C	$\frac{m^4-s^2}{Kg}, \frac{m^5}{N}$	$\frac{in^5}{lb}$
density (mass)	ρ	$\frac{Kg}{m^3}$	$\frac{lb-s^2}{in^4}$
Diameter	D	m	in
efficiency	η	dimensionless	
Force	F	N, $\frac{(Kg-m)}{s^2}$	lb
frequency	f	Hz	Hz
gain (overall = G) (incremental = G_i)			
volume flow	G_Q, G_{Qi}	dimensionless	
mass flow	G_M, G_{Mi}	dimensionless	
pressure	G_P, G_{Pi}		
gravitational constant	g	m/s^2	in/s^2
impedance	Z	$\frac{Kg}{m^4-s}, \frac{N-s}{m^5}$	$\frac{lb-s}{in^5}$
inertance	L	$\frac{Kg}{m^4}, \frac{N-s^2}{m^5}$	$\frac{lb-s^2}{in^5}$

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TABLE 1B

Quantity	Symbol	SI Units	English (lb-in-s)
LaPlace operator	s	1/s	1/s
length	l	m	in
Mach Number	N_M, M (=v/v_c)		dimensionless
mass	m	Kg	$\frac{lb-s^2}{in}$
mass flow rate	m	Kg/s	$\frac{lb-s}{in}$
power	W	J/s, $\frac{N-m}{s}$, Watts	in-lb/s
Prandtl Number	N_{PR}, PR (=c_p μ/k_t)		
pressure	P	N/m^2, Pa	lb/in^2, psi
static	P_s		
total	P_t		
absolute	P_a		
gage	P_g		
resistance	R	$\frac{N-s}{m^2-Kg}$, m^{-1}-s^{-1}	in^{-1}-s^{-1}
Reynolds Number	N_R, Re $\left(=\frac{\rho vD}{\mu}\right)$ dimensionless		
Signal to noise ratio	S/N dimensionless		
specific heat C		$\frac{J}{Kg-°K}$	$\frac{BTU}{lb-°R}$
const. volume	c_v		
const. pressure	c_p		
ratio	k=c_p/c_v dimensionless		
Stokes Number	N_{SK} dimensionless		

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TABLE 1B (Continued)

Quantity	Symbol	SI Units	English (lb-in-s)
Strouhal Number	N_S, S (=tv/l) dimensionless		
thermal conductivity	k_t	$\frac{Watt}{m-°K}$	$\frac{in-lb-}{in-s-°R}$
time	t	s	s
velocity			
general	v	m/s	in/s
mean	v	m/s	in/s
acoustic	v_c	m/s	in/s
viscosity			
absolute	μ	$\frac{Kg}{m-s}, \frac{N-s}{m^2}$	$\frac{lb-s}{in^2}$
kinematic	ν	m^2/s	in^2/s
volume	V	m^3	in^3
volume flow rate	Q	m^3/s	m^3/s

2.2.9.1 General Subscripts:

a. Control: c

(1) quiescent: co
(2) differential: cd

b. Incremental:

c. Output: o

(1) differential: od

d. Supply: s

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2.2.9.2 Conversion Factors and Constants: Conversion factors are listed such that exact conversion constants are given first, whenever such exist, i.e., 1 inch = 2.540000 cm. This practice permits exact conversion, wherever possible, to the precision of the computing device used.

1 Atmosphere = 101325 Pa = 14.696 psi_a
1 BTU = 9338.5 in-lb = 1055 Joules = 1.4148 HP-s
1 Bar = 10^5 Pa = 10^5 N/m^2 = 14.503 psi (lb/in^2)
1 gallon (US) = 231 in^3 = 3785.41×10^{-6} m^3
1 gravitational constant g = 386.088 in/s^2 = 9.80665 m/s^2
1 inch = 0.0254000 m 1 m = 39.37 in
1 Newton = 0.2248 lb_f
1 N-m (1 Joule) = 8.8504 in-lb_f = 0.0002388 Kcal = 0.0009478 BTU
1 Poise = 0.1 N-s/m^2 = 14.503×10^{-6} lb-s/in^2
R (Universal Gas constant)= 8309.2 J/Kg-mol-°K =
= 1544.3 ft-lb_f/lb_m-mol-°R
1 Stoke = 1 cm^2/s 1 cS (centistoke) = 1 mm^2/s = 0.00155000 in^2/s

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3. GRAPHIC SYMBOLOGY:

The purpose of graphic symbols is to enable the circuit designer to communicate in unambiguous terms with the user of his technology. The symbols are employed to convey the arrangement and function of circuit elements. They must transcend linguistic barriers which often impede verbal and written communications.

The recent developments in electronic logic and control circuitry have brought about a broadly based understanding of the logic functions, which was not available in the early days of the fluidic technology. The initial version of this document showed specific fluidic logic symbols. These functional symbols, both digital and analog, have been overtaken by the more general logic symbology denoting the functions of amplification, logic and control as represented by ANSI and IEEE standards. For this reason, the functional symbology of the previous ARP has been omitted in this edition.

The symbols shown in the following section are representative of the currently used operating principles and devices known today. Additional diagrams may be added to this listing at any time when new devices become prevalent and standardization appears to be in order.

Examples of typical operating circuits are shown. In actual practice, the circuit designer will use the nomenclature and units listed in 2.9 to define the impedance values and power levels of various components shown in the circuit diagram as necessary for the purpose intended. Thus, if a diagram is to convey simply a functional arrangement of components, no more than the circuit elements need be shown on the circuit drawing. If, however, the drawing is to denote a specific operating arrangement of parts, which is to be implemented by a manufacturer, then resistance, capacitance, and port impedance values can be added, or component model numbers can be specified on the drawing.

3. (Continued):

Fluidics frequently form a bridge between the electronic and fluid power technologies. Every effort has been made to use symbology commonly accepted and standardized for fluid power technology as well as for the electronic technology, for similar functions encountered in the fluidic technology.

The symbols listed in the following section denote normally accepted venting practice. This is analogous to the electrical ground connection (earth), or common signal ground. In special cases, the component vent may have to be connected to a different potential. This should then be clearly indicated by an appropriate resistance to ground, or another connection replacing the customary |____| symbol used in fluid power circuitry.

3.1 Functional Logic Symbols:

The symbols in Figure 7 are used to represent various logic elements in logic drawings. The letters A, B, C, and D are inputs; the letter Y is the output. The NOT operator is never used alone; it is always connected to the input or output of another logic element. An element that performs only the NOT operation is called an inverter. The symbol for an inverter is the triangle with the NOT circle at either the input or output.

3.2 Fluidic Circuit Components (See Figure 8):

Diagrams for "passive" pneumatic and hydraulic circuit elements generally follow the fluid power symbols performing similar functions. The distinction between laminar (linear) and orifice (square-law) resistances is of obvious importance in fluidic control circuits to preserve linearity of output and signal/noise ratio. The general symbol of fluid resistance taken over from fluid power nomenclature, does not specifically demand laminar flow.

The power supply symbol, while not a passive control element in the strict sense of the word, is included in this group of symbols also.

3.3 Typical Circuit Diagrams (See Figure 9):

The two diagrams shown in Figure 9 are typical of digital (logic) and proportional (control) circuits and include the input/output characteristics, the digital circuit in the form of a logic diagram and the analog circuit in the form of an amplitude versus log frequency plot. The latter may be expanded to an amplitude and phase versus log frequency plot (Bode Diagram).

3.4 Digital Fluidic Devices (See Figure 10):

Eight commonly encountered digital fluidic devices are diagrammed in Figure 10. Their logic (truth table) is shown where applicable, or their input/output characteristic is shown in the form of a time graph. Most fluidic devices require a vent or "ground" connection. These have been added to each symbol in this edition.

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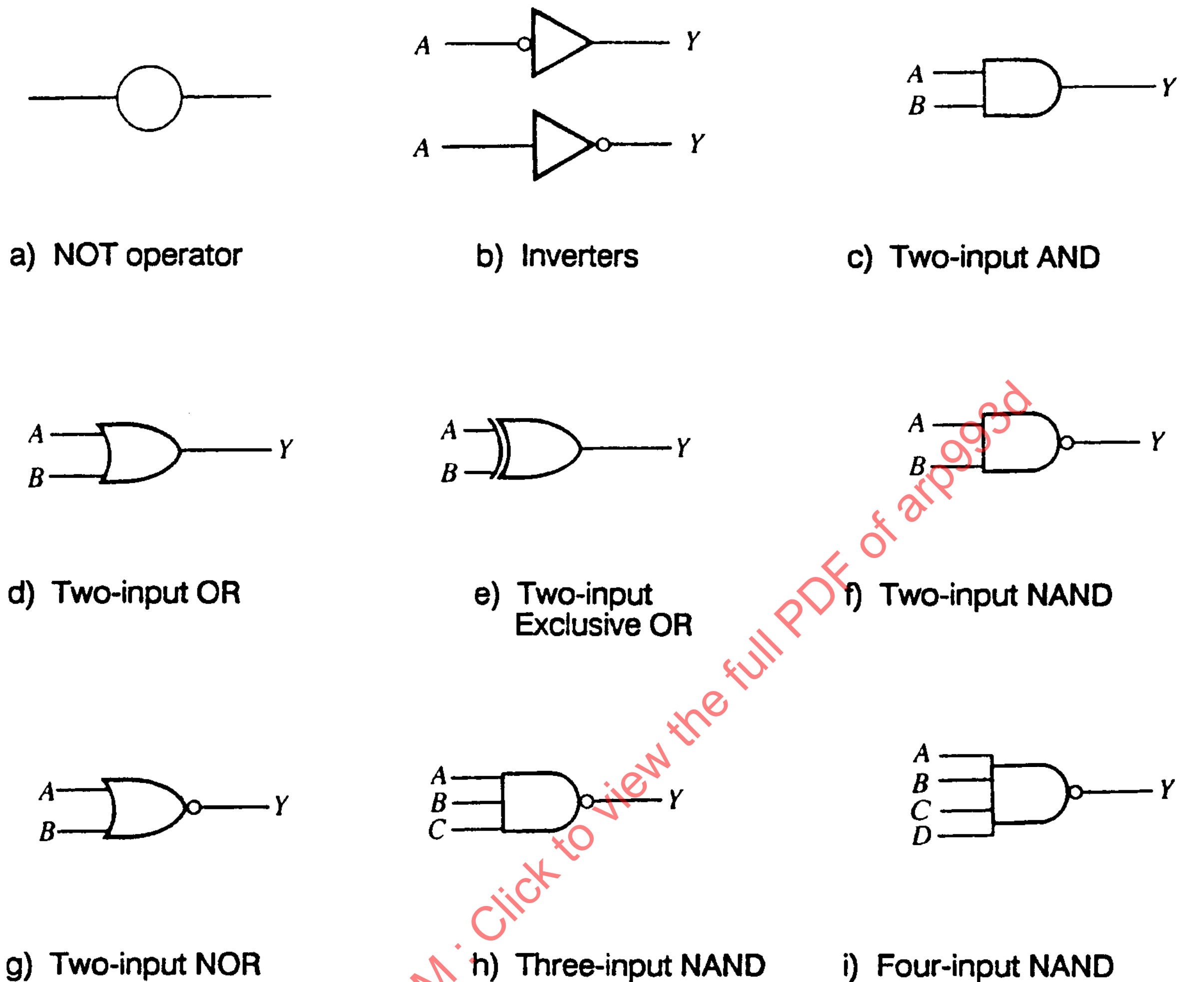

FIGURE 7 - Functional Logic Symbols

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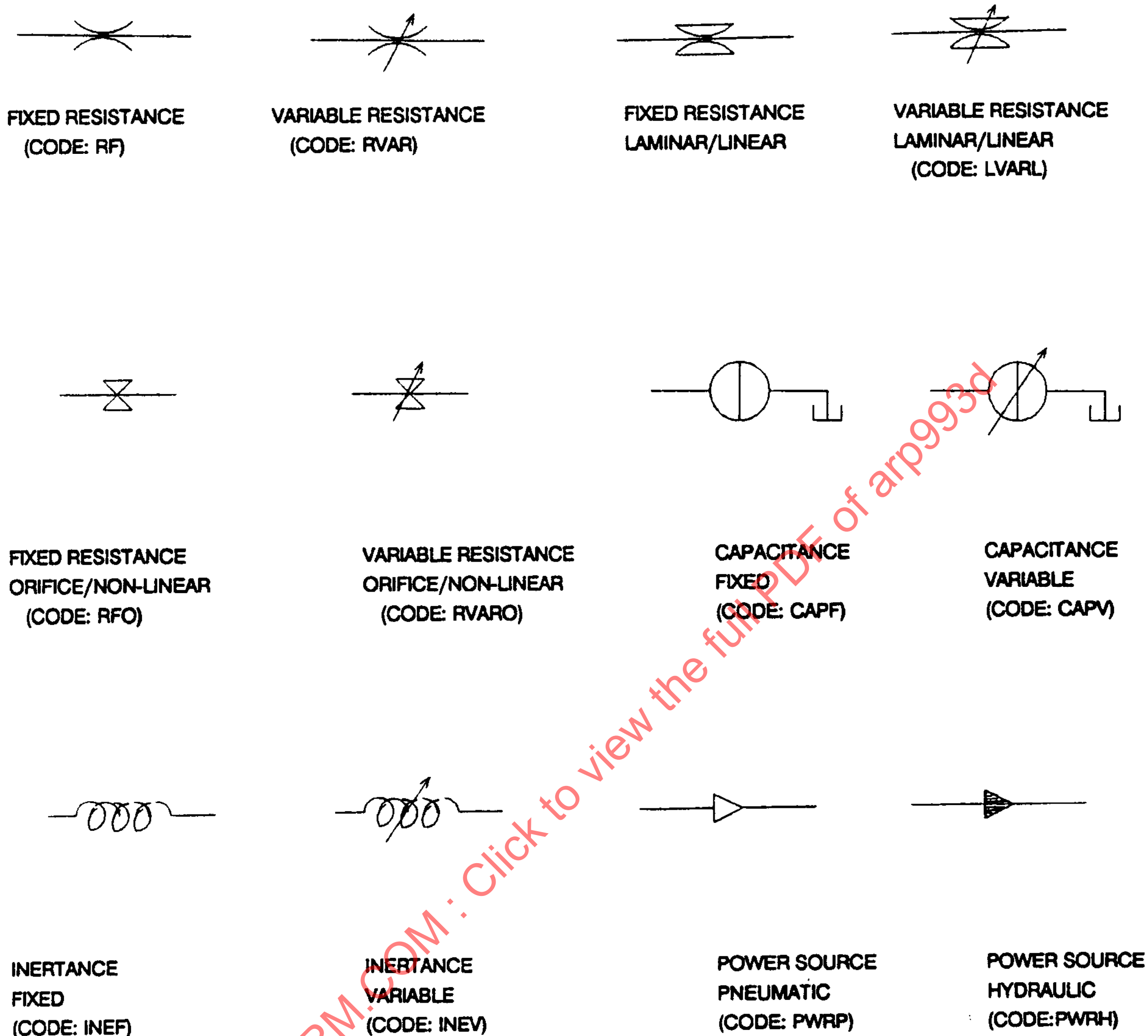

FIGURE 8 - Fluidic Circuit Components

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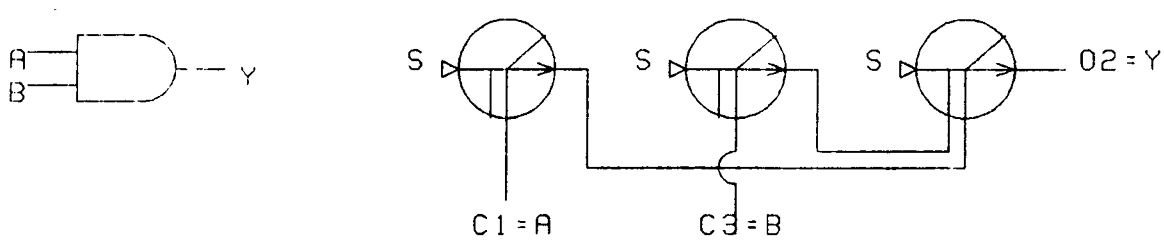
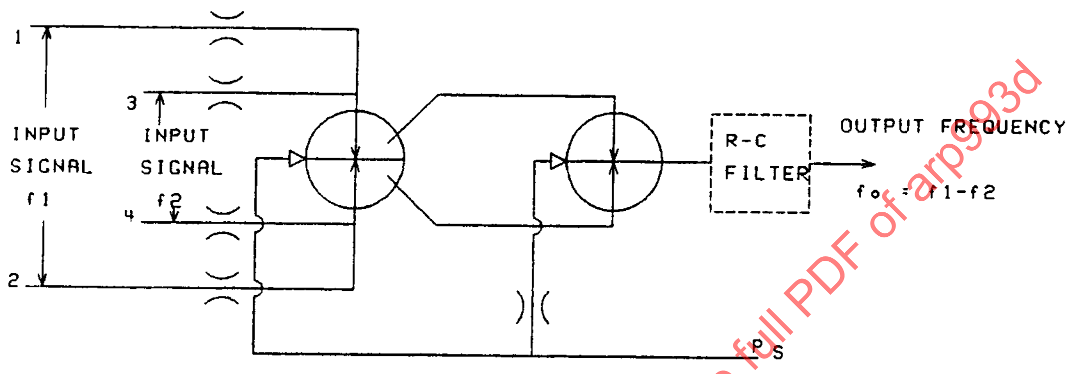
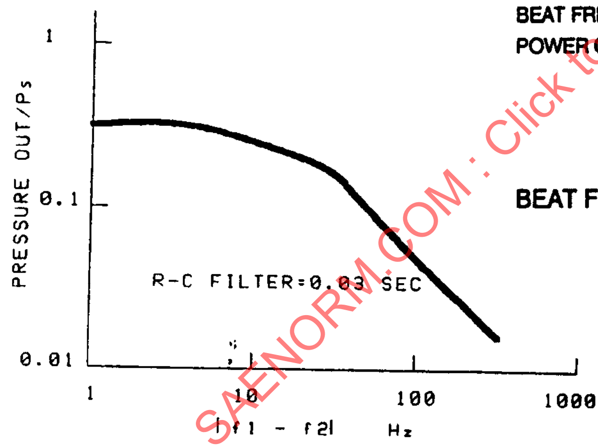




SUPPLY PRESSURE 0.2 - 0.7 BAR
INPUT FREQUENCIES , 3 KHz
BEAT FREQUENCY RANGE +/- 25% OF CENTER FREQUENCY
POWER CONSUMPTION 0.11 G/Sec AT 0.5 BAR



BEAT FREQUENCY DETECTOR CIRCUIT

FIGURE 9 - Typical Circuit Diagrams

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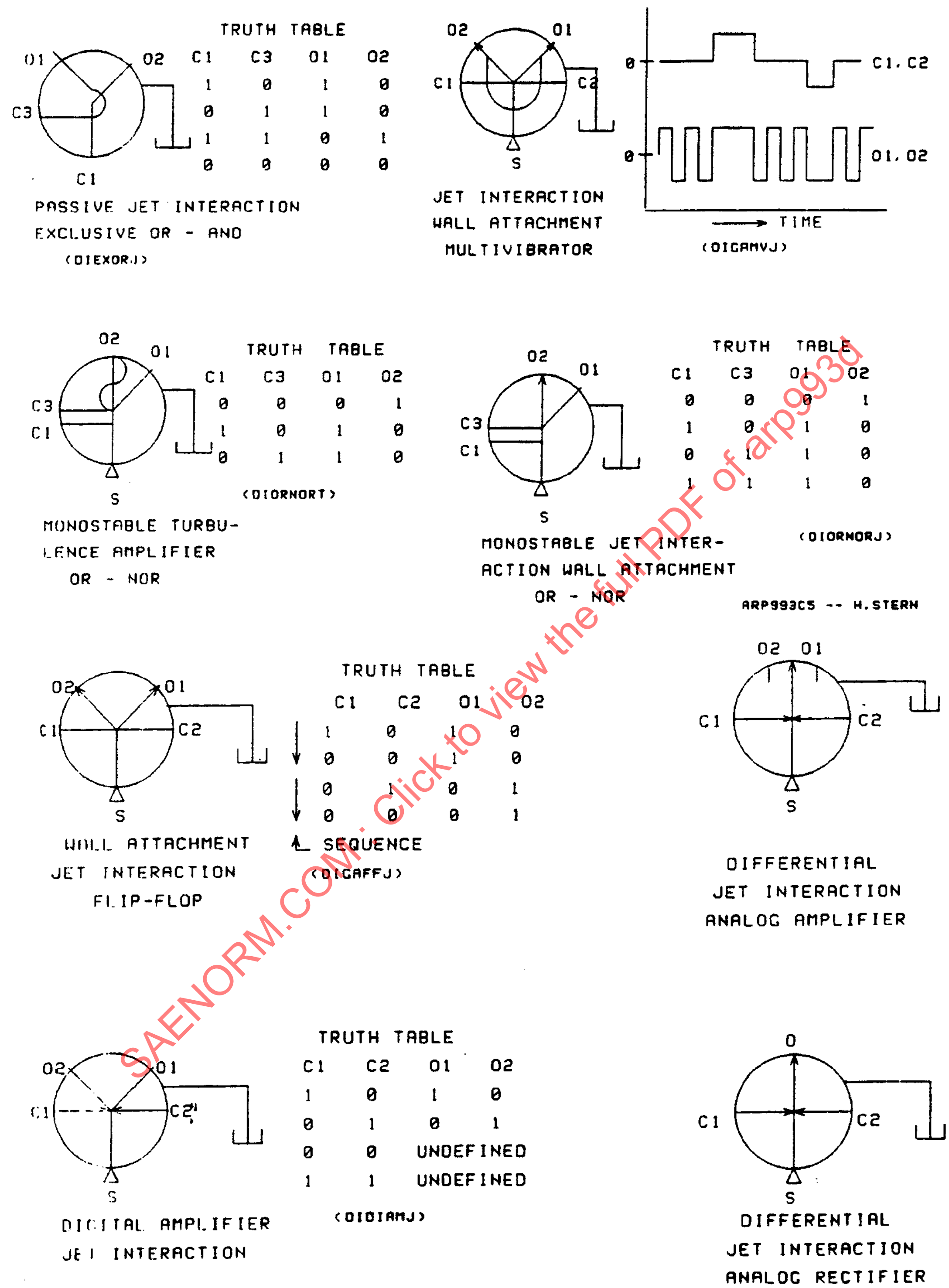

Passive jet interaction exclusive OR - AND, TRUTH TABLE:

C1	C3	O1	O2
1	0	1	0
0	1	1	0
1	1	0	1
0	0	0	0

Monostable turbulence amplifier OR - NOR, TRUTH TABLE:

C1	C3	O1	O2
0	0	0	1
1	0	1	0
0	1	1	0

Monostable jet interaction wall attachment OR - NOR, TRUTH TABLE:

C1	C3	O1	O2
0	0	0	1
1	0	1	0
0	1	1	0
1	1	1	0

Wall attachment jet interaction flip-flop, TRUTH TABLE:

C1	C2	O1	O2
1	0	1	0
0	0	1	0
0	1	0	1
0	0	0	1

Digital amplifier jet interaction, TRUTH TABLE:

C1	C2	O1	O2
1	0	1	0
0	1	0	1
0	0	UNDEFINED	
1	1	UNDEFINED	

FIGURE 10 - Digital Fluidic Devices

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3.5 Analog Fluidic Devices (See Figure 11):

Five analog fluidic devices have been diagrammed in Figure 11 together with their input/output curves. These symbols are generally applicable for either turbulent or laminar regime operation. When either one or the other operating mode is mandatory for circuit function, then specific symbology must be employed (see 3.6) to denote the type of flow regime required for the circuit.

3.6 Laminar Versus Turbulent Flow-Fluidic Devices (See Figure 12):

Whenever laminar or turbulent flow devices are not interchangeable in a fluidic circuit, then the special symbols shown in Figure 12 for turbulent and laminar flow nozzels must be used. This applies to both digital and analog circuit elements. In the absence of either symbol, flow in the element can be presumed to be turbulent.

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4. FLUIDIC DEFINITIONS:

4.1 General:

The analysis of fluidic systems utilizes the well established technology developed for electronic systems analysis. To do so, definitions of the fluidic equivalents of potential, current, resistance, inductance and capacitance are required. In fluidics, two possible sets of definitions are possible:

a. Option A:

(1) potential = pressure (i.e., energy per unit volume)
(2) current = volume flow (i.e., volume per unit time)
(3) so power (i.e., energy per unit time) = potential * current

b. Option B

(1) potential = energy per unit mass
(2) current = mass flow (i.e., mass per unit time)
(3) so power (i.e., energy per unit time) = potential * current

Option A has the advantage of using an easily measured parameter, pressure for fluidic potential. However, when volume flow is used for fluidic current in pneumatic systems, compressibility effects may cause the net steady current leaving a point in a circuit to be different from the net steady current entering, thus apparently contravening Kirchoff's law of current.

Option B overcomes this problem by the use of mass flow as fluidic current which must conform to Kirchoff's law, but it introduces the complication of using energy per unit mass to represent fluidic potential. In the case of pneumatic systems, energy per unit mass is represented by a temperature term, whereas with hydraulic systems it can be measured quite simply by pressure divided by the constant density. This situation leads either to the use of different definitions for pneumatic and hydraulic fluidic systems, or back to the use of pressure as fluidic potential.

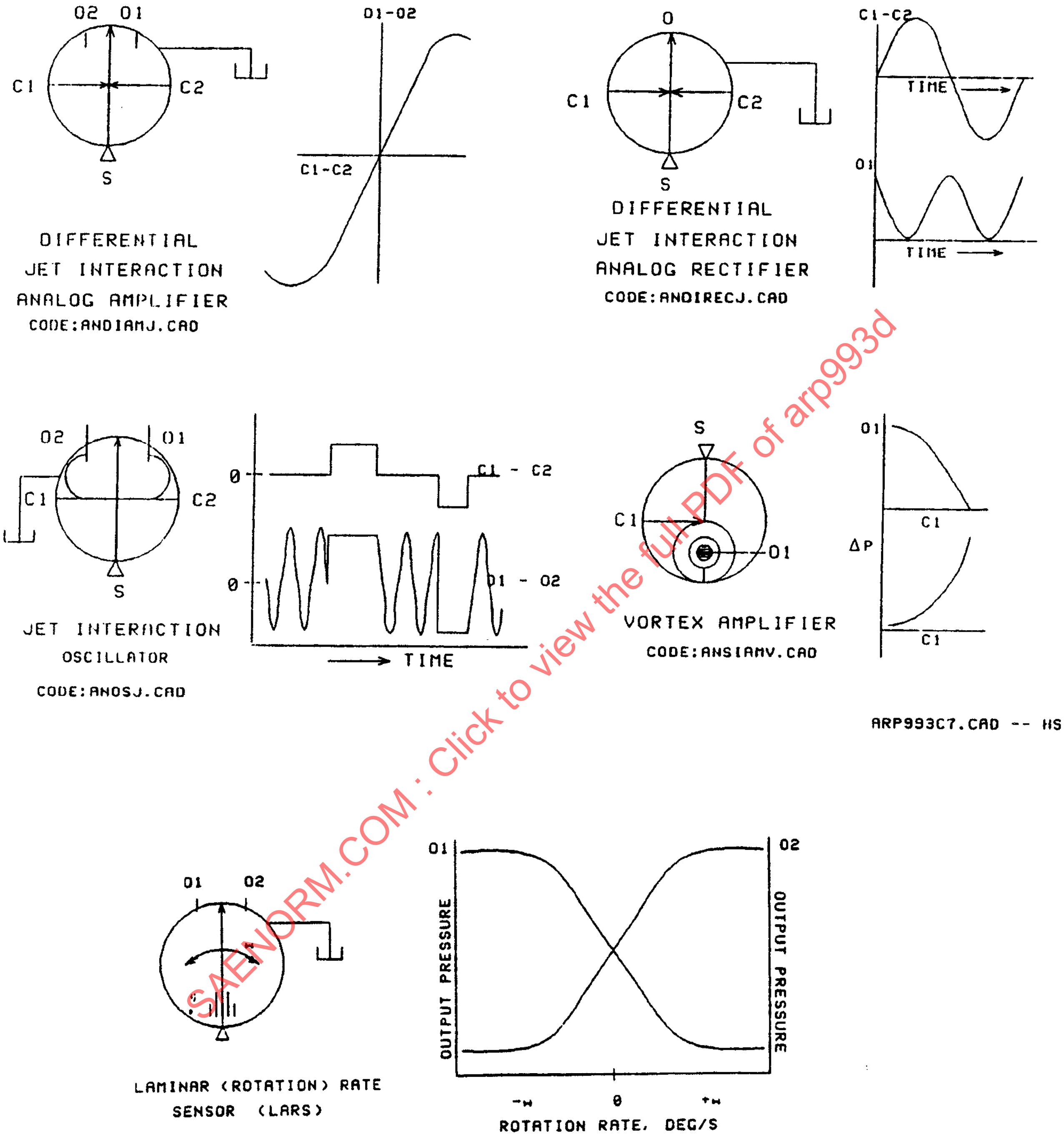

FIGURE 11 - Analog Fluidic Devices

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(IN ABSENCE OF SPECIFIC SYMBOL FLOW IS PRESUMED TURBULENT)

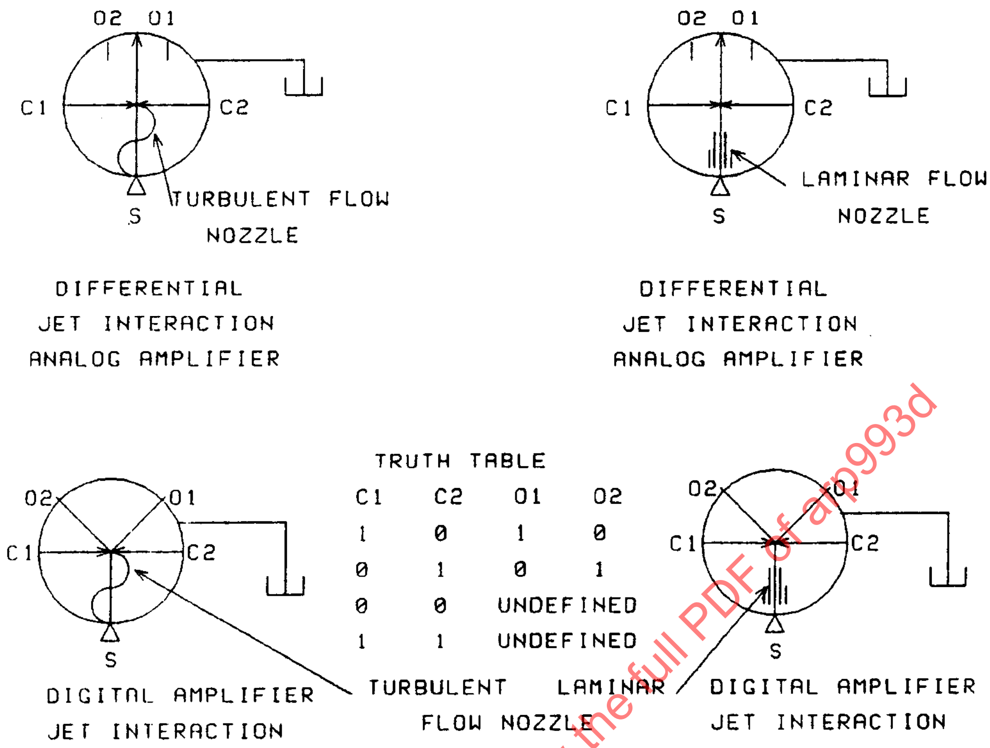

FIGURE 12 - Laminar Versus Turbulent Flow Fluidic Devices

4.1 (Continued):

Accordingly, it is recommended that option A be adopted as the basis for the definition of the fluidic equivalents of potential, current, resistance, inductance and capacitance. It should be noted that the fluidic equivalent of inductance is known as inertance, whereas the other terms may be used as they are. It should also be emphasized that the continuity equation (i.e., mass flow for a pneumatic system) must be applied when calculating fluidic current at any point.

4.1.1 Fluid Resistance (Equation 1): For average value, R is the ratio of pressure drop to volume flow rate entering the resistor. For incremental values, dP/dQ is used. The units are $Kg/(m^4s)$ or $Pa\text{-}s/m^3$.

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4.1.2 Fluid Capacitance (Equation 1): C is the ratio of the volume flow to the rate of change of pressure.

$$C = \frac{Q}{\frac{(dP)}{(dt)}} \text{ The units are } m^4s^2/Kg \text{ or } m^3/Pa \qquad \text{(Eq. 1)}$$

4.1.3 Fluid Inertance (Equation 2): L is the ratio of pressure difference to the rate of change of volume flow.

$$L = \frac{\Delta P}{\frac{(dQ)}{(dt)}} \text{ The units are } Kg/m^4 \text{ or } (Pa - s^2)/m^3 \qquad \text{(Eq. 2)}$$

4.1.4 Fluid Current (Flow): Q, is the volume of fluid per unit time passing an arbitrary cross section of a fluid conductor. It should be noted that in pneumatic systems, the net steady fluid current leaving an element in the circuit may differ from the net steady fluid current entering because of compressibility effects. The units are m^3/s.

4.2 Digital Elements:

4.2.1 Pressure Gain (Amplification): The ratio of output pressure change to control pressure change required for switching to occur. Data shall be taken in the vicinity of the operating point indicated by the reference column of Figure 13 and the load shall be specified.

4.2.2 Flow Gain (Amplification): The ratio of output flow change to control flow change required for switching to occur. Data shall be taken in the vicinity of the operating point indicated by the reference column of Figure 13 and the load shall be specified.

4.2.3 Power Gain (Amplification): The ratio of output power change to control power change required for switching to occur. Data shall be taken in the vicinity of the operating point indicated by the reference column of Figure 13 and the load shall be specified.

4.2.4 Fanout: The number of digital elements which can be controlled from the output of a single identical element operating at a common power nozzle supply pressure. It should be noted that fanout may be affected by operating speed (signal frequency).

4.2.5 Response: An indication of response characteristics is the propagation delay which occurs in response to the approximate step control of recommended amplitude. Propagation delay is the time between the instant the control step reaches 50% of the final value and the instant the output reaches 50% of the final value as illustrated in Figure 14. Load shall be specified if the response is load sensitive.

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FUNCTION ______________________________

TYPE ___________________________________ (Refer to appropriate figure)

CONFIGURATION _________________________

Performance Points (see *1)

PERFORMANCE (At Null)			I	II	III	IV	V
a) b)	Fluid Temperature		Air 294°K				
c)	Pres- sure Pa or Bar	Power Part 1 Power Part 2 Outlet Vent Control	1.6 Bar 1.8 Bar 1 Bar 1 Bar Bar				
d)	Flow Kg/s	Power Part 1 Power Part 2 Outlet Vent Control	4×10^{-4} 5×10^{-4} variable 10×10^{-4} max 1×10^{-4} max				
e)	Gain	Pressure Flow Power (see *4)	50 10 500				
f)	Ampli- fica- tion	Pressure Flow Power (see *3)	50 7 350				
g)		Fan-out (see *3)					
h)	Res- ponse	Frequency Response H_z @ z = 45° (see *2) or Propagation Delay (see *3)					
k)	Noise	Generated Amplitude Noise % of Pomax - Pomin					

*1 Refer to curve sheet *2 Proportional *3 Digital Devices *4 When the term Power Gain is used a definition shall be provided with it.

FIGURE 13 - Sample Performance Presentation Sheet

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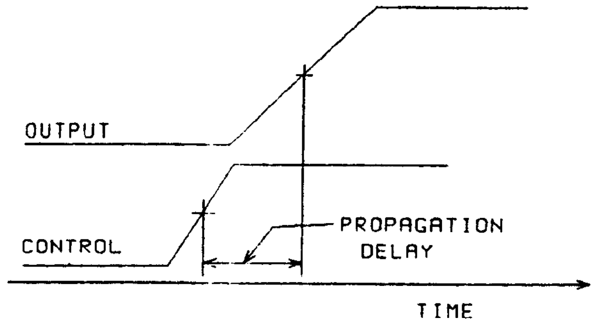

FIGURE 14 - Propagation Delay

4.2.6 Noise: The peak-to-peak amplitude of the pressure noise in the output shall be listed as a fraction of the output pressure difference between high and low states of the device.

4.2.7 Hysteresis: The difference between the value of the control parameter which will switch the element in one direction and that value of the control parameter which will switch it in the opposite direction. It is measured on a control output curve as in Figure 15 and is expressed as a percentage of the supply conditions, e.g., flow hysteresis is the width of the hysteresis loop divided by the supply flow. See Figure 15.

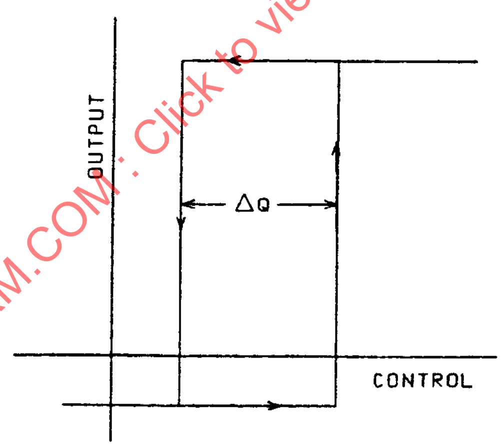

FIGURE 15 - Hysteresis $= \frac{\Delta Q}{\Delta_c} \times 100$

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4.2.8 Control Impedance: Z_C, is the ratio of control pressure change to flow change measured at a control port. The value depends on the operating point of the element since the control pressure/ flow curve may not be linear.

4.2.9 Output Impedance: Z_O, is the ratio of output pressure change to flow change measured at a output port. The value depends on the operating point of the element since the output pressure/flow curve may not be linear.

4.3 Proportional Elements:

4.3.1 Pressure Gain (Local): The slope of the curve of output pressure versus control pressure (see. Figure 16 in the vicinity of the operating point.

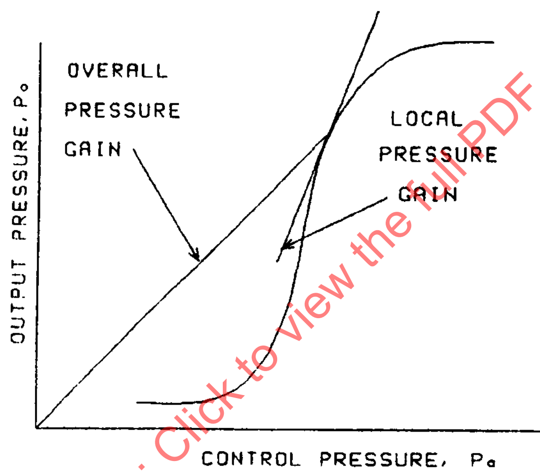

FIGURE 16 - Pressure Gain

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4.3.2 Flow Gain (Local): The slope of the curve of output flow versus control flow (see Figure 17) in the vicinity of the operating point.

4.3.3 Power Gain (Local): The slope of the curve of output power versus control power in the vicinity of the operating point. Power gain shall be calculated for small changes (less than 10% of saturation) of control power. See Note 4, Figure 13.

4.3.4 Pressure Gain (Overall): The slope of the line drawn between the operating point and the origin of the pressure gain curve (see Figure 16).

4.3.5 Flow Gain (Overall): The slope of the line drawn between the operating point and the origin of the flow gain curve (see Figure 17).

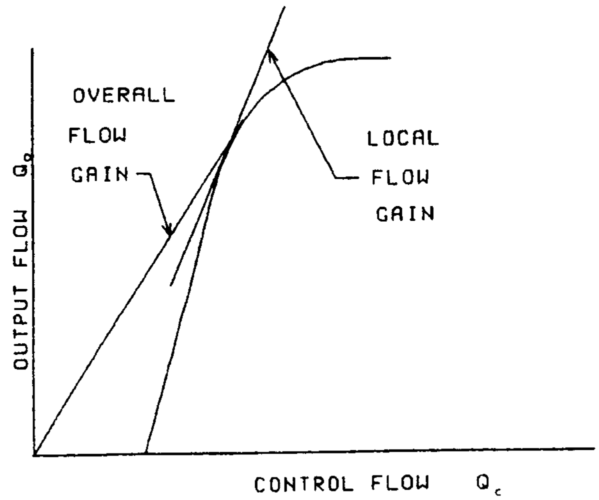

FIGURE 17 - Flow Gain

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4.3.6 Power Gain (Overall): The slope of the line drawn between the operating point and the origin of the power gain curve.

4.3.7 Frequency Response: This parameter is fully described by a gain/phase plot. An indication of the frequency response is that frequency at which the output lags the control signal by 45° for a specified load and control amplitude.

4.3.8 Noise: The peak-to-peak amplitude of the pressure noise of the device will be listed as a fraction of the pressure difference between maximum and minimum output at a specified load.

4.3.9 Saturation: The maximum output value regardless of the control magnitude (see Figure 18).

4.3.10 Linearity: The deviation of the measured gain curve from the straight line average gain approximation. It is defined as the ratio of the peak-to-peak output deviation to peak-to-peak output range, expressed as a percentage. Range shall be defined if other than maximum output level. See Figure 19.

4.3.11 Hysteresis: The total width of the hysteresis loop expressed as a percentage of the peak-to-peak saturation control signal. The measurement is to be made at frequencies below those where dynamic effects become significant in the device. See Figure 20.

NOTE: This definition differs from the hysteresis definition for digital elements.

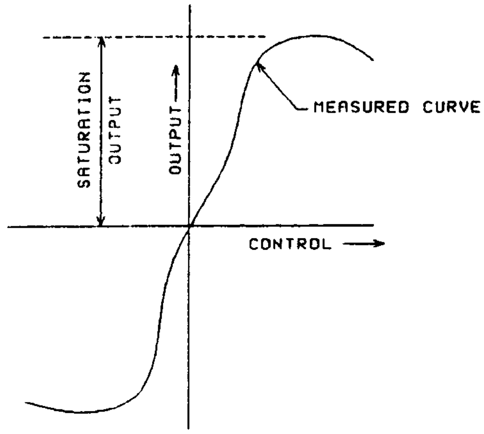

FIGURE 18 - Saturation

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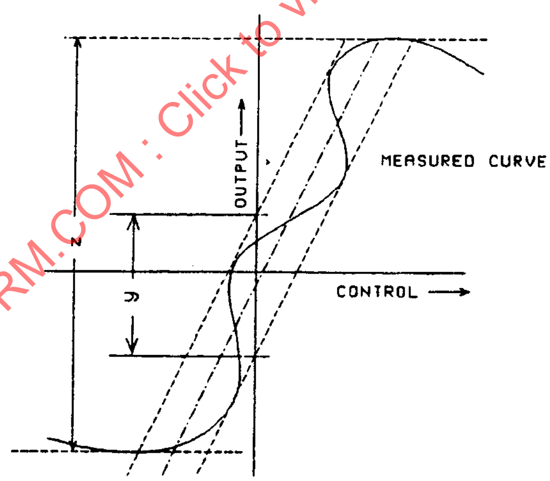

FIGURE 19 - Linearity

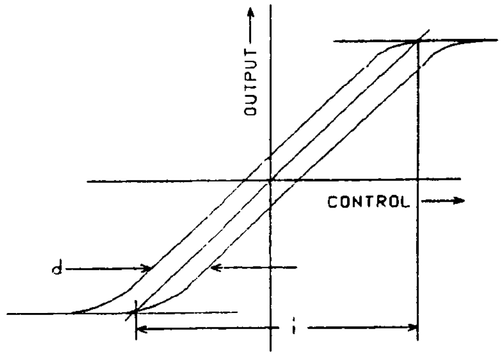

FIGURE 20 - Hysteresis in Proportional Elements

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4.3.12 Control Impedance: Z_C, is the ratio of pressure change to flow change measured at the control port. The numerical value may depend on the operating point since control pressure/flow curve may not be linear. See Figure 21. For active elements the power source should be connected at the time of measurement.

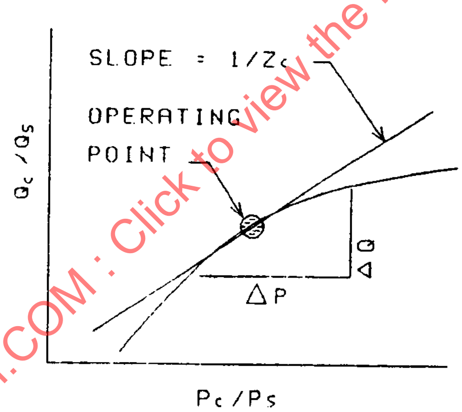

FIGURE 21 - Control Impedance

4.3.13 Output Impedance: Z_O, is the ratio of pressure change to flow change measured at the output port of the element. The numerical value may depend on the operating point since the output pressure/ flow curve may not be linear. See Figure 22.