LAND SEA AIR SPACE

Society of Automotive Engineers, Inc.

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AEROSPACE RECOMMENDED PRACTICE

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FLUIDIC TECHNOLOGY

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PREPARED BY THE FLUIDICS PANEL OF
SUBCOMMITTEE A-6D, FLUID POWER UTILIZATION,
OF COMMITTEE A-6, AEROSPACE FLUID POWER & CONTROL TECHNOLOGIES

REAFFIRMED
7-'92

1. INTRODUCTION

1.1 PREFACE

The following document represents a first attempt to establish a set of standards in the rapidly advancing technological field of fluidics. It is the hope of the Fluidics Panel of the SAE Committee A-6 - Aerospace Fluid Power Technologies that this document reflects currently accepted practice in the industry and governmental agencies concerned with the design, fabrication and use of fluidic devices and systems.

The term fluidics has here been applied to the fluid logic, amplification, and control field employing no-moving-part (flueric) devices and to those peripheral moving part elements such as valves, actuators, switches, and push buttons which are directly connected with the flueric elements in the system.

The content of this document is considered incomplete and is expected to be expanded and revised on a continuing basis as the growing 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 preliminary guideline to the types of parameters which have so far been found of importance. Similarly, it is difficult to establish test procedures in a new field where wide variations in devices exist, where new devices of a highly proprietary nature are continually being added, and where the newness of the technology itself has not permitted performance standards to settle out.

It is therefore hoped that this document will become a starting point for standard practices rather than a fixed platform in the fluidics field. It is requested that its users will freely contribute to its subsequent changes and additions by their comments, suggestions, and criticism.

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

1.3 SCOPE

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

2. TERMINOLOGY

2.1 General

FLUIDICS - The general field of fluid devices or 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 proportioned amplifier or an OR-NOR logic gate. These are the least "common denominators" of the fluidics technology.

ANALOG - The general class of devices or circuits whose output is utilized as a continuous function of its control port; for example, a proportional amplifier.

DIGITAL - The general class of devices or circuits whose output is utilized as a discontinuous function of its control port; for example, a bistable amplifier.

ACTIVE - The general class of devices which control power from a separate supply.

PASSIVE - The general class of devices which operate on the signal power alone.

2.2 Amplifiers

AMPLIFIER - An active fluidic component which provides a variation in output signal greater than the impressed control signal variation. The polarity of the output signal may be either positive or negative relative to the control signal. The level of the control signal may be greater or less than the output level.

PRESSURE AMPLIFIER - A component designed specifically for amplifying pressure signals.

FLOW AMPLIFIER - A component designed specifically for amplifying flow signals.

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

VENTED VS. CLOSED AMPLIFIER - A vented amplifier utilizes auxiliary ports to establish a reference pressure in a particular region of the amplifier geometry. A closed amplifier has no communication with an independent reference. Terminology usage for the geometry is illustrated in Figure 2.1(a) and 2.1(b)

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 2.1(a) and 2.1 (b).

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 2.2.

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 2.3.

BOUNDARY LAYER AMPLIFIER - An amplifier which utilizes the control of the separation point of a power stream from a curved or plane surface to modulate the output. Terminology usage for the geometry is illustrated in Figure 2.4.

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 2.5.

AXISYMMETRIC FOCUSSED-JET AMPLIFIER - An amplifier which utilizes control of the attachment of an annular 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 2.6.

IMPACT MODULATOR - An amplifier which utilizes the control of the intensity of two directly opposed, impacting power jets thereby controlling the position of the impact plane to modulate the output. Terminology usage is illustrated in Figure 2.7.

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 or negative (suction) quiescent control flow.

2.3 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.

2.4 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.

2.5 Actuators

ACTUATOR - A component which converts a fluid signal into an equivalent mechanical output.

2.6 Displays

DISPLAY - A component which converts a fluid signal into an equivalent visual output.

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.

2.8 Circuit Elements

RESISTOR - Passive fluidic element which because of viscous losses 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 fluid compressibility, produces a pressure across the device which lags net flow into it by essentially 90 deg. See section 4. for definition of fluidic capacitance.

INDUCTOR - A passive fluidic element which, because of fluid inertance, has a pressure drop across it which leads flow through it by essentially 90 degrees. See section 4. for definition of fluidic inductance.

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

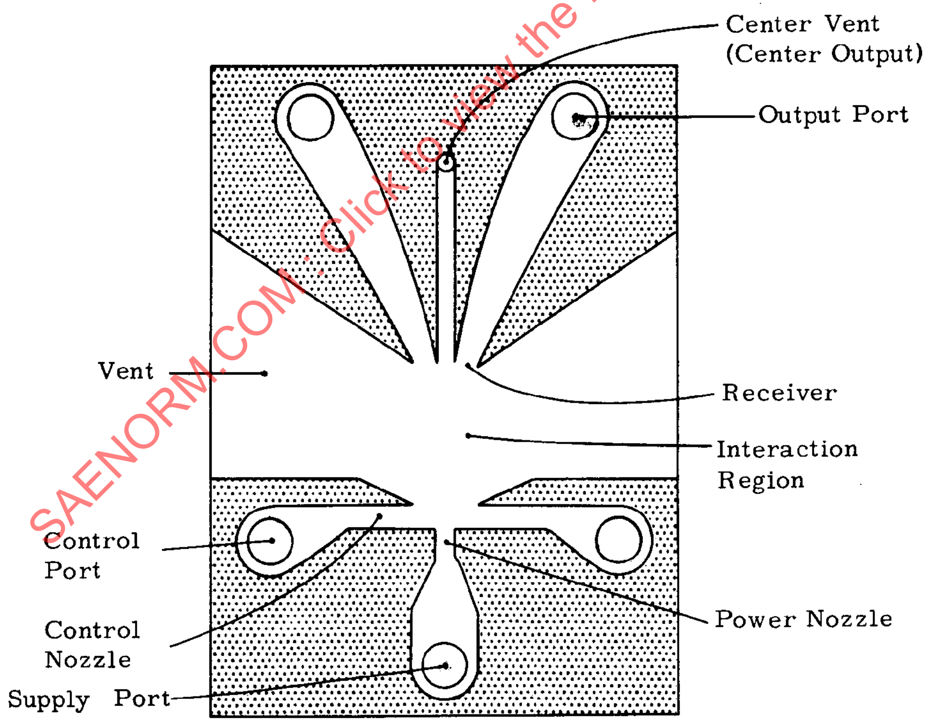


Figure 2.1(a) Vented Interaction Amplifier.

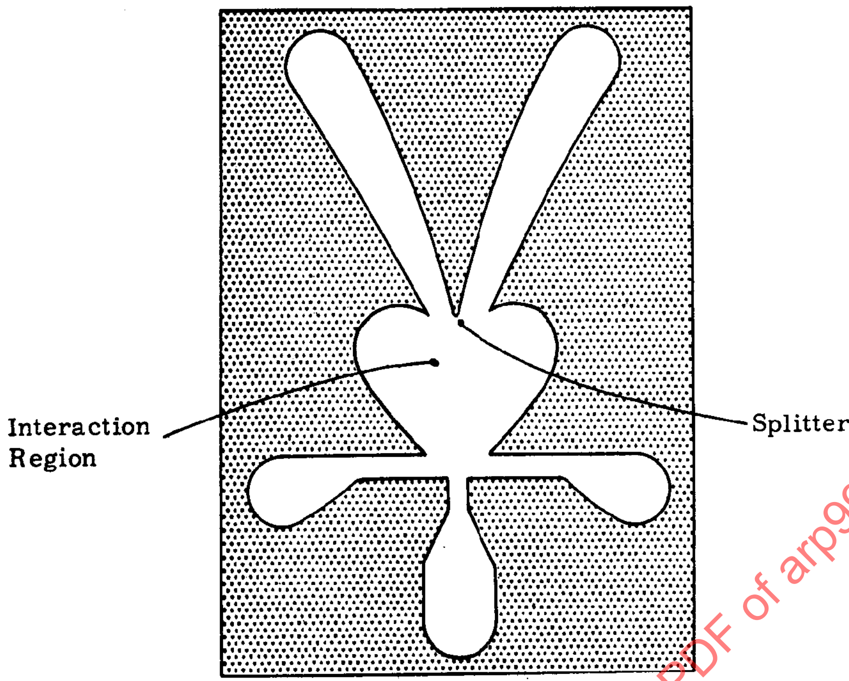


Figure 2. 1(b) Closed Jet Interaction Amplifier.

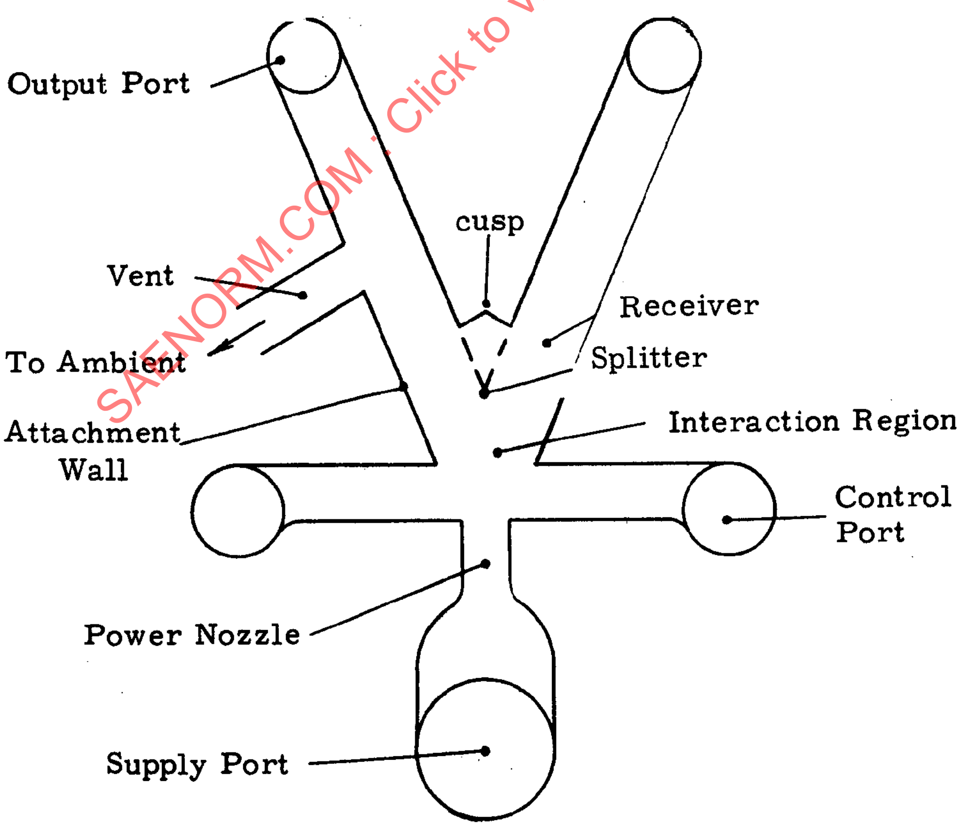


Figure 2. 2 Wall Attachment Amplifier

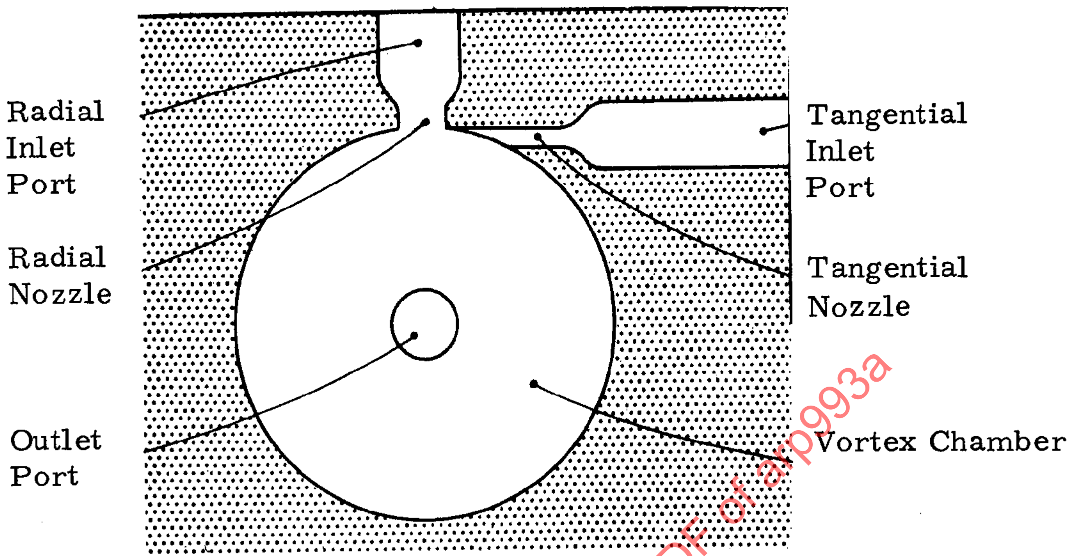


Figure 2. 3 Vortex Amplifier

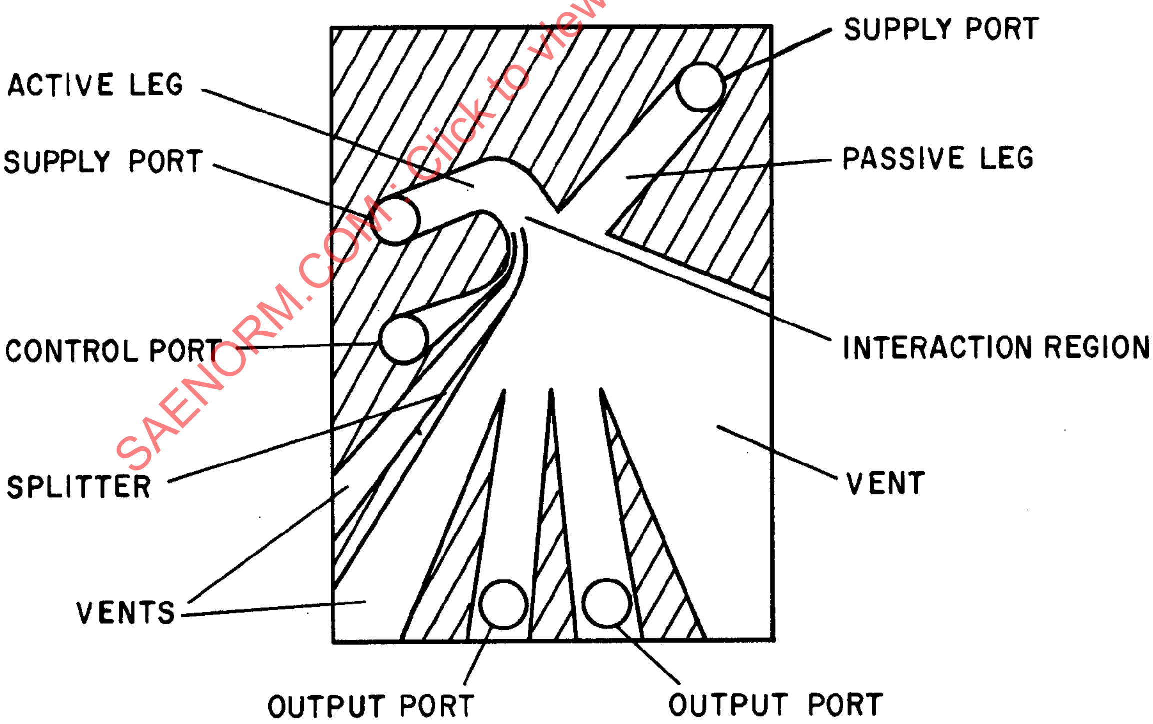


Figure 2. 4 Boundary Layer Control Amplifier (Vents Optional)

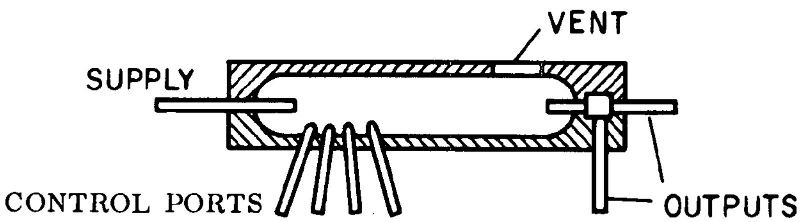
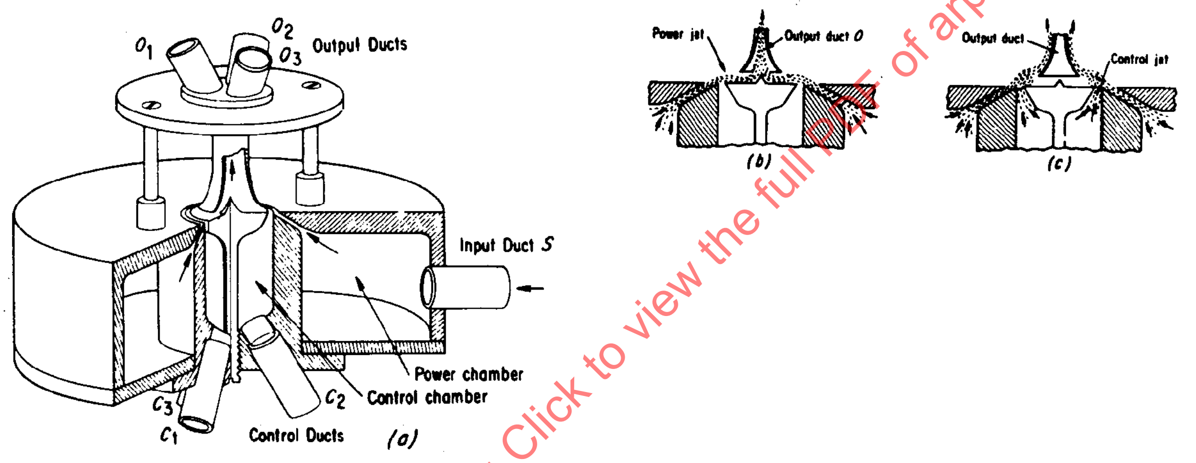


Figure 2.5 Turbulence Amplifier



Focused-jet amplifier: Typical cross section, a. Flow pattern with no control flow, b. Flow pattern with control flow, c.

Figure 2. 6

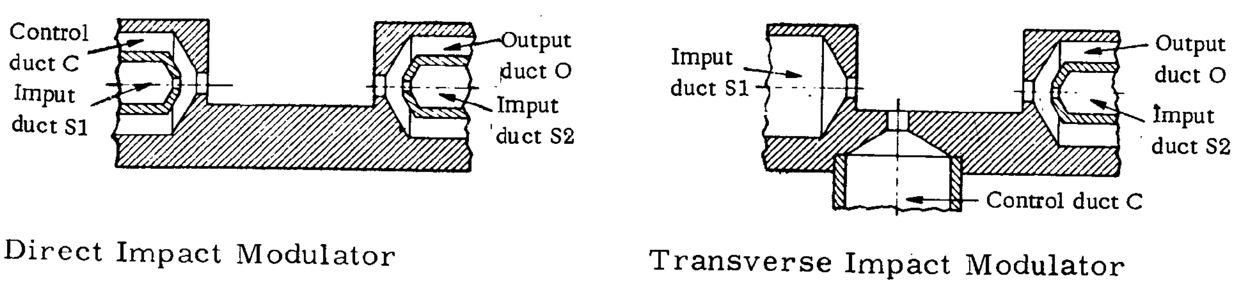


Figure 2. 7 Impact Modulator

2.9 Nomenclature and Units

2.9.1 Basic Quantities

The quantities listed below are general; specific quantities should be identified by subscripts (e.g., P_{02} would be pressure at port 02).

Quantity	Nomenclature	Units (std)	Units (SI)*
Length	--	inch; in	(meter, m)
Force	F	pound, lb	(newton; N)
Mass	m	$lb\text{-}sec^2/in$	(kilogram; kg)
time	t	seconds; sec	(seconds; s)
angle	--	degrees; ^{o}	(radians; rad)
frequency	f	cycles/sec; cps	(hertz; H_z)
area	A	in^2	(m^2)
acceleration	a	in/sec^2	(m/s^2)
gravitational constant	g	in/sec^2	(m/s^2)
temperature, static	T	degrees Rankin; ^oR	(degrees Kelvin; ^oK)
temperature, total	T_o	^oR	^oK
velocity, angular	ω	rad/sec	(rad/s)
acceleration, angular	α	rad/sec^2	(rad/s^2)
volume	V	in^3	(m^3)
weight density	γ	lb/in^3	(N/m^3)
mass density	ρ	$lb\text{-}sec^2/in^4$	(kg/m^3)
weight flow rate	w	lb/sec	(N/s)

*System International Units

Quantity	Nomenclature	Units		
mass flow rate	$\dot{m}$	lb-sec/in	(kg/s)	
volume flow rate	Q	in^3/sec	(m^3/s)	
velocity, general	u	in/sec	(m/s)	
velocity, mean	$\bar{u}$	in/sec	(m/s)	
velocity, acoustic	u_c	in/sec	(m/s)	
pressure, general	P	lb/in^2 or psi	(N/m^2)	
pressure, absolute	P_a	psia	(N/m^2)	
pressure, gage or drop	P_g	psig	(N/m^2)	
power	W	lb in/sec	(Nm/s)	
specific heat ratio	k	dimensionless		
absolute viscosity	μ	lb-sec/in^2	(N-s/m^2)	
kinematic viscosity	ν	in^2/sec	(m^2/s)	
liquid bulk modulus	β	lb/in^2	(N/m^2)	
efficiency	η	dimensionless		
fluid impedance	Z	sec/in^2	(N-s/m^2-kg)	See Section 4. for definitions
fluid resistance	R	sec/in^2	(N-s/m^2-kg)	
fluid capacitance	C	in^2	(kg-m^2/N)	
fluid inductance	L	sec^2/in^2	(N-s^2/kg-m^2)	
Mach number	M	dimensionless		
Laplace operator	s	1/sec	(1/s)	
pressure gain	G_P	dimensionless		
flow gain, average	G_F	dimensionless		

Quantity	Nomenclature	Units
flow gain, incremental	G_{Fi}	dimensionless
power gain, average	G_P	dimensionless
power gain, incremental	G_{Pi}	dimensionless
signal - noise ratio	S/N	dimensionless

2.9.2 General Subscripts

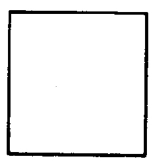
control	c
output	o
supply	s
control, quiescent	co
control differential	cd
output differential	od

3. GRAPHICAL SYMBOLOGY

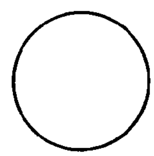
The purpose of the graphic symbols is to enable the circuit designer to employ meaningful and specific symbols in drawings and schematics which will clearly define the function or type of device employed to perform that function.

In the course of preparing this document, it was recognized that fluidic symbols were required to satisfy two basic needs. The first was the need of the system designer interested primarily in the function of the device. The second was the circuit designer primarily interested in the operating principle of the device.

The following is an integrated set of symbology which satisfies both requirements. Functions of the devices are defined by symbols enclosed within square envelopes. Operating principles of the devices are defined by symbols enclosed within round envelopes. The difference in envelopes is specifically intended to emphasize the difference in purpose of the symbols as shown below:



Functional Symbol



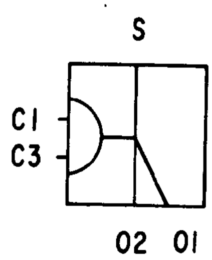
Operating Principle Symbol

By definition, the symbols are intended to show the following:

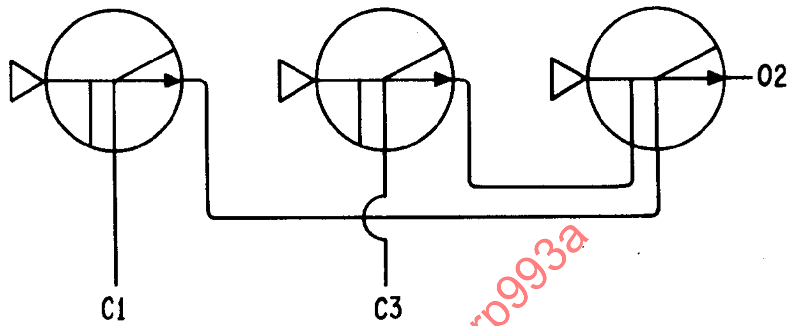
- Functional symbol – Depicts a function which may be performed by a single fluidic element or by an interconnected circuit containing multiple elements.
- Operating principle symbol - Depicts the fluid phenomena in the interaction region which is employed to perform the function as well as the function of the fluidic element.

In the cases where no operating principle is shown, it is implied that, at present, no single operating principle or interaction region is adequate to perform the function. In these cases a combination of operating principles or interaction regions is required to represent the function.

To further emphasize this point, consider the case of a 2-input AND made up from OR-NORs as follows:



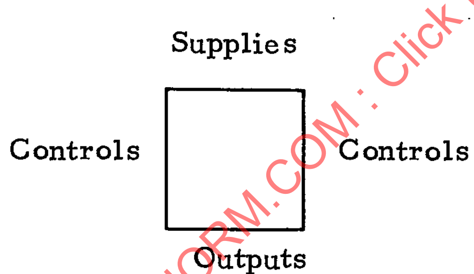
Functional
Symbol

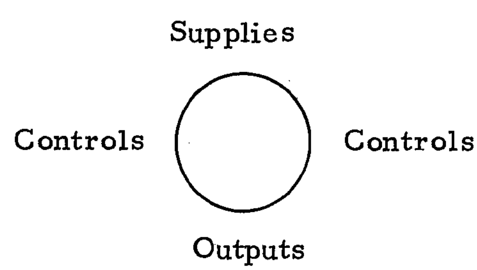


Interconnection of
Operating Principle Symbols

3.1 General Conventions

3.1.1 The relative port locations for the symbols are patterned in the following manner:





All symbols may be oriented in 90-degree increments from the position shown.

3.1.2 Specific ports are identified by the following nomenclature:

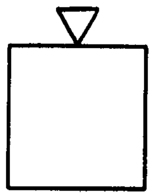
Supply port - S

Control port - C

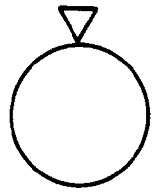
Output port - O

The nomenclature shown on the graphic symbols need not be used on schematic diagrams. It is primarily intended to correlate the function of each port with the truth table.

3.1.3 Supply ports can be either active or passive. An inverted triangle, ∇, denotes a supply source connected to the supply port (active device).



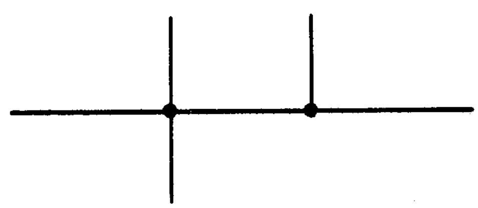
Active Devices



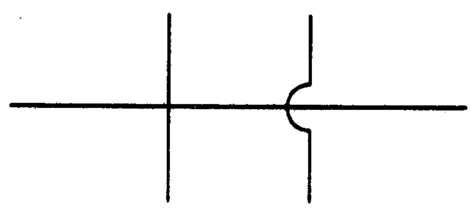
3.1.4 An arrowhead on the control line inside the symbol envelope indicates continual flow is required to maintain state (no memory, no hysteresis):

Indicates no memory

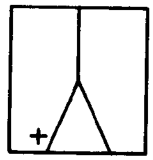
3.1.5 (a) Interconnecting fluid lines shall be shown with a dot at the point of interconnection:

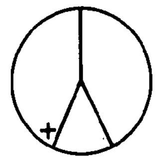


(b) Crossing fluid lines are to be shown without dots:



3.1.6 A small + on the output of a bistable device indicates initial or start-up flow condition.





3.1.7 Logic Notation

A . B ≡ A "and" B

A + B ≡ A "or" B

$\overline{A}$. $\overline{B}$ ≡ "not" A and "not" B

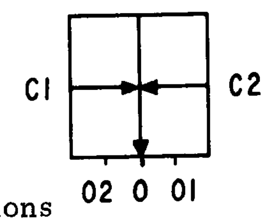
3.1.8 Port Marking

Port nomenclature shown on schematics need not be used on schematic diagrams; the nomenclature may be useful, however, in correlating test data and specification data with the physical device.

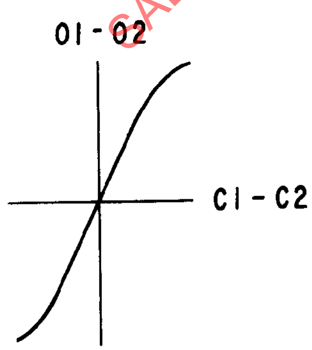
3.2 Analog Fluidic Devices

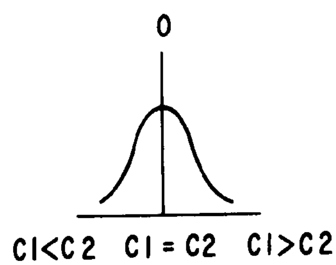
3.2.1 Proportional Amplifiers

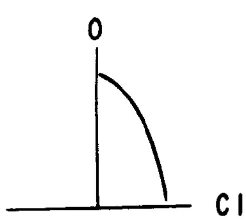
Functional Symbol

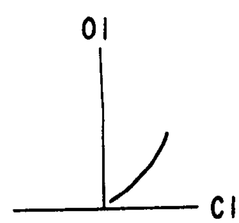


Functions

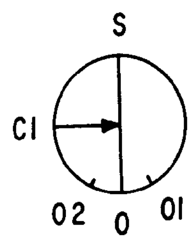




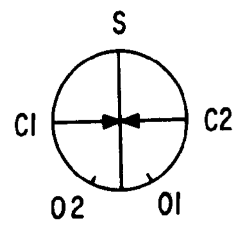




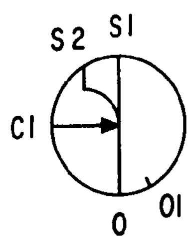
Operating Principle Symbols



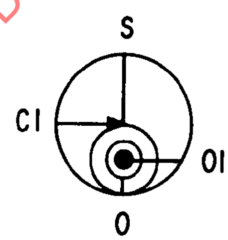
Single Input
Jet Interaction



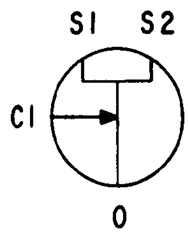
Differential
Jet Interaction



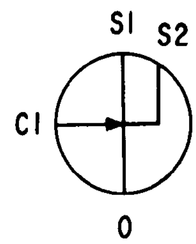
Separation
Point Control



Vortex



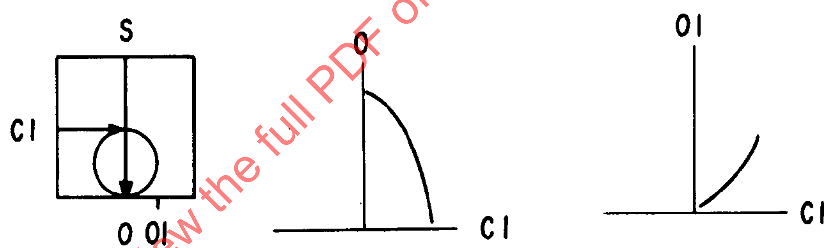
Transverse
Impact Modulator



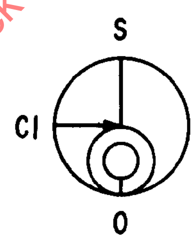
Direct
Impact Modulator

3.2.2 Throttling Valve

Functional Symbol



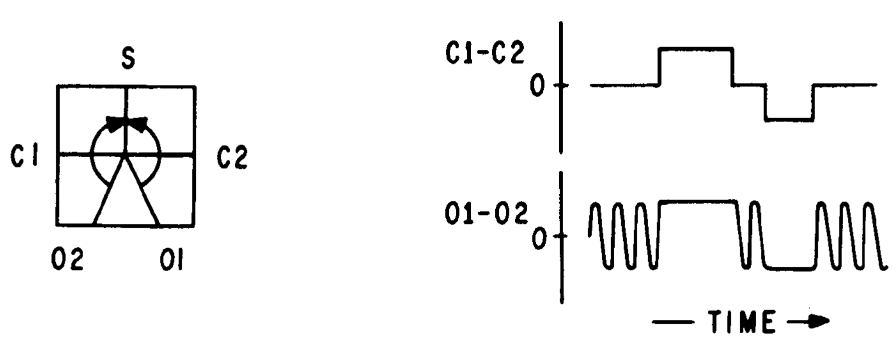
Operating Principle Symbol



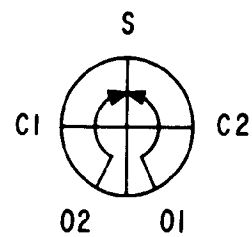
Vortex

3.2.3 Oscillator (Sine Wave)

Functional Symbol

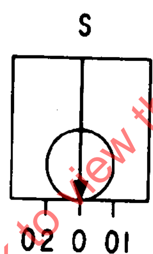


Operating Principle Symbol

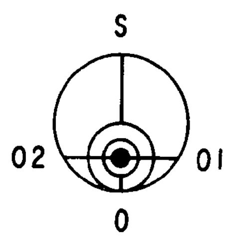


3.2.4 Rate Sensor

Functional Symbol



Operating Principle Symbol

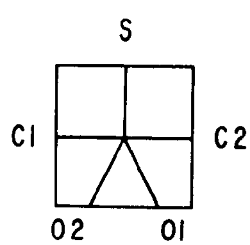


Vortex

3.3 Bistable Digital Devices

3.3.1 Flip Flop

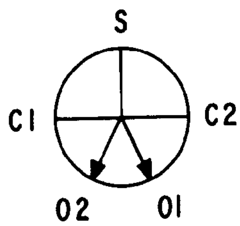
Functional Symbol



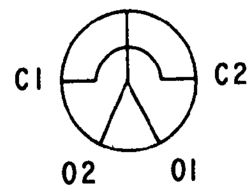
Truth Table

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

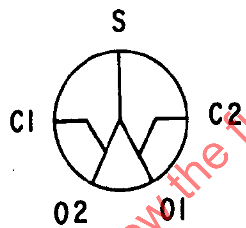
Operating Principle Symbols



Wall Attachment



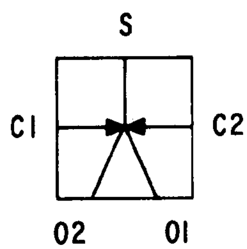
Edgetone



Induction

3.3.2 Digital Amplifier

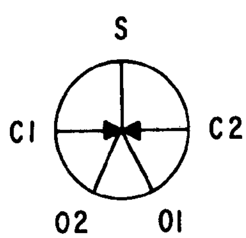
Functional Symbol



Truth Table

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

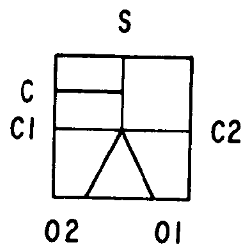
Operating Principle Symbol



Jet Interaction

3.3.3 Binary Counter

Functional Symbol

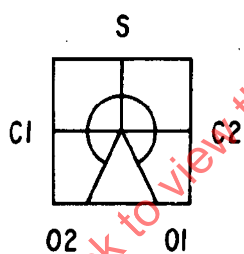


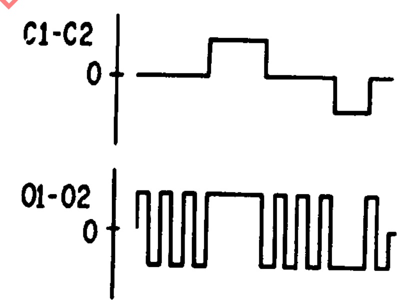
Truth Table

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

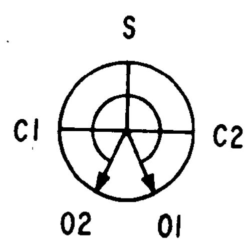
3.3.4 Multivibrator

Functional Symbol





Operating Principle Symbol

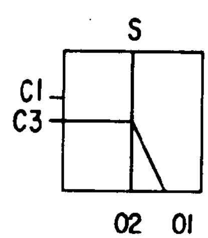


Wall Attachment

3.4 Monostable Digital Devices

3.4.1 OR-NOR

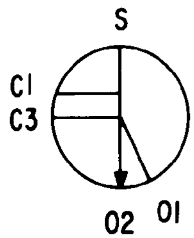
Functional Symbol



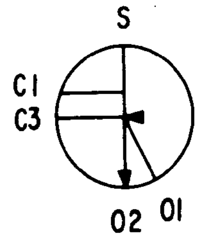
Truth Table

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

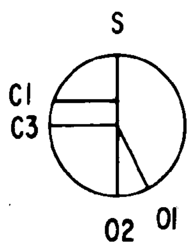
Operating Principle Symbols



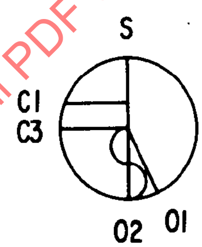
Wall Attachment



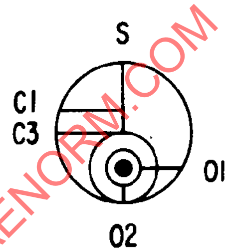
Wall Attachment
Internal Fluid Bias



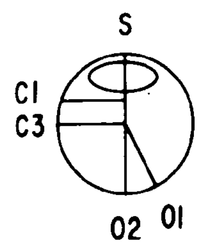
Jet Interaction
Geometrical Bias



Turbulence



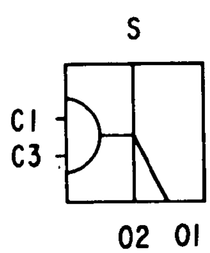
Vortex



Focused Jet

3.4.2 AND-NAND

Functional Symbol

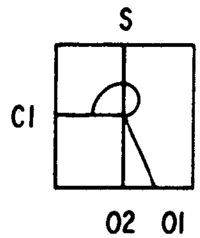


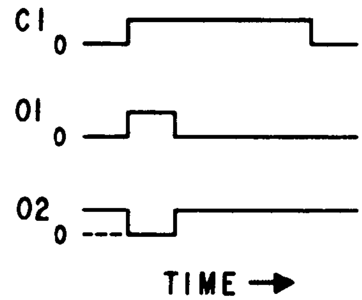
Truth Table

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

3.4.3 One-Shot

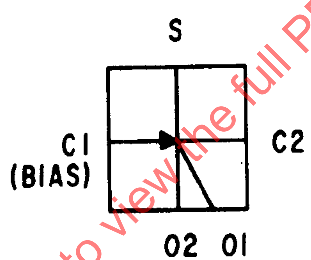
Functional Symbol





3.4.4 Schmitt Trigger

Functional Symbol

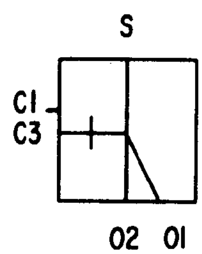


Truth Table

	O1	O2
C1 > C2	1	0
C1 < C2	0	1
C1 = C2	Undefined	

3.4.5 Exclusive OR

Functional Symbol



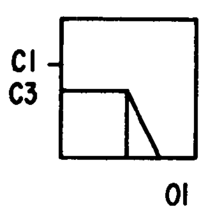
Truth Table

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

3.5 Passive Digital Devices

3.5.1 OR

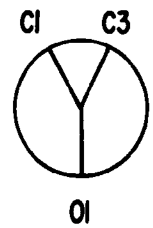
Functional Symbol



Truth Table

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

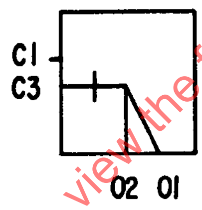
Operating Principle Symbols



Passive
Jet Interaction

3.5.2 Exclusive OR-AND

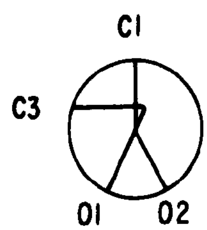
Functional Symbol



Truth Table

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

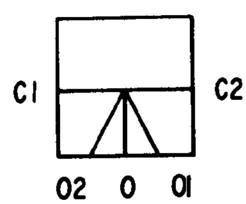
Operating Principle Symbols



Passive
Jet Interaction

3.5.3 AND - 2/3 AND

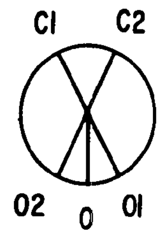
Functional
Symbol



Truth Table

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

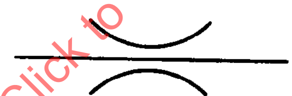
Operating Principle Symbols



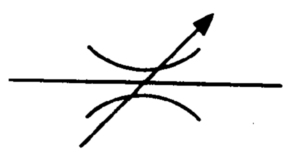
Passive
Jet Interaction

3.6 Fluidic Impedances

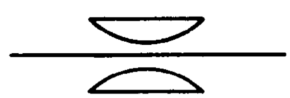
3.6.1 General Resistance - Fixed



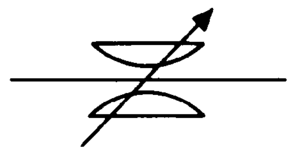
3.6.2 General Resistance - Variable



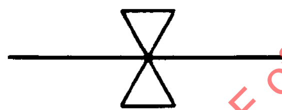
3.6.3 Linear Resistance - Fixed



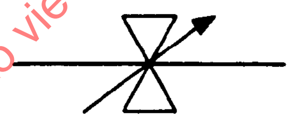
3.6.4 Linear Resistance - Variable



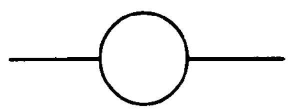
3.6.5 Nonlinear Resistance - Fixed



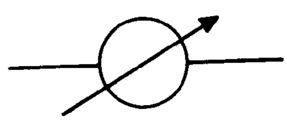
3.6.6 Nonlinear Resistance - Variable



3.6.7 Capacitance - Fixed



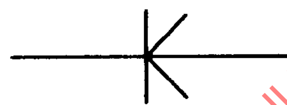
3.6.8 Capacitance - Variable



3.6.9 Inductance - Fixed

3.6.10 Inductance - Variable

3.6.11 Diode



4. DEFINITIONS

4.1 General

4.1.1 Fluid Resistance

- R; for average value, resistance is the ratio of pressure drop (ΔP) to weight flow rate:

$$R = \frac{\Delta P}{w} \quad \frac{sec}{in^2} \quad \left(\frac{Ns}{m^2\ kg}\right)$$

For incremental fluid resistance:

$$R = \frac{dP}{dw} \quad \frac{sec}{in^2} \quad \left(\frac{Ns}{m^2\ kg}\right)$$

4.1.2 Fluid Capacitance

- C; ratio of integrated weight flow to change in pressure.

for gases $C = \frac{V}{k\ R\ T}$ in^2 (m^2 -kg/N).

for liquids $C = \frac{\gamma V}{\beta}$ in^2 (m^2 -kg/N).

where R is gas constant.

In general $\Delta P = \frac{1}{Cs} \Delta w$

where ΔP represents a small change in pressure and Δw represents a small change in net weight flow rate.

(s = Laplace operator)

4.1.3 Fluid Inductance

- L; ratio of pressure change (ΔP) to rate of change of weight flow ($s\Delta w$)

$$L = \frac{y}{gA} \quad \frac{sec^2}{in^2} \quad \left(\frac{s^2\ N}{m^2\ kg}\right)$$

where y = channel length and A = channel cross sectional area.

In general $\Delta P = Ls\Delta w$

where ΔP represents a small change in pressure drop along a channel and Δw represents a small change in weight flow rate.

4.2 Digital Elements

4.2.1 Pressure Gain - The ratio of the 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 5.2) and load shall be specified.

4.2.2 Flow Gain - The ratio of the 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 5.2) and load shall be specified.

4.2.3 Power Gain - The ratio of the change in output power to the change in control power required for switching to occur. Data shall be taken in the vicinity of the operating point indicated by the reference column of the table. (See note 4, Figure 5.2) Load shall be specified.

4.2.4 Pressure Amplification - The ratio of the absolute value of the maximum output pressure divided by the absolute value of the maximum control pressure shall be used to determine the pressure amplification. Data is understood to be at the switch points and load shall be specified.

4.2.5 Flow Amplification - The ratio of the maximum output flow level divided by the maximum control flow shall be used to determine flow amplification. Data is understood to be at the switch points and load shall be specified.

4.2.6 Power Amplification - The ratio of the output power to the control power in the switching region shall be used to determine the power amplification. (See note 4, Figure 5.2) Load shall be specified.

4.2.7 Fanout - The number of digital elements which can be controlled from the output of a single identical element operating at a common power nozzle pressure. It should be noted that fanout may be affected by operating speed.

Rows h) and k) shall be used to tabulate response and noise characteristics of digital devices using the following definitions:

4.2.8 Response - An indication of response characteristics is the propagation delay which occurs in response to an approximate step control of recommended amplitude. Propagation delay is the time between the instant the control reaches 50% of final value and the instant the output reaches 50% of the final value as indicated in Figure 4.1. Load shall be specified if the response is load sensitive.

4.2.9 Noise - The peak-to-peak amplitude of the pressure noise of the device in psi will be listed. Load shall be specified.

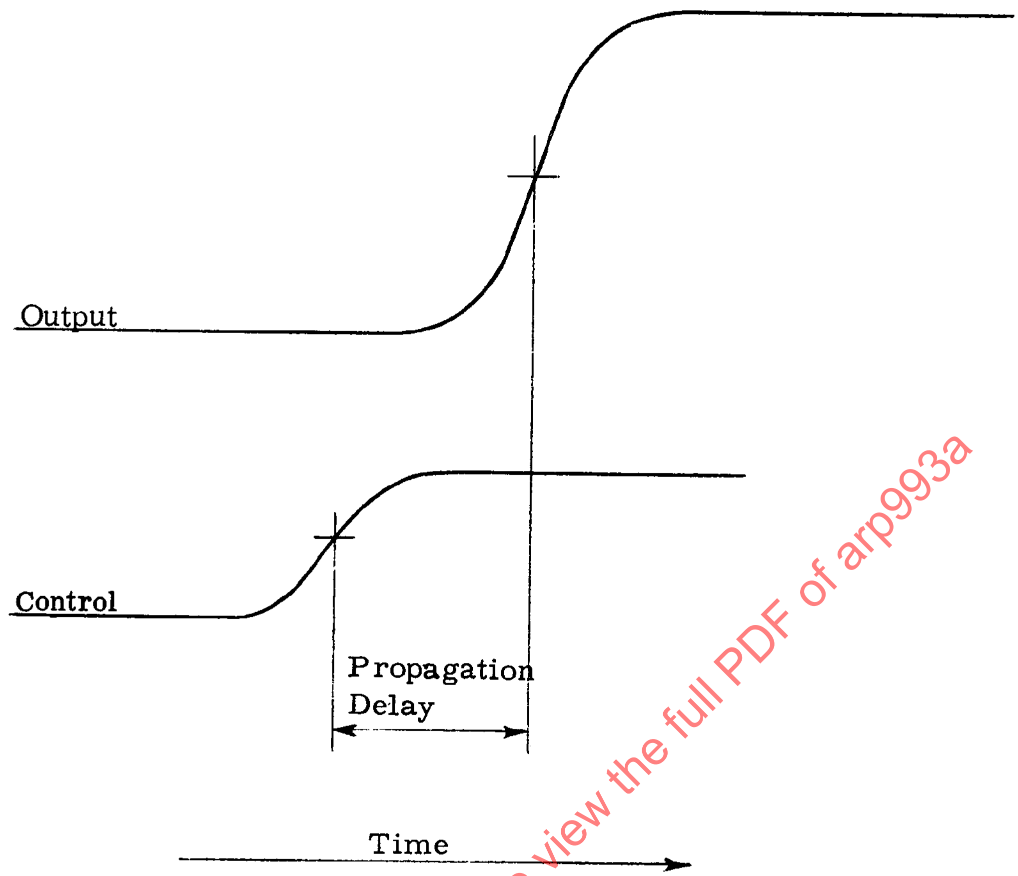


Figure 4.1 Propagation Delay Definition

4.2.10 <u>Hysteresis</u> - Width of the hysteresis loop as measured on a control output curve and expressed as a percentage of the supply conditions, e.g., flow hysteresis is the hysteresis loop width (measured on a control output flow curve) divided by the supply flow. (See Figure 4.2).

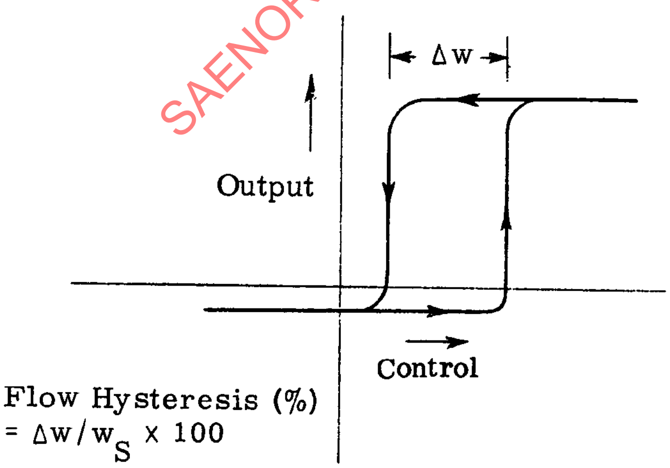


Figure 4.2 Hysteresis Definition

4.2.11 Control Impedance - Z_C, the ratio of control pressure change to flow change measured at a control port; value may depend on operating point since control pressure flow curve may not be linear.

4.2.12 Output Impedance - Z_O, the ratio of output pressure change to flow change measured at an output port; value may depend on operating point since output pressure-flow curve may not be linear.

4.3 Proportional Elements

4.3.1 Pressure Gain - The slope of the curve of output pressure versus control pressure (See Figure 4.3A) in the vicinity of the operating point shall be used to establish pressure gain.

4.3.2 Flow Gain - The slope of the curve of output flow versus control flow (See Figure 4.3B) in the vicinity of the operating point shall be used to establish gain.

4.3.3 Power Gain - The change in output power divided by the change in control power. Power gain shall calculated around the operating point for small changes (less than 10% of saturation) of control power. (See Note 4, Figure 5.2).

4.3.4 Pressure Amplification The ratio of the absolute value of output pressure divided by the absolute value of the control pressure shall be used to determine the pressure amplification. End point values of the useful range or saturation values may be used (See example Figure 4.3A).

4.3.5 Flow Amplification - The ratio of the outlet flow divided by the control flow shall be used to determine the flow amplification. End point values of the useful range or saturation values may be used (See example Figure 4.3B).

4.3.6 Power Amplification - The ratio of the outlet power to the control power shall be used to determine the power amplification. As in pressure and flow amplification, the end point values of the useful range or saturation values may be used. (See Note 4, Figure 5.2).

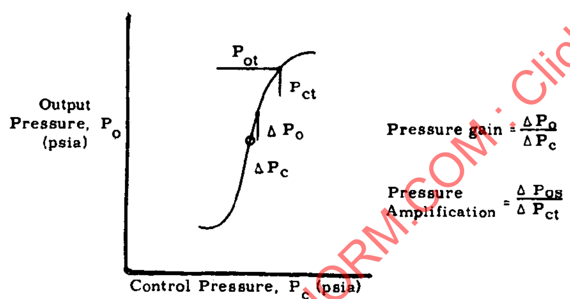


Figure 4.3A. Pressure Gain Definition

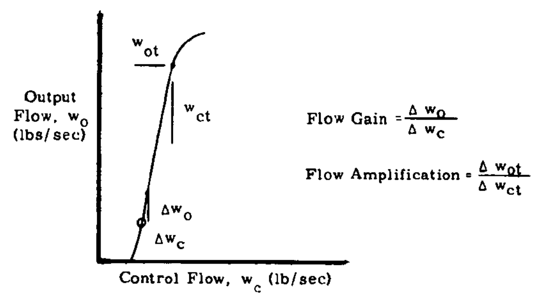


Figure 4.3B. Flow Gain Definition

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

4.3.8 Noise - The peak-to-peak amplitude of the pressure noise of the device in psi will be listed. Element load used during test shall be specified.

4.3.9 Saturation - The maximum output value regardless of control magnitude. (See Figure 4. 4)

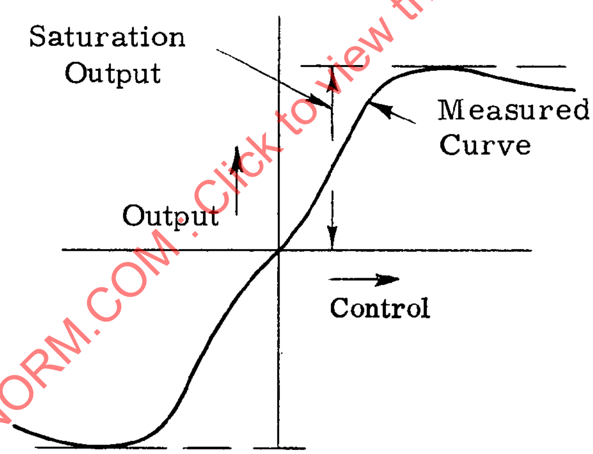


Figure 4. 4 Saturation Definition

4.3.10 Linearity - Deviation of the measured curve from the straight-line average gain approximation; defined as the ratio of the peak-to-peak output deviation to peak-to-peak output range (range should be stated if other than maximum output level) expressed as a percentage. (See Figure 4. 5)

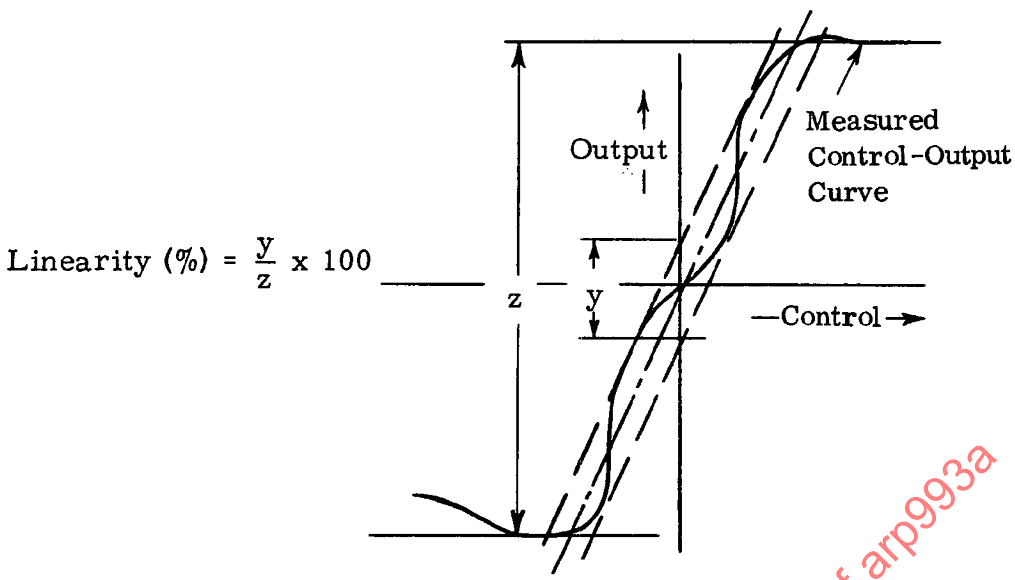


Figure 4. 5 Linearity Definition

4.3.11 Hysteresis - Total width of hysteresis loop expressed as a percent of peak-to-peak saturation control signal. Measurement to be at frequencies below those where dynamic effects become significant. (See Figure 4. 6)

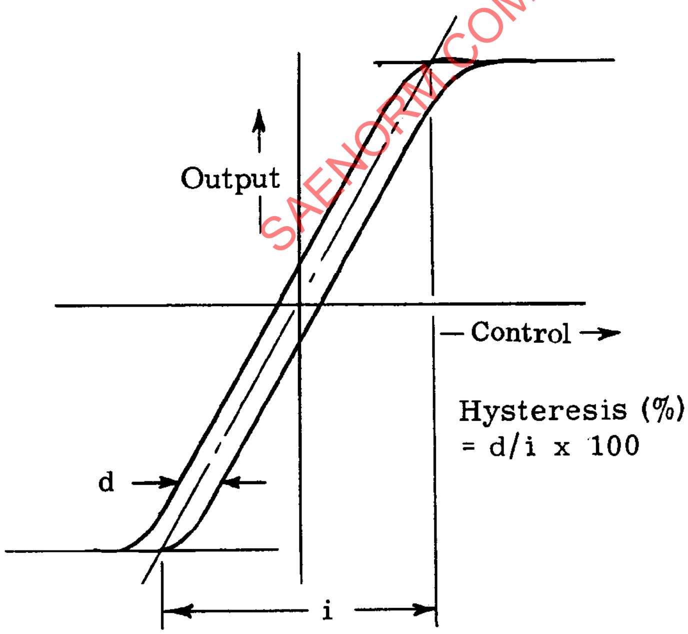


Figure 4. 6 Hystersis Definition

4.3.12 Control Impedance - Z_C, the ratio of pressure change to flow change measured at a control port. Numerical value may depend on operating point since control pressure-flow curve may not be linear. (See Figure 4.7). For active elements the power source should be connected for measurements.

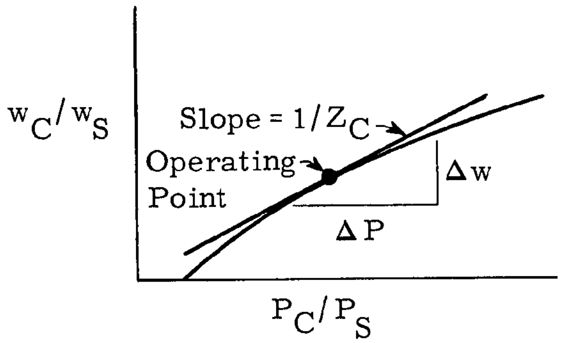


Figure 4.7 Control Impedance Definition

4.3.13 Output Impedance - Z_O, the ratio of pressure change to flow change measured at an output port. Numerical value may depend on operating point since output pressure-flow curve may not be linear. (See Figure 4.8).

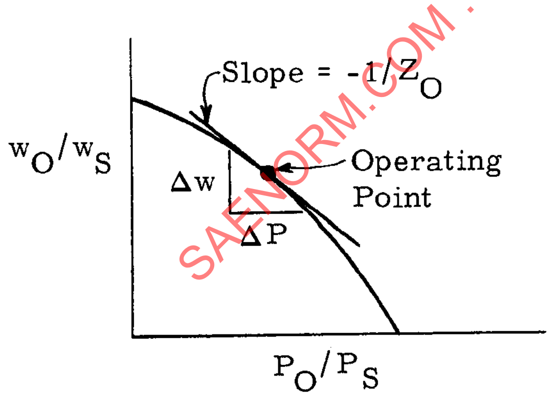


Figure 4.8 Output Impedance Definition

5. SUGGESTED SPECIFICATION GUIDELINES

Sample performance presentation sheets are included in the following pages and may be used as a reference for the preparation of specifications.

5.1 Function

This item shall be used to describe the basic function of the device.

For example:

Proportional Amplifier
Pressure Regulator
Digital Amplifier
Logic Device - OR
Logic Device - NOR
Logic Device - AND
Etc.

5.2 Type

This item shall be used to describe the operating principle of the device. A descriptive trade name is acceptable.

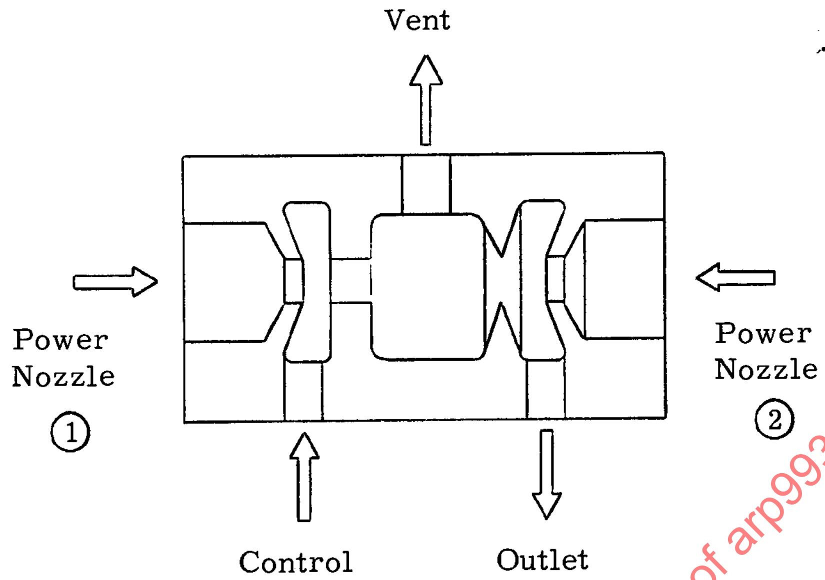
For example:

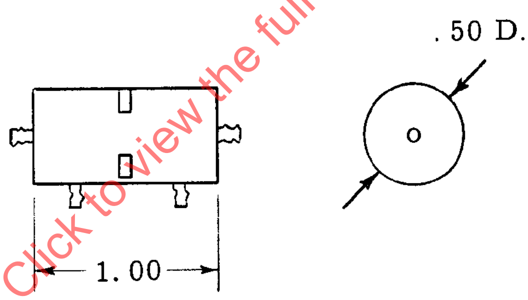
Jet Interaction Amplifier
Wall Attachment Amplifier
Impact Modulator
Vortex Amplifier
Boundary Layer Amplifier
Turbulence Amplifier
Etc.

5.3 Configuration

A schematic drawing shall be included, which shows (See example, Figure 5.1) enough detail to give an understanding of the operating principle, and includes the following additional information:

Number of Control and Output Signals
Number of Power Jets
Number of Vent Ports
Nozzle Sizes (Power, Control, Output, and Vent)
Body Material
Temperature Rating of Unit
Pressure Rating of Unit





Nozzle Sizes

Power (1) - . 040 in. dia.
Power (2) - . 040 in. dia.
Control - . 080 in. dia.
Outlet - . 080 in. dia.
Vent - . 200 x . 300 in^2

Body Material - Cast Epoxy
Temperature Rating - 250 F
Pressure Rating - 80 psig
Fittings
Weight - . 007 lbs.

Figure 5.1 Typical Performance Presentation Sheet Data

Envelope Dimensions
Type and Size of Fitting
(if used)
Weight

5.4 Performance

5.4.1 General - Applicable to all functions and types. A performance data sheet (see example, Figure 5.2) shall be provided which gives information about the device at one or a number of fixed operating points. A series of columns shall be provided to tabulate the data at each of the selected steady state operating points. These columns shall have Roman numeral headings which correspond to the identification of the characteristic curves.

The following items shall be included on the table in rows labeled:

a) Fluid - air, water, oil, nitrogen, etc.

b) Temperature - The operating temperature of the fluid.

c) Pressure

Power Nozzle Pressures	-psia	(N/m^2)*
Outlet Pressures	-psia	(N/m^2)
Vent Pressures (Common Sink)	-psia	(N/m^2)
Control Pressures	-psia	(N/m^2)

d) Flow

Power Nozzle Flows	-lb/sec	(N/s)
Outlet Flows	-lb/sec	(N/s)
Vent Flows	-lb/sec	(N/s)
Control Flows	-lb/sec	(N/s)

5.4.2 Digital Amplifiers

The following information shall be included on the performance data sheet in rows e) through g) using one or more of the following, as appropriate:

e) Pressure Gain

* SI Units, see page 12

Flow Gain

Power Gain

f) Pressure Amplification

Flow Amplification

Power Amplification

g) Fanout

Rows h) and k) shall be used to tabulate response and noise characteristics of digital devices.

h) Response

k) Noise

5.4.3 Characteristic Curves - (Digital Amplifiers)

The characteristic curves for the device may be non-dimensionalized with respect to the highest supply pressure, and the total supply flow. The curves will be clearly identified to a reference column of the performance table. The device should be operated with typical-terminations at the control and output ports.

The recommended curves are shown in Figure 5.3.

PERFORMANCE PRESENTATION SHEET

FUNCTION ______________________

TYPE ______________________ (Refer to appropriate figure)

CONFIGURATION ______________________

Performance Points ①

PERFORMANCE (At Null)			I	II	III	IV	V
a)		Fluid	Air				
b)		Temperature	530°R				
c)	Pressure (psia)	Power ①	23.0				
		Power ②	26.0				
		Outlet	14.7				
		Vent	14.7				
		Control	14.7				
d)	Flow (lb/sec)	Power ①					
		Power ②					
		Outlet					
		Vent					
		Control					
e)	Gains	Pressure	50				
		Flow	10				
		Power ④	500				
f)	Amplification	Pressure	50				
		Flow	7				
		Power ④	350				
g)		Fan-out ③ only					
h)	Response	Frequency Response-cps @ φ = 45° ② or Propagation Delay(sec) ③					
k)	Noise	Generated Noise Amplitude-PSI					

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

Figure 5.2 Sample Performance Presentation Sheet

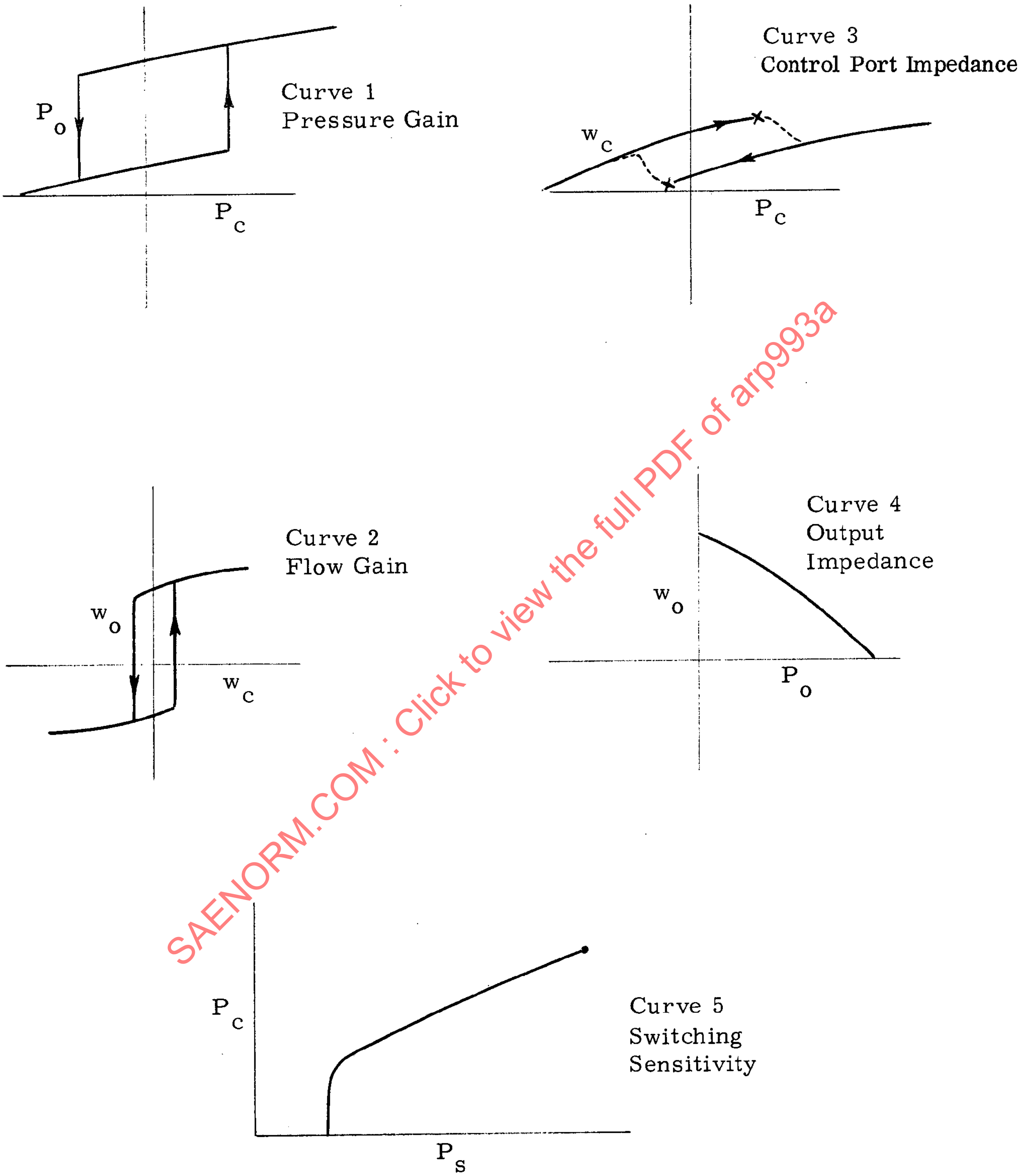


Figure 5. 3 Digital Element Performance Curves