



# AEROSPACE RECOMMENDED PRACTICE

## ARP 993

SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.

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Revised

### 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 TECHNOLOGIES

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## 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. TERMINOLOGY2.1 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 FOCUSED-  
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.

IMPACT MODULATOR

Usually employed as a digital amplifier. Terminology usage is illustrated in Figure 2. 6.

- 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 in-ertance, 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

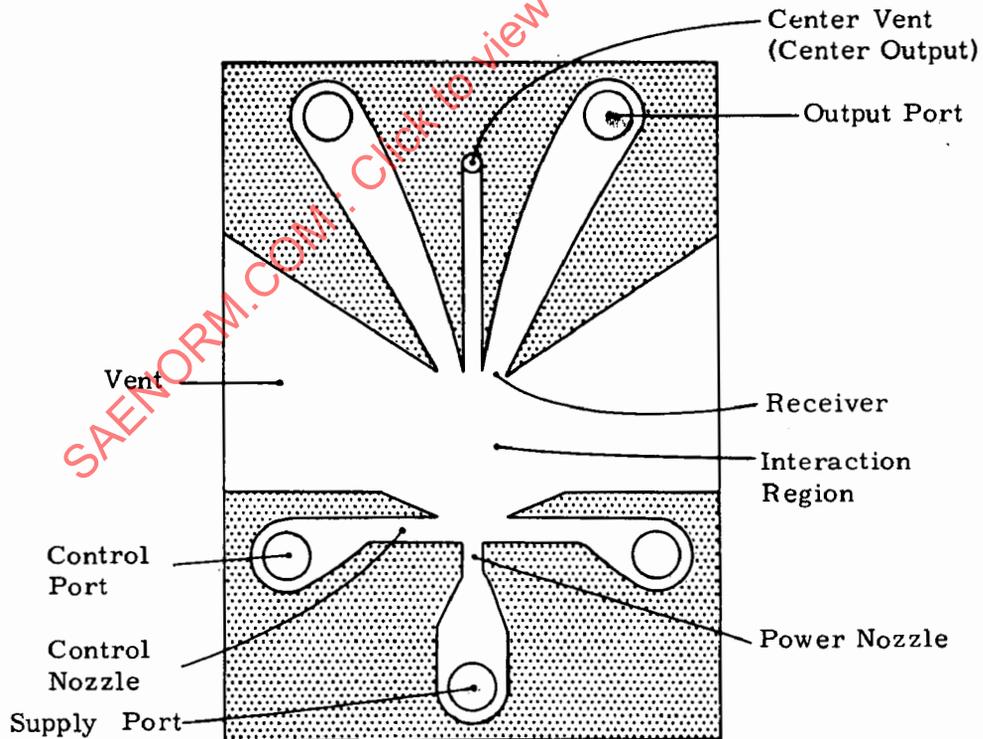


Figure 2.1(a) Vented Interaction Amplifier.

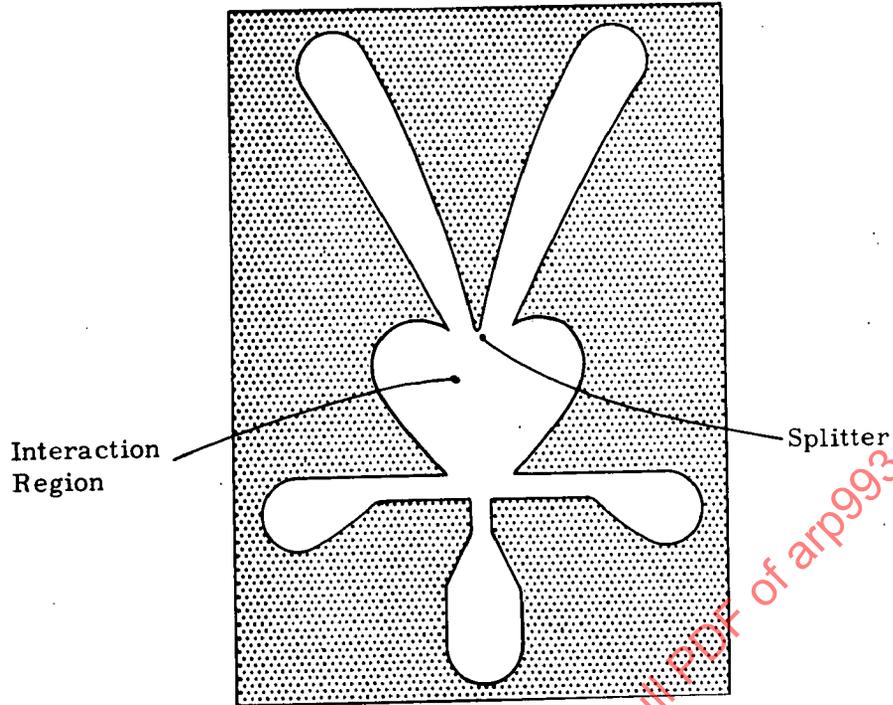


Figure 2.1(b) Closed Jet Interaction Amplifier.

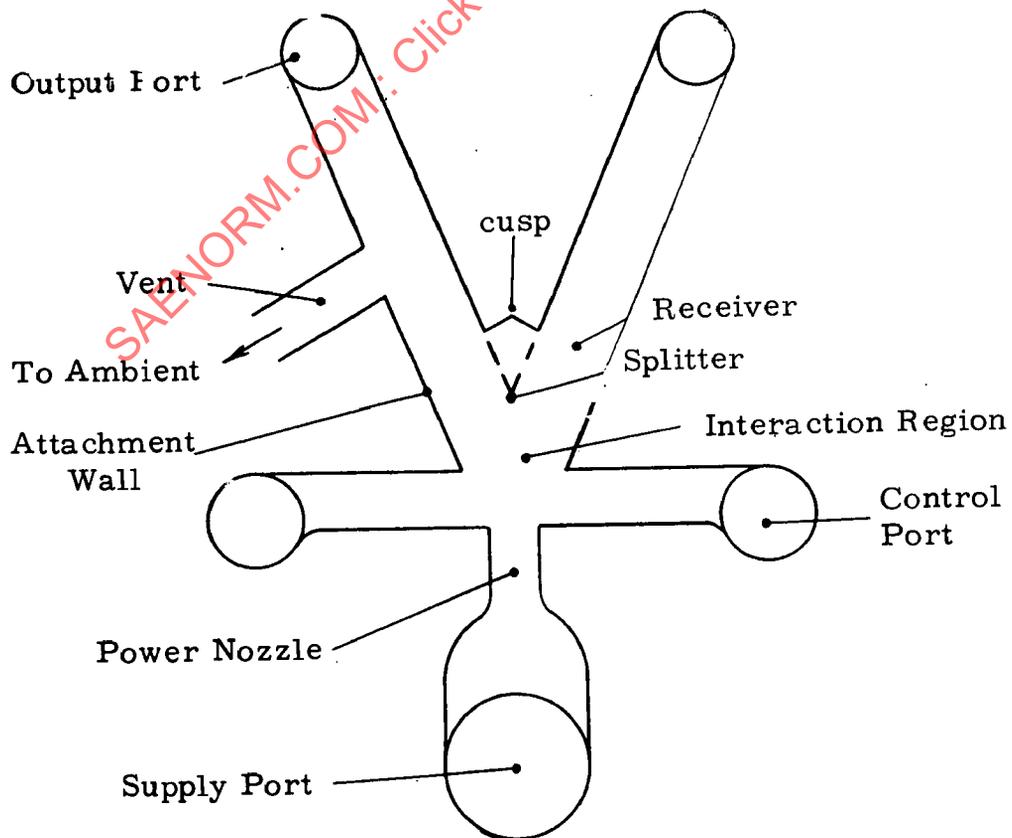


Figure 2.2 Wall Attachment Amplifier

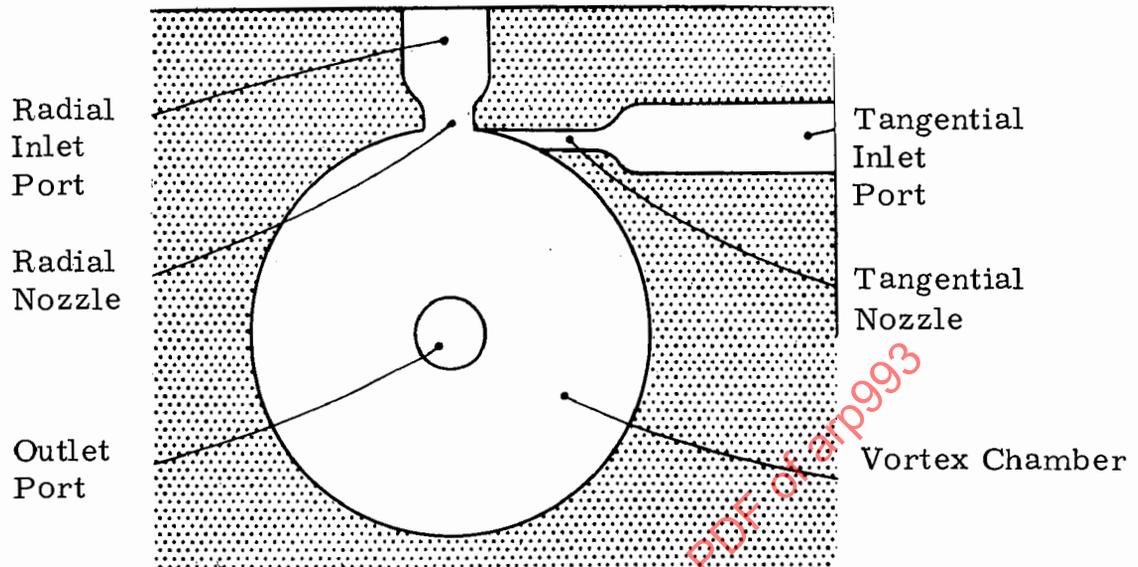


Figure 2.3 Vortex Amplifier

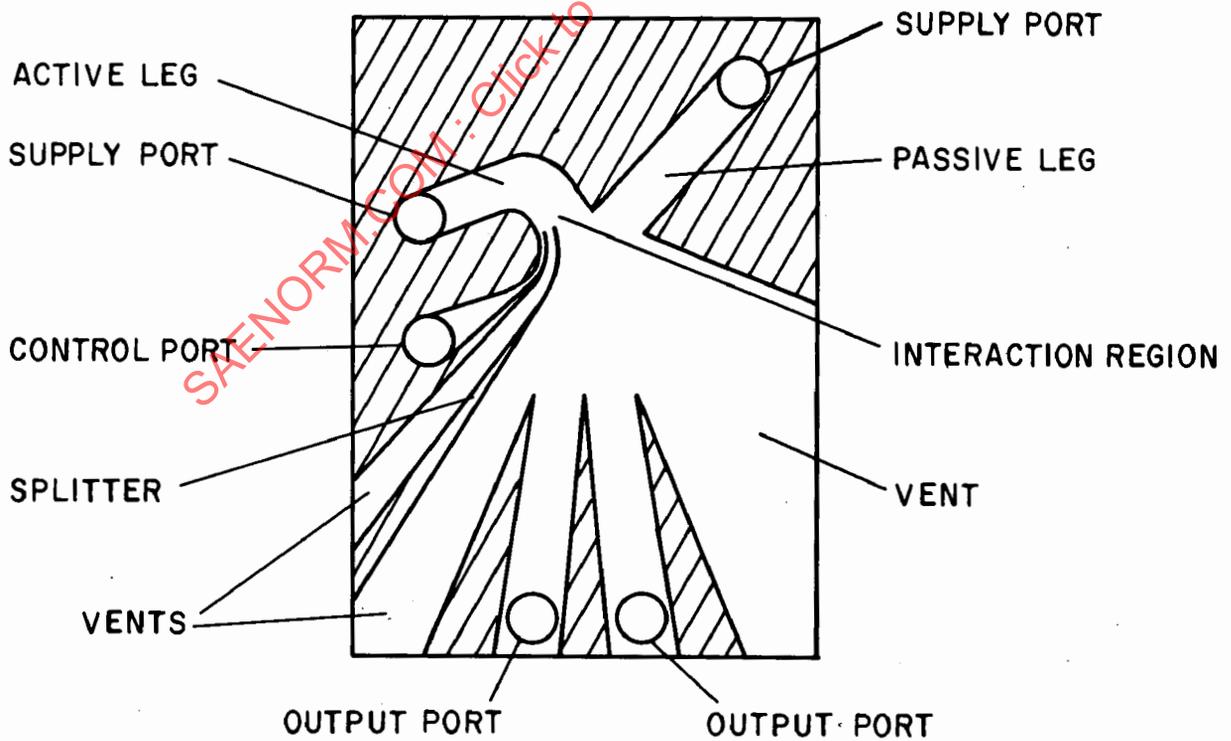


Figure 2.4 Boundary Layer Control Amplifier (Vents Optional)

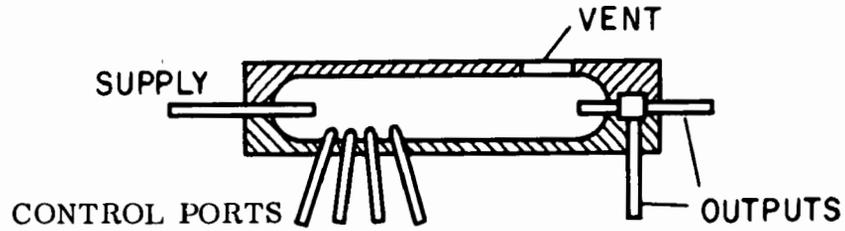
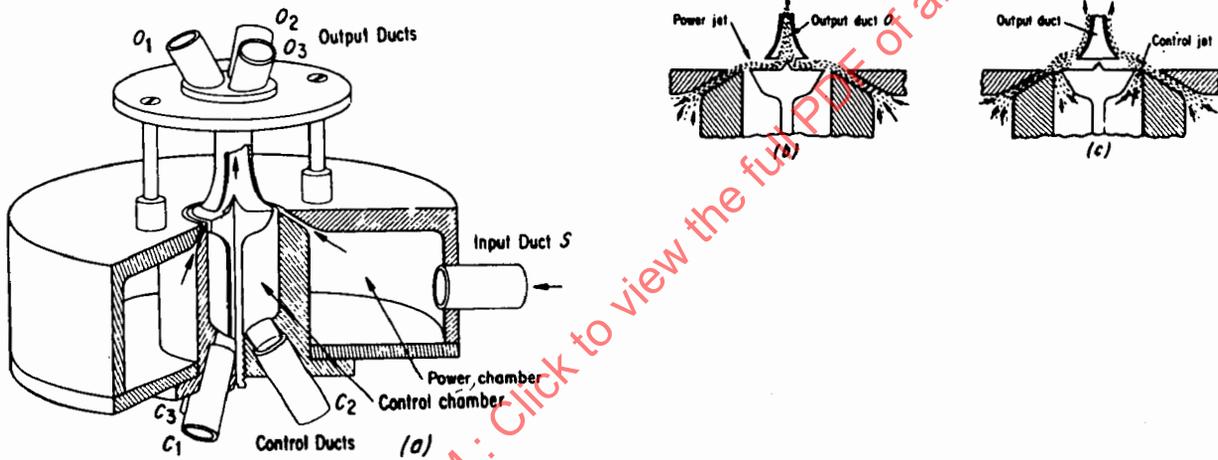
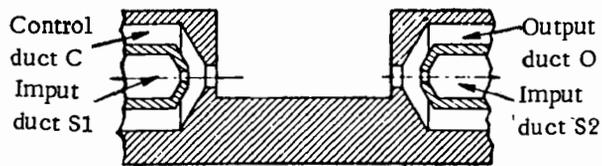


Figure 2.5 Turbulence Amplifier

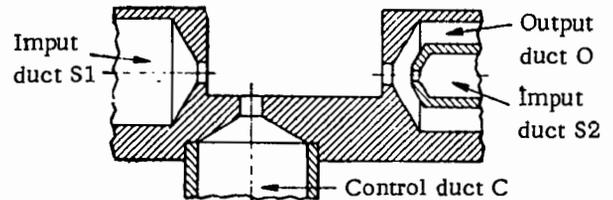


Focused-jet amplifier: Typical cross section, a. Flow pattern with no control flow, b. Flow pattern with control flow, c.

Figure 2.6



Direct Impact Modulator



Transverse Impact Modulator

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).

<u>Quantity</u>	<u>Nomenclature</u>	<u>Units</u>	<u>Units</u>
		(std)	(SI)*
Length	--	inch; in	(meter, m)
Force	F	pound, lb	(newton; N)
Mass	m	lb-sec <sup>2</sup> /in	(kilogram; kg)
time	t	seconds; sec	(seconds; s)
angle	--	degrees; °	(radians; rad)
frequency	f	cycles/sec; cps	(hertz; H <sub>z</sub> )
area	A	in <sup>2</sup>	(m <sup>2</sup> )
acceleration	a	in/sec <sup>2</sup>	(m/s <sup>2</sup> )
gravitational constant	g	in/sec <sup>2</sup>	(m/s <sup>2</sup> )
temperature, static	T	degrees Rankin; °R	(degrees Kelvin; °K)
temperature, total	T <sub>0</sub>	°R	°K
velocity, angular	ω	rad/sec	(rad/s)
acceleration, angular	α	rad/sec <sup>2</sup>	(rad/s <sup>2</sup> )
volume	V	in <sup>3</sup>	(m <sup>3</sup> )
weight density	γ	lb/in <sup>3</sup>	(N/m <sup>3</sup> )
mass density	ρ	lb-sec <sup>2</sup> /in <sup>4</sup>	(kg/m <sup>3</sup> )
weight flow rate	w	lb/sec	(N/s)

\*System International Units

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

<u>Quantity</u>	<u>Nomenclature</u>	<u>Units</u>
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

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### 3. SCHEMATICS

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

#### 3.1 General

Submerged jet path and flow channels

\_\_\_\_\_

Supply port     O

vent port

\_\_\_\_\_ V

Control

—▶ arrow-head on control line indicates continual flow required to maintain state, no memory (no hysteresis)

—— no arrow-head on control line indicates element has memory (has useful hysteresis).

Logic Notation

$A \bullet B \equiv A \text{ "and" } B$

$A + B \equiv A \text{ "or" } B$

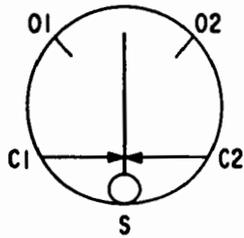
$\bar{A} \bullet \bar{B} \equiv \text{"not" } A \text{ and "not" } B$

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 Amplifiers

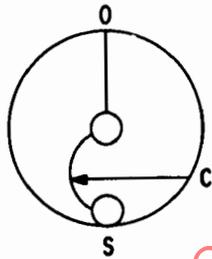
JET INTERACTION AMPLIFIER



- S - supply
- C1 - left control port
- C2 - right control port
- O1 - left output
- O2 - right output

Operating Principle - Jet interaction (proportional)

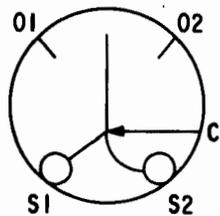
VORTEX AMPLIFIER



- S - supply
- C - control port
- O - output

Operating Principle - vortex

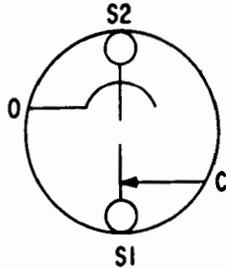
BOUNDARY LAYER CONTROL AMPLIFIER



- S1 - passive leg supply
- S2 - active leg supply
- C - control port
- O1 - left output
- O2 - right output

Operating Principle - separation point control

IMPACT MODULATOR

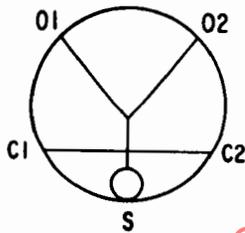


- S1 - controlled supply
- S2 - supply
- C - control port
- O - output

Operating Principle - Jet impact

3.3 Digital Amplifiers

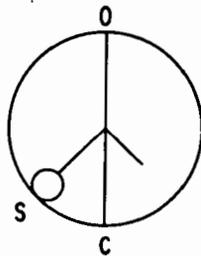
WALL ATTACHMENT FLIP-FLOP  
(has memory - relatively wide hysteresis loop)



- S - supply
- C1 - left control port
- C2 - right control port
- O1 - left output
- O2 - right output

Operating Principle - wall attachment

AXISYMMETRIC FOCUSSED-JET FLIP-FLOP

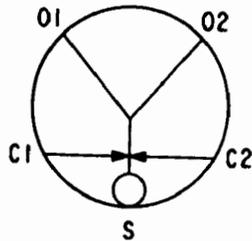


- S - supply
- C - control port
- O - output

Operating Principle - annular wall attachment

DIGITAL AMPLIFIER

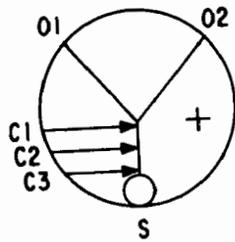
(no memory - essentially zero width hysteresis loop)



- S - supply
- C1 - left control port
- C2 - right control port
- O1 - left output
- O2 - right output

Operating Principle - Jet interaction

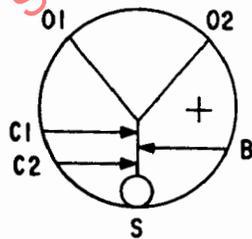
OR-NOR



- S - supply
- C1, C2, C3 - control ports
- O1 -  $\overline{C1} \cdot \overline{C2} \cdot \overline{C3}$  - output
- O2 -  $C1 + C2 + C3$  - output
- + - indicates OR

Operating Principle - wall attachment, geometrical biasing

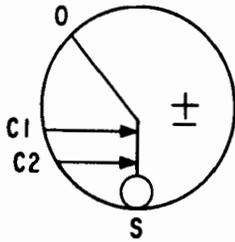
OR-NOR



- S - supply
- C1, C2 - control ports
- O1 - left output
- O2 - right output
- B - bias port
- + - OR output

Operating Principle - wall attachment, fluid biased

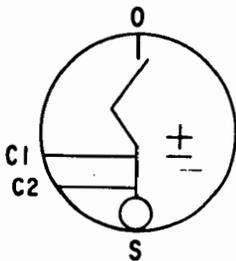
NOR



S - supply port  
 C1, C2 - control ports  
 O1 - output port  
 ± - indicates NOR

Operating Principle - wall attachment

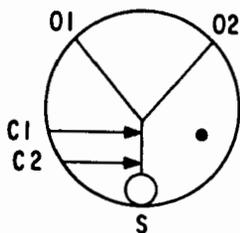
NOR



S - supply  
 C1, C2 - control ports  
 O1 - output  
 ± - indicates NOR

Operating Principle - turbulence

AND/NAND



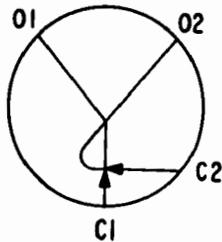
S - supply  
 C1, C2 - control ports  
 O1 -  $C1 + C2$  output  
 O2 -  $C1 \cdot C2$  output  
 ● - indicates AND

Operating Principle - wall attachment

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3.4 Passive Logic Devices

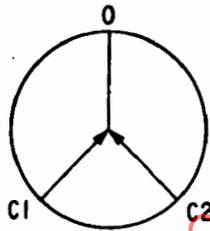
EXCLUSIVE OR/AND



C1, C2 - control ports  
O1 -  $C1 \bullet C2$  output  
O2 -  $C1 + C2$  output

Operating Principle - wall attachment

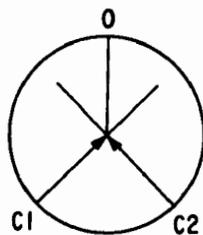
OR



C1, C2 - control ports  
O - output

Operating Principle - Jet interaction

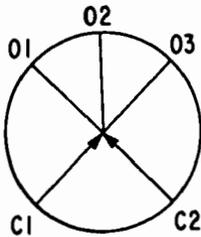
AND



C1, C2 - control ports  
O - output

Operating Principle - Jet interaction

2/3 AND

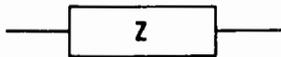


C1, C2 - control ports  
O1, O2, O3 - outputs

Operating Principle - Jet interaction

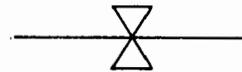
3.5 General Circuit Elements

GENERAL IMPEDANCE

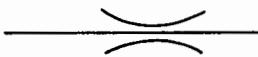


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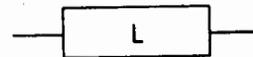
(TURBULENT RESTRICTION)



CAPILLARY (LAMINAR) RESTRICTION



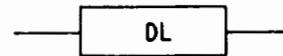
INDUCTANCE



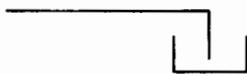
VOLUME CAPACITANCE



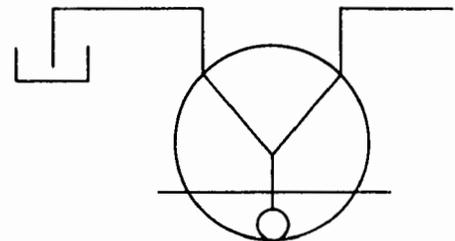
DELAY LINE



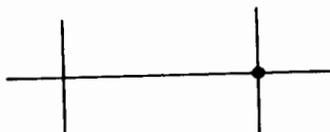
RETURN TO RESERVOIR



EXAMPLE OF RESERVOIR RETURN



LINE CROSSING



no

connection

connection

4. DEFINITIONS4.1 General4.1.1 Fluid Resistance

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

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

For incremental fluid resistance:

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

4.1.2 Fluid Capacitance

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

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

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

where R is gas constant.

In general  $\Delta P = \frac{1}{C_s} \Delta w$   
 where  $\Delta P$  represents a small change in pressure and  $\Delta w$  represents a small change in net weight flow rate.

(s = Laplace operator)

4.1.3 Fluid Inductance

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

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

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

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

where  $\Delta P$  represents a small change in pressure drop along a channel and  $\Delta w$  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.

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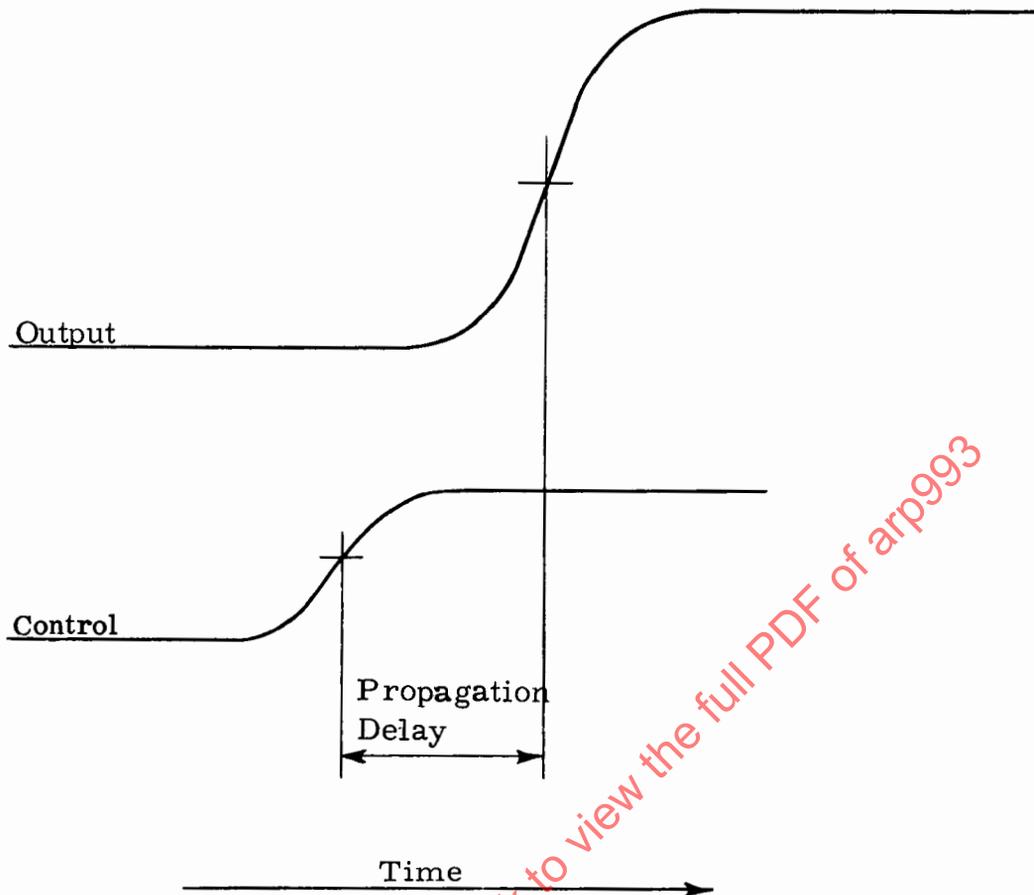


Figure 4.1 Propagation Delay Definition

4.2.10 Hysteresis

- 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).

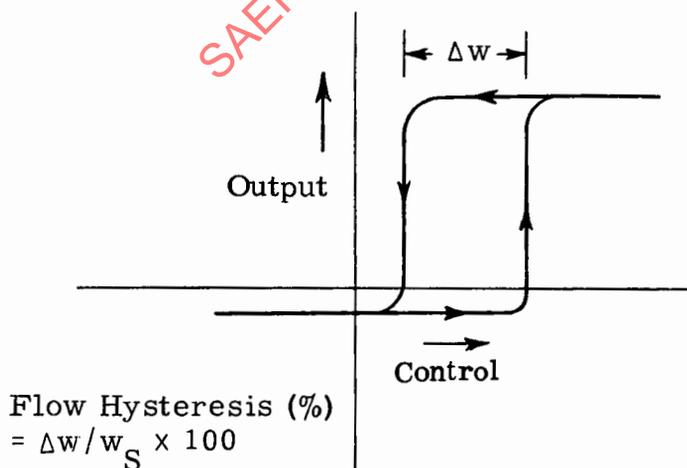


Figure 4.2 Hysteresis Definition

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 be 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).

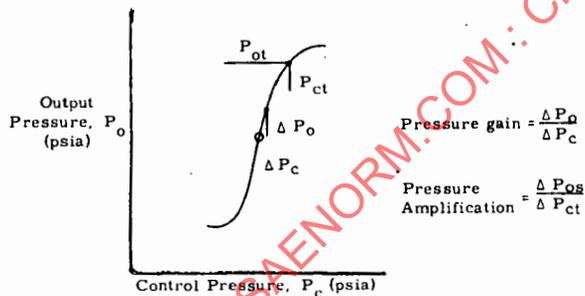


Figure 4.3A. Pressure Gain Definition

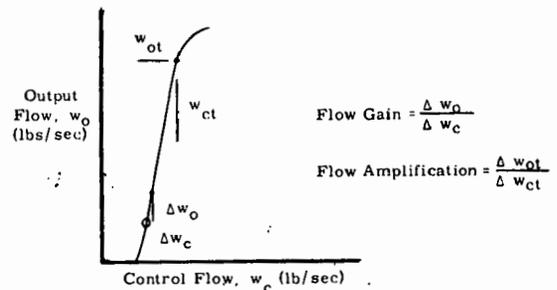


Figure 4.3B. Flow Gain Definition

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)

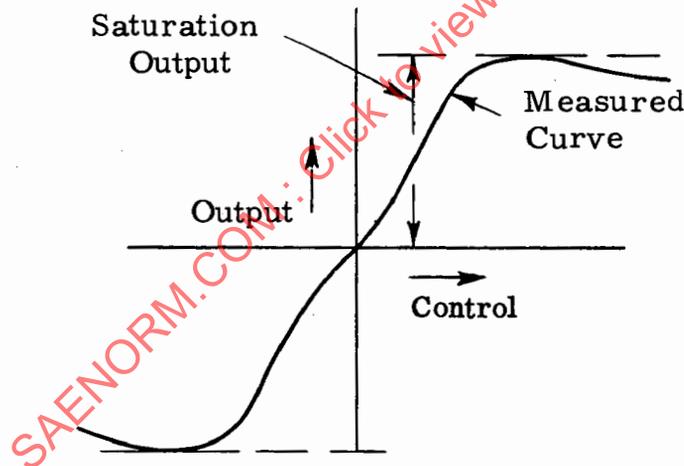


Figure 4.4 Saturation Definition

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)

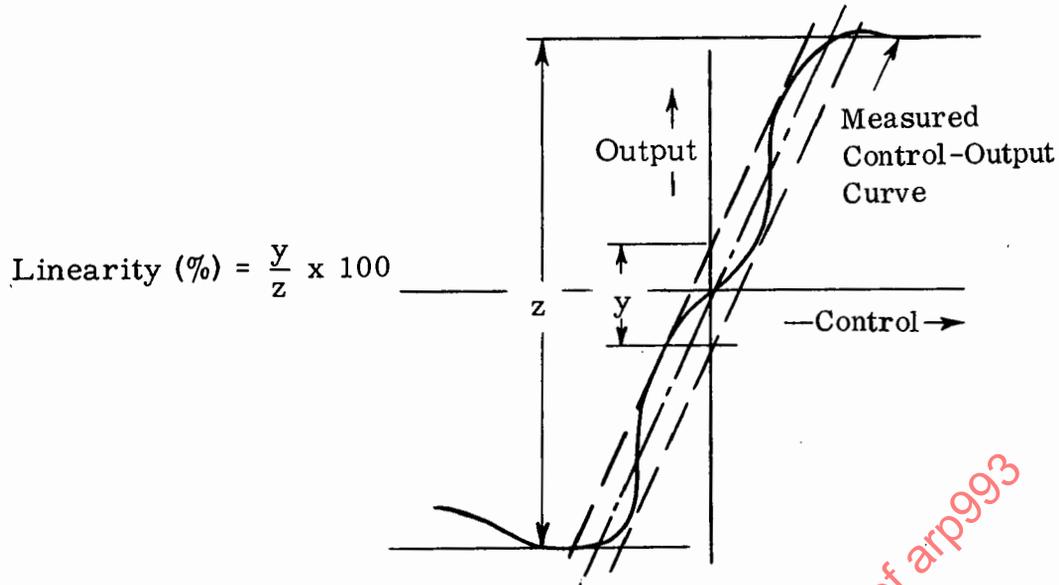


Figure 4.5 Linearity Definition

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)

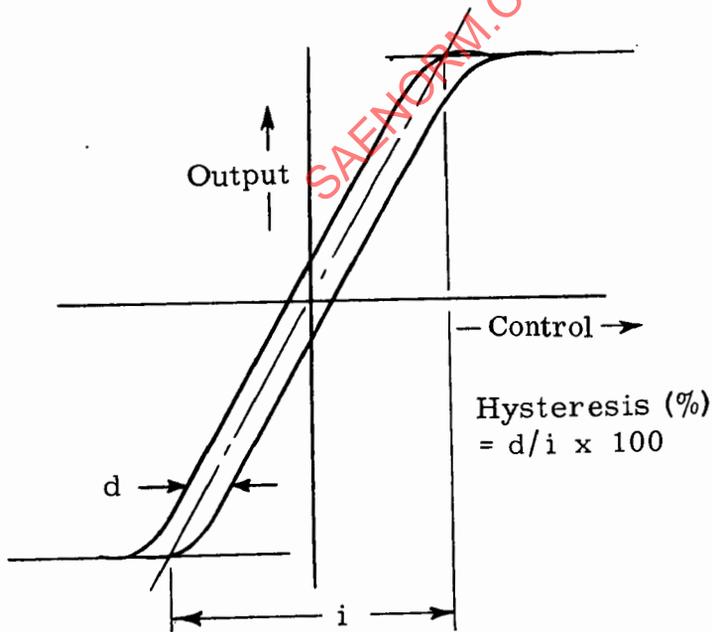
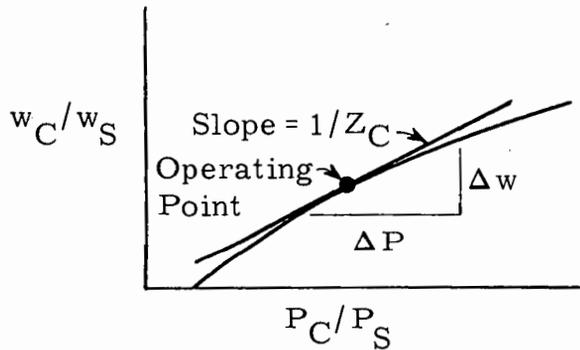


Figure 4.6 Hysteresis Definition

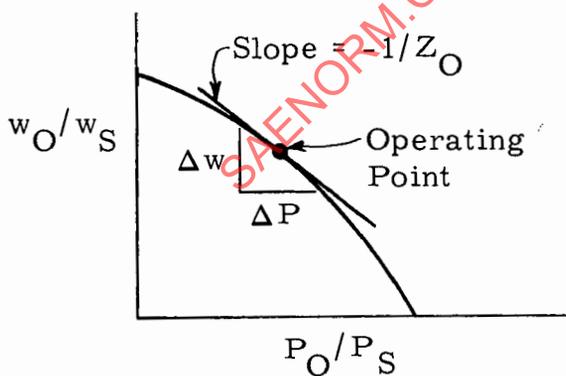
4.3.12 Control Impedance



- $Z_C$ , 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

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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.

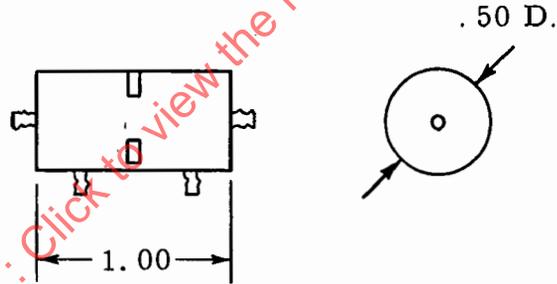
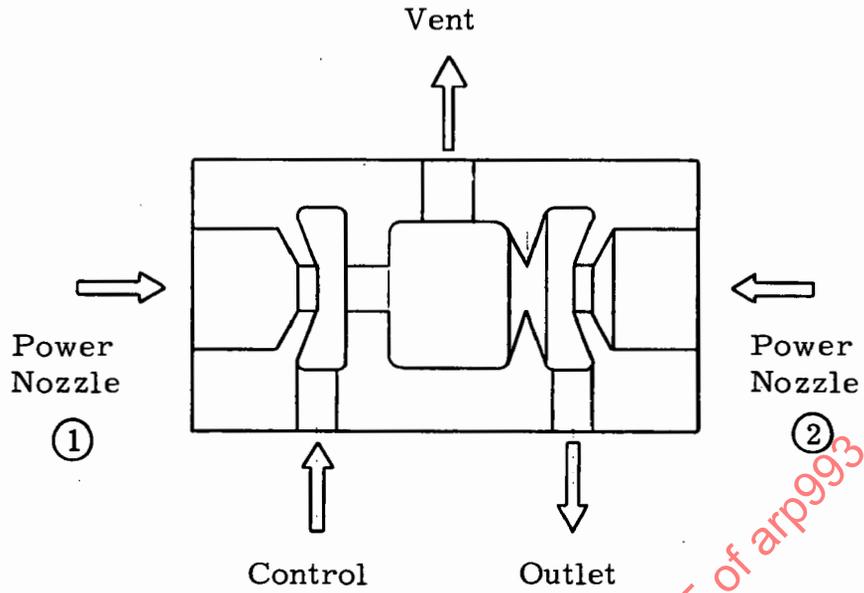
For example:

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<sup>2</sup>

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 <sup>2</sup> )*
Outlet Pressures	-psia	(N/m <sup>2</sup> )
Vent Pressures (Common Sink)	-psia	(N/m <sup>2</sup> )
Control Pressures	-psia	(N/m <sup>2</sup> )

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)

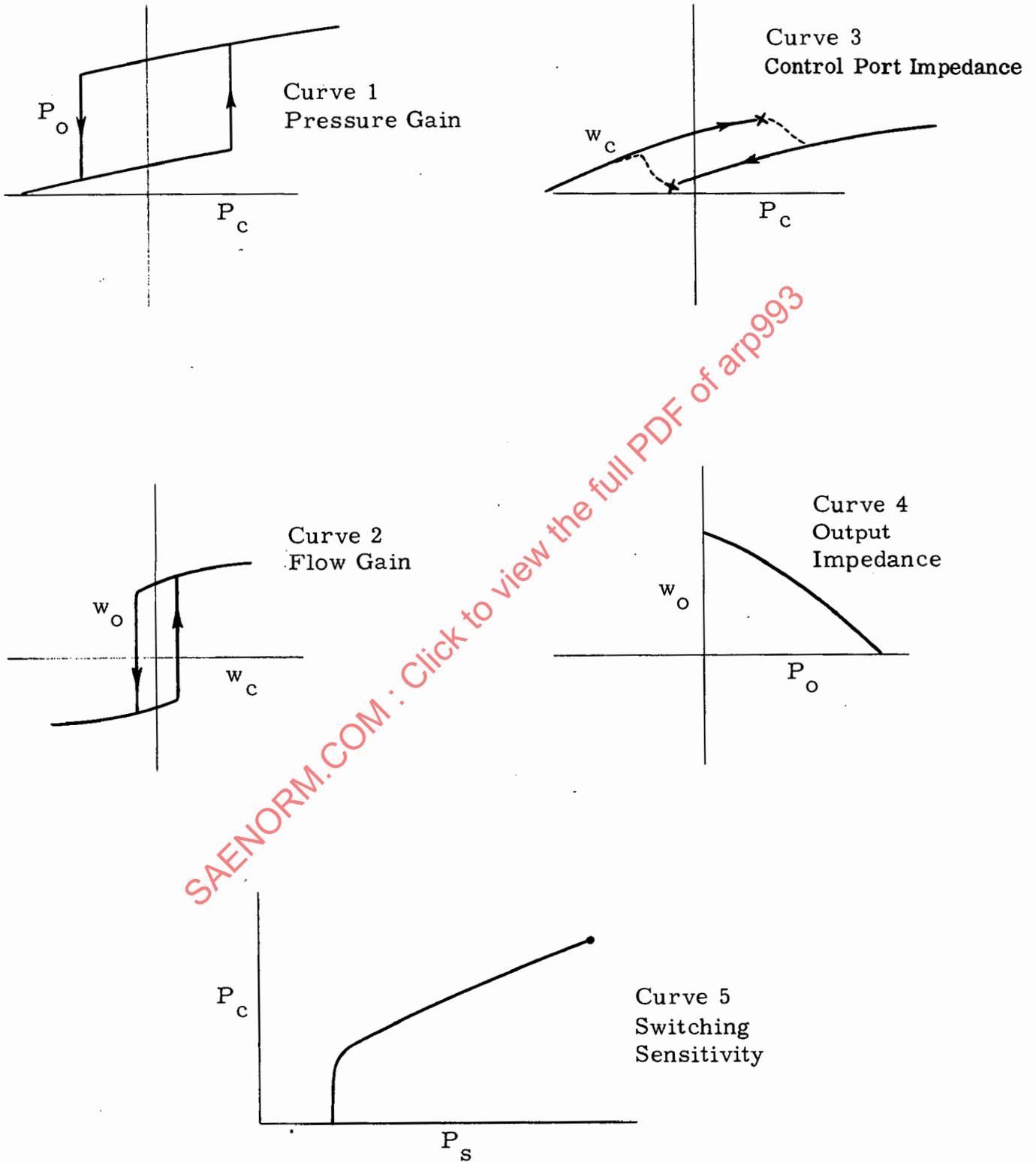
CONFIGURATION \_\_\_\_\_

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)	Amplification	Fan-out ③ only				
h)	Response	Frequency Response-cps @ $\phi = 45^\circ$ 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



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Figure 5.3 Digital Element Performance Curves

CURVE 1 Pressure-Gain Curve

The output pressure is plotted against the control pressures.

CURVE 2 Flow-Gain Curve

The output weight flow is plotted against the control weight flow.

CURVE 3 Control Port Impedance Curve

The control weight flow is plotted against the control pressure.

CURVE 4 Output Impedance Curve

The output weight flow is plotted against the output pressure.

Both or all output ports shall have equal-impedance loading. Measurements need only be taken on one of the output ports if performance of others is similar.

(As an option, the spillover and aspiration characteristics of the inactive output port may be included)

CURVE 5 Switching Sensitivity

The change of input pressure required for switching is plotted against supply pressure. This curve is intended to show the operating limits of the device.

5.4.4 Proportional Amplifiers

The following information shall be included on the performance data sheet in rows e) and f) using one or more of the following as appropriate.

e) Pressure Gain

Flow Gain

Power Gain

f) Pressure Amplification

Flow Amplification

Power Amplification

g) Frequency Response

Noise

5.4.5 Characteristic Curves - (Proportional Amplifiers)

The individual curves will be clearly identified to a reference column of the performance data sheet, Figure 5.2.

The recommended curves are shown in Figure 5.4.

CURVE 1 - Pressure Gain Curve

The output pressure is plotted against the control pressure. Differential pressures shall be used for differential amplifiers.

CURVE 2 - Flow Gain Curve

The output flow is plotted against the control flow. Differential flows shall be used for differential amplifiers.