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SCHOOL OF ENGINEERING

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

THE EFFECTS OF ENVIRONMENTAL NOISE

ON VENTED FLUID AMPLIFIERS

THESIS

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AFLC-WPAFB-JUL 67 35

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THESIS

Presented to the Faculty of the School of Engineering of
the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

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June 1967

Preface

When I first chose the topic of noise effects on fluid amplifiers, I envisioned a wide range of tests on many amplifiers--both static and dynamic testing of digital and proportional amplifiers under broad-band and pure tone noise environments.

The thesis, however, is often the first real-life experiment encountered by the student. Previously, the student had but to follow a simple checklist and record the data from equipment which was completely set up, fully instrumented, and ready to operate. For the thesis, however, the student must not only set up the equipment, but often must even build the setup himself, as well as completely instrument it. He may be forced to try several different setups or types of instrumentation before finding one which performs adequately. Often, the equipment or instruments must be shared with other users over the lengthy period of time the study is in progress.

So it was with this study. A great deal of time was spent in locating the instrumentation; several types of instruments were tried and found unsuitable. It was very educational to learn how much time is required to set up, in working order, something that at first glance seems so simple and straight forward.

Consequently, due to lack of time, equipment, and facilities, my delusions of grandeur gradually faded--and, one by one, the tests had to be eliminated until the study finally evolved in its present form.

Had it not been for the efforts of a great many people, the study would not have turned out as well as it did. I am greatly indebted to the Biodynamics and Bionics Division of the Aeromedical Research Laboratory, which provided the noise-generating and noise measuring equipment used in the tests. My special thanks to Mr. John Cole and Mr. Robert England who more than once dropped what they were doing to help me with my problems. Mr. James Hall of the Air Force Flight Dynamics Laboratory was very helpful by providing some of the fluid amplifiers and much of the equipment used in this study. Had it not been for the loan of their X-Y plotters by the Air Force Institute of Technology Department of Mathematics, this study could not have been completed except with considerably more difficulty. Finally, I wish to express my thanks to Professor Milton Franke, my thesis advisor, who offered many helpful suggestions along the way.

Eldridge C. Koppen, Jr.

Contents

List of Figures

List of Tables

List of Symbols

A	Area
B	Boundary
F	Force
P	Pressure
Q	Volumetric Flow Rate
SPL	Sound Pressure Level

Subscripts

b	Bias
c	Control
d	Differential
i	Initial
l	Left
n	Noise
o	Output
r	Right
s	Supply

Abstract

The effects of environmental noise on the static performance of vented fluid amplifiers was investigated. Two proportional amplifiers and one bistable amplifier were tested. A broad-band noise environment was used with sound pressure levels up to 163 decibels. Noise was allowed to enter the amplifier only through the vents. Proportional testing included input, gain, and output tests. Bistable testing included only switching pressure and switching flow rate tests.

Results of the proportional amplifier noise tests showed that control flow and input resistance decreased, while control pressure increased. Amplifier gain decreased in the non-linear portion of the gain curve. The output pressure and flow decreased on the side of the amplifier having the lower control pressure, and increased on the opposite side. The phenomena of radiation pressure and jet spreading were related to these effects. These effects are minimized in amplifiers having high control flow rates and operating at high supply and control pressures. Results of the bistable amplifier tests indicated that less control pressure and control flow were required to switch the amplifier in the presence of noise than when noise was not present.

THE EFFECTS OF ENVIRONMENTAL NOISE ON VENTED FLUID AMPLIFIERS

I. Introduction

The Problem

In the past several years, much progress has been made in the field of fluid amplifier technology. Fluid amplifiers have demonstrated a high tolerance to many different environments; however, they have yet to demonstrate fully their tolerance to high noise levels. Eventually, fluid amplifiers may be used in or near jet and rocket engines. It is therefore desirable to insure that the amplifiers will still operate effectively while exposed to the noise encountered in such environments.

Most fluid amplifiers are vented to the ambient atmosphere. The vents allow the elimination of any fluid not required for amplifier operation. Since noise is a variation of atmospheric pressure, it is possible that the vents might allow noise to enter the amplifier. The noise might then interfere with the steady flow of fluid through the amplifier, causing changes in fluid amplifier performance.

Previous Investigations

In the literature surveyed, no evidence was found to indicate that any type of fluid amplifier has ever been tested to determine its ability to operate effectively in a broad-band noise environment. Broad-band noise is noise composed of an infinite number of sound frequencies at various amplitudes.

Several studies (Ref 5, 7, 11) have been made in single-frequency noise environments. Fluid amplifiers were tested in variable amplitude, single-frequency noise environments by Gottron (Ref 5), Hansen (Ref 7), and Weinger (Ref 11). Gottron introduced noise to the control port of a bistable amplifier and found that switching would occur when the noise was increased beyond a certain level. When noise was introduced to the control port of a proportional amplifier, the amplifier ceased proportional operation and began operating as an oscillator. Hansen found that bistable amplifier memory decreased as the environmental noise level was increased. Weinger found that the wall attachment point of the output fluid stream in a bistable amplifier moved downstream as the environmental noise level was increased beyond a certain level. The common conclusion of these tests is that noise of various amplitudes and frequencies does affect the operation of fluid amplifiers.

Purpose and Scope

The purpose of this study was to further determine how the operation of vented fluid amplifiers is affected by environmental noise. The study was limited to steady state fluid amplifier operation. Dynamic testing was not feasible due to a lack of suitable instrumentation. Two proportional amplifiers and one bistable amplifier were tested using air at room temperature as the working fluid. In the case of the proportional amplifiers, the investigation included noise effects on input and output flow rates, pressures, and resistances, as well as the pressure gain. In the case of the bistable amplifier, the only effects investigated were the effects on switching pressure and flow rate. The noise environment was limited to broad-band noise since it approximates jet and rocket engine noise more closely than does single-frequency noise. The maximum sound pressure level (SPL), or noise level, used during the testing was 163 decibels (re: 0.0002 dynes/cm^2).

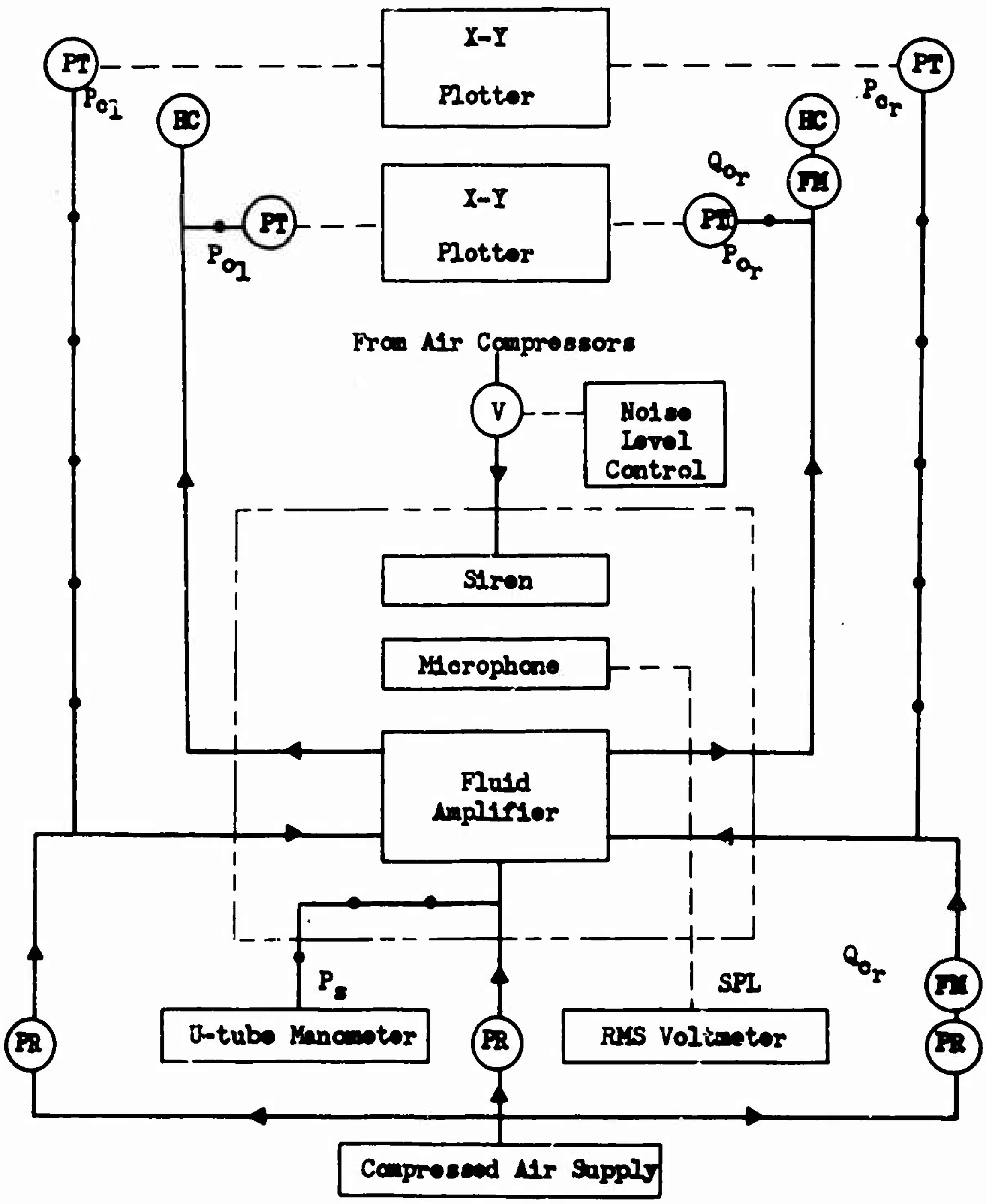
II. Apparatus

The experimental setup may be divided into two major sections: the equipment located within the noise environment and the equipment located outside of the noise environment. Except for some of the controls (described in Appendix B) and the siren, all of the equipment is available commercially. Equipment specifications are listed in Appendix B. Figure 1 is a schematic of the apparatus used in the experimental setup.

Equipment Located Within the Noise Environment

The equipment located within the noise environment is shown in Figure 2. The noise environment was provided by the siren, which is described fully in Ref 3. The siren is located in the reverberation chamber of the Air Force Aeromedical Research Laboratories, Biodynamics and Bionics Division. Typical octave band spectra analyses of the siren noise are shown in Figure 3. The noise spectrum 105 feet from an Atlas missile during launch is shown for comparison (Ref 8:23).

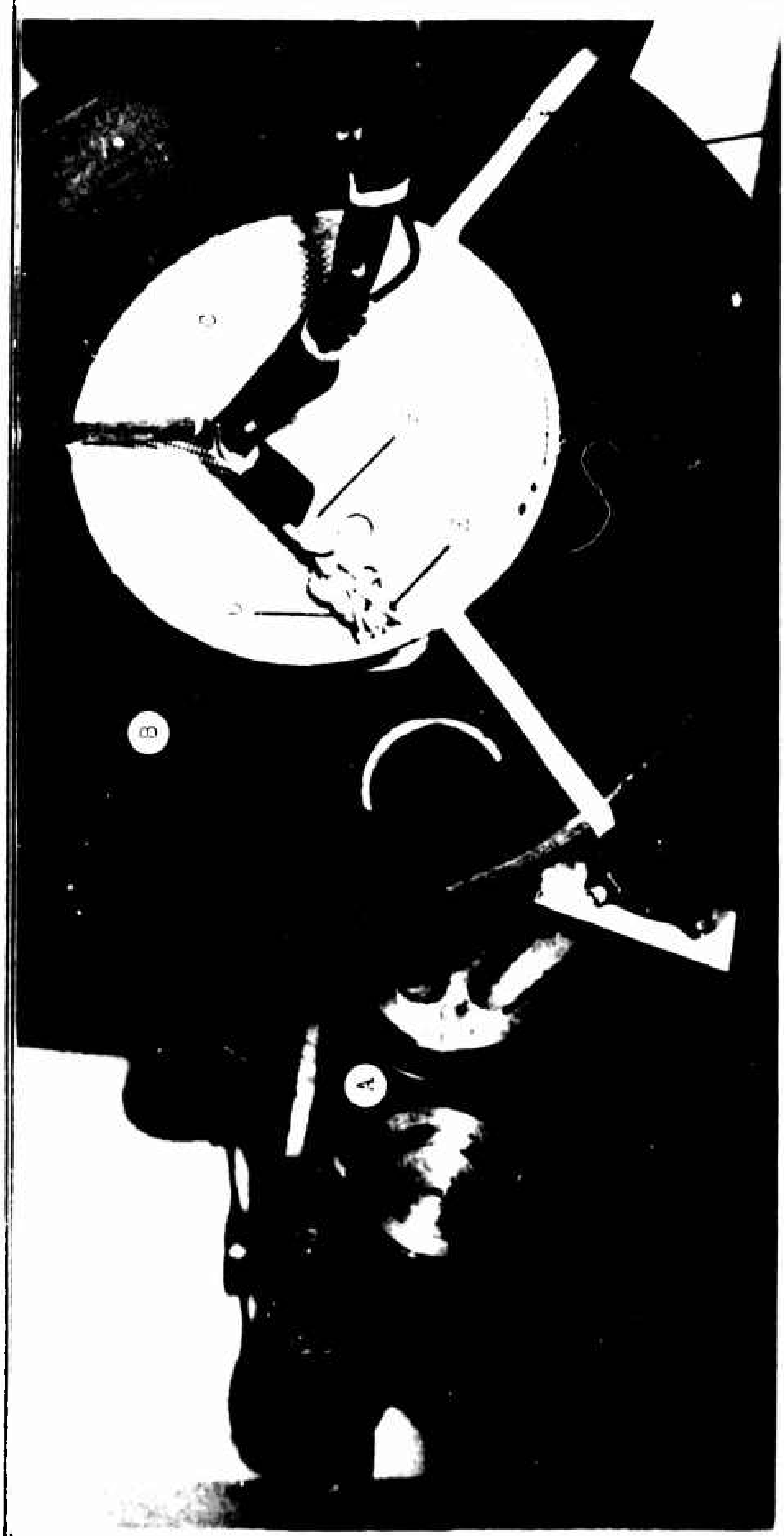
The fluid amplifiers used are shown in Figures 4 and 5. The amplifier being tested was located inside the horn, Figure 2, 16 in from the mouth of the horn. This was done to obtain higher noise levels than would otherwise have been possible. The microphone was located directly above the amplifier being tested so that the head of the microphone was the same distance inside the horn as were the amplifier vents. The microphone was wrapped in foam rubber to prevent vibration which might be picked up by the microphone and erroneously indicated as noise (Ref 2:757). A conical windscreen, Figure 2, was placed upstream of the microphone and fluid amplifier to reduce the siren airflow striking these components. The windscreen thereby



Legend:

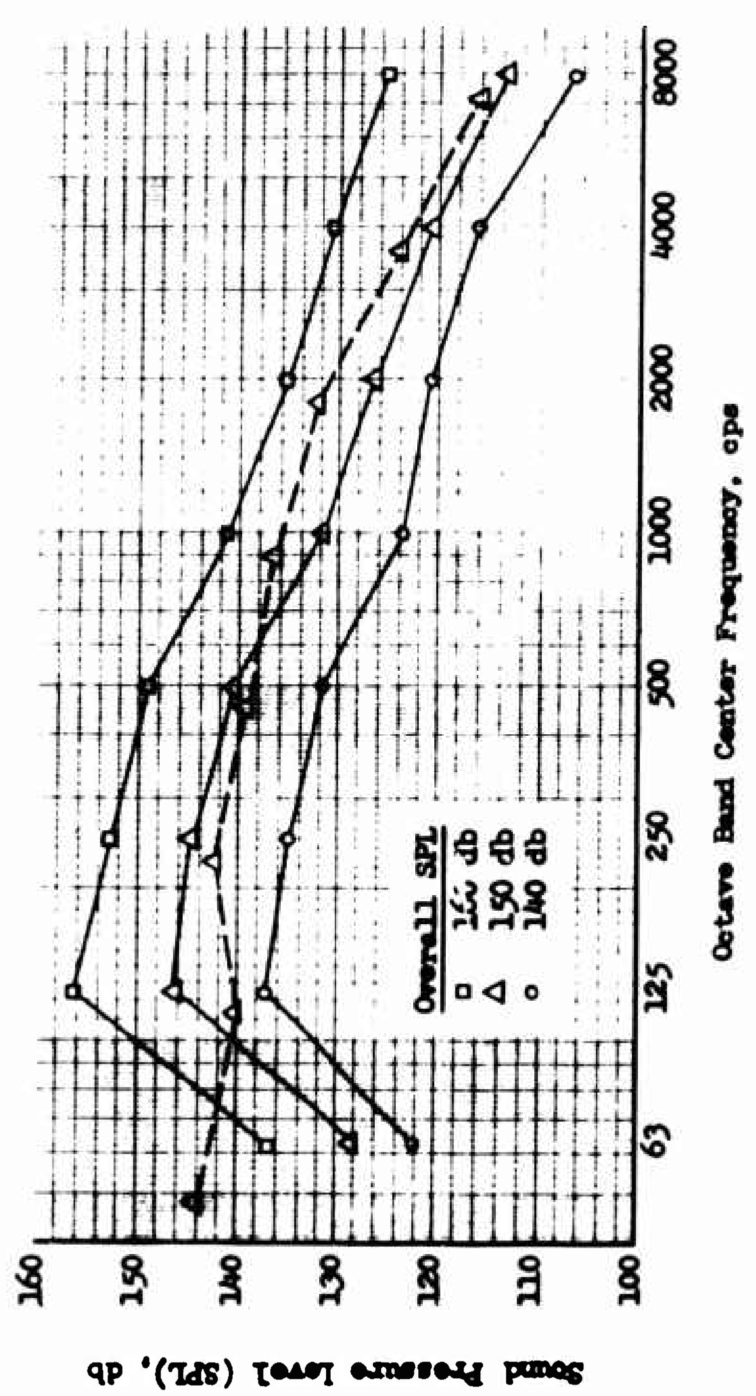
FM...Flow Meter — Fluid Line
HC...Hose Clamp — Direction of Flow
PR...Pressure Regulator — Electrical Line
PT...Pressure Transducer — Pressure Line
V....Valve — Chamber Boundaries

Figure 1. Apparatus Schematic



A: Siren
B: Horn
C: Conical Windscreen
D: Microphone
E: Fluid Amplifier
F: Pressure Taps

Figure 2. Equipment Located Within the Noise Environment



Solid Line: Siren Spectra   Dashed Line: Atlas Missile Spectrum

Figure 3. Typical Noise Spectra

Left: Amplifier A Right: Amplifier B

Figure 4. Proportional Fluid Amplifiers

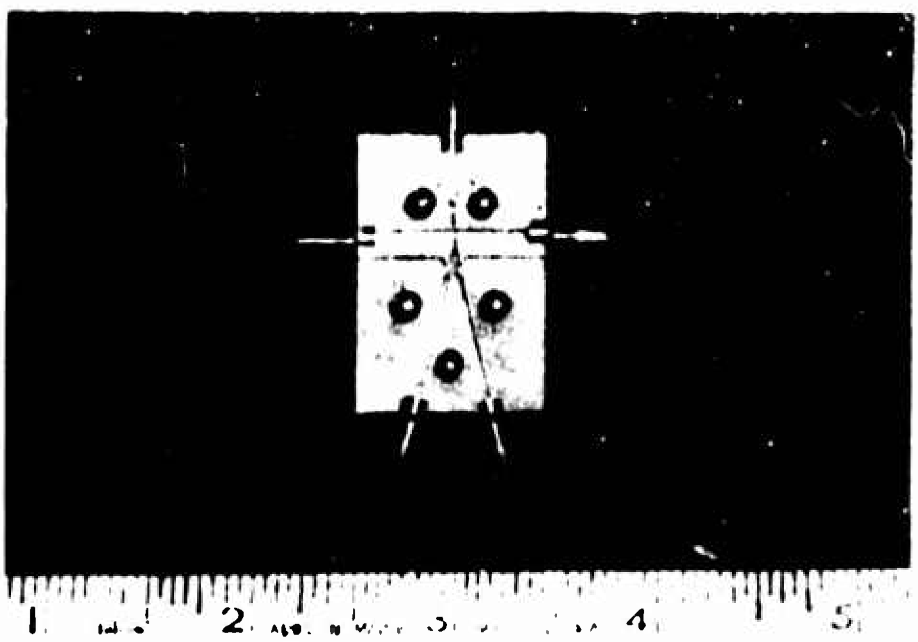


Figure 5. Amplifier C (Bistable)

reduced sound pressure level errors as well as dynamic pressure effects on amplifier operation (Ref 2:258). The direction of the siren airflow relative to amplifiers A and C was from top to bottom in Figures 4 and 5, and out of the page relative to amplifier B in Figure 4.

Short lengths of neoprene tubing were used to connect the ports of the amplifier to a static pressure tap for each port. The pressure taps were connected to the pressure lines. The five flow lines and the five pressure lines were run between the foam rubber seals of the two chamber doors to the control and monitoring equipment outside of the chamber.

Equipment Located Outside of the Noise Environment

The equipment located outside of the noise environment is shown in Figure 6. The noise level in the chamber was controlled by means of the noise level control unit. This device actuated an electro-mechanical valve in the air line upstream of the siren. A root-mean-square (rms) vacuum tube voltmeter was used to measure the sound pressure level. This type of voltmeter provides more accurate measurements of broad-band noise levels than any other type of voltmeter (Ref 10:42).

Control and supply pressures were controlled by pressure regulators, while the output pressures were controlled by mechanical tubing clamps at the ends of the output flow lines. The supply pressure was measured by means of a U-tube mercury manometer. Differential pressure transducers referenced to ambient conditions outside the noise chamber provided input signals to X-Y plotters which recorded the control and output pressures. Control and output volumetric flow rates (Q_c and Q_o) were determined by means of flowmeters (rotometers).

A: X-Y Plotters

B: Amplifier Air Supply

C: Pressure Regulator Panel

D: Flow Meters

E: RMS Voltmeter

F: Noise Level Control

Figure 6. Equipment Located Outside of the Noise Environment

III. Test Procedures

Terminology

Before describing the test procedures used, it is necessary to define several terms which will be used throughout the remainder of the report. Several of these terms are shown in Figure 7. For explanatory purposes, a time varying signal has been used even though time varying parameters were not considered in this study.

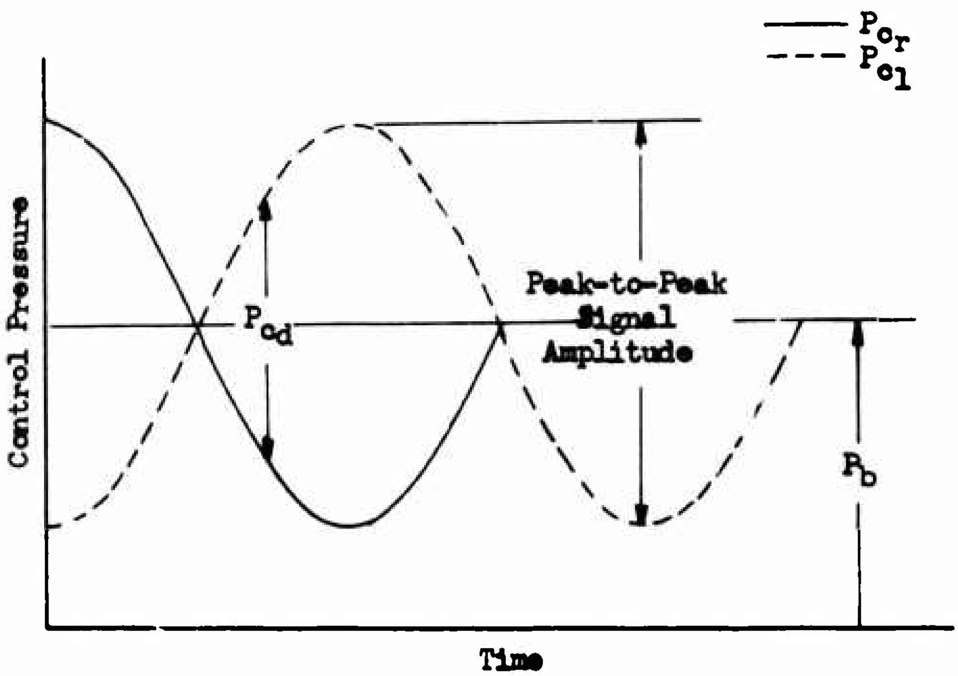


Figure 7. Typical Input Signal

The peak-to-peak signal amplitude is the difference between the maximum and minimum values of the input signal. Unless stated otherwise, the term "signal amplitude" refers to the peak-to-peak signal amplitude. Bias pressure (P_b) is defined as the instantaneous mean value of the left and right control pressures (P_{c_l} and P_{c_r}). If similar input signals 180° out of phase are applied to the control ports of a proportional fluid amplifier, P_b will remain constant.

Differential control pressure (P_{c_d}) is defined as the difference between the instantaneous values of control pressure at the left and right control ports, $P_{c_l}-P_{c_r}$. Similar terminology applies to flow signals and output pressure signals. Q_{c_d} is the differential control flow, P_{o_d} the differential output pressure, and P_{o_l} and P_{o_r} the left and right output pressures.

Proportional Amplifier Test Procedures

General. The behavior of a fluid amplifier can be described by three sets of data: input characteristics, transfer characteristics, and output characteristics. The input characteristic of a single control port is the variation of control flow rate due to a change in control pressure. The input characteristics determine the load an input signal sees when it is applied to the control ports. The transfer characteristics are the pressure gain curves of the amplifier; they show what happens to the output signal when an input signal is applied. The output characteristic of a single output port is the variation of output flow rate and output pressure due to a change in control pressure or amplifier output loading. The output characteristics thus determine how the output signal is affected when an external load is connected to the output ports (Ref 1:21).

Proportional fluid amplifiers like those used in this study are mechanically symmetrical, so far as manufacturing tolerances will allow. For this reason, any measurements made on the right control or output ports would agree closely with those made on the left control or output ports, provided the same input signal and output load were used on the left ports as had been used on the right ports. For this reason, input and output characteristics data were taken only on the right side of the amplifiers tested.

Input Tests. Initial values of supply pressure, bias pressure, and differential control pressure were set with the noise off. The noise off condition referred to is one in which no air was flowing through the siren. The siren rotors were in operation, however, and produced a sound pressure level of 109 db at the amplifier location during noise off operation. The sound pressure level was increased and recorded at various intervals, along with the resulting right control pressure and flow rate. The procedure was repeated for other values of differential control pressure. Additional runs were made using other combinations of supply and bias pressure. Control pressure values were recorded at a sound pressure level of 162 db.

Gain Tests. Initial values of supply pressure and bias pressure were set with the noise off. The differential control pressure was set to 0 in Hg, and the output pressures were balanced by adjusting the hose clamps on the output flow lines. The values of the control and output differential pressures were recorded with the noise off and at a sound pressure level of 161 db. The procedure was repeated for other values of differential control pressure. Other gain curves were obtained by resetting the hose clamps or by changing the supply pressure and repeating the above procedure.

Output Tests. Output tests were conducted only on amplifier B, since the flowmeters available were not sensitive enough to determine the effects on amplifier A. The differential control pressure was initially set to 0 in Hg, and the output pressures were balanced by adjusting the hose clamps on the output flow lines. The output pressure and flow rate were recorded with the noise off and at a sound pressure level of 161 db. The procedure was repeated for differential control pressures of plus and minus 5 percent of supply pressure. Additional runs were made by resetting the differential control pressure to 0 in Hg, rebalancing the output pressures at a new value, and repeating the above procedure.

Bistable Amplifier Test Procedures

Switching Pressure Tests. The supply pressure and left control pressure were set to their initial values with the noise off. The left control pressure was set to 0 in Hg gage for all runs. At the start of each test, the jet was attached to the left wall of the amplifier. The right control pressure was decreased until the jet switched and attached to the right wall. The right control pressure was recorded at the time switching occurred. The sound pressure level was then set to 157 db and the test repeated. Additional runs were made at other values of supply pressure. The jet was not switched by increasing the control pressure on the side of the amplifier to which the jet was attached because the results obtained in that manner were not reproducible. At times the switching pressure was reduced due to noise, at other times, increased. The 157 db noise level was the highest that could be obtained without continuous adjustment of the noise level control. Use of this noise level thereby eliminated operation of one control and monitoring of one instrument during the test.

Switching Flow Rate Tests. The procedure used was essentially the same as that used for the switching pressure tests above. During the flow rate tests, however, the left control port was open to the ambient atmosphere outside of the noise environment. In addition, the flow rate was recorded rather than the pressure, and the noise level was 160 db rather than 157 db. Use of the flow-metering clamp described in Appendix B made adjustment of the pressure regulator unnecessary, thereby making feasible the continuous adjustment of the noise level control required to obtain the higher noise level. In addition to the above test, the switching flow rate was determined for various noise levels for one value of supply pressure.

IV. Results and Discussion

Two preliminary tests were performed to insure that any measurements taken would reflect only the effect of noise on the fluid amplifier. The first test was to insure that the noise level outside the chamber would not affect the transducers, which were referenced to the ambient atmosphere. The transducers were located behind the pressure regulator panel, Figure 6. With the sound pressure level in the chamber at 163 db, the noise level at the transducer location was found to be 113.5 db. This figure represents a pressure fluctuation of less than 0.002 psi. Since the most sensitive transducer used had a full scale range of 1 psid, this figure would represent a fluctuation of only 0.2 percent of full scale--a smaller value than the hysteresis claimed for the transducer. The second test was to insure that pressure and flow measurements would not be in error due to compression of the lines by the large amplitude sound pressure levels inside the chamber. A control flow line was connected directly to an output flow line at the amplifier location, bypassing the amplifier. The sound pressure level was then increased to 163 db, but no detectable changes occurred in the steady state flows and pressures.

The test results which follow are presented in the same order as were the test procedures. In the Input Tests section of the proportional amplifier test results, there are several graphs which have been plotted from the same data. The purpose of displaying the same information in different forms is to show how the magnitude of the noise effects are determined by the various parameters involved. All values of control pressure were obtained with the noise off, unless otherwise indicated. In many instances, pressure or flow signals are discussed.

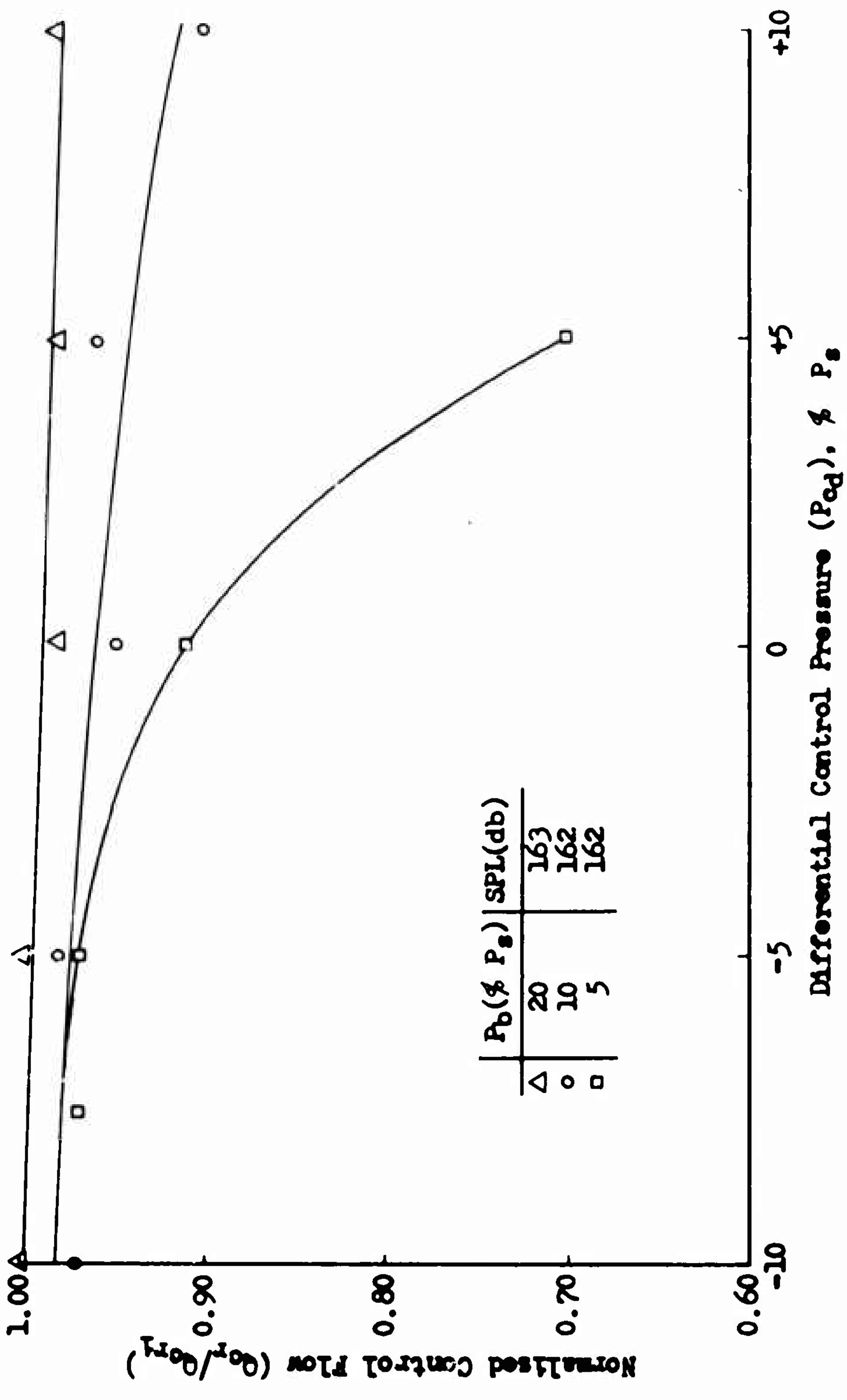
These discussions assume a slowly varying signal--one in which the frequency is so low that no dynamic effects are encountered. The tabulated data from which the graphs were plotted can be found in Appendix A.

Proportional Amplifier Test Results

Input Tests. Figure 8 shows the decrease in control flow due to noise for several values of bias pressure. For a given supply pressure and input signal amplitude, the decrease in control flow is greatest for the lowest bias level. For any given bias level, it can be seen that the decrease in the right control flow is small at negative differential control pressures, i.e., when $P_{c_r} > P_b > P_{c_l}$. Conversely, the decrease in the right control flow is large at positive differential control pressures, i.e., when $P_{c_l} > P_b > P_{c_r}$. This indicates that if the input flow signal distortion is to be reduced, higher bias levels are required for large input pressure signal amplitudes than for small input signal amplitudes. The bias pressure is normally chosen so as to give the highest pressure gain possible. Depending on the application, however, it may be necessary to sacrifice gain by choosing a bias level greater than that which would give maximum gain so as to maintain input flow signal fidelity.

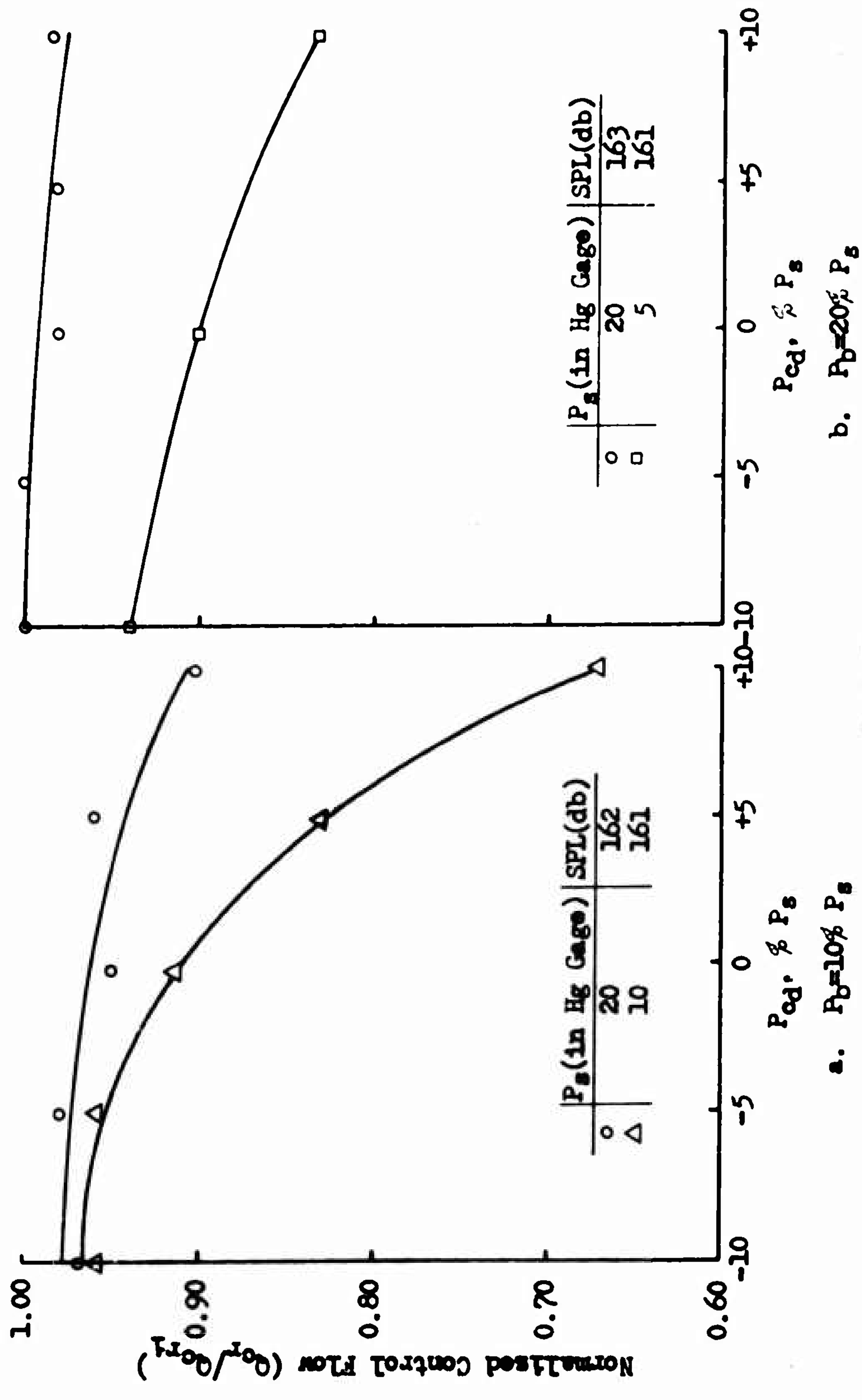
In Figure 8 and many of the following figures, a normalized flow rate, $Q_{c_r}/Q_{c_{r_i}}$, is used. The initial control flow, $Q_{c_{r_i}}$, is constant only if the plotted curve is one for which the control pressure is constant, as can be seen in Table A-5, Appendix A. If the plotted curve is not a line of constant control pressure, then $Q_{c_{r_i}}$ has a different value for each data point, as can be seen in Table A-1, Appendix A.

Figure 9a shows the decrease in control flow due to noise for two values of supply pressure at a 10 percent bias level. Figure 9b shows



Amplifier A P_s=20 in Hg Gage

Figure 8. Effect of Bias Level on Control Flow Decrease Due to Noise

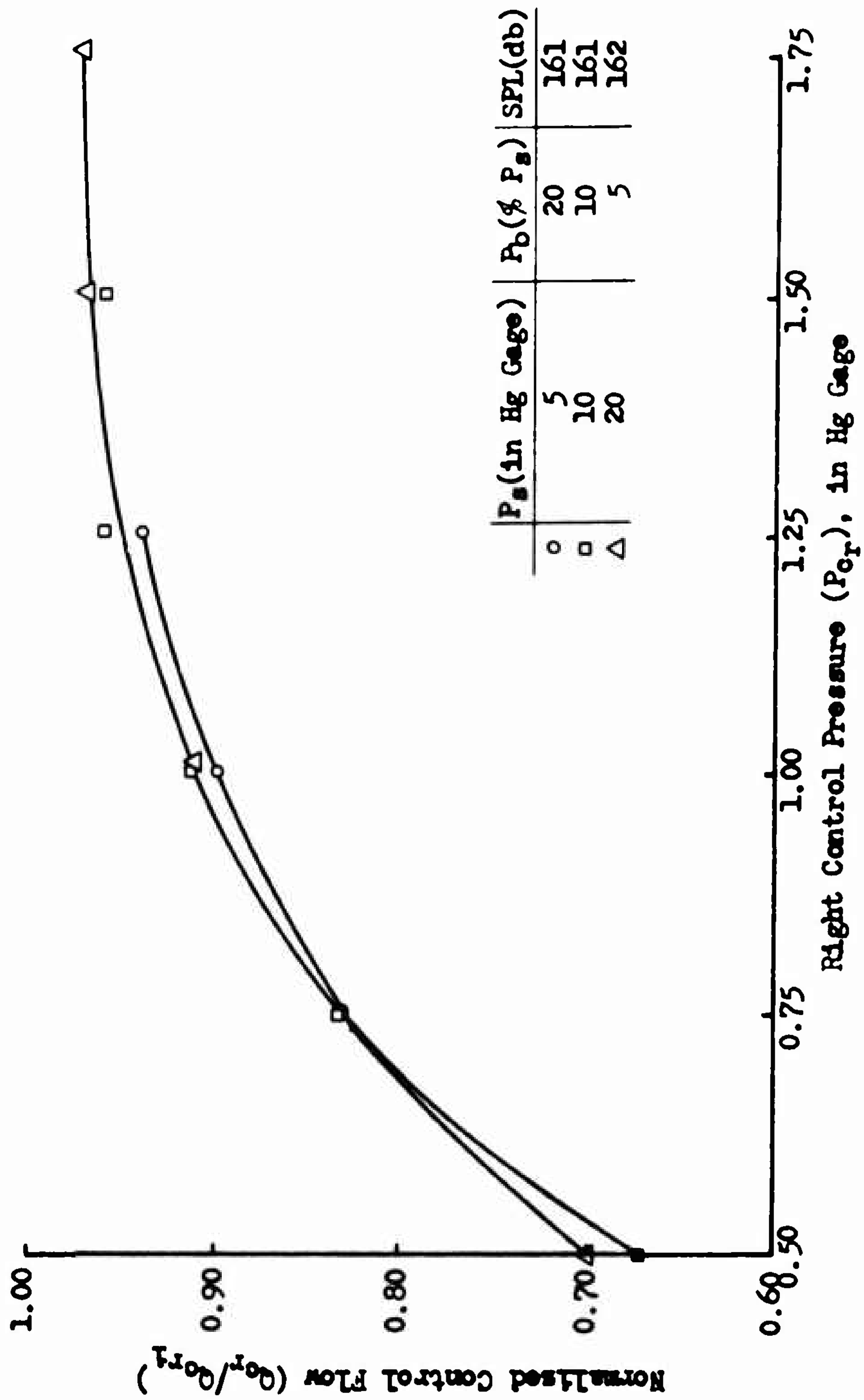


Amplifier A

Figure 9. Effect of Supply Pressure on Control Flow Decrease Due to Noise

similar data for a 20 percent bias level. In both cases, it can be seen that for a given bias level and input signal amplitude, the decrease in control flow is greater at the lower value of supply pressure. For any given supply pressure, it can be seen that the decrease in the right control flow is small at negative differential control pressures, when $P_{c_r} > P_b > P_{c_l}$. Conversely, the decrease in the right control flow is large at positive differential control pressures, when $P_{c_l} > P_b > P_{c_r}$. This indicates that if the input flow signal distortion is to be reduced, higher supply pressures are required for large input pressure signal amplitudes than for small input pressure signal amplitudes.

In Figure 8 it was shown that high bias levels reduce the effect of noise on flow rate. In Figure 9 it was shown that high supply pressures had a similar effect. These observations indicate that it is a high bias gage pressure that is actually desirable. In both figures it was shown that the noise effects on the right control flow were greater when the right control pressure was less than the left control pressure. This observation indicates that high values of control pressure are less affected by noise than low values of control pressure. This is shown explicitly in Figure 10. Figure 10 shows the effect of control pressure on the control flow decrease due to noise. Data have been plotted for three combinations of supply pressure and bias level. From the close agreement between these curves, it is concluded that any combination of supply pressure, bias level, and input signal that would produce a control pressure within the range shown would result in a control flow decrease approximately equal to that given for the curves shown in Figure 10. Referring to

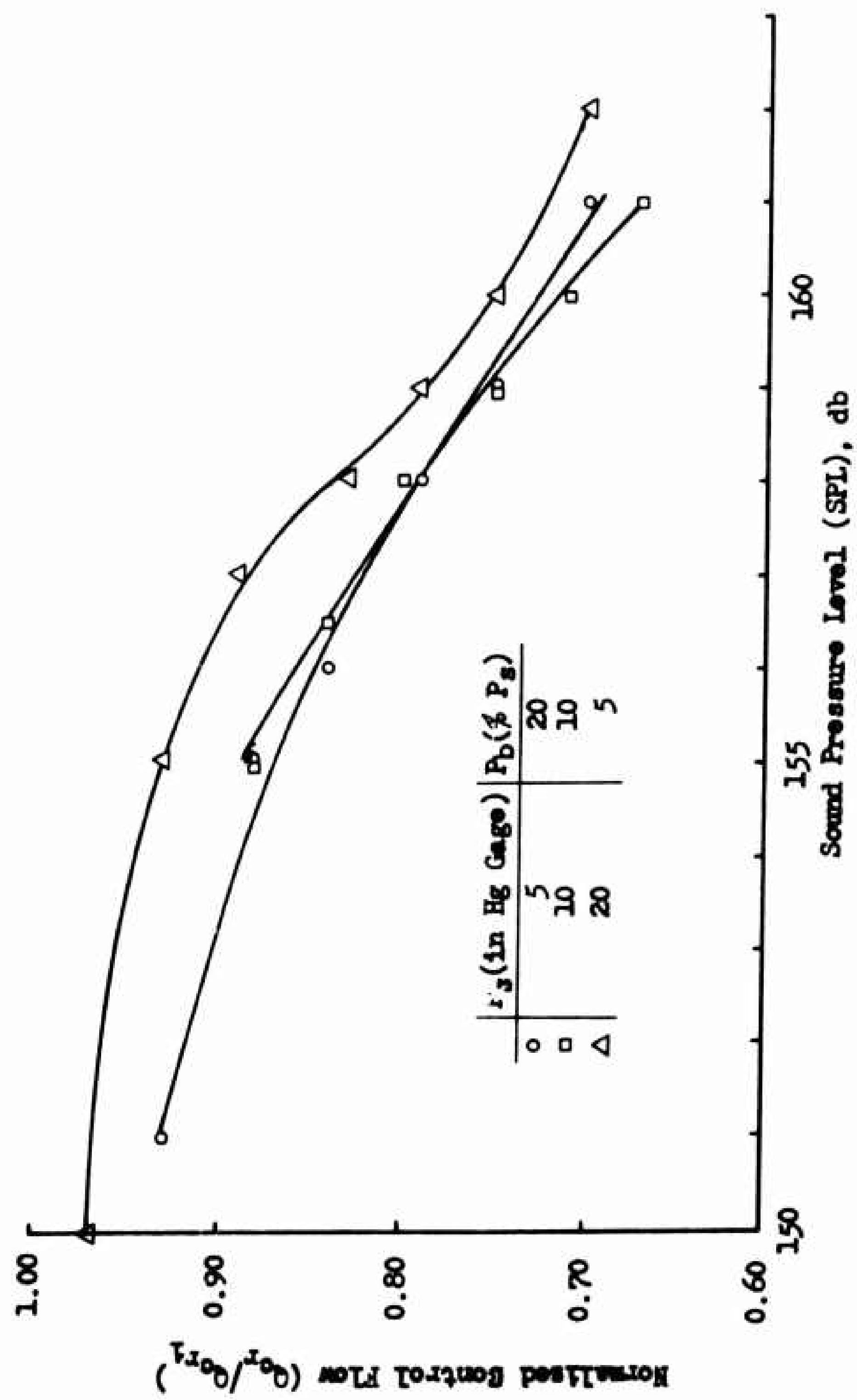


Amplifier A

Figure 10. Effect of Control Pressure on Control Flow Decrease Due to Noise

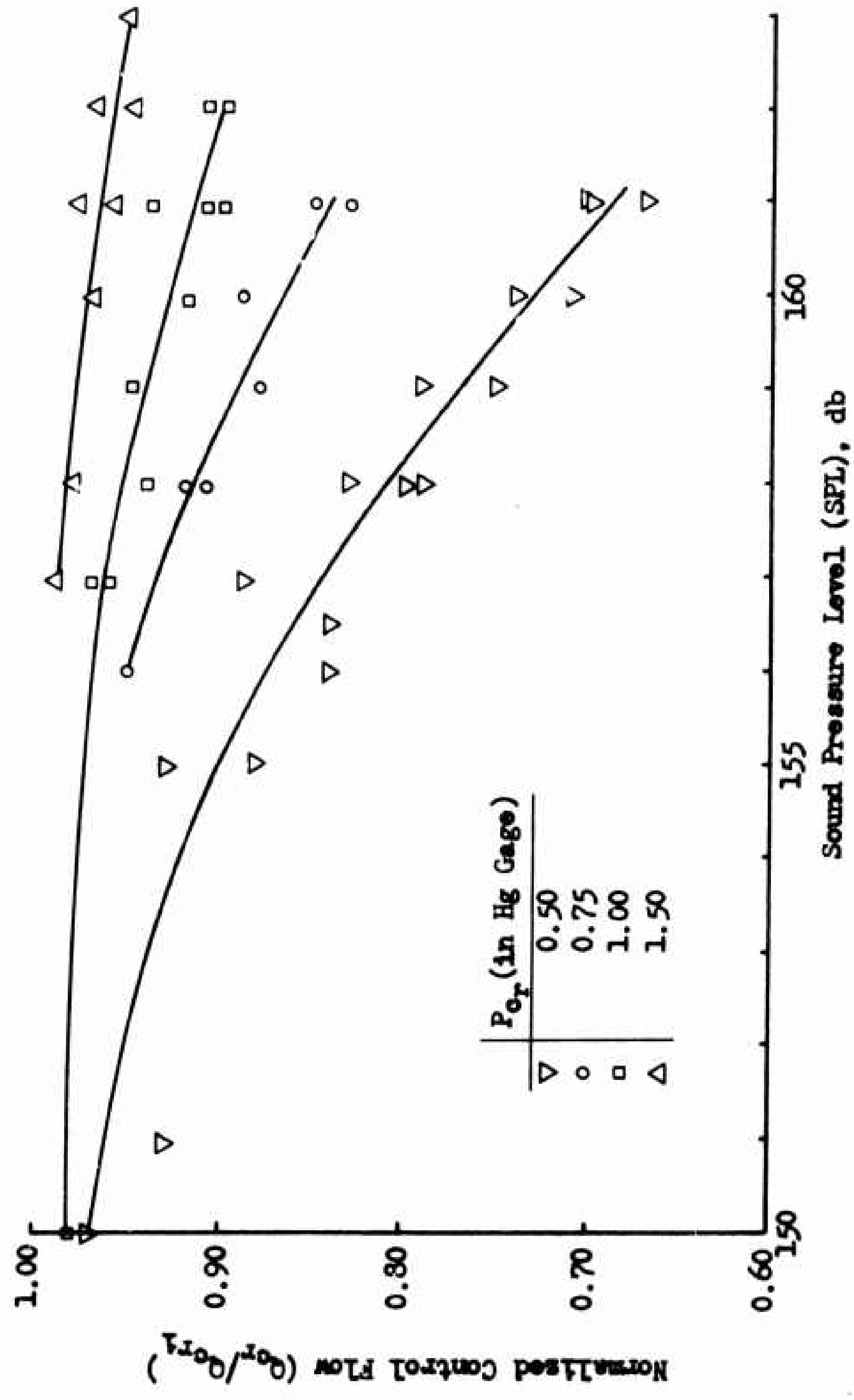
Figure 10, if a 0.5 in Hg peak-to-peak input pressure signal varies between 1.25 and 1.75 in Hg gage, it can be seen that the variation in control flow decrease and the resulting distortion of the input flow signal will be small. If the same amplitude signal is applied between 0.50 and 1.00 in Hg gage, the variation in control flow decrease and resulting distortion will be quite large. In either case, input pressure signal with an amplitude less than 0.5 in Hg would result in a smaller variation in control flow decrease. Consequently, a high value of bias gage pressure, as previously suggested, together with a small amplitude input pressure signal will result in minimum distortion of the input flow.

Figure 11 shows the effect of noise level on control flow decrease for a control pressure of 0.5 in Hg gage. Data for three combinations of supply pressure and bias level have been plotted individually to show the variation between runs having different values of these parameters. At higher values of control pressure, variations between runs were less. There were few data points obtained on any given run because the flowmeter could not be read accurately unless the float was aligned with one of the scale divisions. Consequently, data points from several runs were plotted to define the curves in Figure 12. Figure 12 shows the effect of control pressure on control flow decrease with noise level for several values of control pressure. Control flow decrease and rate of decrease with respect to noise level are both seen to be greater at low values of control pressure than at high values. Other data were obtained for values of control pressure ranging from 1.75 to 5.00 in Hg gage. In general, the above trend continues, with no decrease in control flow with noise levels up to 163 db when the



Amplifier A $\quad P_{o_r}$=0.50 in Hg Gage

Figure 11. Effect of Noise Level on Control Flow Decrease for P_{o_r}=0.5 in Hg Gage



Amplifier A

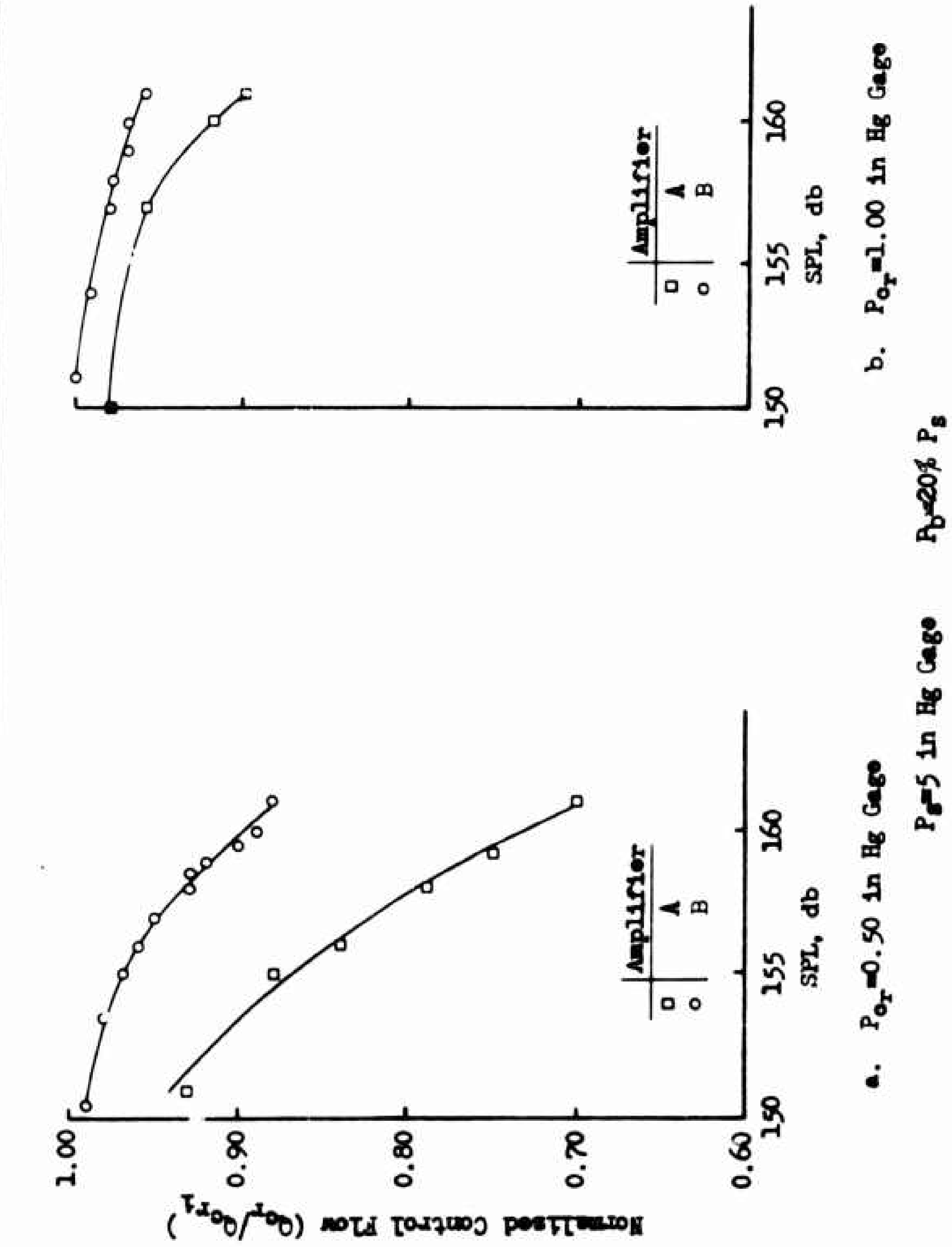
Figure 12. Effect of Control Pressure on Control Flow Decrease With Noise Level

control pressure was above 4.5 in Hg gage.

Figure 13 shows the effect of control flow on the decrease in control flow with noise level. Data for both amplifiers are plotted for two values of control pressure. For a given value of control pressure, the amplifier having the higher control flow is seen to be affected least. In this case, amplifier B had an average control flow 7.6 times that of amplifier A. At 161 db, a change in control pressure from 1.0 to 0.5 in Hg gage resulted in a decrease in control flow of 22 percent in amplifier A, but only 8 percent in amplifier B.

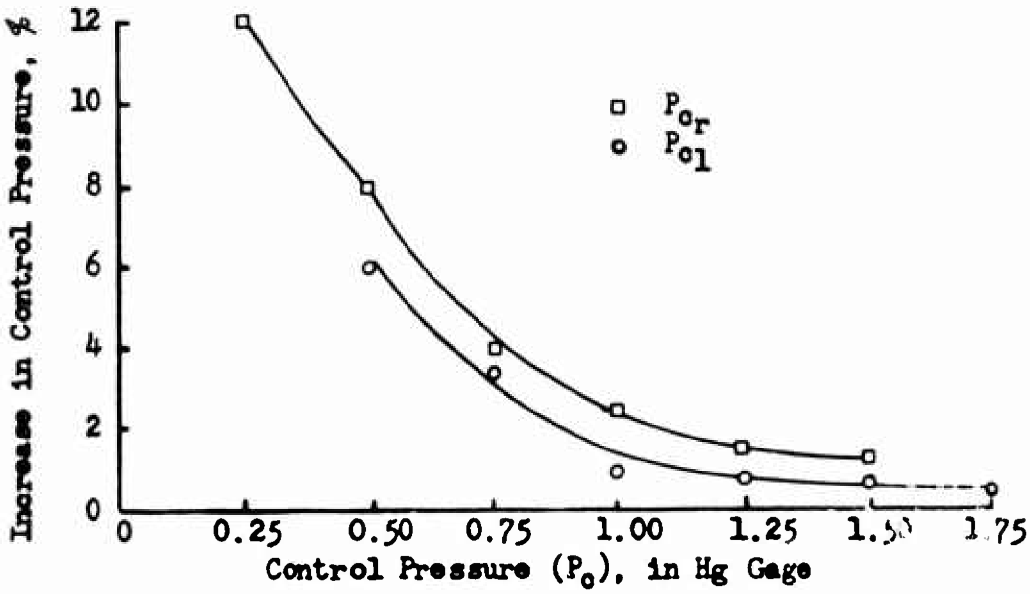
Figure 14 shows the effect of control pressure on the increase in control pressure due to noise. The incremental and percentage increases in control pressure are greatest at low noise-off values of control pressure, P_c. Since all values of control pressure increased with noise, the bias pressure also increased. This increase ranged between 1 and 3 percent for the data plotted in Figure 14. Since low pressures are increased more than high pressures, the magnitude of differential control pressure decreases due to noise.

Figure 15 shows the effect of noise on the right input characteristic of amplifier A for a bias pressure of 1 in Hg gage. Noise causes a larger decrease in control flow at low values of control pressure than at high values, causing distortion of the input flow signal. This variation in flow decrease was shown in Figures 10 and 12, and can be seen again in Figure 15. The input resistance of a fluid amplifier is defined as the reciprocal of the input characteristic slope at the point where the control pressure equals the bias pressure. Since the slope of the input characteristic increased due to noise, the input resistance of the amplifier decreased. Under the operating conditions



P_s=5 in Hg Gage P_b=20% P_s

Figure 13. Effect of Control Flow on the Decrease in Control Flow With Noise Level

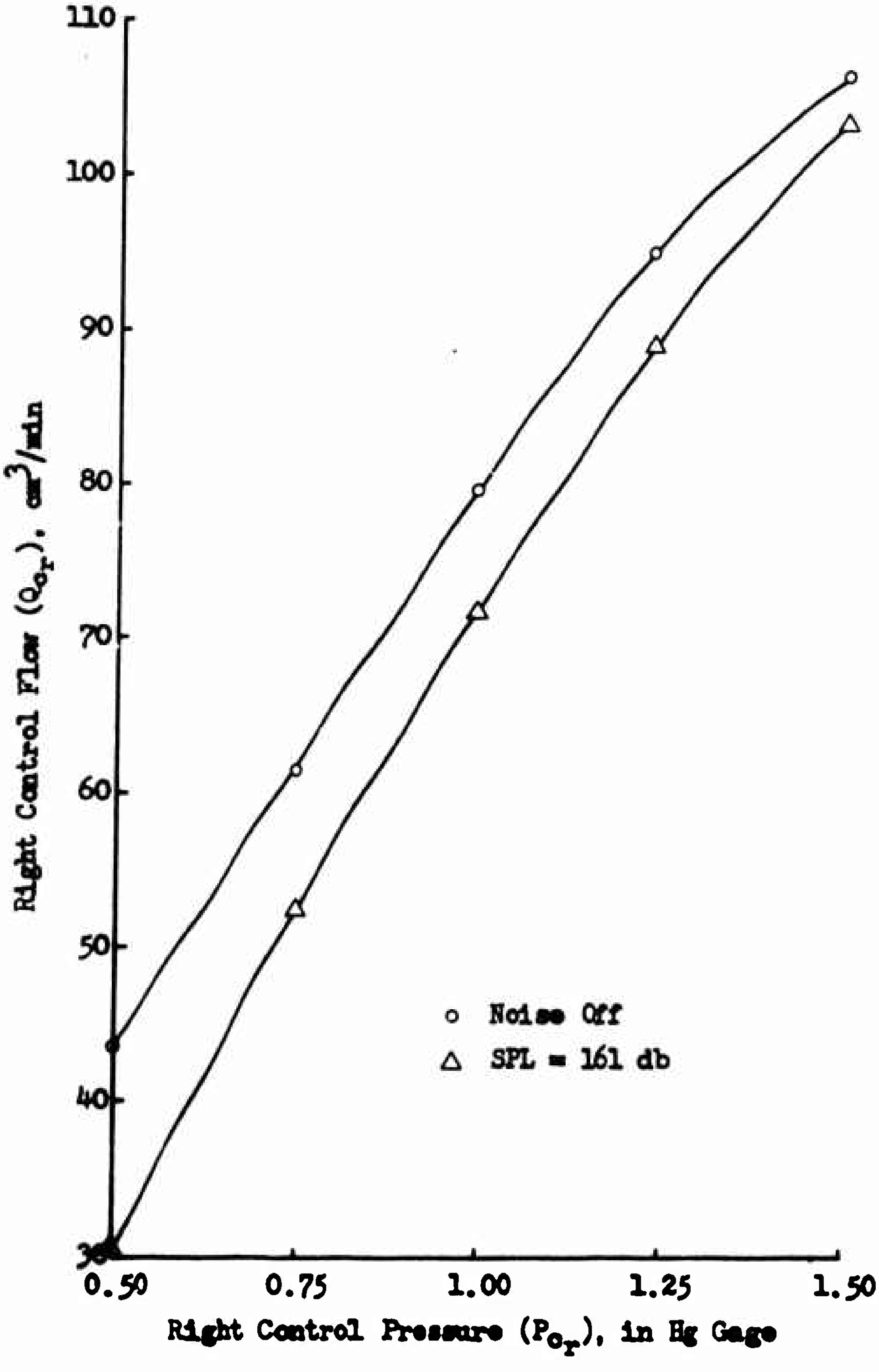


Amplifier B P_s=5 in Hg Gage P_b=20% P_s SPL=162 db

Figure 14. Effect of Control Pressure on the Increase in Control Pressure Due to Noise

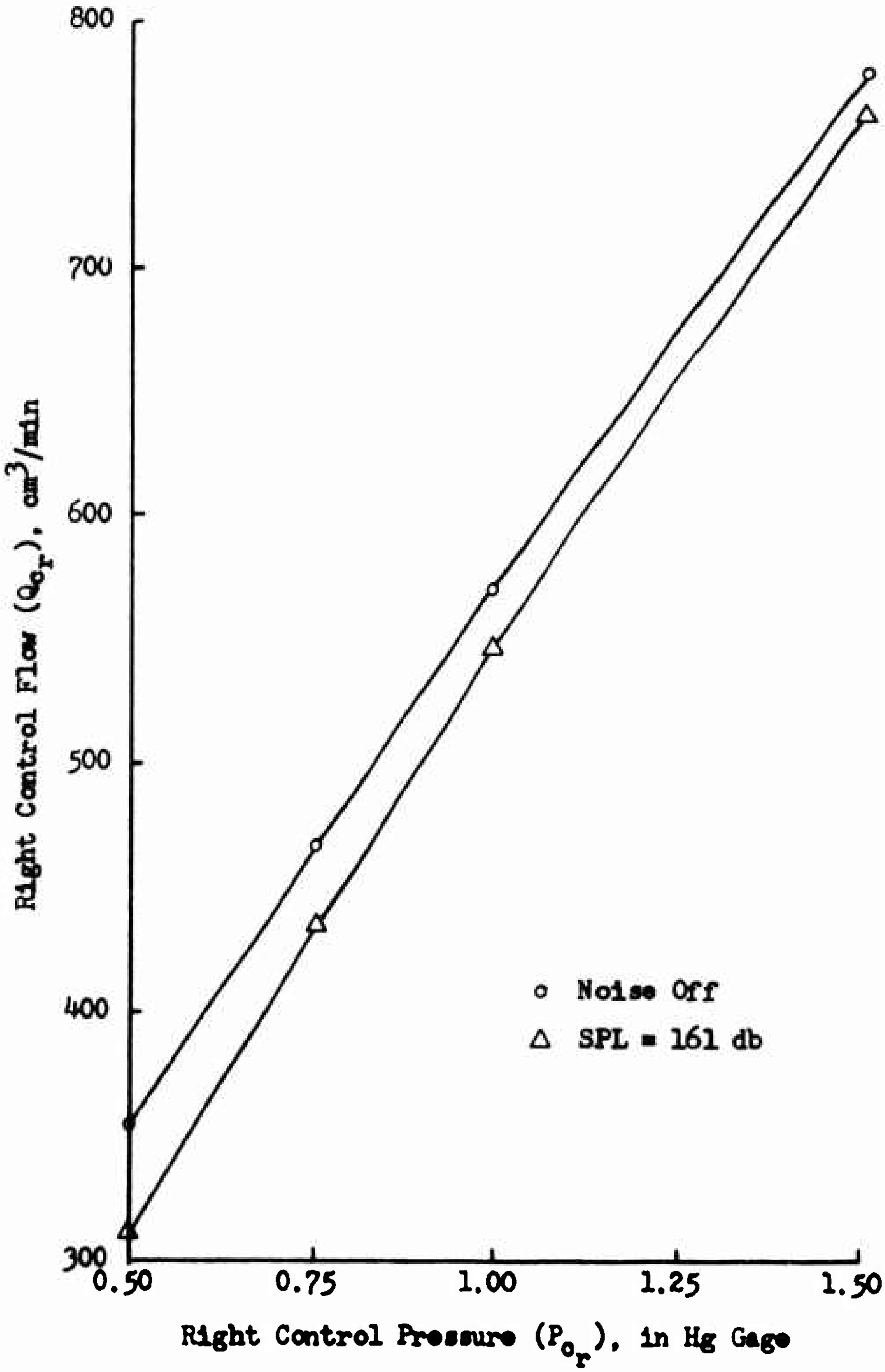
indicated in Figure 15, the decrease in input resistance was found to be 5 percent.

Figure 16 shows the effect of noise on the right input characteristic of amplifier B for a bias pressure of 1 in Hg Gage. The values of supply, bias, and differential control pressure were the same as those used with amplifier A, Figure 15. Due to the near linearity of the curves for amplifier B, it was difficult to obtain the input resistance as defined. However, using the end points of the two curves to obtain their average slopes to calculate the change in input resistance, the decrease obtained was 6 percent. Using the same points of Figure 15 to calculate the change in input resistance of amplifier A, a decrease of 11 percent was obtained. In Figures 15 and 16, only flow rate changes were plotted. The control pressure increase due to noise was not plotted in Figures 15 and 16, since data was taken only for



Amplifier A P_s=5 in Hg Gage P_b=20% P_s

Figure 15. Effect of Noise on Input Characteristics



Amplifier B P_s=5 in Hg Gage P_b=20% P_s

Figure 16. Effect of Noise on Input Characteristics

amplifier B. A check of the control pressure increase due to noise in amplifier A indicated that they were similar in magnitude to those obtained in amplifier B. Had the control pressure increase due to noise been included in the input characteristic curves, the effect would have been to further increase the slopes of the curves, thus further decreasing the input resistance. Inclusion of the pressure changes in Figures 15 and 16 would not affect the conclusion that the input resistance decreases less for the amplifier having the larger control flow at a given control pressure.

<u>Gain Tests</u>. Figure 17 shows the effect of gain on the variation of gain due to noise. The pressure gain of a fluid amplifier is defined as the change in differential output pressure divided by the change in differential control pressure. When the amplifier was in a high gain mode, Figure 17a, the variation in gain due to noise was negligible. When the amplifier was in a low gain mode, Figure 17b, the gain decreased at large values of differential pressure.

Figure 18 shows the effect of supply pressure on the variation of gain due to noise. When a high supply pressure was used, Figure 18a, the variation in gain was negligible. When a low supply pressure was used, the gain decreased at large values of differential pressure. In both Figures 17 and 18, the decrease in gain is seen to occur in the non-linear portion of the gain curve. Normally, fluid amplifiers are designed to operate at high gain in the linear portion of the gain curve. Consequently, the variation in gain due to noise will probably not be a problem in a practical situation.

<u>Output Tests</u>. Figures 19 and 20 show the effect of noise on the output characteristics of amplifier B for two values of supply pressure.

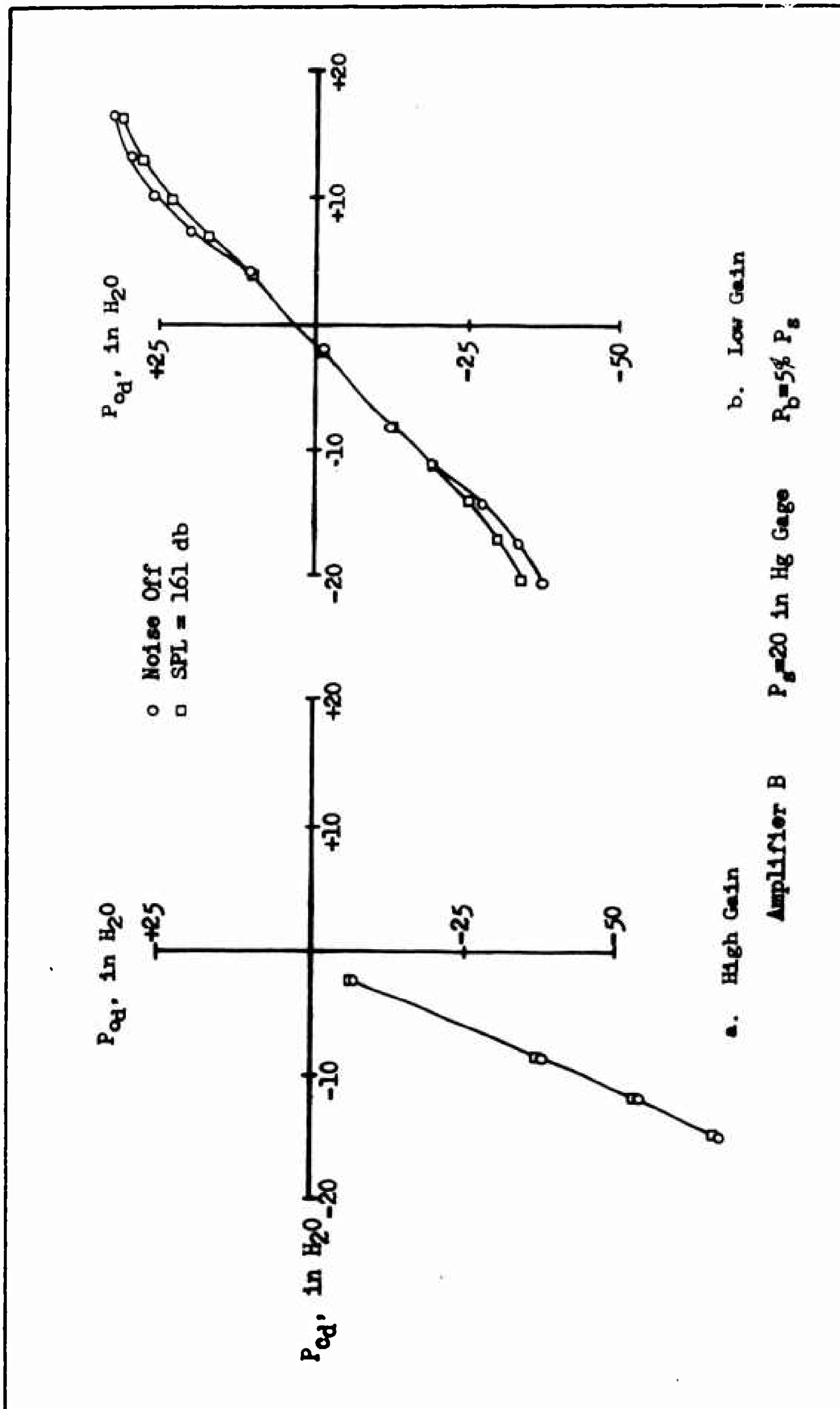
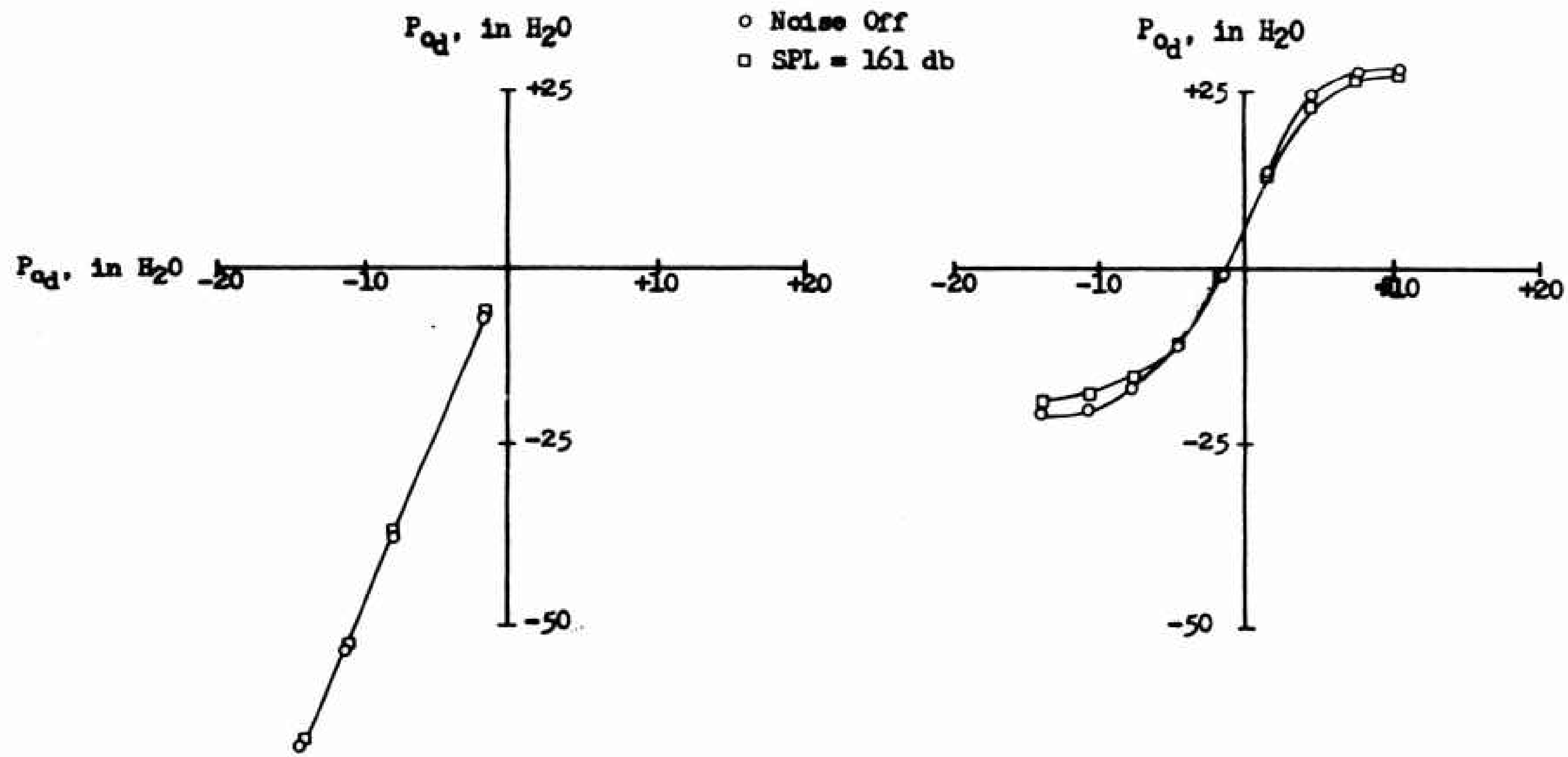


Figure 17. Effect of Gain on the Variation of Gain Due to Noise

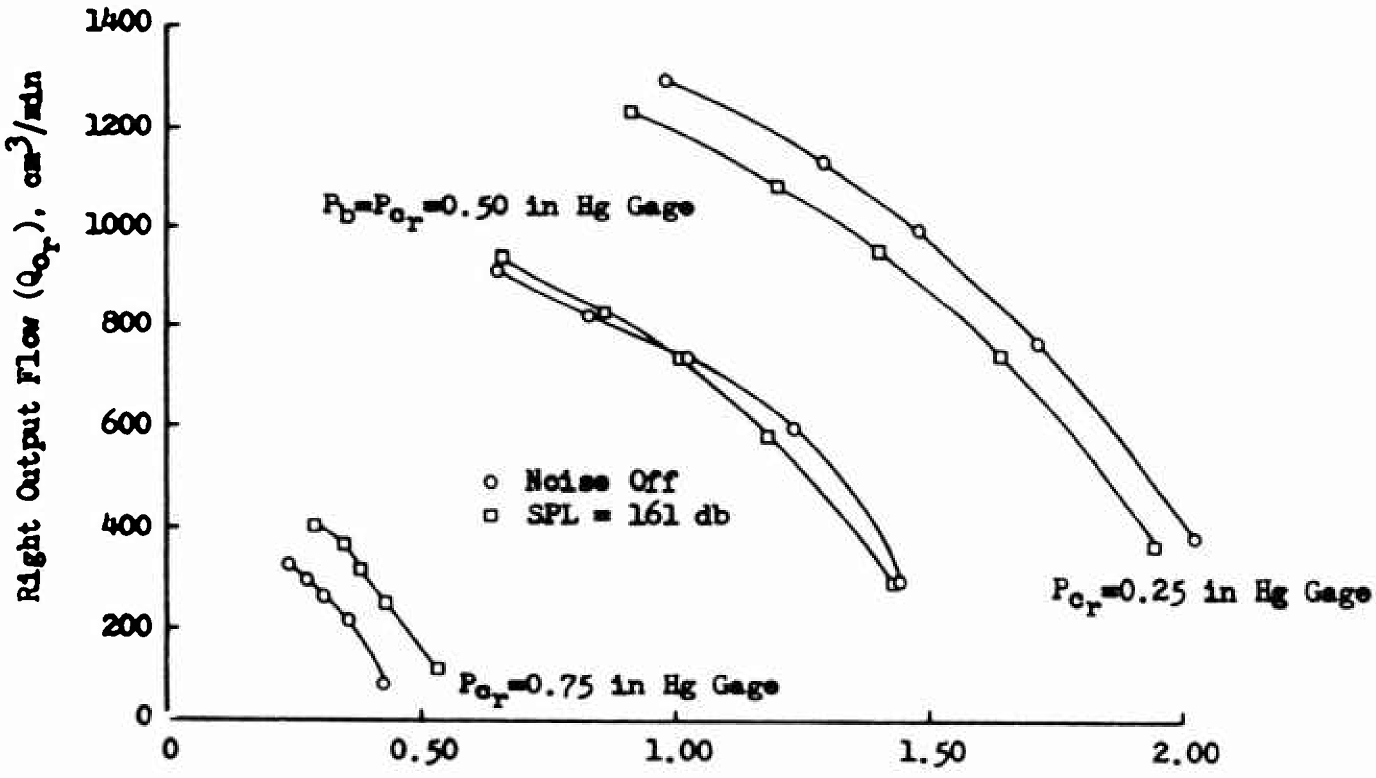


a. P_s=20 in Hg Gage

b. P_s=5 in Gage

Amplifier B

Figure 18. Effect of Supply Pressure on the Variation of Gain Due to Noise



Amplifier B $P_s=5$ in Hg Gage $P_b=10\%$ P_s

Figure 19. Effect of Noise on Output Characteristics

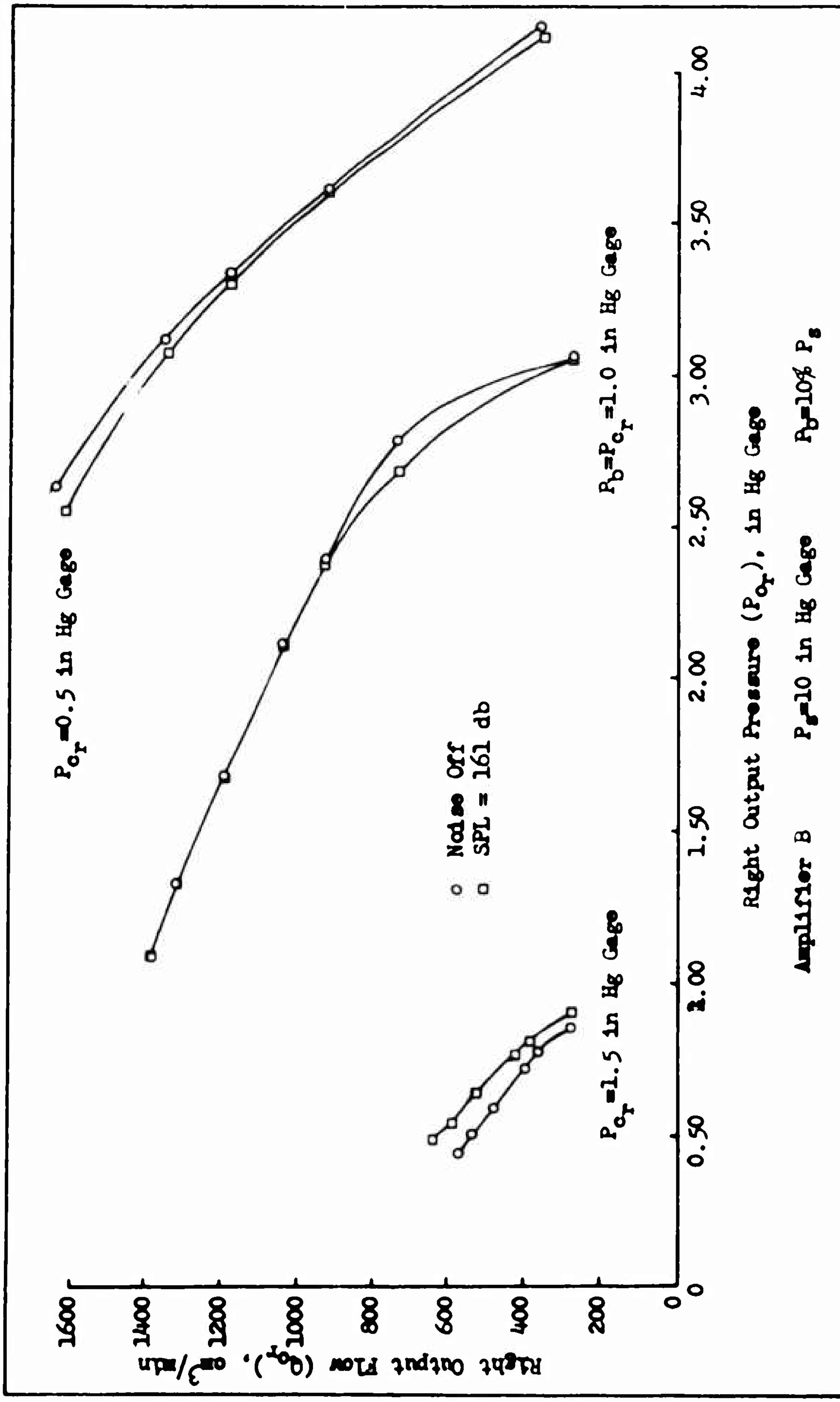


Figure 20. Effect of Noise on Output Characteristics

The trends are similar in both figures. When the right control pressure was less than the bias pressure, noise caused a decrease in the right output pressure and flow rate. When the right control pressure was greater than the bias pressure, noise caused an increase in the right output pressure and flow rate. These observations indicate that the differential output flow and pressure both decreased. The magnitude of the decrease depends on the load connected to the amplifier and the amplitude of the input signal to the amplifier.

A previous investigation of the parameters affecting power jet deflections in fluid amplifiers (Ref 9) offers possible reasons for the occurrences shown in Figures 19 and 20. It was found that the deflection angle is a function of many variables. Among these are the following: supply pressure, the ratio of bias pressure to supply pressure, and the control port area. As supply pressure is decreased, the jet deflection increases for constant values of control pressure (Ref 9: 126). As the ratios of bias pressure or differential control pressure to supply pressure increase, the jet deflection increases. As the control port area increases, the jet deflection increases (Ref 9:129).

In the present study, it was shown that the bias pressure increased due to noise, while the differential control pressure decreased due to noise. The changes in the two are approximately the same magnitude, therefore, they will make no net contribution to jet deflection. However, a change in control port area would still have an effect on jet deflection as discussed above. Consider the geometry of a proportional fluid amplifier as shown in Figure 21. The solid line B_1 represents the control jet boundary initially with no noise applied. The atmospheric pressure P_1 in the vent region causes the force F_1

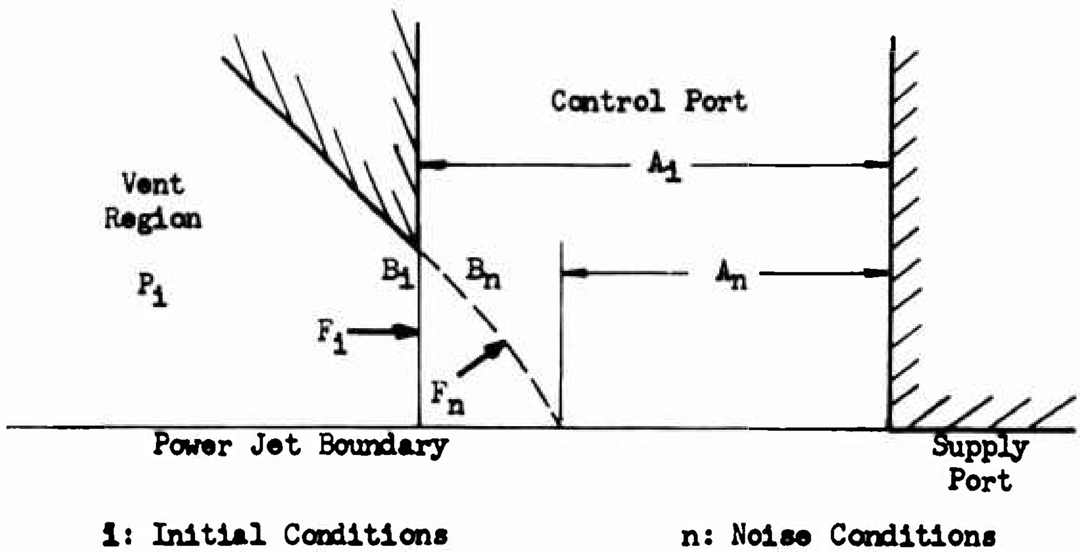


Figure 21. Proportional Amplifier Geometry

to be applied to the control jet boundary, giving it its initial shape. When a high noise level is present, the radiation pressure at the control jet boundary increases to P_n, increasing the force applied to the control jet boundary to F_n. This increase in force is very small--on the order of 0.02 in H_2O for a sound pressure level of 151 db (Ref 6:9). Although small, the increase in force may be sufficient to cause a deflection of the control jet boundary, thereby reducing the effective area of the control jet from A_1 to A_n.

In accordance with the findings of Moynihan (Ref 9), this would cause the power jet to deflect toward the control jet having the higher pressure. The effect would be to cause an increase in flow rate and pressure of the output stream nearer the high pressure control jet. As can be seen in Figures 19 and 20, this is precisely what happened.

Gottron (Ref 5:282) showed that noise applied to a digital fluid amplifier caused the differential output pressure to decrease, as it did in the proportional amplifier used in the present study. This phenomenon can probably be best explained as being caused by jet spreading. It has been shown (Ref 4) that noise has a definite effect on a free jet. When the jet was laminar, noise caused the jet to break up and spread, or "fan out" (Ref 4:1). This would cause part of a jet attached to one wall of a bistable fluid amplifier to spread over into the opposite output channel, as occurred in Gottron's experiment (Ref 5:282). Similarly, in a proportional amplifier, the output port having the greater amount of flow would show a decrease in flow and pressure due to jet spreading while the output port having the lesser amount of flow would show an increase in flow and pressure, causing the differential output pressure to decrease. When the jet was turbulent, noise caused the jet breakup point to move further upstream toward the supply nozzle (Ref 4:1). Consequently, there would be less jet spreading and a smaller resulting effect in the case of high supply pressures than there would be at low supply pressures, as can be seen in Figures 19 and 20. Thus, the effects noted in the proportional fluid amplifier due to noise can be explained by the phenomena of radiation pressure and jet spreading.

Bistable Amplifier Test Results

Switching Pressure Tests. Table 1 shows the effect of noise on the minimum right control pressure required to prevent the amplifier from switching when the left control pressure was set at 0 in Hg gage. Each run was repeated at least once, and in some cases as many as three times, to determine the scatter. There was relatively little scatter at low supply pressures, but large scatter at higher supply pressures.

For example, up to a supply pressure of 7 in Hg gage, the scatter was less than 0.01 in Hg. At a supply pressure of 18 in Hg gage, the scatter was 0.12 in Hg. The data given in Table 1 are average values of the control pressure required to prevent switching. In all cases, the 0 in Hg gage pressure at the left control port could effect switching against a higher right control pressure when noise was present than when it was not. Thus, for a fixed value of P_{c_r}, there would be a smaller value of P_{c_l} required to affect switching with noise present than without.

Table 1

Effect of Noise on Minimum Control Pressure

Required to Prevent Switching

P_s, in Hg Gage	Minimum P_{c_r} to Prevent Switching, in Hg Gage	
	Noise Off	SPL = 157 db
3	-0.03	0.07
4	-0.03	0.06
5	-0.02	0.08
6	-0.01	0.07
7	0.02	0.12
8	0.04	0.12
10	0.10	0.17
12	0.12	0.17
14	0.13	0.23
16	0.19	0.28
18	0.24	0.29

<u>Switching Flow Rate Tests.</u> Figure 22 shows the effect of noise on the switching flow for several values of supply pressure. The switching flow with noise is less than the switching flow without noise in all cases.

Figure 23 shows the effect of noise level on the switching flow. It can be seen that as the noise level increases, the switching flow decreases.

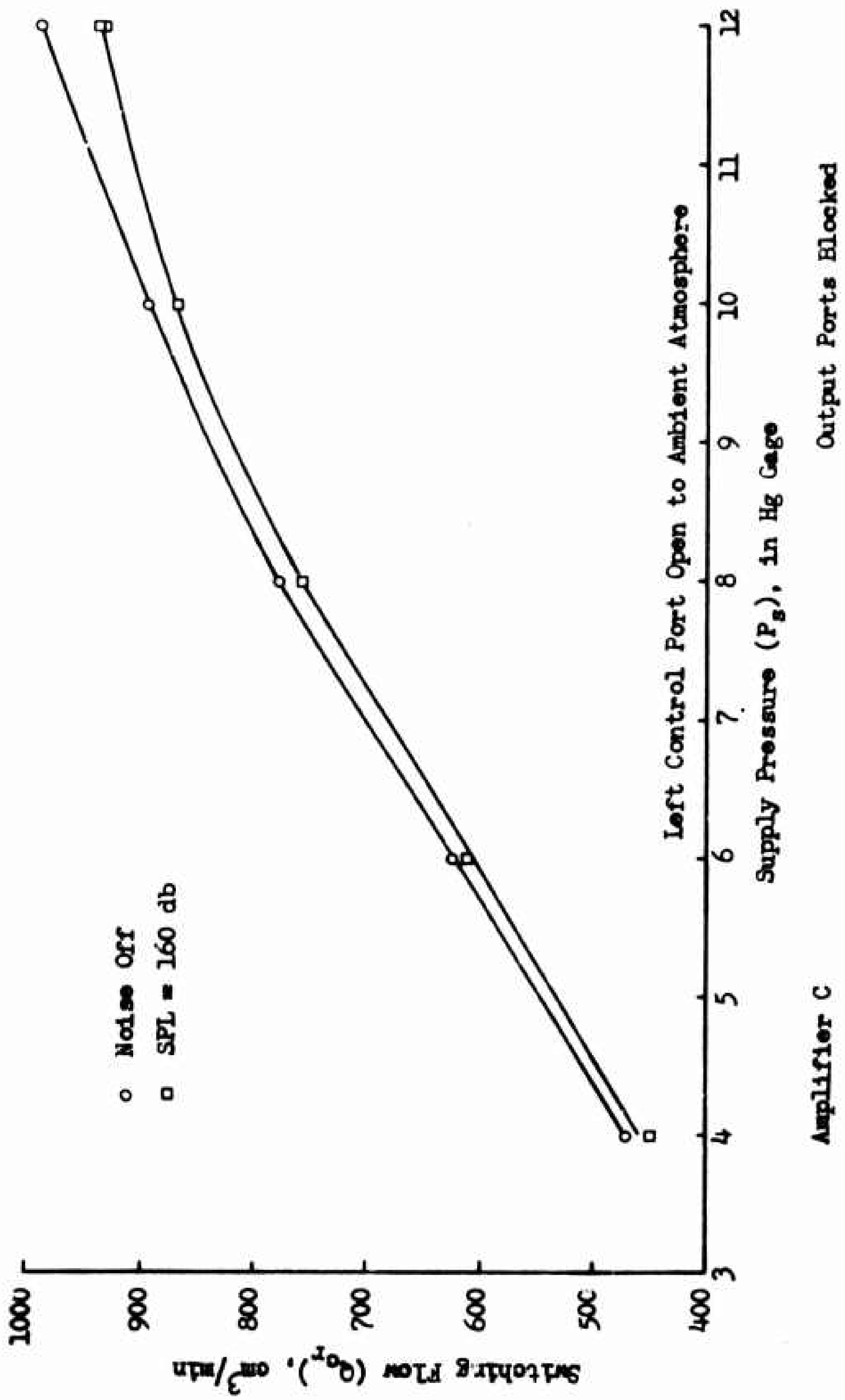
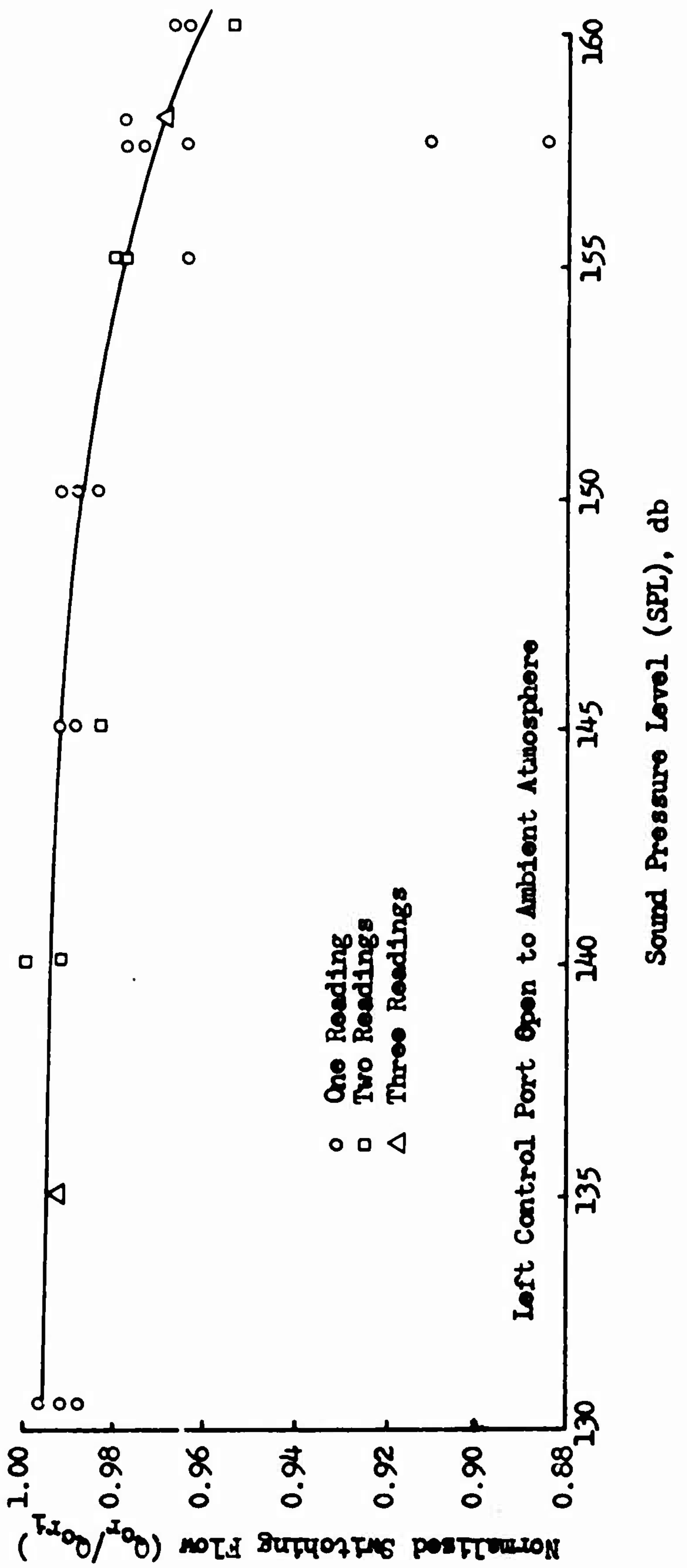


Figure 22. Effect of Noise on Switching Flow



Amplifier C P_s=10 in Hg Gage Output Ports Blocked

Figure 23. Effect of Noise Level on Switching Flow

V. Conclusions

1. Noise causes the input resistance of a proportional fluid amplifier to decrease; control pressures increase while control flow rates decrease, as shown in Figures 15 and 16. This effect is minimized in amplifiers having high control flow rates which operate at high control pressures, as shown in Figures 10, 12, 13 and 14.

2. Noise causes the pressure gain of a proportional fluid amplifier to decrease in the non-linear portion of the gain curve. This effect is minimized by using small amplitude input signals and operating the amplifier at high gain, as shown in Figures 17 and 18.

3. Noise causes the output pressure and flow rate of a proportional fluid amplifier to increase on the side of the amplifier having the greatest control pressure, and decrease on the opposite side. It is proposed that this effect is caused by radiation pressure and jet spreading. This effect is minimized in amplifiers which operate at high supply and control pressures with high control flow rates, as shown in Figures 19 and 20.

4. Noise causes switching to occur in a bistable fluid amplifier at lower values of control pressure and control flow rate than it does in the absence of noise, as shown in Table 1 and Figure 22. As the noise level is increased, the switching flow rate decreases, as shown in Figure 23.

VI. Recommendations

The following recommendations are made:

1. Testing of a complete family of geometrically similar proportional fluid amplifiers in order to determine an empirical equation relating the effects of noise and the various parameters involved.
2. A large instrumented fluid amplifier model, such as that described in Ref 9 should be obtained in order to determine the static pressure changes in the interaction region when noise is present.
3. A large scale transparent amplifier model should be obtained to permit flow visualization studies. If sufficiently low supply pressures are used, the noise amplitude required for study would be low enough that vibration of a Schlieren setup would not be a problem.
4. In the proportional amplifier input tests results, it was shown that small amplifiers are affected more than large amplifiers. Thus, miniaturization is a problem in noise environments. A study should be made with the smallest amplifier available to determine how drastic this effect may be.
5. Dynamic testing of fluid amplifiers remains an unsolved problem. By using a large scale model at low supply pressures, the noise level required for study would be low enough that the investigator could work in the same room with the apparatus and transducers could be located very close to the amplifier, making the problem of long fluid lines negligible.

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Appendix A

Experimental Data

Table A-1

Data for Figure 8

Amplifier A P_s = 20 in Hg Gage

P_b (% P_s)	P_{c_d} (% P_s)	$Q_{c_{r_i}}$ (cm^3/min)	$Q_{c_r}/Q_{c_{r_i}}$
20	-10	173.0	1.00
	- 5	162.5	1.00
	0	152.0	0.98
	+ 5	138.5	0.93
	+10	125.5	0.98
10	-10	154.5	0.97
	- 5	137.0	0.98
	0	121.0	0.95
	+ 5	100.5	0.96
	+10	78.0	0.90
5	- 7.5	113.0	0.97
	- 5	104.5	0.97
	0	79.0	0.91
	+ 5	49.0	0.70

Table A-2a

Data for Figure 9a

Amplifier A P_b = 10 %P_s

P_s (in Hg Gage)	P_{c_d} (% P_s)	$Q_{c_{r_i}}$ (cm^3/min)	$Q_{c_r}/Q_{c_{r_i}}$
10	-10	104.5	0.96
	- 5	91.5	0.96
	0	81.0	0.91
	+ 5	64.5	0.83
	+10	46.0	0.67
20	-10	154.5	0.97
	- 5	137.0	0.98
	0	121.0	0.95
	+ 5	100.5	0.96
	+10	78.0	0.90

Table A-2b

Data for Figure 9b

Amplifier A $\qquad P_b = 20\% \ P_s$

P_s (in HgGage)	P_{c_d} (% P_s)	$Q_{c_{r_i}}$ (cm^3/min)	$Q_{c_r}/Q_{c_{r_i}}$
5	-10	95.0	0.94
	0	80.0	0.90
	+10	61.5	0.83
20	-10	173.0	1.00
	- 5	162.5	1.00
	0	152.0	0.98
	+ 5	138.5	0.98
	+10	125.5	0.98

Table A-3

Data for Figure 10

Amplifier A

P_s (in Hg Gage)	P_{c_r} (in Hg Gage)	$Q_{c_{r_i}}$ (cm^3/min)	$Q_{c_r}/Q_{c_{r_i}}$
5	1.25	95.0	0.94
	1.00	80.0	0.90
	0.75	61.5	0.83
10	1.50	104.5	0.96
	1.25	91.5	0.96
	1.00	81.0	0.91
	0.75	64.5	0.83
	0.50	46.0	0.67
20	1.75	113.0	0.97
	1.50	104.5	0.97
	1.00	79.0	0.91
	0.50	49.0	0.70

Table A-4

Data for Figures 11 & 12

Amplifier A		P_{c_r} = 0.5 in Hg Gage	
P_s (in Hg Gage)	$Q_{c_{r_i}}$ (cm^3/min)	SPL (db)	$Q_{c_r}/Q_{c_{r_i}}$
5	43.5	151	0.93
		155	0.88
		156	0.84
		158	0.79
		159	0.75
		161	0.70
10	46.0	155	0.88
		156.5	0.84
		158	0.80
		159	0.75
		160	0.71
		161	0.67
20	49.0	150	0.97
		155	0.93
		157	0.89
		158	0.83
		159	0.79
		160	0.74
		162	0.70

Table A-5

Data for Figure 12

Amplifier A

P_{c_r} (in Hg Gage)	P_s (in Hg Gage)	P_b (% P_s)	$Q_{c_{ri}}$ (cm^3/min)	SPL (db)	$Q_{c_r}/Q_{c_{ri}}$
0.75	5	20	61.5	156	0.95
				158	0.92
				160	0.89
				161	0.85
	10	10	64.5	156	0.95
				158	0.91
				159	0.88
				161	0.83
1.00	5	20	80.0	150	0.98
				157	0.96
				160	0.92
				161	0.90
	10	10	81.0	158	0.94
				161	0.91
	20	5	79.0	157	0.97
				161	0.94
				162	0.91
	20	10	78.0	159	0.95
				160	0.92
				162	0.90
1.50	5	20	106.5	160	0.97
	10	10	104.5	157	0.99
				161	0.96
	10	20	98.0	161	0.98
				163	0.95
	20	5	104.5	162	0.97
	20	10	100.5	158	0.98
				162	0.95

Table A-6a

Data for Figure 13a

P_s = 5 in Hg Gage P_b = 20% P_s P_{c_r} = 0.50 in Hg Gage

Amplifier	$Q_{c_{r_i}}$ (cm^3/min)	SPL (db)	$Q_{c_r}/Q_{c_{ri}}$
A	43.5	151	0.93
		155	0.88
		156	0.84
		158	0.79
		159	0.75
		161	0.70
B	354.0	150.5	0.99
		153.5	0.98
		155	0.97
		156	0.96
		157	0.95
		158	0.93
		158.5	0.93
		159	0.92
		159.5	0.90
		160	0.89
		161	0.88

Table A-6b

Data for Figure 13b

P_s = 5 in Hg Gage P_b = 20% P_s P_{c_r} = 1.00 in Hg Gage

Amplifier	$Q_{c_{r_i}}$ (cm^3/min)	SPL (db)	$Q_{c_r}/Q_{c_{ri}}$
A	80.0	150	0.98
		157	0.96
		160	0.92
		161	0.90
B	570.0	151	1.00
		154	0.99
		157	0.98
		158	0.98
		159	0.97
		160	0.97
		161	0.96

Table A-7

Data for Figure 14

Amplifier B SPL = 162 db

P_c (in Hg Gage)	P_{c_r} (in Hg Gage)	Increase %	P_{c_l} (in Hg Gage)	Increase %
1.75	--	--	1.76	0.5
1.50	1.52	1.3	1.51	0.7
1.25	1.25	1.6	1.26	0.8
1.00	1.025	2.5	1.01	1.0
0.75	0.78	4.0	0.775	3.4
0.50	0.54	8.0	0.53	6.0
0.25	0.28	12.0	--	--

Appendix B

Details of the Apparatus and Procedure

Apparatus Specifications

Fluid Amplifiers.

Proportional Amplifiers, Honeywell, Inc.

Number SK 87633 (Amplifier A)

Number 63122 (Amplifier B)

Bistable Amplifier, Honeywell, Inc.

Number 17 M (Amplifier C)

Flow Measuring Apparatus

Flowmeter, Brooks Instrument Company

Tube: R-2-15-A Float: Glass Range: 0-845 cc/min

Tube: R-2-15-A Float: Steel Range: 0-1700 cc/min

Pressure Measuring Apparatus

Differential Pressure Transducers, Statham Instruments, Inc.

Model Number PM-60TC Ranges: ± 1, ± 2.5, ± 5 psid

Model Number P-25-5D-350 Range: ± 5 psid

Transducer Calibration Potientiometer, Helipot Corp.

Model Number T-10-A Range: 0-100,000 ohms ± 1%

Transducer Power Supply, Consolidated Avionics Corp.

Model Number 1R-51-5M Range 25-35 volts DC

X-Y Recorders, Electronics Associates, Inc.

Model Number 1130 Sensitivity: 1 mv/in

Noise Measuring Apparatus

Condenser Microphone, Altec Lansing Corp.

Model Number 21-BR-200

Microphone Preamplifier, Altec Lansing Corp.

Model Number 157 A

Preamplifier Power Supply, Altec Lansing Corp.

Model Number 4A

Band-Pass Filter, Krohn-Hite Instrument Company

Model Number 330-C

True Root-Mean-Square Vacuum Tube Voltmeter, Ballantine Laboratories, Inc.

Model Number 320

Notes on Apparatus and Procedure

For the benefit of those who may continue this work in the future, some of the problems encountered during this study are listed below, along with some equipment improvisations used during the study.

1. Although X-Y recorders were used to record pressures, an oscilloscope and a strip-chart recorder had been considered for that use. The oscilloscope trace drifted considerably, and photographs of the trace were required unless the operator recorded the data directly. There was also electrical interference which obscurred the trace and could not be eliminated. The channel-width of the strip chart recorder was too narrow to be of use when widely varying input amplitudes were used.

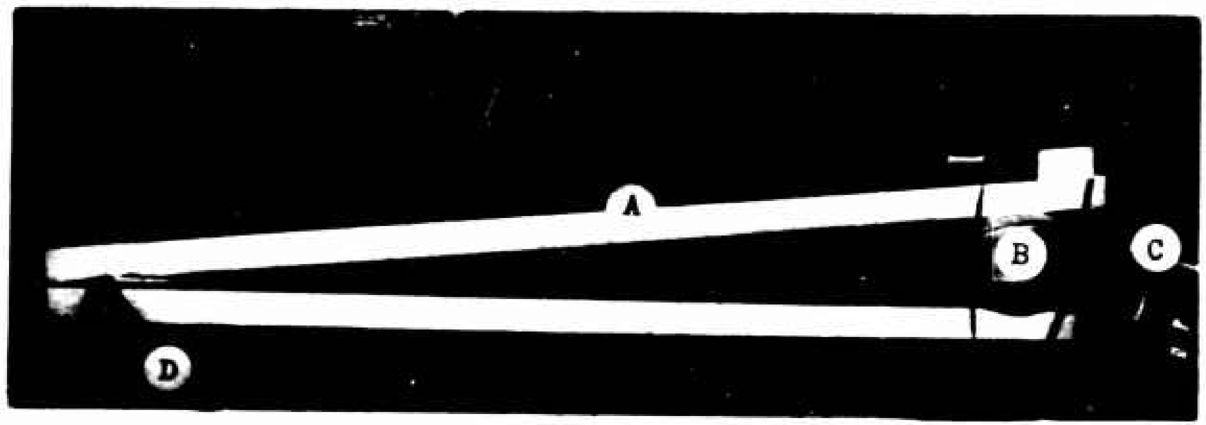
2. The pressure regulator panel shown in Figure 6 also served as a housing for the transducer power supply, balance potentiometers, and calibration unit. The four transducers in use were wired in parallel according to the manufacturer's wiring diagram. A precision potentiometer was used to calibrate the transducers as it offered greater flexibility than did individual precision calibration resistors.

3. During some runs, a flowmeter tube-float combination could not be

used for the entire run because the maximum range of the tube was exceeded. The smallest range flowmeter available during this study would be too large were a smaller amplifier to be tested in the future. A basic problem with flowmeters of this type is that the flow can not be precisely determined at any given instant, but only when the float is at one of the scale divisions. Electrical flowmeters that provide a continuous value of flow which can be automatically recorded on X-Y or strip-chart recorders would be preferable, but were not available during this study.

4. It was very difficult to balance the output flows of the amplifier by means of the mechanical hose clamps used in this study. Because of the small number of threads per inch on the clamp screw, a very small adjustment of the screw would cause a large change in output pressure and flow. A possible alternative for future testing is the use of a precision needle valve to meter the flow from a termination chamber to which the output flow lines are attached. Another possibility is to terminate the output lines in the bases of hollow tubes which can be filled with water to provide the required backpressure.

5. When the bistable amplifier flow readings were taken, it was difficult to operate the noise level control and the pressure regulator simultaneously. To eliminate one control, the automatic flow clamp in Figure B-1 was devised. The bladder was connected to the unused pressure regulator. The flow through the regulator allowed the bladder to inflate smoothly, spreading the clamp and allowing more flow to pass through the control line located at the apex of the clamp.



A: Flow Clamp

B: Bladder

C: Line to Pressure Regulator

D: Control Flow Line

Figure B-1. Automatic Flow-Regulating Clamp

Appendix C

Effect of Air Flow on Amplifier Performance

Effects of Air Flow on Amplifier Performance

A test was run subsequent to the noise tests included in the body of the report to determine the effects of air flow past a vented fluid amplifier. The operating conditions of Figure 15 were used, with amplifier A mounted at the same location used during the previous tests. The siren rotors were not in operation during this test. The noise level control was set approximately at the setting that gave 161 db when the rotors were in operation. The SPL obtained with this configuration was 136 db.

With the windscreen in place and with no air flow, the right control pressure was set to 1.5 in Hg gage and the control flow noted. The air flow was then set as described above. No changes in control pressure or control flow were observed. The right control pressure was reset to 0.5 in Hg gage with the air flow off and the procedure repeated. Again, no changes in control pressure or control flow were observed. The windscreen was removed so as to expose the amplifier directly to the siren air flow. The above procedure was repeated for right control pressures of 0.5 and 1.5 in Hg gage. Again, no changes were observed in either case.

The reason that no changes were noted may be due to the amplifier design. The vents were coupled to the atmosphere via $\frac{1}{4}$ in passageways which were oriented normal to the siren air flow. The length and orientation of these passageways may have minimized the effects of the air flow.

Vita

Eldridge Chester Koppen, Jr. was born [redacted]. After graduating from [redacted] he attended Illinois Institute of Technology, Chicago, Illinois, and obtained the degree of Bachelor of Science in Business and Economics in June 1956. He received his commission as Lieutenant in the USAF reserve upon graduation, and entered active duty in October 1956. After completing pilot training, he served as a bomber copilot with the 506th Bombardment Squadron at Chennault AFB, Louisiana from September 1958 to March 1960 during which time he accepted his commission as Lieutenant in the Regular USAF. From August 1960 to August 1964, prior to attending the Air Force Institute of Technology, he was assigned as a bomber copilot with the 764th Bombardment Squadron at Amarillo AFB, Texas. In September 1964 he entered the Air Force Institute of Technology where he obtained the degree of Bachelor of Science in Aerospace Engineering with Distinction in August 1966. Upon graduation, he was assigned to the graduate school of the Air Force Institute of Technology. He is a member of Tau Beta Pi.

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This thesis was typed by [redacted]