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SUMMARY

A large butterfly valve (1.37 m diam) was acoustically tested to measure the noise generated and propagating in both the upstream and downstream directions. The experimental investigation used wall mounted pressure transducers to measure the fluctuating component of the pipe static pressure upstream and downstream of the valve. Microphones upstream of the pipe inlet and located in a plenum were used to measure the noise radiated from the valve in the upstream direction. Comparison of the wall pressure downstream of the valve to a prediction were made. Reasonable agreement was obtained with the valve operating at a choked condition. The noise upstream of the valve is 30 dB less than that measured downstream.

INTRODUCTION

Noise generated by valves in large lines connected to acoustic test facilities can mask the noise of the test hardware. Proposed modification of NASA Lewis Research Centers Altitude Wind Tunnel (AWT) to include acoustic testing capability created a need for tenth scale model test of tunnel components. A test section design point of 120 dB overall sound pressure level (OASPL) was specified. In order to reach the design point it is necessary to evaluate individual components and the acoustic treatment used to suppress unwanted noise. Components are connected to the centers altitude exhaust system used to draw air through the model. Large butterfly valves, used for control, are placed in the line between the model and the exhausters.

Noise generated by the exhaust system may be effectively blocked from reaching the model component by operating the valve at a choked condition. However any noise generated by the valve upstream of the sonic point in the flow will be propagated in both the upstream and downstream directions. The vena contracta for an orifice occurs at some point in the flow downstream of the orifice plate. In a similar manner flow through butterfly valves reaches sonic velocity downstream of the valve disc. Mixing, upstream of the vena contracta, creates noise that is free to propagate in the upstream direction creating a noise source that could exceed that generated by the model component under test. Butterfly valve noise has been the subject of a number of papers, references 1 to 8. A number of noise predictions exist in the literature; references 9 to 13 are examples. The predictions, for the most part are intended to determine the dominant noise emanating from the valve. Most of the noise is generated downstream of the valve body by mixing processes similar to jet noise producing mechanisms (ref. 2). If, as in the case of wind tunnel noise tests, one is interested in measuring the noise generated by models located upstream of air flow control valves the noise generated by the valve and propagating upstream to the model should be less than the model generated noise by 10 to 20 dB.

To determine the magnitude and the spectrum of the noise generated by large butterfly valves, similar to that used in AWT test rigs, acoustic measurements were made on a similar valve located in the Lewis Research Center's 8- by 6-ft supersonic wind tunnel (SWT) plenum chamber. The results of these test are reported herein.

APPARATUS AND PROCEDURE

Test Rig Description

A 1.37 m butterfly valve is used to control the pressure in the plenum surrounding the test section during tunnel operation. The valve is located in the lower part of the plenum chamber and, as shown in figure 1(a), is placed in the exhauster line just downstream of a bellmouth inlet. Figure 1(a) to (c) show the plenum chamber as it existed for the acoustic tests. Figure 1(d) shows the butterfly disc configuration at the 90° position (full open).

During the test the exhausters were capable of maintaining a choking pressure ratio at the valve up to a valve position of approximately 35°. For larger openings the pressure downstream of the valve began to increase due to the limitations on the exhauster system flow rate. Data were recorded from the valve fully closed to fully open position, that is from 0 to 90° valve disc position.

Instrumentation

Acoustic measurements were made both upstream and downstream of the valve on the pipe wall using 101 kN/m^2 pressure transducers. Their output passed through a signal conditioner, amplifier and then to an FM tape recorder. The location of the transducers is shown in figure 2. In addition to the four wall mounted pressure transducers, two 0.635 cm condenser type microphones were mounted at the pipe centerline in front of bellmouth inlet; the distance is given in figure 2. The microphone output passed through amplifiers and then to an FM tape recorder.

In addition to the acoustic instrumentation the transducers were used to measure the absolute pressure in the pipe. Thus the wall static pressures both upstream and downstream of the valve were measured. The plenum chamber temperature and pressure were recorded manually from transducers located in the plenum chamber.

Data Reduction

Flow rate. - The mass flow rate of air through the valve was calculated using the static pressure measured just downstream of the bellmouth and the plenum pressure and temperature. The Mach number was calculated using the ratio of wall to plenum pressure and a specific heat ratio equal 1.4. From the Mach number, with the simplifying assumption that the plenum chamber temperature approximates the static temperature in the flow at low Mach numbers, the flow velocity is calculated. From the measured pipe static pressure and plenum chamber temperature the static density is calculated for a perfect gas. The density, velocity, and pipe cross-sectional area are then used in the continuity equation to calculate the mass flow rate.

Acoustic data. - A one-third - octave spectrum analyzer was used to obtain the one-third - octave spectrum and the OASPL reported herein. A Fast Fourier Transform analyzer was used to obtain the narrow band spectra and the coherence and phase angle information.

Table I lists the overall sound pressure levels for all the wall mounted pressure transducers and the two microphones along with the valve angular position.

RESULTS AND DISCUSSION

Both steady state (static) and fluctuating pressures were measured as discussed above. The plenum chamber pressure was assumed to be the total pressure of the flow to the valve. A discussion of the flow and acoustic data follows.

Mass Flow

The curve drawn through the data shown by the circular symbols in figure 3 may be used for determining the mass flow rate through the valve. Scatter of the data is attributed to the low Mach number at the measuring station and resulting small difference between the wall static pressure and the plenum chamber pressure. The curve faired through the data appears to be accurate enough for use in any acoustic correlation of sound pressure with valve position.

Acoustic Pressure

The overall sound pressure level as a function of valve position given in Table I is shown graphically in figure 4. OASPL are shown upstream and downstream of the valve location. Downstream OASPL follow a smooth curve with valve position. The peak occurs at the valve choke point around the 35° disc position. The upstream OASPL peak at the 45° valve position or just before the valve chokes. The OASPL upstream of the valve deviates from the smooth curve at the 10°, 15°, and 20° valve position. This deviation, as will be shown later, is due to tones generated by the valve. For example, a plot of the sound pressure level (SPL) at a frequency of 1000 Hz (fig. 5), shows that the SPL upstream of the valve follows a smooth curve. The shape of the OASPL and SPL curves with valve disc position are the same if tones are neglected in the upstream spectra.

The OASPL upstream of the valve on the pipe wall and at the two pipe centerline locations upstream of the bellmouth are shown in figure 6. The OASPL data show similar trends though different levels. This indicates that the noise trends measured by microphones away from the flow field are in substantial agreement with the OASPL measured on the pipe wall. The difference in level is attributed to the usual drop in SPL with distance from its source. One may conclude from this discussion that the OASPL measured at the wall location upstream of the valve gives a reasonable approximation of the noise being propagated in the upstream direction. Referring to figure 4 then, one may conclude that the minimum noise generated by the valve and transmitted in the upstream direction will be in the order of 125 dB and occurs at a 25° disc position. The maximum OASPL of 138 dB will occur just before the valve chokes at a 45° disc position. At a constant power level any decrease in the pipe area with distance from the valve will tend to increase these values. Hence for the tenth scale model test, with a test section diameter of approximately 0.7 m, one must add 6 dB to the maximum OASPL of 138 dB giving a maximum of 144 dB in the tenth scale model. It is obvious from these numbers that valve noise suppression is required for the tenth scale AWT model tests if the design OASPL goal of 120 dB is to be obtained.

To design a muffler capable of absorbing the acoustic energy radiated from the valve the sound pressure spectrum must be known. The wall SPL spectra of the 1.37 m valve are shown in figure 7 for valve disc positions of 15°, 25°, and 30°. As stated previously tones existed upstream of the valve when the valve was operated in an almost closed position that is 10°, 15°, and 20° disc positions. These tones occurred around a frequency of 5000 Hz, figure 7(a), at the 15° valve position. Hay stacking around this frequency occurred at valve positions of 25° and 30°. Below 5000 Hz the 15° disc position spectrum given by the circular symbols in figure 7(a) is flat. However as the valve disc is opened to the 25° and 30° disc positions a low frequency hump around 200 Hz appears. This hump is similar to jet noise spectra. The tones at 5000 Hz are attributed to a feedback mechanism that has been observed in small diameter supersonic jet noise studies. The sound pressure level spectrum downstream of the valve, figure 7(b), shows that for all three valve positions the sound pressure is greater than that at the upstream measurement location. The tones do not appear in all probability because they are masked by the mixing noise in the region downstream of the valve.

The bellmouth centerline acoustic pressure spectra are shown in figure 8 for valve disc positions of 15°, 25°, and 30°. Trends similar to the upstream wall SPL spectra are observed. However for the valve nearly closed, 15° disc position, the low frequency portion of the spectrum below 315 Hz drops in level compared to the flat shape of the wall spectra shown in figure 7(a).

One may conclude then that for purposes of valve muffler design, as in the tenth scale AWT test and for valves this size, the muffler should be designed for two peak frequency regions; one broad banded at 200 Hz and the other at 5000 Hz. The suppression of noise upstream of the valve judging from figure 4 should be on the order of 34 dB. This is determined from the difference between the expected OASPL in the tenth scale model test with out muffler (144 dB) and the design goal of 120 dB minus 10 dB (where the 10 dB is used to insure that the muffled valve noise will be negligible compared to the 120 dB background noise goal in the test section).

Any analysis of acoustic data should include representative narrowband data. Figure 9 shows the narrowband SPL spectra (40 Hz bandwidth) upstream and downstream of the valve for valve disc positions of 10°, 30°, and 60°. At a valve disc position of 10° (fig. 9(a)), the tones appear in the upstream spectrum at multiples of 5750 Hz. The tones are not present in the downstream spectrum. Downstream of the valve a hump in the spectrum exist between 4000 and 5000 Hz. The tones appear not to propagate in the downstream direction. At the 30° valve disc position (fig. 9(b)), the discrete tones are not present either upstream or downstream of the valve. The downstream spectrum is on the order of 33 dB higher then the upstream. The upstream spectrum still shows irregularities around 4750 Hz and at the lower frequencies. As the valve unchokes and is opened farther the local velocities decrease and the valve disc presents smaller blockage to the acoustic waves. As a result, the differences between the upstream and downstream spectra become less as shown in figure 9(c) for the valve disc at the 60° position. The spectra are also smoother; this should be expected because the disc as shown in figure 1(d) now presents a more streamlined shape to the flow.

Cross correlation of the two transducers located on the pipe wall upstream of the valve indicate that pressure signals at these locations are acoustic in nature. The signal that the transducers are receiving appears to be coming from the region of the valve disc that moved upstream when the valve is opened. This information was obtained from the phase angle existing between the two signals. The cross correlation of the downstream pair of pipe wall transducers yielded less clear results.

Predicted OASPL

A prediction of the OASPL calculated over the frequency range 80 to 8000 Hz is shown in figure 10. The prediction was made using the method given in reference 13. The wall attenuation correction from reference 13 was not used because the measurement was made on the inside wall surface. The predicted value is given by the solid line. The dashed lines show the accuracy of the prediction; that is, the predicted value should be within ±5 dB of the measured value. The symbols represent the OASPL measured at the downstream location in the duct just downstream of the valve disc, sensor number one. The data agrees very well with the prediction when the valve is choked. As the valve unchokes the prediction begins to over predict the valve noise and therefore one may conclude that the prediction may not be applied above the choke point.

CONCLUDING REMARKS

A 1.37 m butterfly valve installed in a vacuum line with inlet open to atmospheric pressure through a bellmouth inlet has been acoustically tested over a range of disc positions from fully closed to fully open. Flow rates, overall sound pressure and spectral data have been obtained. Acoustic data have been obtained both upstream and downstream of the valve in the adjacent piping. Apparent location of the upstream sound source has been determined. The following conclusions have been drawn with regard to the valve noise and its effect on acoustic tests in the tenth scale AWT model tests:

1. The upstream valve noise exceeds the 120 dB overall sound pressure level design goal placed on the AWT by 5 to 18 dB.

2. Butterfly valves may exhibit tones when operated near the closed position.

3. Butterfly valves have low frequency broad band noise similar to jet noise.

4. The noise downstream of the valve exceeds the upstream noise over the range of choked valve operating conditions by approximately 30 dB.

5. The noise downstream of a butterfly valve operating in a choked condition can be accurately predicted. However if the valve unchokes the predicted OASPL will be much higher than the measured value.

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TABLE I. - OVERALL SOUND PRESSURE LEVEL

dB ref 20 μN/m²

Valve position, deg	Transducer number				Microphone number	
	1	2	3	4	5	6
0	122	122	115	115	85	82
10	146	147	140	137	122	113
15	152	153	137	137	121	115
20	154	154	127	127	117	112
25	157	156	126	125	116	113
30	161	160	129	128	122	115
35	162	161	132	132	122	120
40	162	161	137	136	130	123
45	159	158	139	138	132	124
50	154	151	137	137	131	123
60	142	141	133	133	124	118
70	130	130	129	129	119	110
80	126	126	128	128	116	107
87	126	126	128	129	116	107

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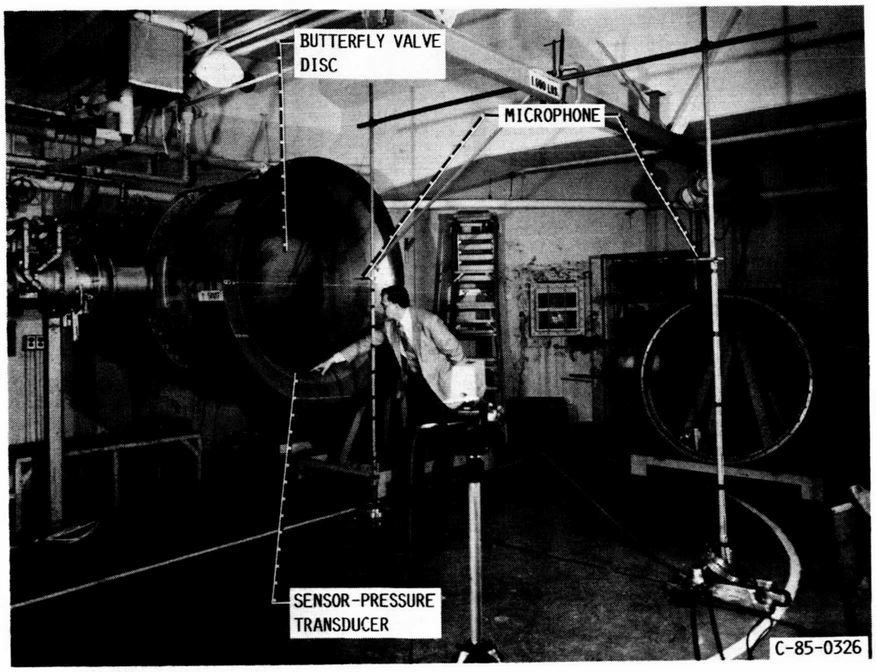
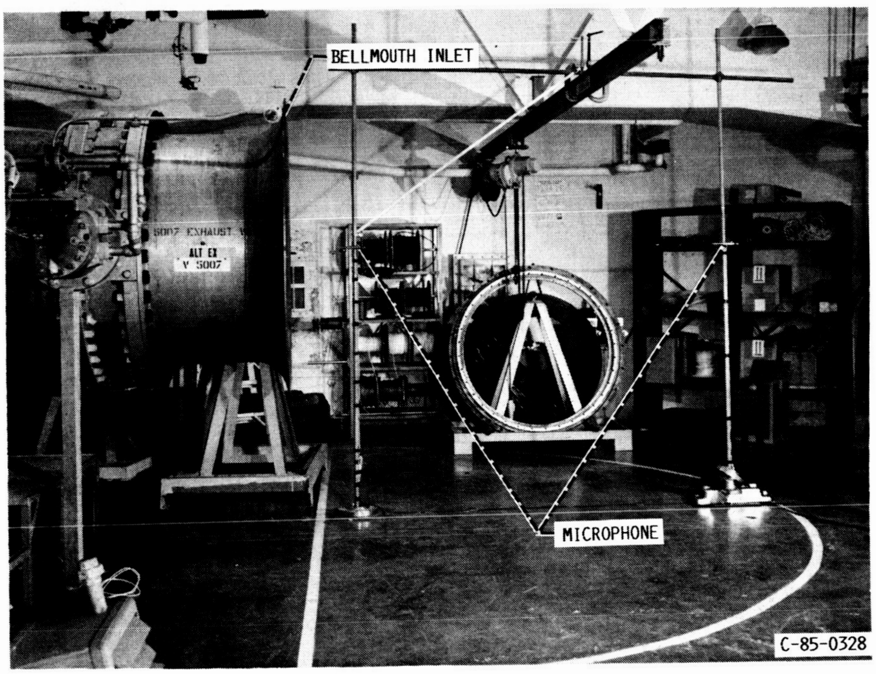
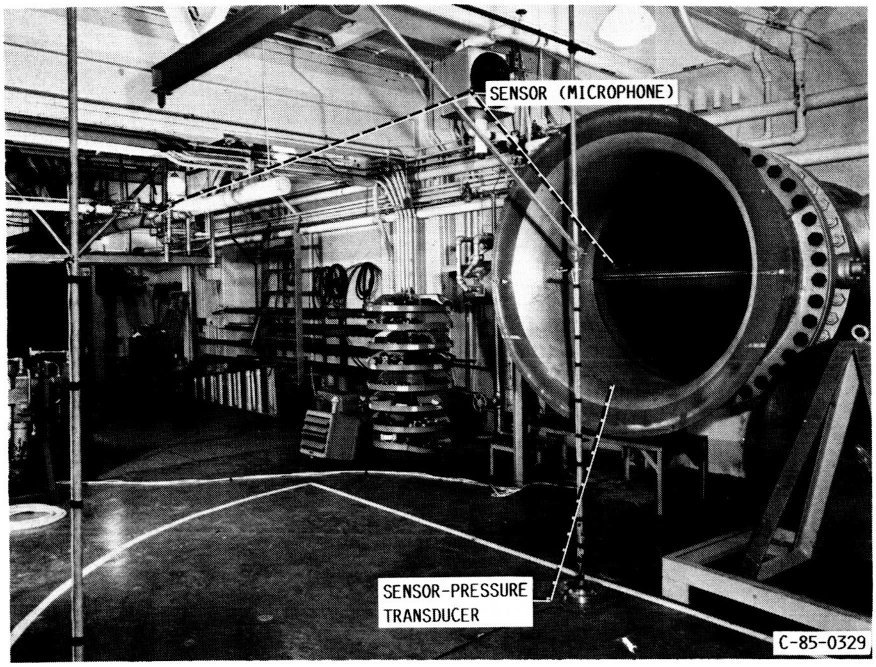


(A) SENSOR LOCATION.

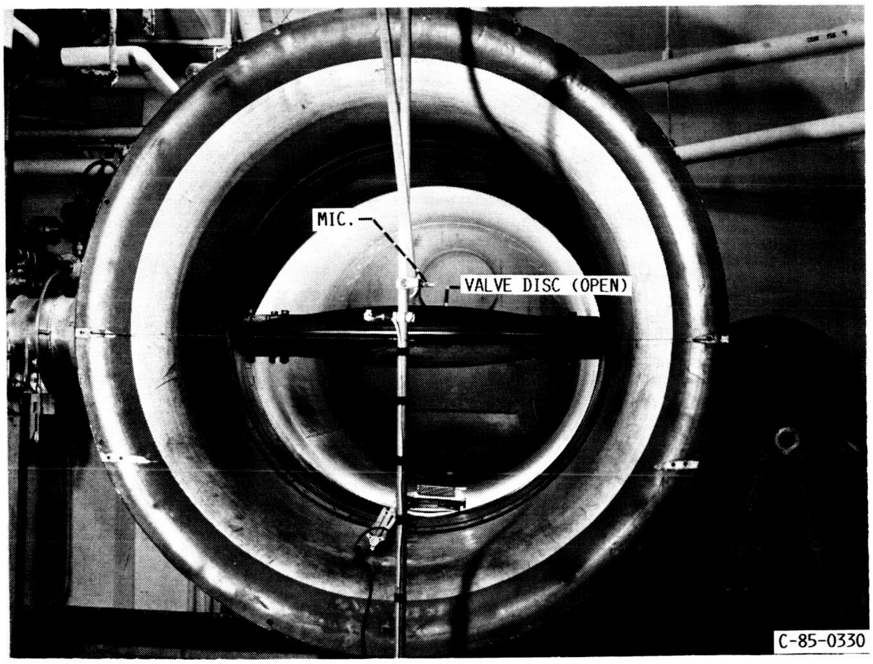


(B) BELLMOUTH CONFIGURATION.

FIGURE 1. - 1.37 METER BUTTERFLY VALVE AS INSTALLED IN THE 8 X 6 SWT PLENUM CHAMBER.



(C) PLENUM CHAMBER.



(D) VALVE DISC CONFIGURATION AND PIPE INTERNAL FLOW PASSAGE.

FIGURE 1. - CONCLUDED.

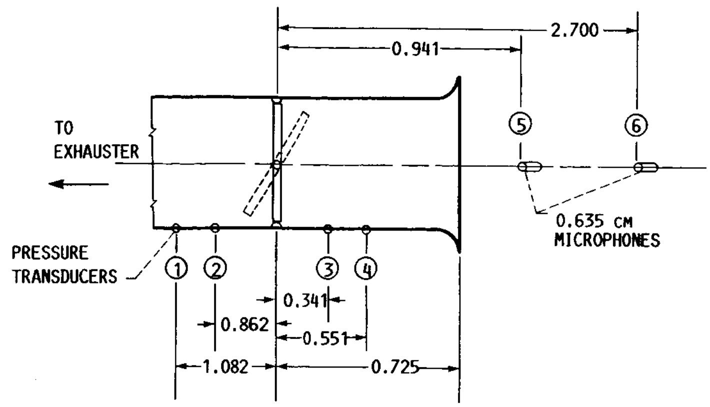


FIGURE 2.- ACOUSTIC INSTRUMENTATION LOCATION RELATIVE TO VALVE LOCATION, DIDENSIONS IN PIPE DIAMETERS, PIPE DIAMETER EQUALS 1.37 METER, DIMENSIONS NOT TO SCALE.

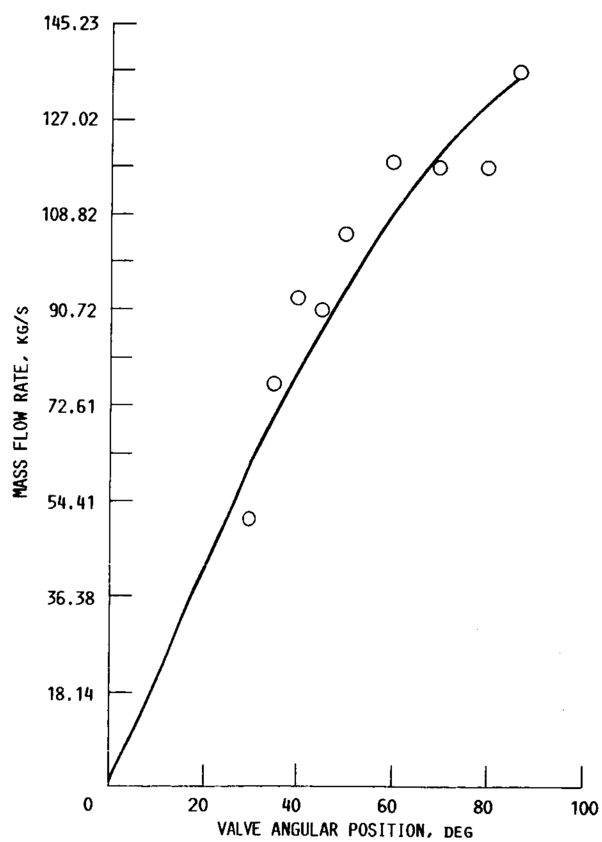


FIGURE 3.- VARIATION OF VALVE MASS FLOW RATE WITH VALVE ANGULAR POSITION.

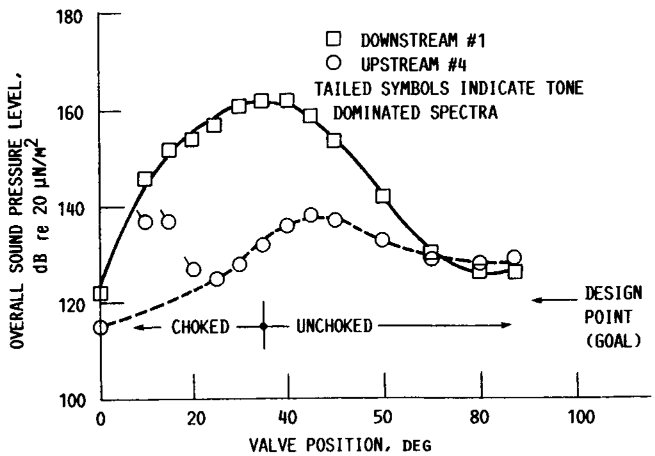


FIGURE 4.- OASPL AS A FUNCTION OF VALVE POSITION.

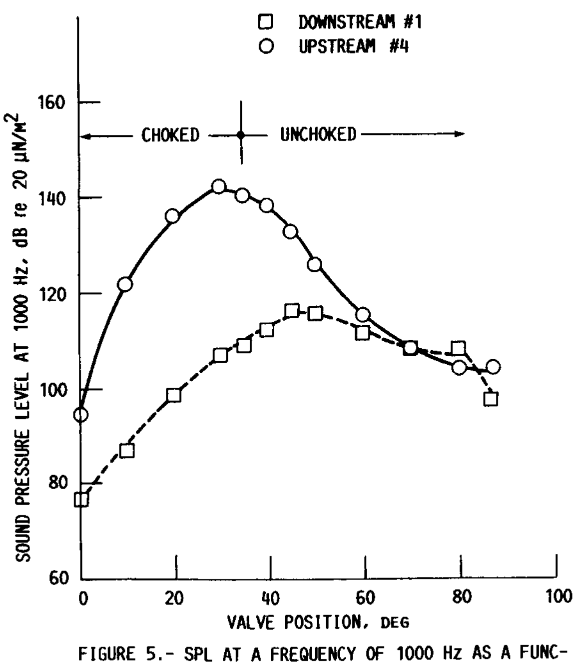


FIGURE 5.- SPL AT A FREQUENCY OF 1000 Hz AS A FUNCTION OF VALVE POSITION.

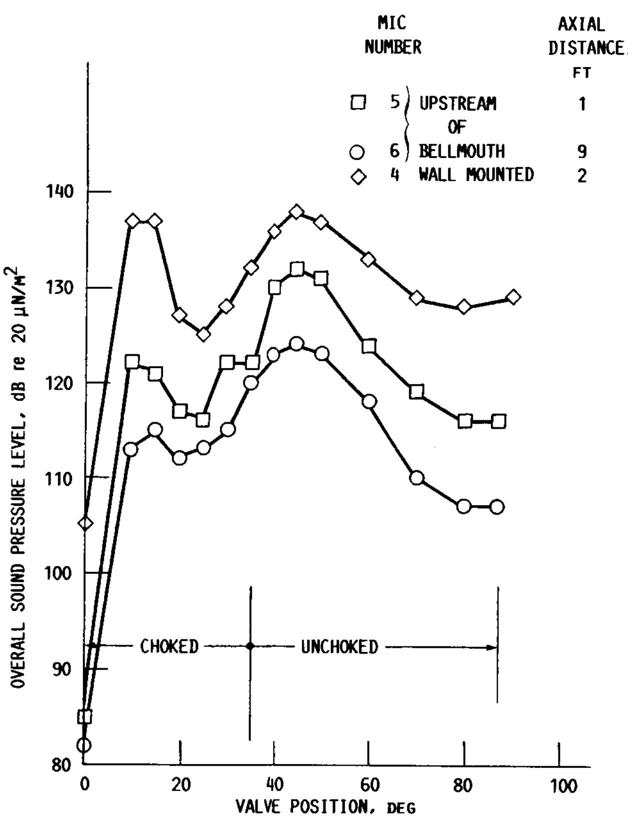
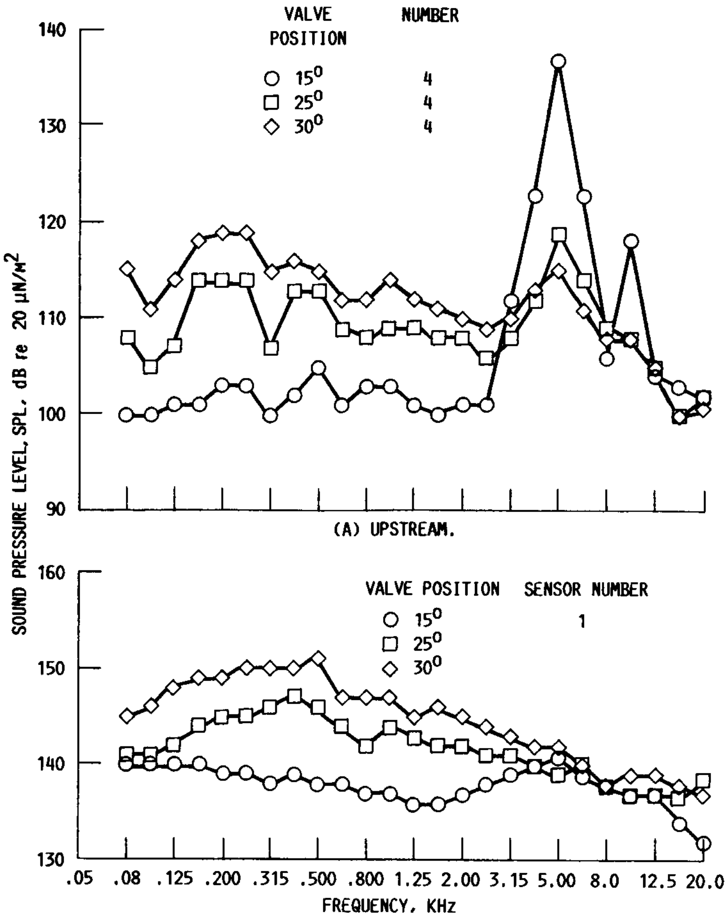


FIGURE 6.- OVERALL SOUND PRESSURE LEVEL AS A FUNCTION OF VALVE POSITION.



(B) DOWNSTREAM.

FIGURE 7.- WALL MOUNTED PRESSURE TRANSDUCER, 1-THIRD OCTAVE SPECTRUM.

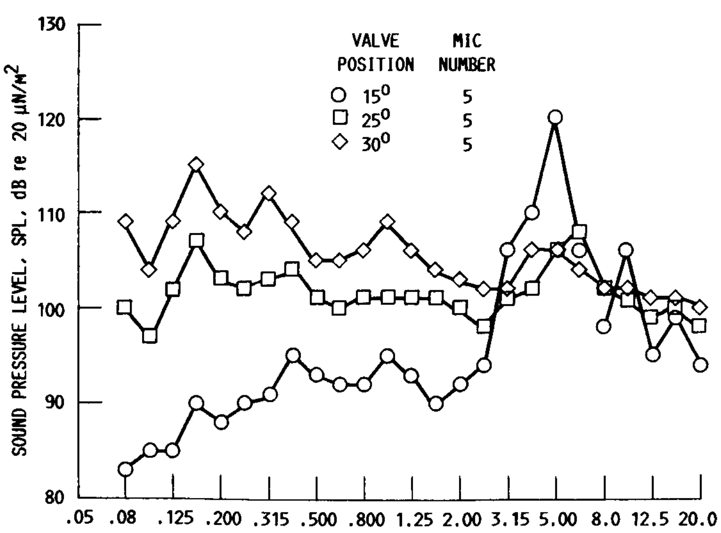


FIGURE 8.- 1-THIRD OCTAVE ACOUSTIC PRESSURE SPECTRA UPSTREAM OF THE BELL MOUTH.

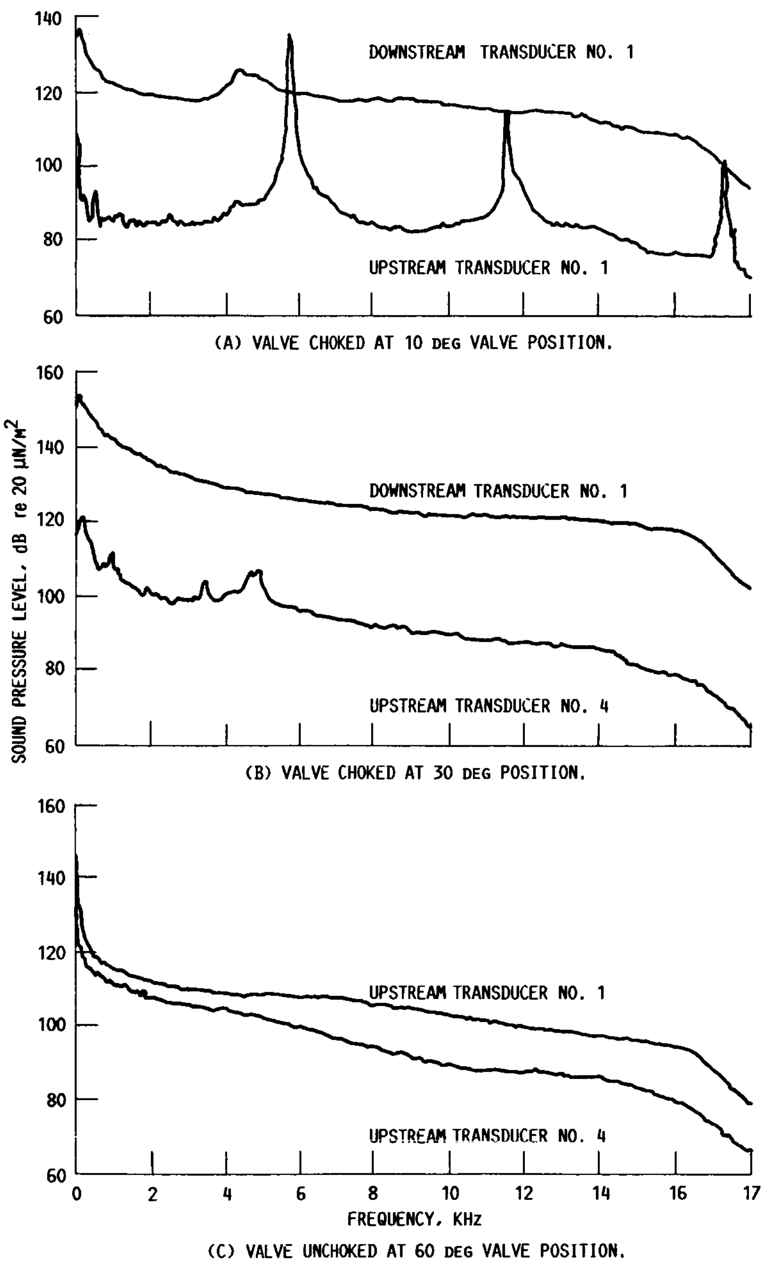


FIGURE 9.- 1.37 METER BUTTERFLY VALVE NOISE TEST, NARROWBAND SOUND PRESSURE LEVEL SPECTRA, 40 Hz BAND WIDTH.

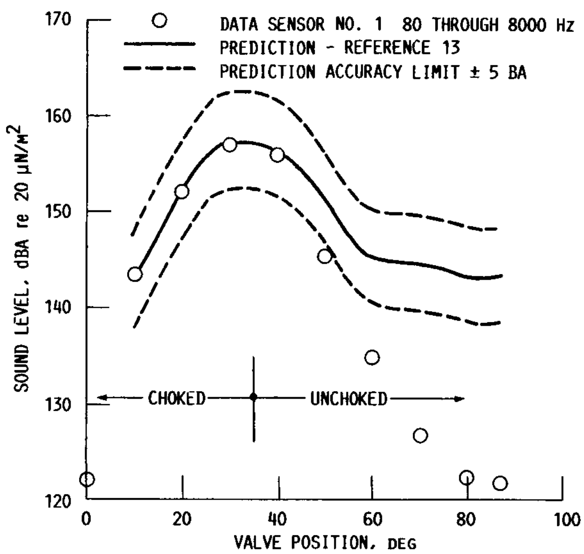


FIGURE 10.- COMPARISON OF MEASURED A-WEIGHTED SOUND LEVEL DOWNSTREAM OF THE VALVE TO PREDICTED VALUE.

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16. Abstract

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