UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS HYDRAULIC LABORATORY

Project Report No. 123

# The Influence of Drag Reducing Polymer on Radiated Noise from Rough Surfaces

by
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ADDITION -- page 3:

The following paragraph should be inserted between para. 4 [ending "...to the flat plate."] and para. 5 [beginning "A rotating carbon pressure seal..."]:

A limited number of average velocity measurements have shown the same upward or downward shifts of the logarithmic velocity profile with the addition of polymer to the water or roughness to the surface, respectively, as observed in a pipe [5].

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## ABSTRACT

Experimental measurements were made of radiated noise from a rough surface moving in water and from the same surface moving in a dilute water solution of a drag reducing polymer. Roughly 10 dB of noise reduction was observed for a concentration of 100 ppmw Polyox 301.

## PREFACE

The work reported herein was an experimental effort to determine the effect of polymer additive on radiated flow noise from a rough surface moving in water. The studies reported were carried out in the period from October 1970 to November 1971 and were sponsored by the Naval Ship Research and Development Center, Department of the Navy, Bethesda, Maryland, under Contract N00014-67-A-0113-0024. Appreciation is expressed to John Almo and Thomas Dostal for their part in collecting the data, to Frank Schiebe and Edward Silberman for reviewing the report, and to Mrs. Shirley Kii for preparing the manuscript.

# THE INFLUENCE OF DRAG REDUCING POLYMER ON RADIATED NOISE FROM ROUGH SURFACES

## I. INTRODUCTION

The work presented here was directed at showing experimentally the effect of water soluble polymers on radiated flow noise from moving rough surfaces. The method involved making comparisons with radiated flow noise from the same surfaces moving in tap water without polymer.

The ability of certain water soluble polymers to reduce the drag force of flowing water is well known. The precise manner in which this effect is produced is not clearly understood. In a general sense, it would not be unreasonable to assume that this drag reduction results from a modification of the turbulent structure of the flow.

The original work of Lighthill [1]* and its extension to boundary layers by Curle [3] show an intimate relationship between the radiated flow noise and the internal stresses of the fluid. The internal stresses are assumed to arise from a particular turbulence structure and its interaction with mean motions of the fluid. If the turbulence structure is a common denominator for both flow noise and drag, the addition of a drag reducing polymer should affect flow noise as well. Unfortunately, available estimates of turbulence and its interaction with drag or noise provide little help with regard to predicting or correlating the effects of the presence of polymers.

## II. EXPERIMENTAL APPARATUS

The generation of radiated flow noise is an inefficient process [1,2,3,4]. Experimental measurements reported in Ref. [4] give a ratio of acoustic power to friction power loss of $3 \times 10^{-7}$ for a smooth surface; consequently, the noise levels to be measured are quite low except at high velocities. These conditions require that a test facility have a low ambient noise level and in addition be capable of high velocities.

The rotating tank facility shown in Fig. 1 was selected for the measurements. It was chosen in preference to a water tunnel or towing tank for the following reasons: It has the smallest moving mass for the active

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*Numbers in brackets refer to references listed on page 9.

area; it has a minimum of moving parts to generate unwanted noise; and it has a naturally rigid structural form. The facility consisted of a hollow rotating cylinder positioned on the axis of a steel tank 6 ft in diameter and 6-1/2 ft high. The tank was supported on three I-beams. A cork pad was installed between the I-beams and the concrete floor of the laboratory for sound isolation. Sandbags were placed against the exterior walls of the tank to provide additional damping of the tank wall as well as some isolation from sound transmitted through the air.

The tank capacity was 1260 gallons. It was filled directly from the municipal water supply or from the St. Anthony Falls Hydraulic Laboratory 6-inch water tunnel; this tunnel is also filled from the municipal water supply, which is processed river water. The water tunnel is equipped with an air separator and pressure control, and thus provides a simple and rapid means of removing dissolved and free air from the water to the concentration level required. Diversion of water from the water tunnel to the tank enabled tests to be conducted with various dissolved air contents. A steam heat exchanger was also installed in the tank to permit adjustment or control of the water temperature.

The rotating cylinder was supported on a hollow stainless steel shaft mounted in water-lubricated rubber bearings. The cylinder itself was 1 ft long with an external diameter of 1 ft. Its top was submerged 2 ft below the static water surface in the tank. The cylinder was hollow to provide space for instruments and was constructed of a synthetic wood material (Renwood) with brass end plates 1/4 in. thick. A wall thickness of 3 in. was selected to reduce cylinder wall vibrations. This type of construction has proved to be free of any detectable resonant peak in the noise spectrum. The cylinder was finished with a heavy coat of epoxy paint. The surface was machined to a 0.001 in. "runout" and the end cones were polished to a high gloss. Surface roughness was produced by spraying the cylinder surface with lacquer and dusting glass beads on the surface while the lacquer was still tacky. Glass beads 0.018 inches in diameter were used.

The cylinder shaft was supported by a wood framework attached to the laboratory floor and wall, avoiding contact with the tank. A water-lubricated bearing and thrust washer connected the cylinder, drive shaft, and pulleys to the support frame. A second rubber guide bearing mounted on a cross frame inside the tank was necessary to hold the cylinder in an axial position. The cylinder was driven by a 20 hp, 3500 rpm induction motor through a "V" belt drive. Speed changes were effected using various combinations of pulleys on the motor and cylinder shaft.

Considerable difficulty was experienced in finding bearings sufficiently quiet for the purpose. Many types of bearing surfaces were tried, including ball bearings and sleeve bearings of both plastic and metal. All these bearing materials were found to give troublesome "spikes" in the measured flow noise spectrum, particularly for the high frequencies. The rubber bearings were found to contribute relatively few of these spikes. The noise level was still unsatisfactory for the lower frequencies (below 500 Hz), which was attributable in part to drive belt vibration and irregularities.

A set of strain gages was mounted on the drive shaft of the rotating cylinder. They were calibrated to measure torque at various speeds. Slip rings mounted on the shaft conducted the signal from the strain gages to the recording instrument. Slip rings were removed during noise measurements. The velocity profile and drag coefficients of the flow system are given in Ref. [5].

The cylinder rotating in a large tank gives rise to two dominant motions: (1) a free vortex where the product of velocity and radius equals a constant $(Vr = C)$ and (2) an approximately logarithmic velocity distribution near the cylinder. The motion of the fluid around a rotating cylinder was investigated for water by Skudrzyk and Haddle [6] and in air by Wilson [4]. Their data show a logarithmic velocity distribution similar to the flat plate. [redacted]

A rotating carbon pressure seal was fitted below the upper rubber bearing. A rubber hose connected the rotating seal and the tank cover to provide sound isolation. Pressures of near zero to 2 atmospheres absolute could be imposed on the test water. A small water line to an auxiliary water tank supplied pressure or vacuum.

The acoustic pressure on the tank was sensed by a Cevite CH1A hydrophone. The hydrophone was supported on a strut mounted midway between the rotating cylinder and the tank wall. Its active surface was located on a horizontal plane passing through the lower edge of the rotating cylinder. The calibrations supplied by the manufacturer were used as a reference.

The signal from the hydrophone was amplified by a Roveti Model 600B preamplifier. A Quan-Tech Model 303 frequency analyzer was used to measure sound intensity in discrete frequency bands.

## III. EXPERIMENTAL PROCEDURE

The test tank was surveyed with a hydrophone to determine the presence of standing waves. These measurements indicated a nearly uniform pressure field throughout the liquid in the tank when excited with a random noise source or flow noise from the rotating cylinder. This fact made possible the measurement of sound power from a pressure measurement at an arbitrary point without providing a means for averaging the standing wave pressure.

To relate the power input to the tank to the pressure measured by the hydrophone, a procedure similar to that of Ref. [7] was followed. A source of acoustic energy was installed in the tank, and the proportionality constant relating the acoustic energy introduced into the tank to the resulting acoustic pressure in discrete frequencies was determined. The acoustic source referred to above is an International Transducer Corporation Model 1002 calibrated spherical transducer. The intensity, $P^2/\rho c$, can then be integrated over a spherical surface surrounding the source to give the total acoustic energy input; $P$ is the pressure, $\rho$ the density of water, and $c$ the velocity of sound in water at the temperature used in the tests.

It was known from previous work [8] that air would be released from the water as tiny bubbles in regions of high shear near the rotating cylinder surface. As an air bubble diffused away from the surface into the liquid of the reverberant chamber, it would produce greater attenuation of the sound, destroying the tank calibration. An effort was made to reduce this effect by filling the tank with water of low dissolved air content so that the released air bubbles would redissolve quickly. The test water was deaerated in the St. Anthony Falls Hydraulic Laboratory 6-inch water tunnel as described previously. Air contents as low as 7 ppmw were used. The water was discarded at approximately 15 ppmw. The total air content of the test water was monitored by a Van Slyke apparatus. It was found to remain constant for several days. In previous work [8] this procedure was found to eliminate the effect of air bubbles on measurements. To reduce the possibility of cavitation on the rough test surfaces, the tank was pressurized during operation at high rotational speeds.

The total torque on the rotating cylinder was also measured at each run. The torque readings served as a check on the quality of the polymer solution with regard to drag reduction. A change in torque was assumed to indicate degradation of the polymer, and a new solution was then introduced into the test apparatus.

## IV. RESULTS

Figures 2 through 6 show spectrum data for radiated flow noise on rough cylinder surfaces as indicated by the diffuse noise level in the tank for five cylinder speeds between 45 and 76 fps with various concentrations of drag reducing polymer (Polyox 301). Data for water only are shown for both rough and smooth surfaces. Pressures superimposed on the tank water are indicated in the figures. These are gage pressures imposed at mid-height of the cylinder. Where no pressure is given, it is 2.2 in. of mercury; where the symbol -- occurs, pressures were not recorded.

The pressure level is given in relative units of dB below 1 microbar. Sound level difference with the addition of drag reducing polymer is the significant factor in this study. Additional information on calibration of the tank is given in Appendix I. The background level in the tank is indicated in Fig. 2. The vertical lines show the amount subtracted to correct the data for background noise.

The effect of superimposed pressure on radiated noise at high speed without polymer can be seen in Figs. 5 and 6. The increase in radiated noise with reduced pressure is probably due to cavitation, which can also be reduced by adding a drag reducing polymer. At lower speeds, Figs. 2 and 4, lower superimposed pressures apparently do not bring on cavitation.

Figure 7 is a cross plot of the variation of radiated noise with speed for a frequency of 20 kiloHertz. It is shown in Refs. [3], [4], and [6] that the flow noise from a smooth surface varies approximately as the sixth power of the velocity. The radiated noise for a rough surface was found to vary as a higher power of velocity [4,6]. The addition of a drag reducing polymer produced a lower level of noise; however, it can be seen that the slope of the curve of sound level with speed is nearly the same as that for roughness-generated noise without polymer additive.

Figure 8 shows the level of radiated noise as a function of surface shear for a range of surface speeds and with the addition of polymer. A line with a slope dependent on $\tau^3$ has been superimposed.

## V. DISCUSSION AND CONCLUSIONS

The inference that the radiated noise level measurements are dependent upon the energy dissipation in the boundary layer requires further experimental work to be completely justified. The most direct approach would require changing the Reynolds number of the flow so that all turbulence was suppressed and dissipation was entirely viscous while maintaining the same velocities and friction. This could be accomplished by using a fluid of much higher viscosity and surrounding the rotating cylinder with a close-fitting stationary shell. It was judged too difficult to do this within the time and funding of the test program.

Indirect evidence can be observed in the data which tends to support the premise that the boundary layer is the primary source of the observed noise. In Fig. 7, which could be duplicated for any frequency between 10 and 100 kilo-Hertz, the noise level increases nearly as the sixth power of the velocity as would be expected from theory [3], while at the same time the power input to the system increases approximately as the velocity cubed. Most mechanically induced vibration would be expected to have the same velocity dependence as the input power. The noise level dependence on the sixth or greater power was used as a criterion for accepting or rejecting a test run. Usually when a lower velocity exponent was observed it was possible to find loose mechanical elements. Particularly troublesome in this regard was a small quantity of sand which was on occasion carried into the test tank by the operator's shoes and could be detected as it rolled around on the bottom. Less conclusive evidence is also found in the "spiked" nature of the frequency spectrum which usually accompanies noise from mechanical vibration and is not present in the part of the spectrum reported on herein.

The pressure-dependent part of the flow noise shown in Figs. 5 and 6 is not easily explained. The velocity dependence and the pressure dependence suggest some form of cavitation or gas release mechanism. However, a true cavitation would be expected to give much broader noise spectra than those observed, particularly at high frequencies. The possibility remains that a layer of gas bubbles is released near the rotating cylinder which could increase the radiating efficiency of the boundary layer in the manner proposed by Creighton and Ffowcs Williams [9].

In any event, radiated noise from a rough surface seems to have a part which could be called independent of pressure and a "pressure-dependent" part as can be seen in Figs. 5 and 6; the latter is most likely caused by cavitation on the roughness elements. The addition of a drag reducing polymer appears to reduce the "pressure-independent" part of the radiated noise in proportion to the reduction of average shear on the surface as shown in Fig. 8. The pressure-dependent part of the flow noise is also reduced by the addition of drag reducing polymer, but no effort was made to study this condition.

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# ILLUSTRATIONS

(Figures 1 through 8)

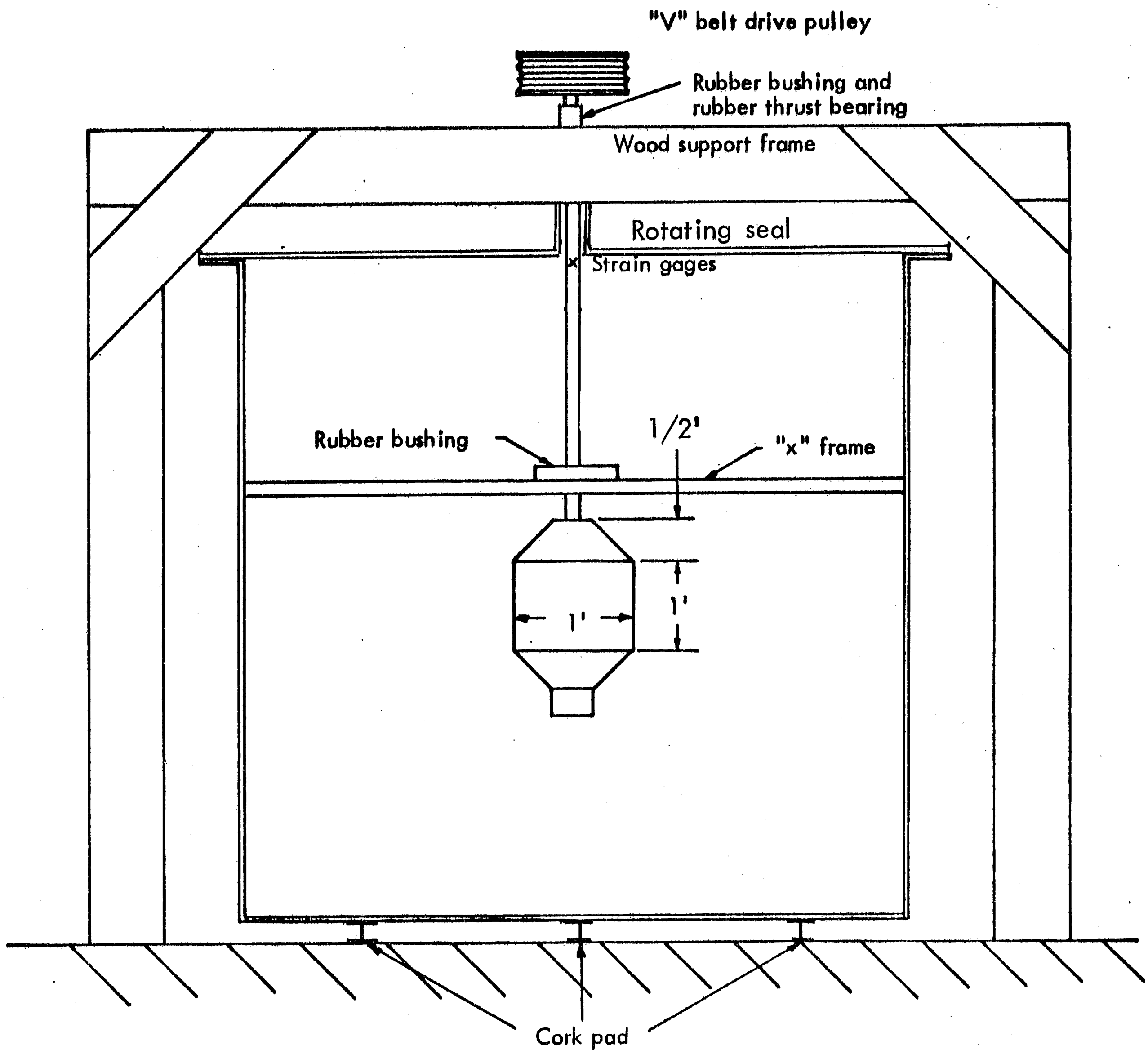


Fig. 1 - Sketch of Test Tank with Rotating Cylinder in Place

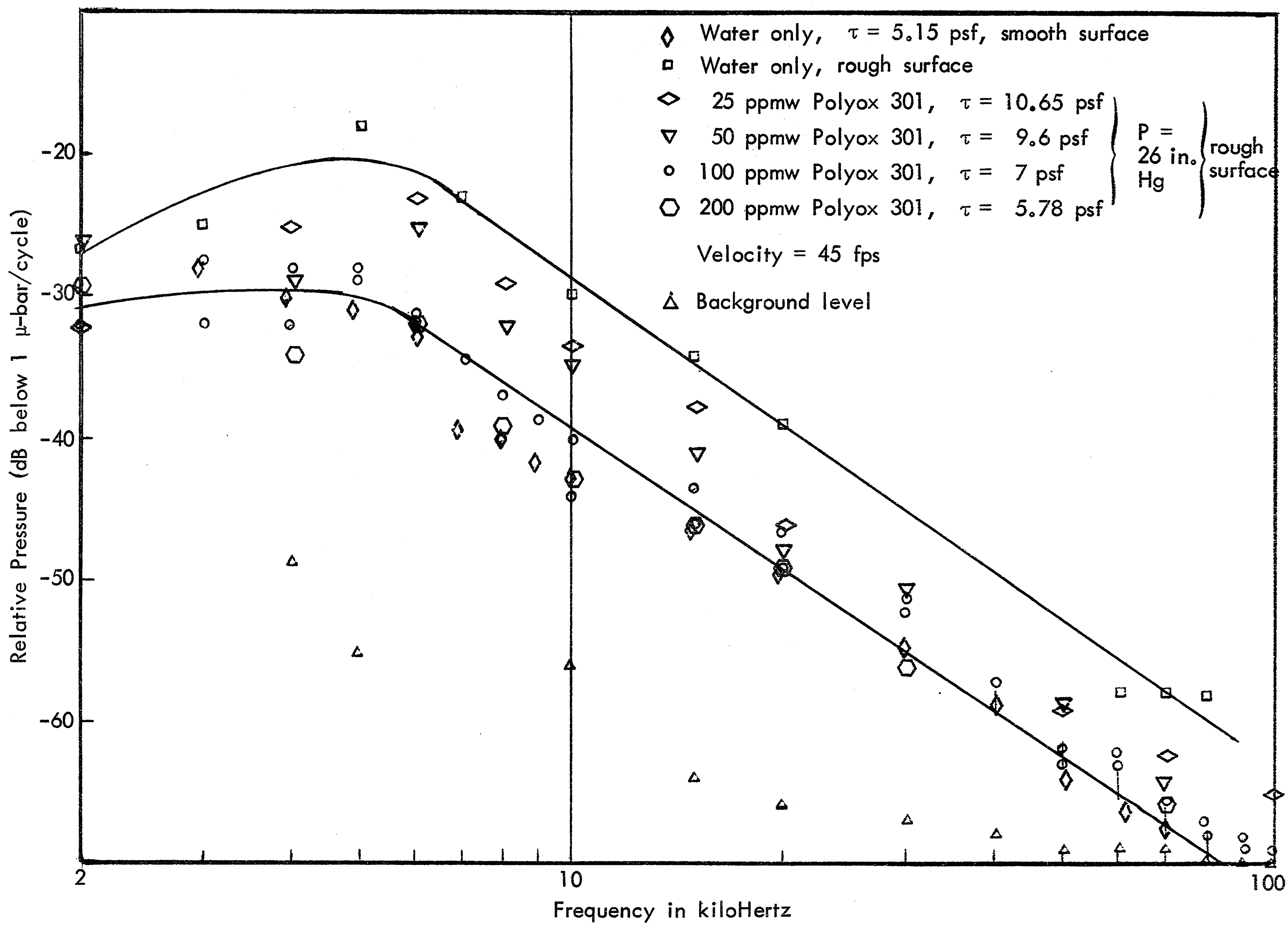


Fig. 2 - Radiated Flow Noise Spectra at 45 fps Surface Speed

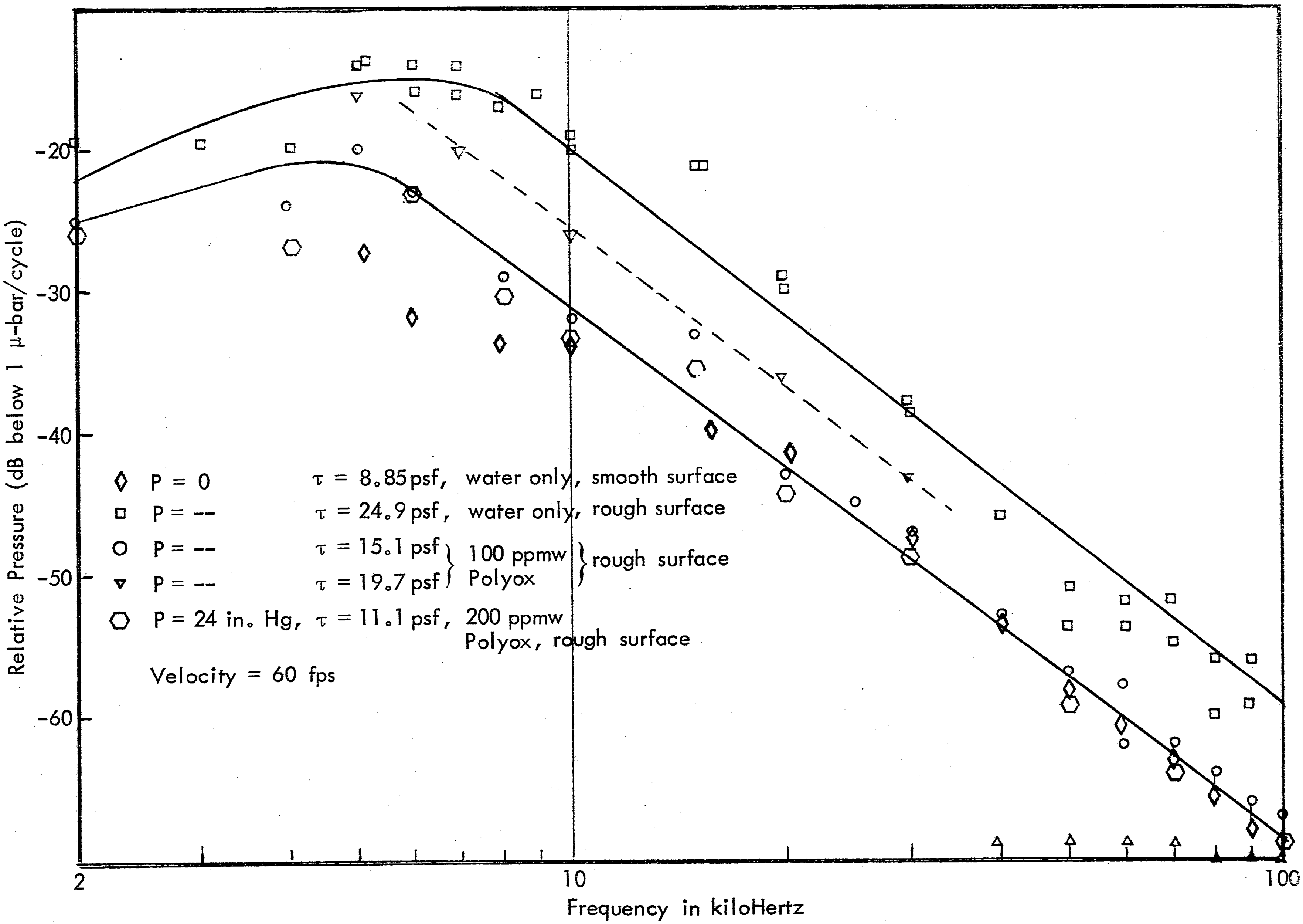


Fig. 3 - Radiated Flow Noise Spectra at 60 fps Surface Speed

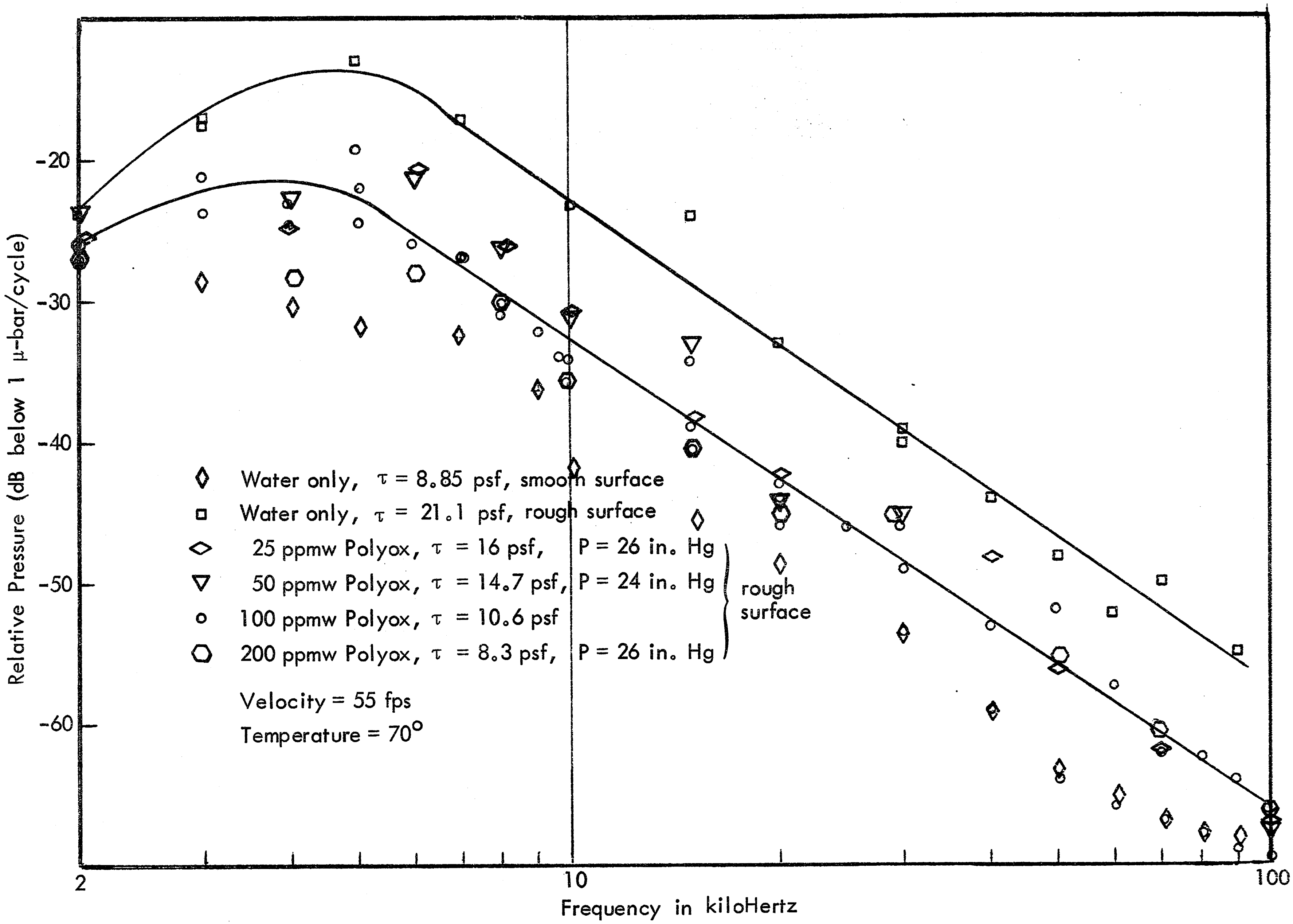


Fig. 4 - Radiated Flow Noise Spectra at 55 fps Surface Speed

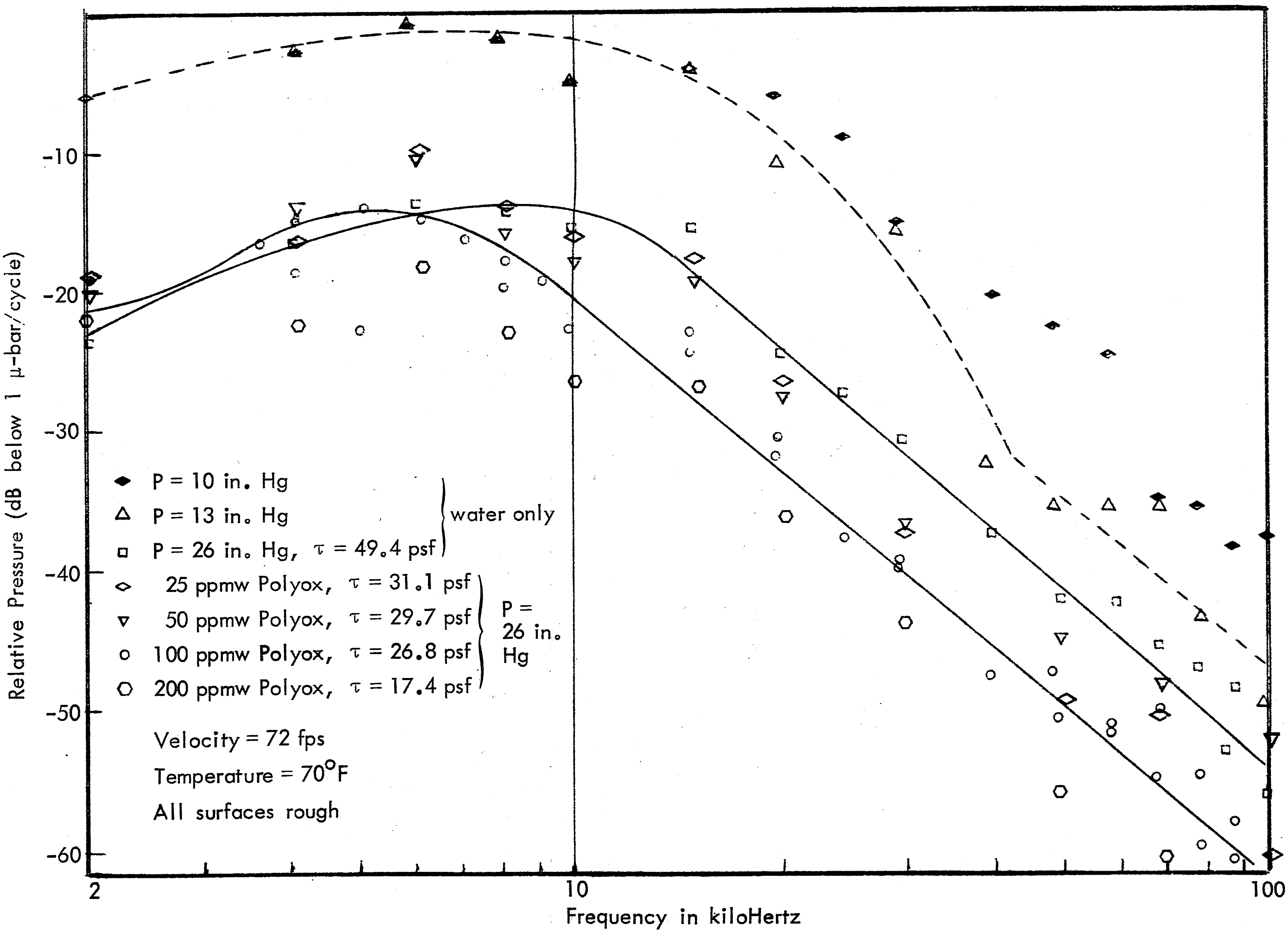


Fig. 5 - Radiated Flow Noise Spectra at 72 fps Surface Speed

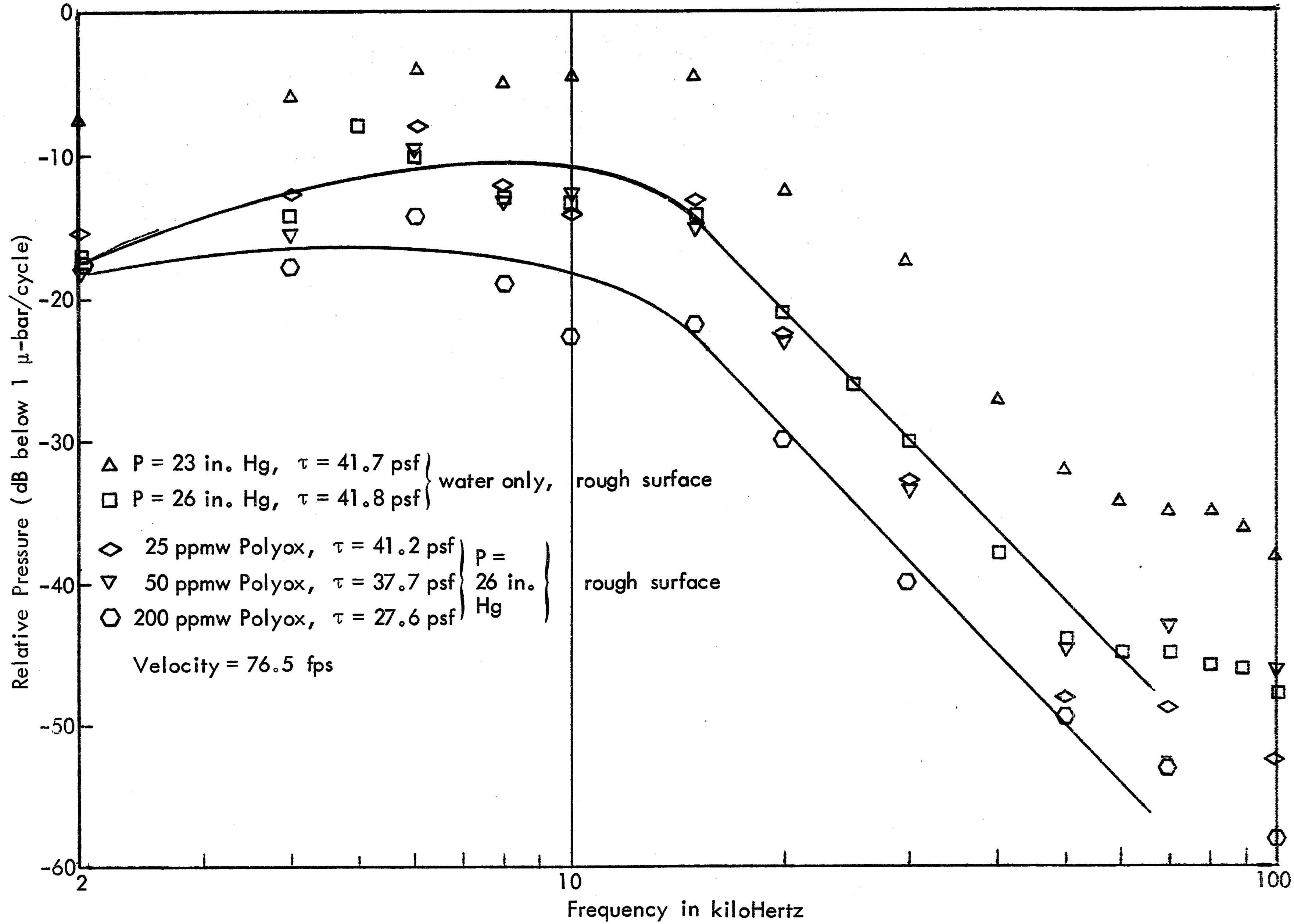


Fig. 6 - Radiated Flow Noise Spectra at 76.5 fps Surface Speed

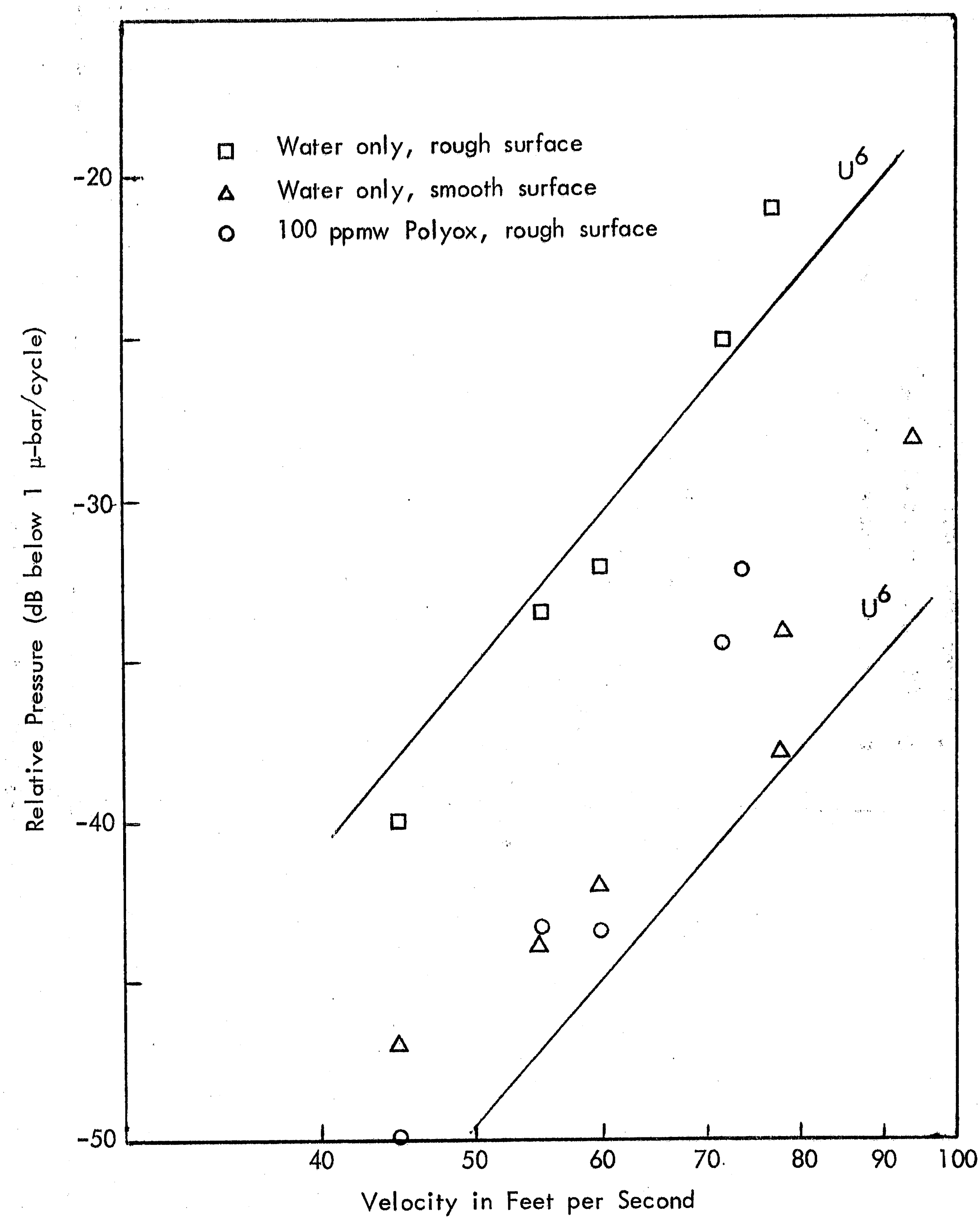


Fig. 7 - Velocity Dependence of Radiated Noise at 20 kiloHertz

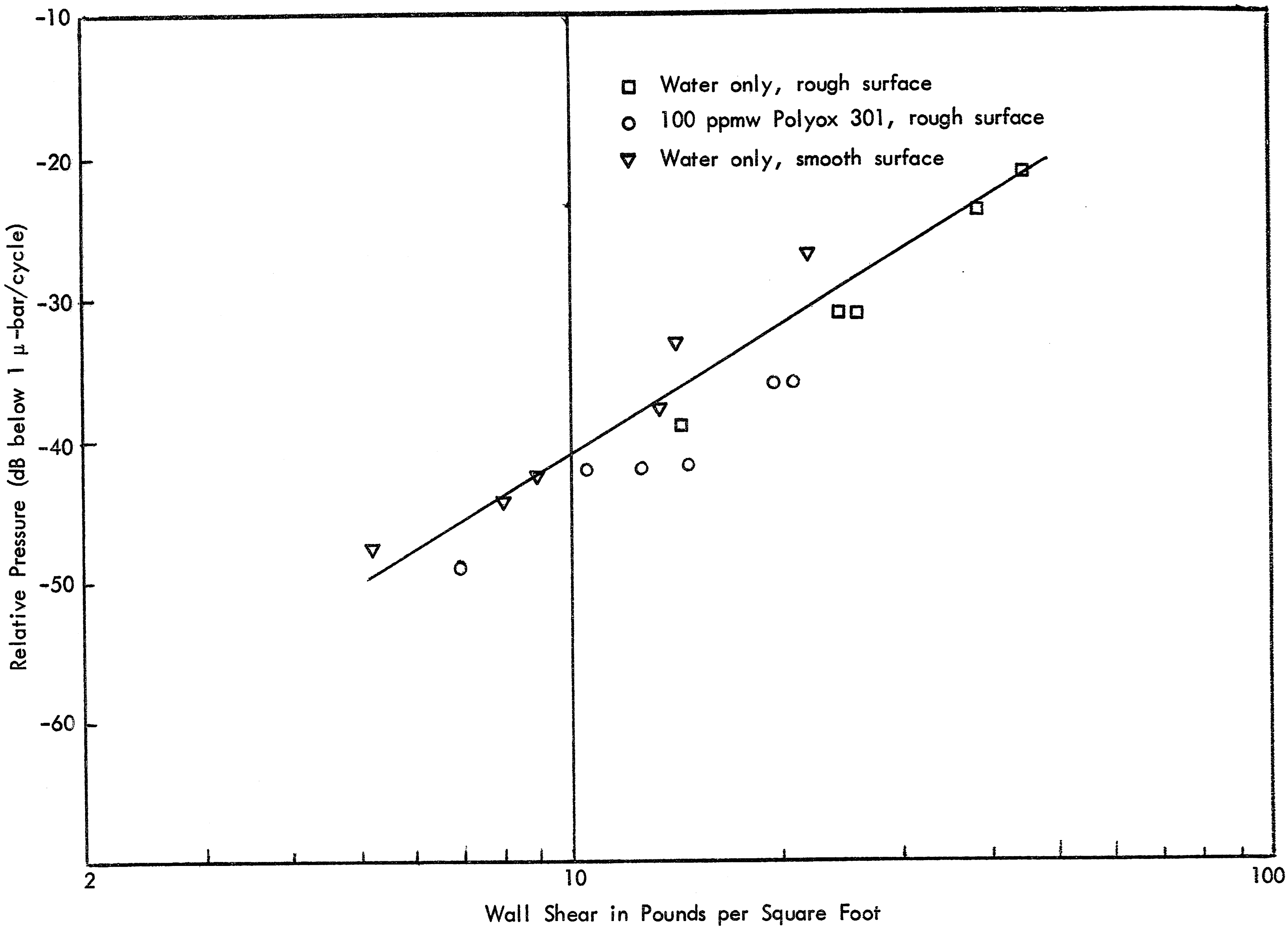


Fig. 8 - Shear Dependence of Radiated Noise at 20 kiloHertz

## Appendix I

CALIBRATION OF THE TANK

To relate the power input to the tank to the pressure measured by the CH1A hydrophone, a spherical acoustic source (International Transducer 1002) was used to excite the tank. A random noise generator supplied the power in a given bandwidth as measured by a wave analyzer. The manufacturer's calibration of the 1002 transmitter gives the equivalent sound pressure at one meter. The total energy delivered by this small source (1 inch diameter) was assumed to be unchanged by the tank.

This unit is also calibrated as a receiver and as such is ideally suited to receiving random incident sound. Comparison of the noise in the tank as measured by the CH1A hydrophone and as measured by the spherical unit (1002) showed it to be the same within the resolution of the measurement system.

Figure 1A gives the equivalent pressure input from a spherical source and the resultant pressure level in the tank for both water alone and water with 200 ppmw Polyox 301. No significant difference due to the presence of Polyox can be noted.

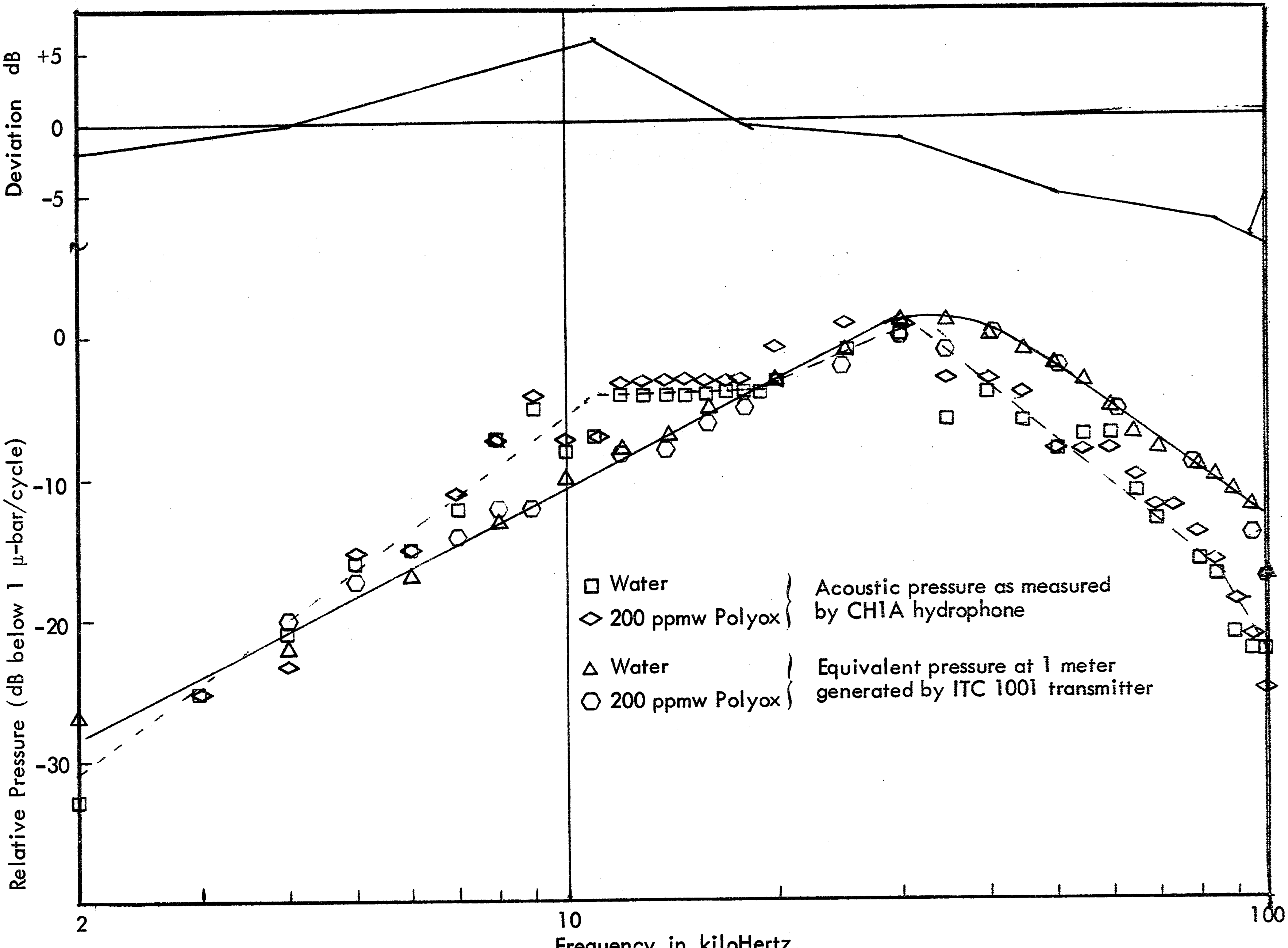


Fig. 1A - Echoic Tank Calibration

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13. ABSTRACT

Experimental measurements were made of radiated noise from a rough surface moving in water and from the same noise moving in a dilute water solution of a drag reducing polymer. Roughly 10 Db of noise reduction was observed for a concentration of 100 ppmw Polyox 301.

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| Radiated flow noise | | | | | | |
| Drag reduction, rough surfaces | | | | | | |