UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS HYDRAULIC LABORATORY

Project Report No. 90

The Effect of Dilute Solutions of Drag Reducing Polymers on Radiated Flow Noise

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PREFACE

The effect of polymer additives on the flow characteristics of water is a subject of continuing study at the St. Anthony Falls Hydraulic Laboratory. These studies include the drag reducing properties of polymer additives in pipe flow, the structure of the developing turbulent boundary layer with additives, the effect of polymer additives on Taylor vortices and the effect of polymer additives on boundary layer pressure fluctuations.

The work reported herein is an experimental effort to determine the effect of a polymer additive on radiated flow noise in water. The studies reported were carried out in the period from October 1964 to October 1966 and were sponsored by Naval Ship Research and Development Center, Department of the Navy, Washington, D.C. under Contract Nonr 710(63). The report was reviewed by J. M. Wetzel and Edward Silberman. Appreciation is expressed to John Almo for part of the data collection, to Paul Edstrom and Edwin Joyce for data reduction, and to Ernst Elguther and his associates for preparation of the graphs. Preparation of the manuscript for printing was carried out by Marjorie Olson and Lorraine Larson.

ABSTRACT

The influence of a drag reducing polymer additive in water on radiated flow noise was experimentally determined. The test facility was a rotating cylinder mounted in the center of a large cylindrical tank which served as an echoic chamber for the sound power measurements. Sound power radiated from the boundary layer of the rotating cylinder was measured for concentrations of 0, 10, 100, and 1000 ppmw of Polyox WSR 301 dissolved in the water. Sound power reductions greater than 20 decibels were noted in a frequency range of 20 to 100 kHz for a concentration of 1000 ppmw. Little influence could be found in a frequency range of 1 to 20 kHz.

The effect of polymer additive on the drag coefficient of a rotating cylinder is also shown.

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I. INTRODUCTION

The work reported herein is an effort to show from laboratory experiment the effect of various concentrations of water soluble polymers on radiated flow noise from moving objects, as compared with radiated flow noise from objects moving in tap water. 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, possibly the rate at which large turbulent eddies break down into smaller and smaller eddies.

The original work of Lighthill [1]* shows an intimate relationship between the radiated flow noise and the internal stresses in 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 assumption of turbulence structure is a common denominator for both flow noise and drag, the addition of a drag reducing polymer should be expected to affect flow noise as well. Unfortunately, available estimates of turbulence and its interaction with drag or noise provide little help in predicting or correlating effects in the presence of polymers.

II. EXPERIMENTAL APPARATUS

The generation of radiated flow noise is an inefficient process [1,2,3]. Experimental measurements reported in Reference [6] give a ratio of acoustic power to friction power loss as 3×10^{-7}; 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.

A rotating cylinder test facility was chosen in preference to a water tunnel or towing tank for the following reasons: It has the smallest moving mass for the active area; it has a minimum of moving parts to generate

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*Numbers in brackets refer to the List of References on page 9.

unwanted noise; and it has a naturally rigid structural form. The rotating cylinder 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 to provide some isolation from sound transmitted through the air.

The tank capacity was 1260 gallons. It was filled to a 6 ft depth from the municipal water supply or the contents of the St. Anthony Falls Hydraulic Laboratory 6 in. water tunnel. The water tunnel is also filled from the municipal water supply which processes 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 polished to a high gloss. It was waxed frequently during the test program to assure an approach to a hydraulically smooth surface.

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 cross frame also supported a 2 ft diameter disk immediately above the cylinder to prevent air from being drawn down the vortex core which occurred in the tank during operation. The cylinder was driven by a 20 hp, 3500 rpm induction motor through a "V" belt drive. Speed changes were affected by various combinations of pulleys on the motor and cylinder shaft. Figure 1 shows a drawing of the tank and cylinder.

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 of 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), 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.

The drag coefficient of the rotating cylinder in tap water was measured as 0.0023 for speeds ranging from 44 to 100 fps. The drag coefficient C_d is defined according to the following equation from Reference [4].

$$C_d = \frac{M}{qsa} = \frac{M}{\pi \rho a^4 \omega^2 \ell}$$

where M = the measured torque corrected for the torque contributed from the ends of the cylinder (correction calculated from disk data of Reference [4]),

ω = the rotational speed in radians per sec,

a = radius of cylinder,

ℓ = length of cylinder,

ρ = water density,

R = Reynolds number = $\frac{\omega a^2}{\nu}$,

ν = kinematic viscosity,

s = surface area of cylinder, and

$q = \frac{1}{2}\rho\omega^2 a^2$.

The drag coefficient so measured and corrected checks very well with the extrapolation of the hydraulically smooth cylinder data of Theodorsen and Regier [4].

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 [5] and in air by Wilson [6]. Their data show a logarithmic velocity distribution similar to the flat plate. The effect of polymer additives is unknown. Flow, no doubt, occurs along the axis of the cylinder, although it was hoped a brief operating period would reduce this effect.

The acoustic pressure in the tank was sensed by a USRL H17 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 USRL were used as a reference.

The signal from the hydrophone was amplified by a Sensonic Model SE 140 preamplifier. A Panoramic Model Sb-7b2 frequency analyzer was used above 10 KC and Hewlett Packard Model 300 frequency analyzer was used below 10 KC to measure sound intensity in discrete frequency bands. Both frequency analyzers were modified by incorporating a true rms voltmeter (Ballentine 320) as a second detector. The equivalent band width of both instruments was also measured to permit expressing data in units of intensity per cycle. The output of the true rms voltmeter was connected to an xy plotter. It is recognized that the Ballentine rms voltmeter does not hold its calibration at the 1.5 MHZ of the Panoramic analyzer's crystal filters. Careful measurement showed, however, that its rms feature still applied and the entire assembly could be calibrated. The frequency analyzers were used to examine a single frequency at a time. The scanning mode of the Panoramic analyzer was used for a "quick look" only. A block diagram is shown in Fig. 2.

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 Reference [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 and the resulting pressure in discrete frequencies were determined. The acoustic source referred to above was a 1/4 in. copper pipe flattened near one end. The pipe was connected to a constant pressure water supply. As water flowed through the flattened part of the pipe, cavitation occurred creating essentially a point source of intense noise.

The energy output of the source was determined by measuring the pressure at a known distance from the cavitating source with a standard hydrophone. The intensity $P^2/\rho c$ was then integrated over a spherical surface surrounding the source. P is the pressure, ρ 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 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 in. 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. It was found from previous work [8] that this procedure would eliminate the effect of air bubbles on measurements.

The following procedure was used to measure flow noise. The entire electronic assembly was calibrated at a single frequency by the introduction of a known voltage across the calibrating resistor in the H17 hydrophone. As illustrated in Fig. 2, an arbitrary electrical input of -120 decibels referred to one volt was used throughout the program. The xy plotter and the drive motor on the rotating cylinder were started simultaneously and a time record of the hydrophone output was taken. This procedure was repeated at each frequency for a series of cylinder surface speeds of 44 to 100 fps. Three concentrations of Polyox WSR 301 of 10, 100, and 1000 ppmw were dissolved in the test water. A typical time record of flow noise at any frequency indicated that the noise level rose sharply during the acceleration period, dropped to a constant value briefly, and then decreased as the vortex built up in the tank and if air was released. The recorded level of flow noise was taken from the level portion of the record. It was hoped by this procedure that the release of air was minimized and that the degradation of the drag reducing polymer was reduced also.

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 in 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

The torque required to drive the cylinder was measured for tap water solutions of 0.0 ppmw, 10 ppmw, and 100 ppmw of Polyox WSR 301. The results are shown in Fig. 3.

The drag coefficient was calculated for water and drag reducing polymer solution and is shown in Fig. 4 superimposed on the data of Reference [4]. The correction for the drag of the cylinder ends was calculated from the data of Reference [4] for the rotating disks. The correspondence of the measured drag coefficient with the smooth cylinder drag measured by Theodorsen et al is regarded as evidence that a hydraulically smooth surface was achieved. The drag coefficient for the DRP solution plotted as a fraction of the "water only" values is shown in Fig. 5. This assumes that the fractional drag coefficient reduction is the same for the cylinder ends as for the surface.

The effect of three concentrations of drag reducing polymer (Polyox WSR 301) on radiated flow noise emitted by the rotating cylinder is shown in Figs. 6, 7, 8, and 9 (solid symbols) as compared with tap water alone (open symbols). Four values of dissolved air are shown. Dissolved air was found to have little effect on flow noise [8] and to have little significance in this study.

The noise level in the tank is shown in the shaded areas of Figs. 7, 8, and 9. The noise level produced by a cavitating rod mounted on the surface of the cylinder is shown on some figures as a qualitative indication of background noise when cavitation is present. This is an equivalent noise power originating at the cylinder. The hydrophone signal is the sum of the background noise pressure and the flow noise pressure. The background energy has been subtracted from the total energy density as measured by the hydrophone to give the flow noise energy density. This energy density is then converted into the flow noise energy emitted by the cylinder by applying the tank calibration. The scattered noise field in the tank becomes less uniform, as expected, at low frequencies which cause much greater scatter in the data.

Figs. 6, 7, 8, and 9 show the plots of radiated flow noise versus velocity with frequency and concentration as parameters. The open symbols indicate the tap water case from Reference [8]*. The work of Lighthill [1] and Curle [3] interpreted radiated flow noise sources in terms of equivalent multipole radiators. From dimensional considerations they have shown that these equivalent sources can be identified from the velocity dependence of radiated flow noise intensity. A U^6 relationship (18 db per speed doubling) corresponds to a dipole radiator, U^8 (24 db per speed doubling) to quadrupoles, etc. The addition of drag reducing polymer reduces the slope of the intensity variation to approximately 10 db per speed doubling, a U^3 relationship in a region where tap water shows a U^{10} variation. This would seem to indicate a considerable alteration in the basic flow at high frequencies, a phenomenon associated with small scale turbulent eddies.

The data of Figs. 6, 7, 8, and 9 have been replotted in Figs. 10, 11, and 12 to show more clearly the frequency dependence of the noise reducing capabilities of DRP. The tap water data are again represented by open symbols and the polymer by closed symbols. The ordinate which has been in watts per cycle per square meter has been divided by $\frac{\rho U^6}{c^3}$ to reduce the variation of data with velocity. The spread of the data is now due to the departure

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*Note a 20 db shift in scale due to an error discovered after publication of [8].

of the data from this U^6 relationship. Tap water shows a higher order variation at high frequencies and DRP shows a lower order variation.

The modification of the small-scale energy dissipating eddies has been postulated as a basic mechanism by which DRP (1000 ppmw Polyox WSR 301) reduces drag. The reduction of radiated flow noise at high frequencies would support the above speculation. A graphical integration of the integrated noise output with the addition of DRP shows a reduction to 0.49 of the total noise output of water alone. The drag coefficient was reduced to 0.425 for a like concentration of polymer which shows the total noise output is reduced in about the same amount as the drag, as would be expected from energy considerations.

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FIGURES

(1 through 12)

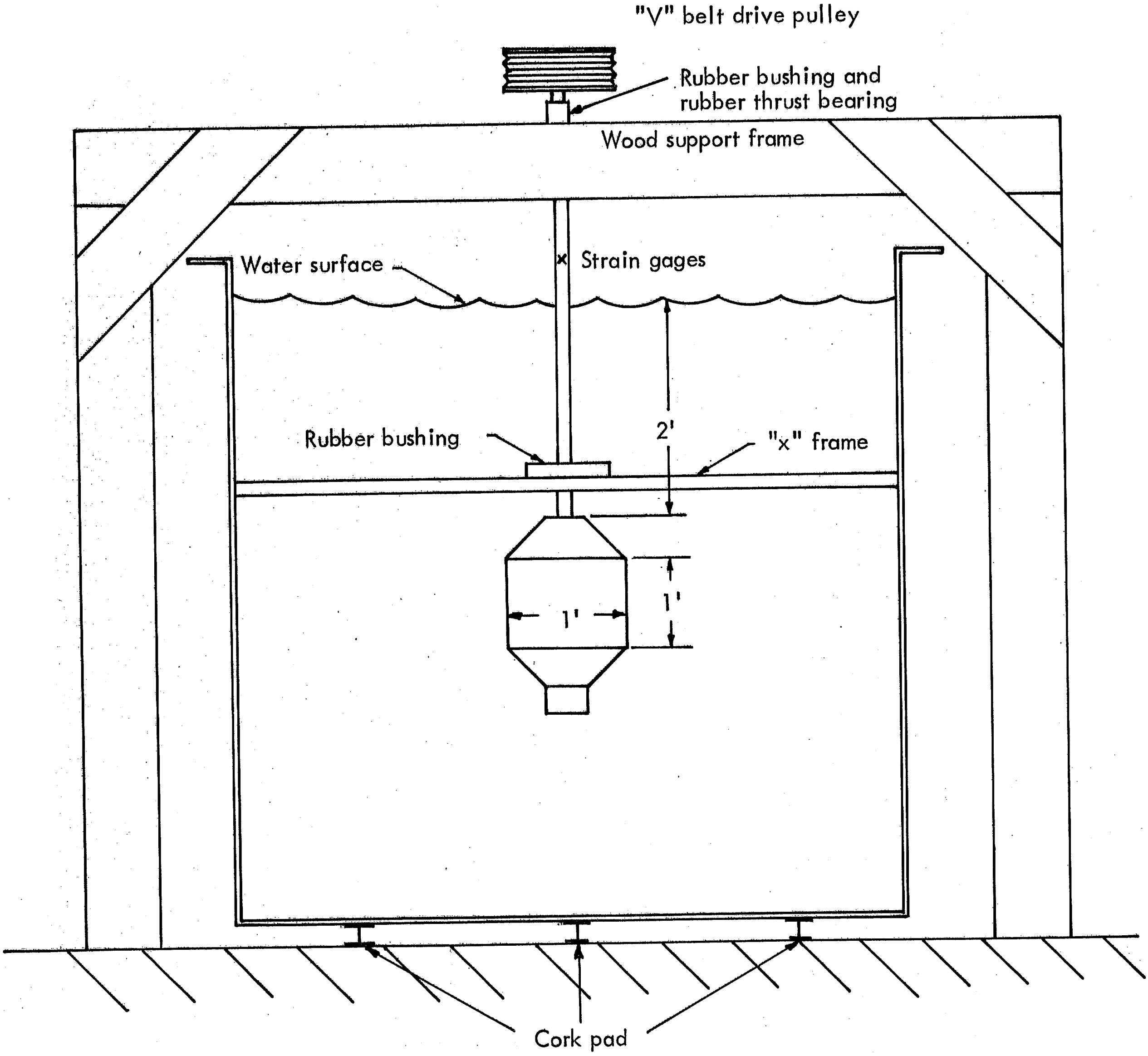

Fig. 1 - Sketch of Test Tank with Rotating Cylinder in Place

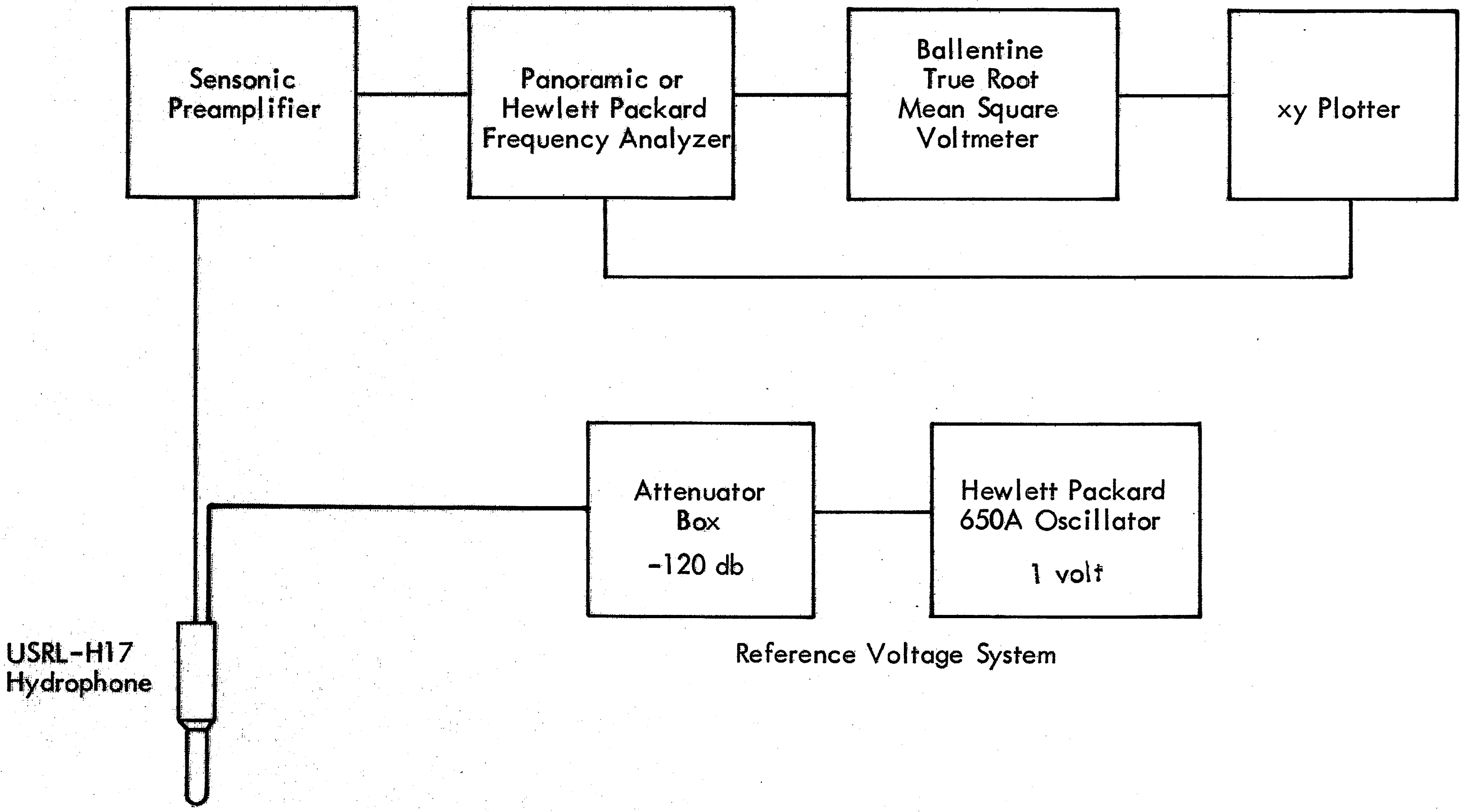

Fig. 2 - Block Diagram of Electronic Measuring Equipment

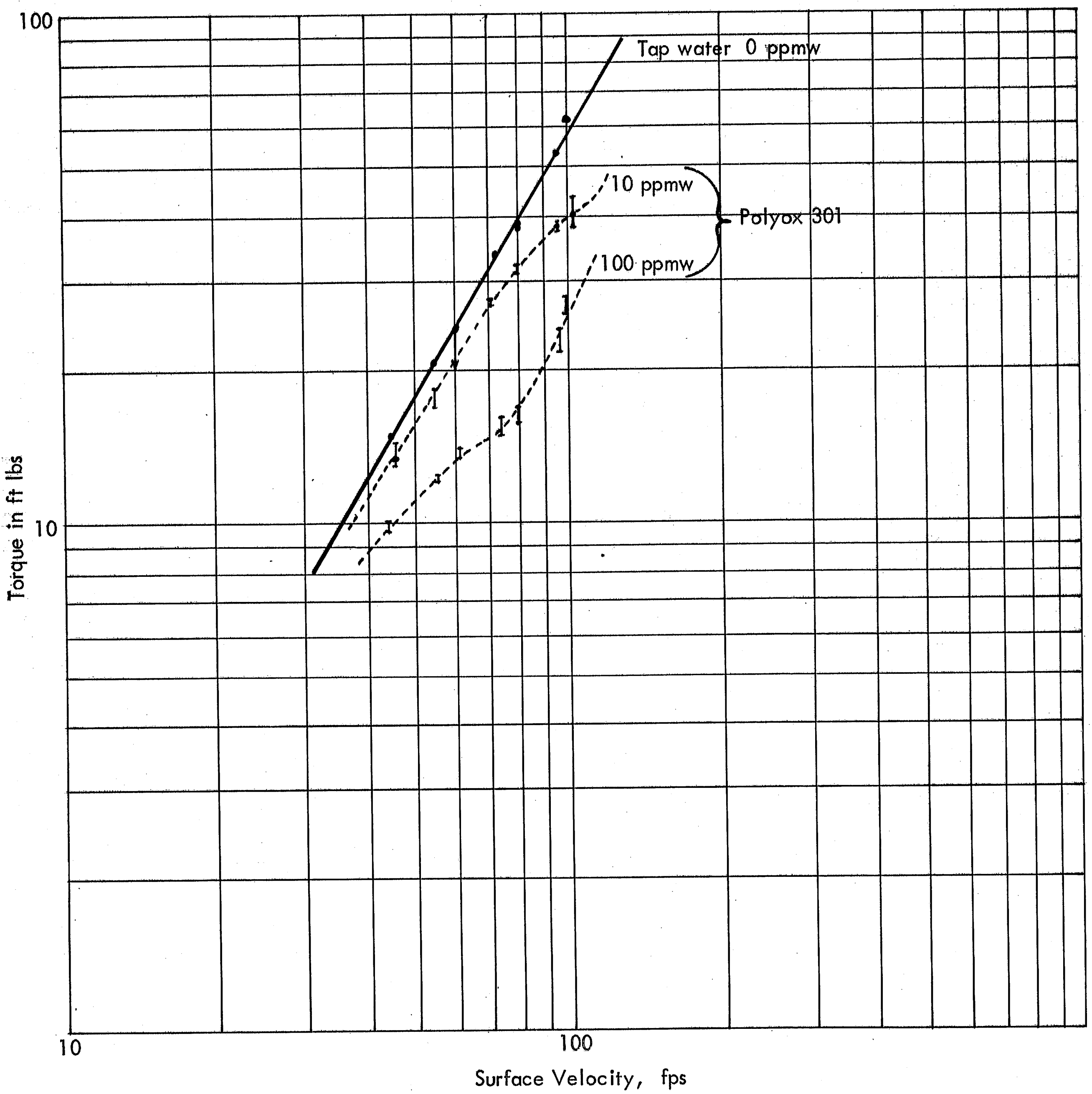

Fig. 3 - Reduction of Driving Torque Required by a Rotating Cylinder in Water as Influenced by the Addition of a Drag Reducing Polymer

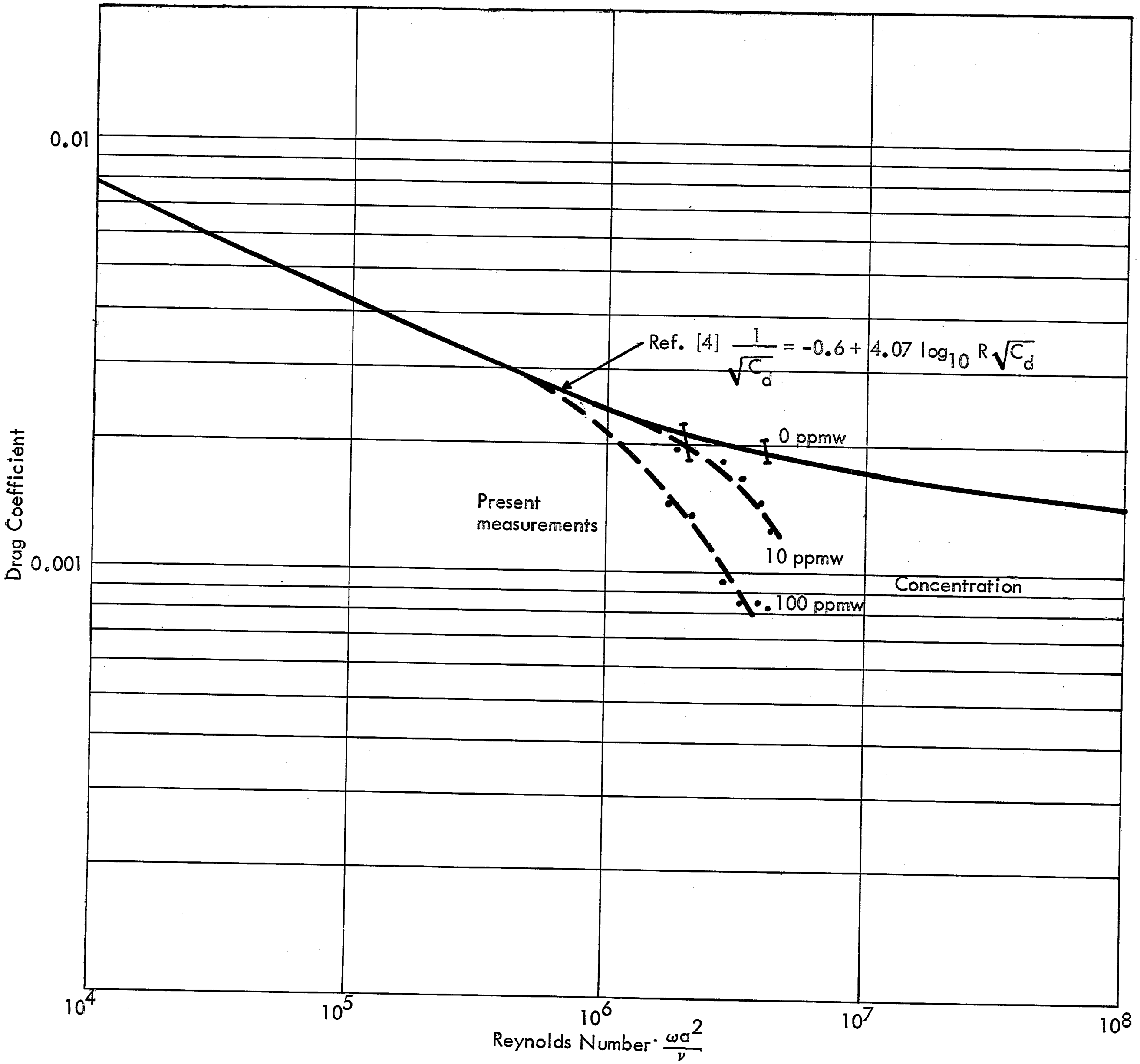

Fig. 4 - Drag Coefficient for Rotating Cylinder

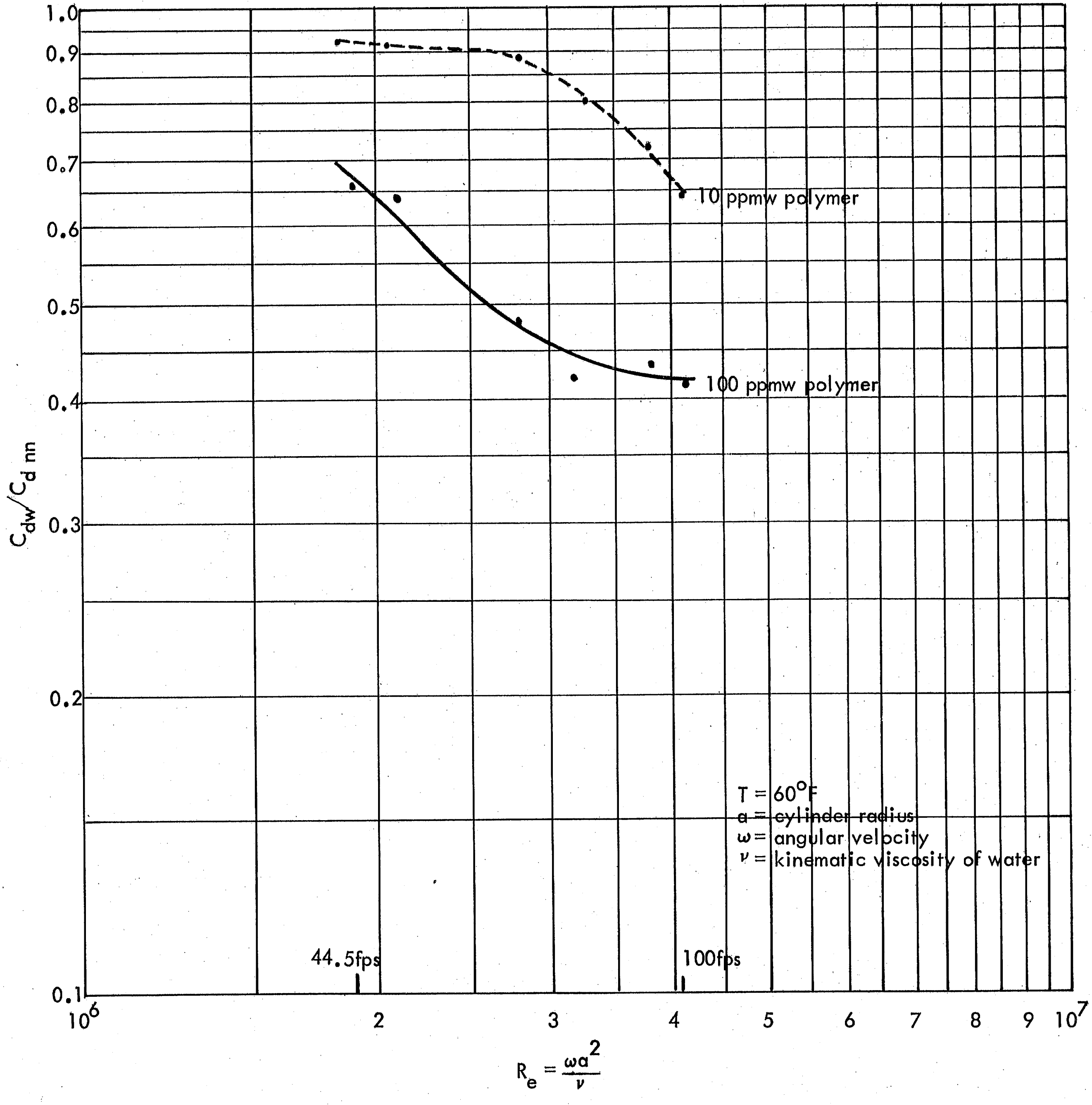

Fig. 5 - Effect of Dissolved Polymer on Drag Coefficient of a Rotating Cylinder

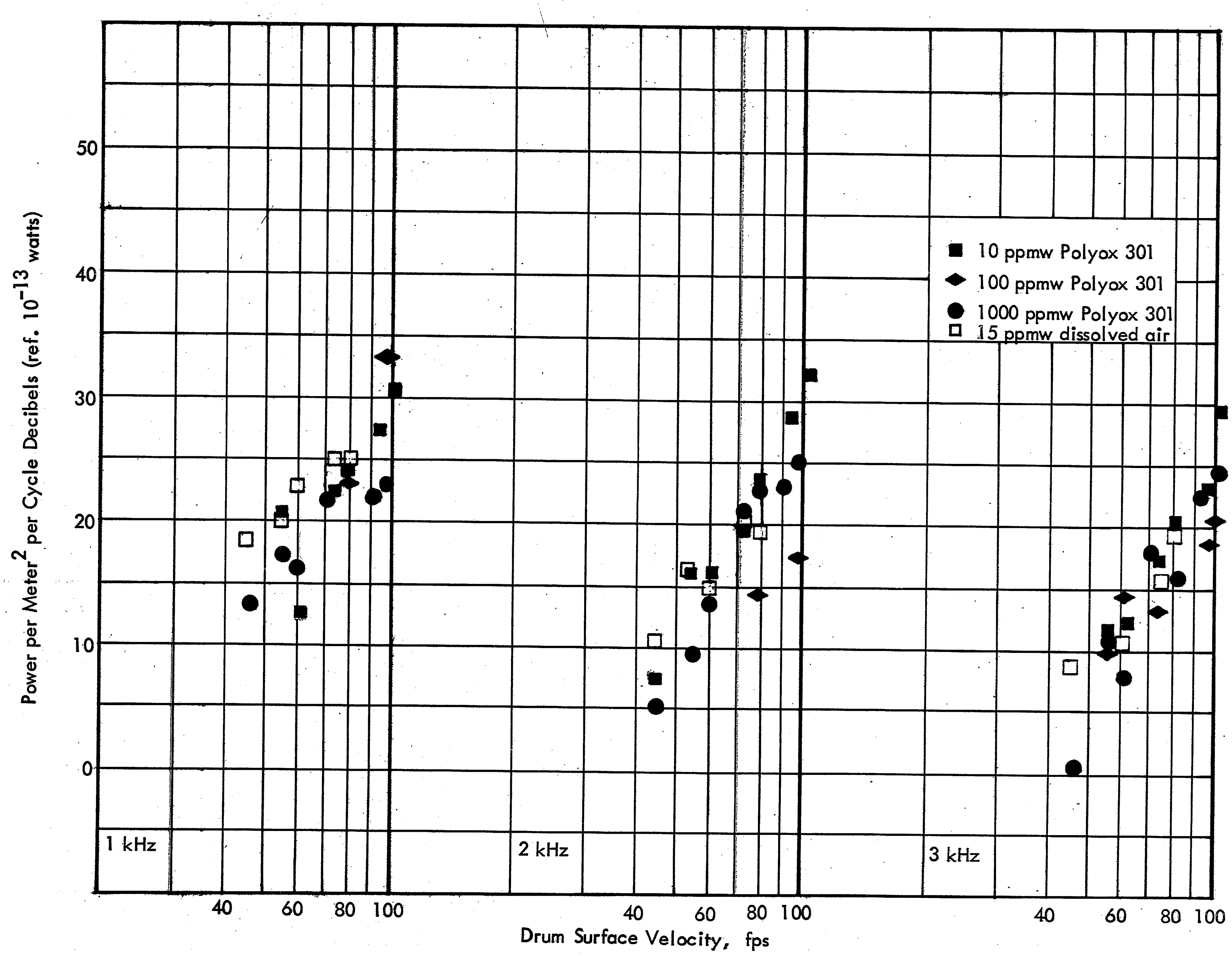

Fig. 6 - Flow Noise Power Measurements - 1 kiloHertz to 3 kiloHertz

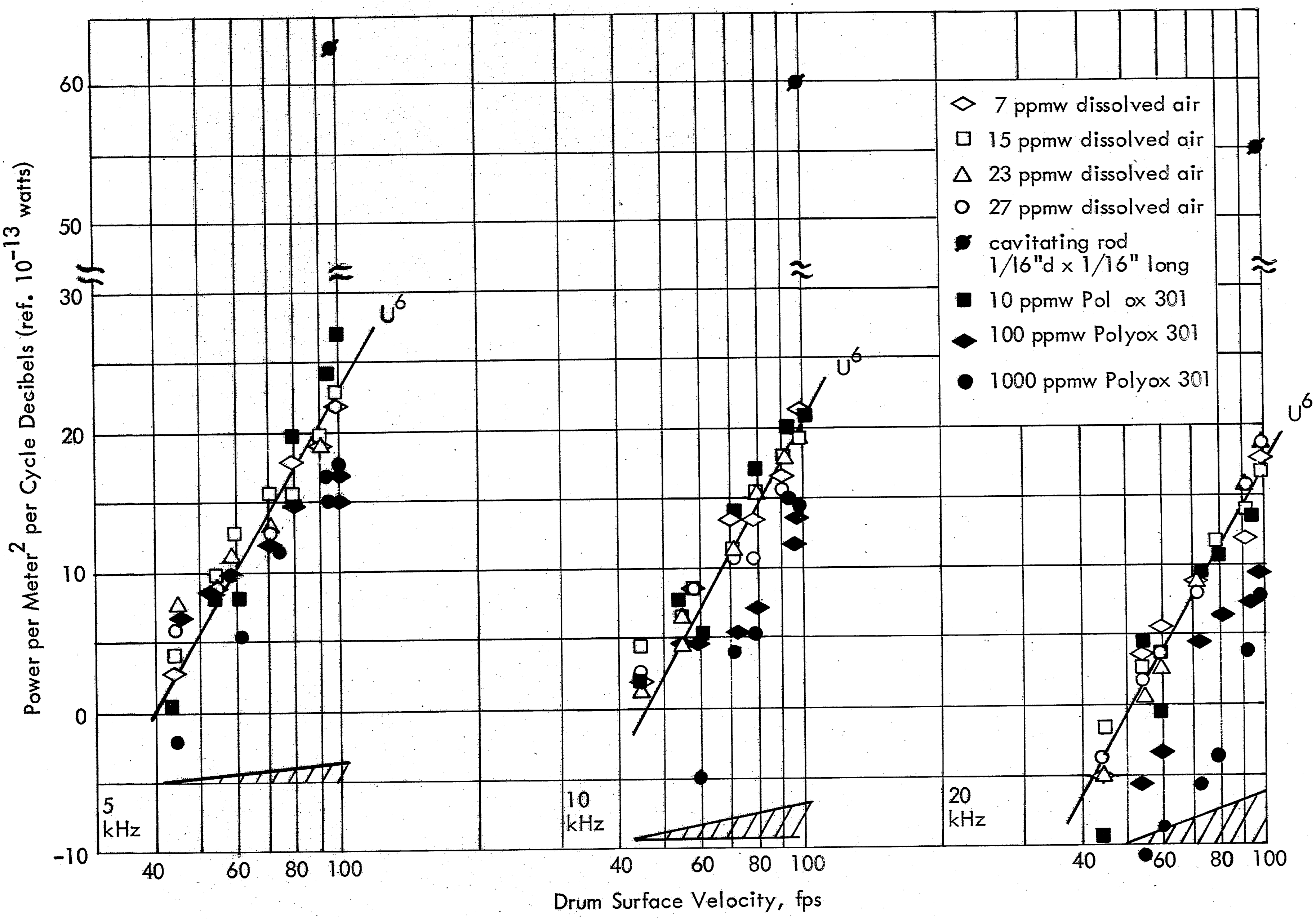

Fig. 7 - Flow Noise Power Measurements - 5 kiloHertz to 20 kiloHertz

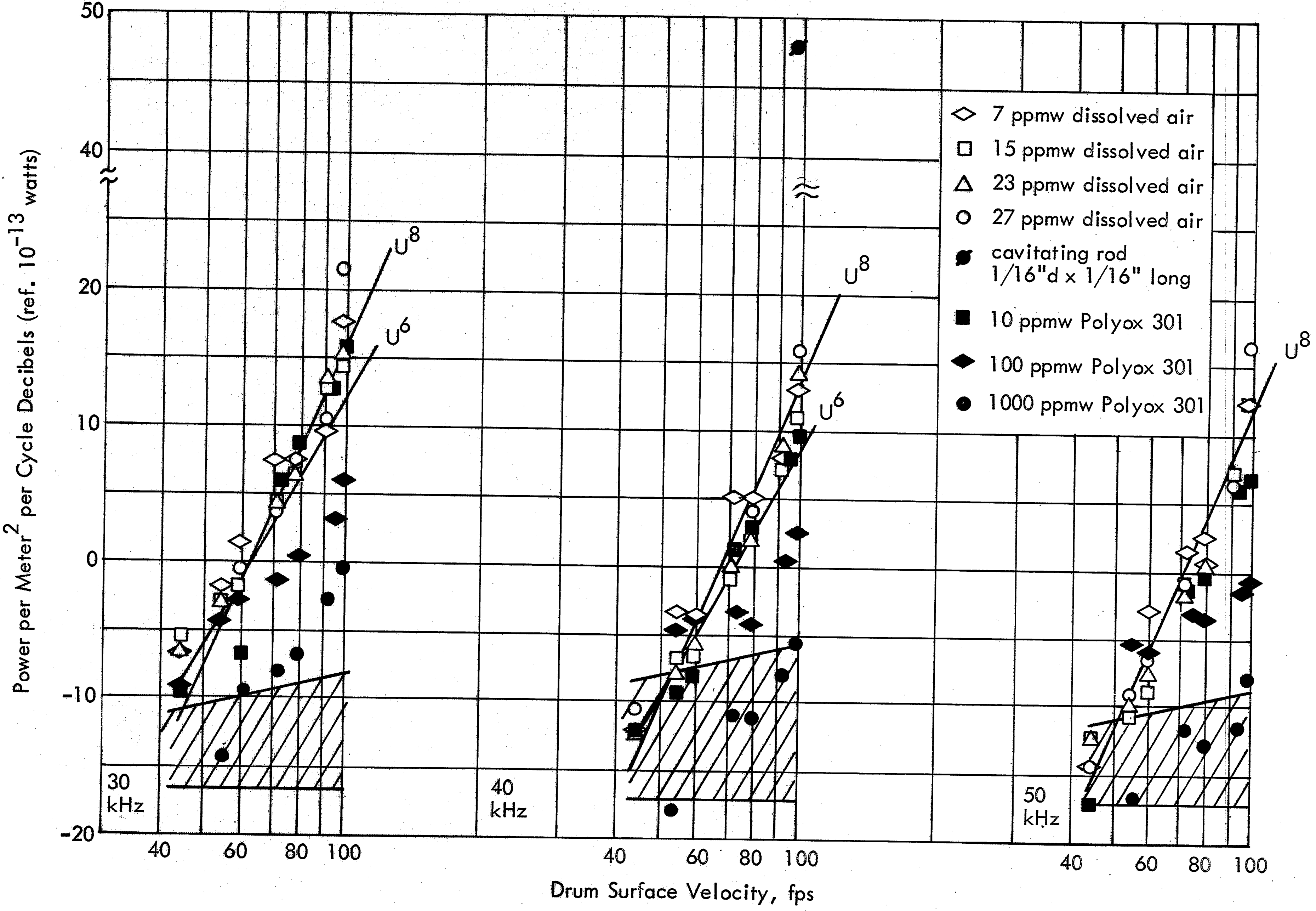

Fig. 8 - Flow Noise Power Measurements - 30 kiloHertz to 50 kiloHertz

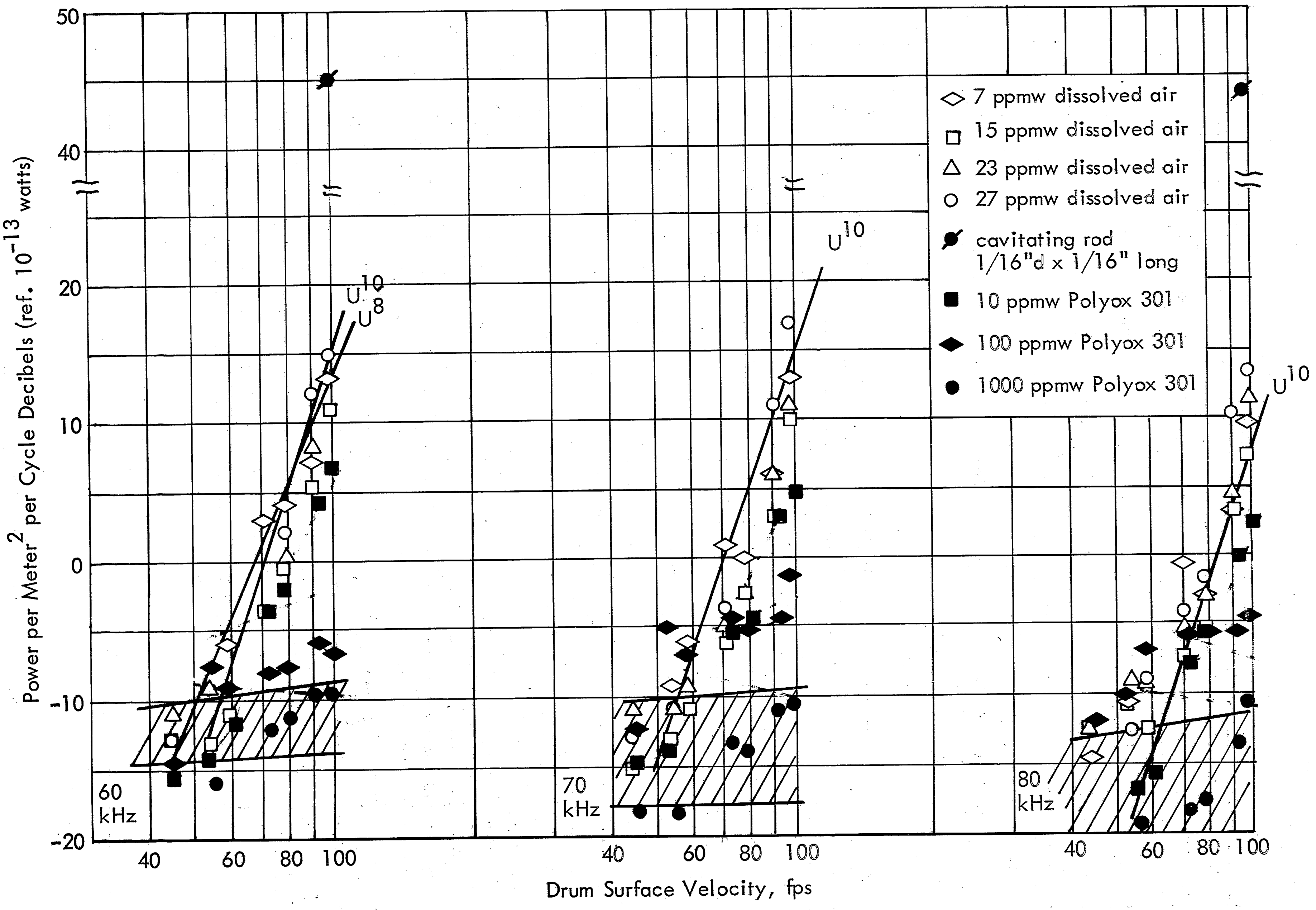

Fig. 9 - Flow Noise Power Measurements - 60 kiloHertz to 80 kiloHertz

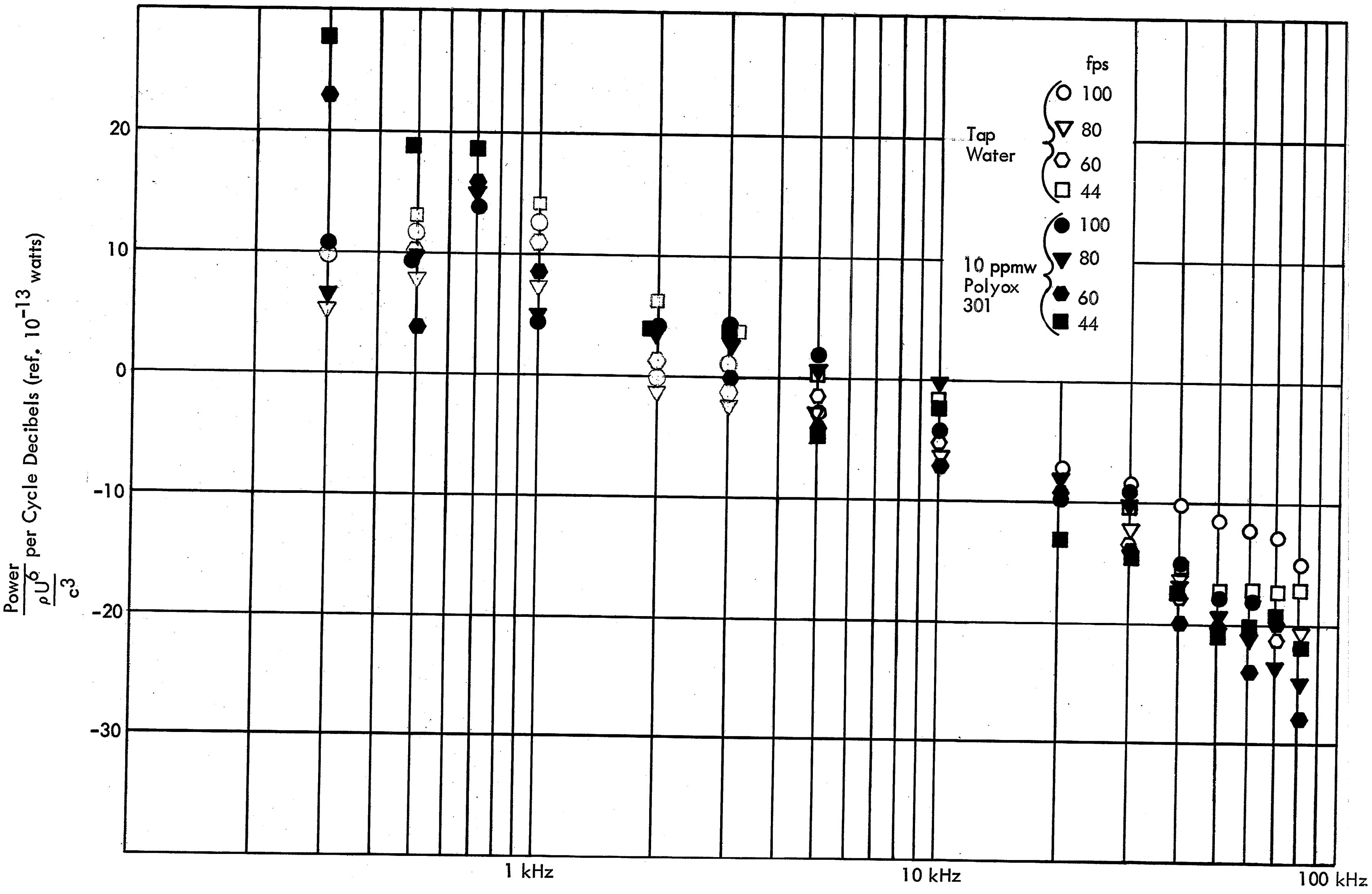

Fig. 10 – Effect of Addition of Drag Reducing Polymer on Radiated Flow Noise

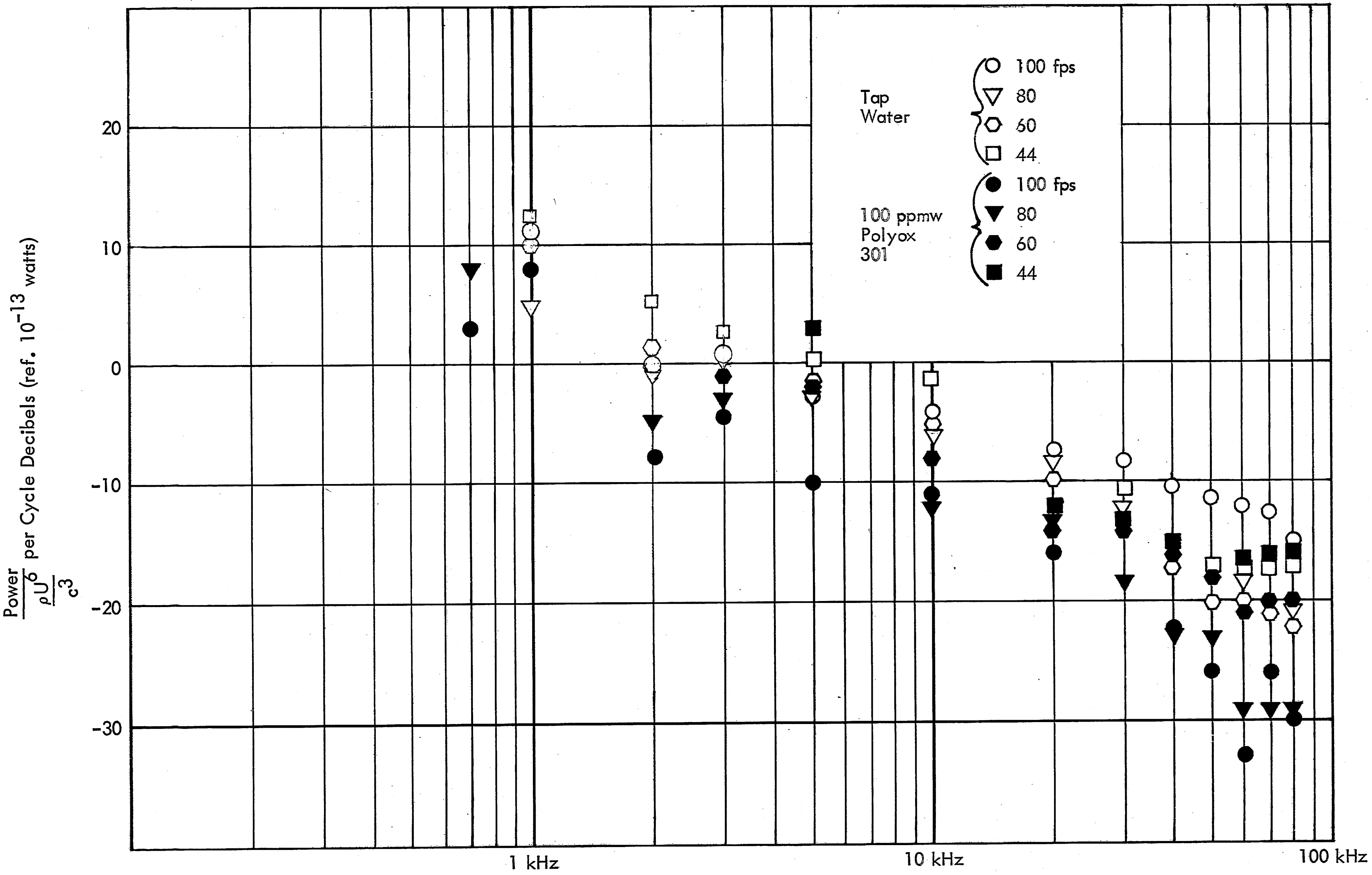

Fig. 11 - Effect of Addition of Drag Reducing Polymer on Radiated Flow Noise

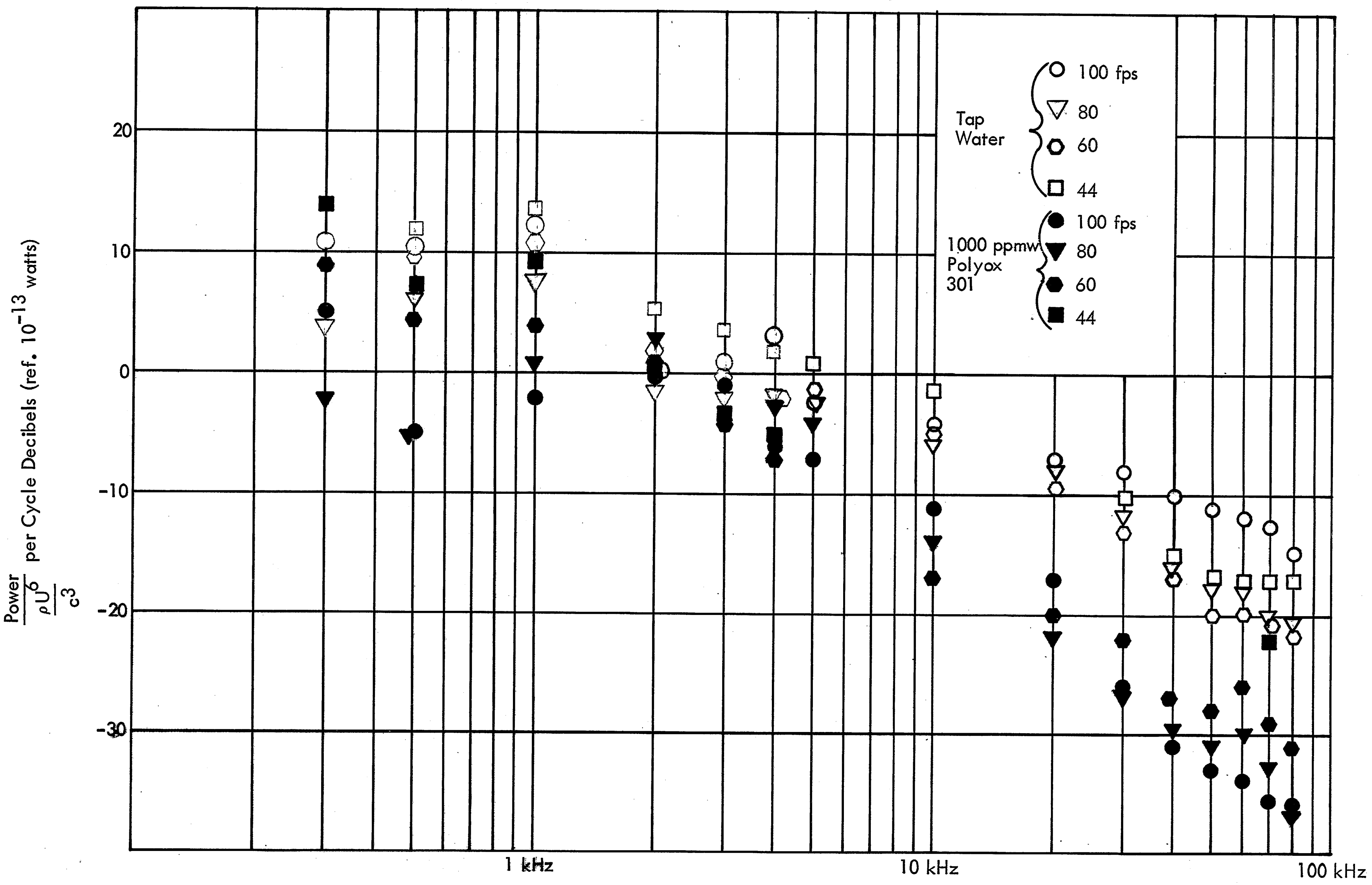

Fig. 12 - Effect of Addition of Drag Reducing Polymer on Radiated Flow Noise

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The influence of a drag reducing polymer additive in water on radiated flow noise was experimentally determined. The test facility was a rotating cylinder mounted in the center of a large cylindrical tank which served as an echoic chamber for the sound power measurements. Sound power radiated from the boundary layer of the rotating cylinder was measured for concentrations of 0, 10, 100, and 1000 ppmw of Polyox WSR 301 dissolved in the water. Sound power reductions greater than 20 decibels were noted in a frequency range of 20 to 100 kHz for a concentration of 1000 ppmw. Little influence could be found in a frequency range of 1 to 20 kHz.

The effect of polymer additive on the drag coefficient of a rotating cylinder is also shown.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Flow Noise						
Hydrodynamic Drag Reduction						
Non-Newtonian Flows						
Polymer (Drag Reducing)						
Acoustics						

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