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FLEXTENSIONAL TRANSDUCER AND REFLECTOR.(U)
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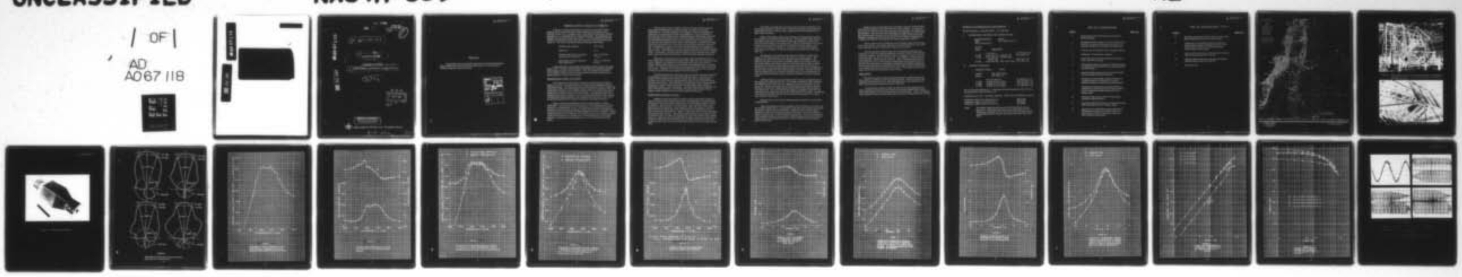

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NA64H-559
(11) 22 May 1964

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TECHNICAL REPORT

UNIVERSITY OF MIAMI

(6) FLEXTENSIONAL TRANSDUCER AND REFLECTOR

(12) 26p.

DISTRIBUTION STATEMENT A

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NORTH AMERICAN AVIATION, INC., COLUMBUS DIVISION

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PREFACE

This technical report incorporates data from the 23-28 March calibration (Report NA64H-358), as well as the data taken during 11-14 May at USNEL's Calibration Station at Lake Pend Oreille.

TECHNICAL REPORT: CONTRACT NO. C 8302-10-64

A contract to develop and fabricate an underwater sound piezo-ceramic projector and an associated 24-foot parabolic reflector was awarded to North American Aviation, Inc., Columbus, Ohio, in late 1963 by the University of Miami (through Dr. J. C. Steinberg and Mr. Morton Kronengold). The combination was designed, fabricated and tested in four months. It is to be installed in 60-85 feet of water off Fowey Rocks with the main lobe aimed across the Florida Straits (see Figure 1). The contract specified the following technical requirements:

Nominal center frequency	420 ± 20 cps
Effective Q	4 ± 1
Acoustic source level of transducer (420 cps) with 10 KW driver	109 ± 1.5 db/u bar at 1 yd.
Source level in reflector (420 cps) with 10 KW driver	123.5 ± 1.8 db/u bar at 1 yd.

A design constraint was that these specifications should be met at the lowest possible cost. Therefore, the transducer was designed to be physically small and with a minimum of piezo-ceramic material. Thus, the effective Q and acoustic power handling capability of the resulting flextensional transducer design are not typical except as a 420 cps economy model.

MEASUREMENTS DURING 23-28 MARCH

The combination of piezoelectric transducer and compliant-tube reflector, Figures 2, 3, and 4, was tested at NEL's Lake Pend Oreille Calibration Station in Idaho during March. The measured behavior of the transducer-reflector combination is depicted in Figures 5-8 while Figures 9 and 10 apply for the transducer alone. The polar patterns in Figure 5 are not unlike those from a 24-foot circular piston which, ideally, has a directivity index of 15.6 db at 400 cps. The directivity index of the compliant-tube reflector is closer to 14.5-15.0 db and the difference is due, in part, to the 90-95% reflection efficiency of the compliant-tube array and, in part, due to the shaded insonification that results from the close-in position of the focus.

Figure 6 shows the transmitting response for the transducer-reflector combination. It is nearly flat from 387 to 427 cps. The 3 db points are at 368 and 444 cps for a "mechanical Q" of 5.3. The 6 db points are at 360 and 456 cps and these more nearly represent the effective Q of the system when due consideration is given also to the electrical Q and the finite impedance of the power amplifier. Figure 7 shows that Q_e has a value less than 3.8 inasmuch as the curve is mostly flat-topped rather than in the form of a resonance curve. The product $Q_e Q_m$ is 18-20 and, therefore, the effective Q of the transducer is 4.2-4.5 in terms of simple filter theory.

The two sets of curves in Figures 8 and 10 are meant to portray and interesting interrelationship between impedance bridge and sound pressure field measurements. The bridge measures, as in Figures 7 and 9, the resistance and capacitance at the electrical terminals of the transducer. Thus, the electrical power per unit volt of excitation can be calculated and the resultant power converted to an equivalent sound pressure field. Since the transducer is not 100% efficient, then the differences between the two curves in Figures 8 and 10 are a measure of the electrical and mechanical power losses in the transducer. In Figure 8 the bridge values were increased by 14.5 db in order to account for the directivity; therefore, the 0.5 db difference at about 410 cps shows that the efficiency by this measure is 90%. In Figure 10 the difference is closer to 1 db and therefore the efficiency by this method is 80%. This difference of apparent efficiency may be due to surface reflection effects. Furthermore, it is likely that the efficiency will be somewhat lower at high power outputs since the dielectric losses in the ceramic stack increase with drive.

High-power measurements were not made at Lake Pend Oreille because of water leakage due to an inadvertent puncture of the rubber boot over the piezo-ceramic stack. Originally, the transducer was tested with a thin-wall (.040" thick AL) metallic enclosure filled with castor oil but found to be unsatisfactory as an acoustic window. As a result the metallic walls have been replaced with a rubber boot for the tests in May. In addition, the compliant tubes within the transducer were shortened in order to raise the resonance frequency from 407 to 420 cps.

The March measurements depicted in Figures 6-10 were made after the castor oil and metallic enclosure were removed from the transducer. Since this was the moment when the puncture occurred at the rubber boot, then all measurements thereafter were made with the potential presence of water in the silicone fluid about the piezo-ceramic stack. More specifically, the difference in the overnight measurements noted in Figure 9 must have been due to water leakage rather than due to temperature change as assumed originally. The May measurements in Figures 11-14 show a different relationship. The bridge and acoustic-pressure measurements suggest a higher efficiency and over a much broader frequency band.

MEASUREMENTS DURING 12-14 MAY

Inasmuch as the polar patterns in Figure 5 and the transmitting response in Figure 6 with the 24-foot reflector appear to be very satisfactory, the principal task during the May period was limited to the further evaluation of the transducer without the reflector. Since the castor oil seems to have a very significant impact on the performance of the transducer, it was decided to explore the response of the transducer both with and without the castor oil and rubber boot combination in order to better resolve the pertinent factor. Figures 11 and 12 show the low-power calibration measurement with castor oil. These differ significantly from those in Figures 9 and 10 recorded in May, but apply almost equally well for the May measurements without castor oil. Figures 13 and 14 do actually show the May measurements without castor oil and correlate closely with the March values in Figures 9 and 10 in terms of the acoustic pressure, but not in terms of efficiency because of the water leakage already noted.

The castor oil arrangement causes the source level/volt to be down by 5 db with a power efficiency of about 45-50%. On the other hand the mechanical Q is less and the efficiency does not seem to depart rapidly from 45-50% for frequencies on either side of resonance.

Figure 15 illustrates the high power behavior of the flextensional transducer as a function of the excitation voltage at 420 cps. When operating without castor oil, the acoustic source level is linear with the excitation voltage up to at least 5,000 volts rms with cavitation as the limiting factor. This was minimized in curves shown in Figure 15 by lowering the transducer to progressively greater depths: 23.97, 43.97, and 73.97 meters. Actually, at 73.97 meters, the onset of cavitation is observed to occur in Figure 15 when the transducer was excited with 4,500-5,000 volts rms.

The response of the transducer with castor oil in Figure 15 is also linear except at 4,000 volts and greater where the source level tends to flatten. This difference in response with castor oil is blamed, in terms of hindsight, to the inability of the piezo-ceramic stack to efficiently dispose of its heat as a result of the viscious nature of the castor oil; that is, it was convenient to employ 3-second pulses every 30 seconds for these calibration tests and, since this was the first calibration run, heat accumulated within the stack to the point where the temperature may have been as high as 50-60°C within portions of the stack. The same 10% duty cycle was employed for the calibration without the castor oil but cooling appears to have been much more effective with the result that cavitation was the only limiting factor.

Additional high power measurements with the castor oil arrangement showed that heating was an appreciable factor. For example, immediately after completing the calibration run at 5,000 volts, the voltage was lowered to 4,000 volts at a 10% duty cycle. However, this state could not be maintained for more than 17 minutes because the current kept creeping upward and the actual acoustic output dropped by more than one db. As a result, the driving voltage was dropped to 3,500 volts and maintained at this voltage and 10% duty cycle continuously for 97 minutes. In switching from 4,000 to 3,500 volts, the current and acoustic output stabilized to a constant value within two minutes time.

Measurements of polar patterns indicated that the transducer was completely omnidirectional.

Figure 16 demonstrates that the impedance of the transducer is not linear with the excitation voltage; that is, the impedance is 780 ohms at low voltages and gradually decreases to about 550 ohms at 5,000 volts. Effectively, the dielectric constant changes from 1200 to 1700 if the temperature of the stack is low, but the change is likely to be much greater if heating raises the temperature. Thus, the measurement of the impedance or the current at constant voltage through the transducer should be a sensitive means of detecting instability or a run-away temperature rise within the piezo-ceramic stack.

Figure 17 shows oscilloscopic traces of the pulse rise time at both the signal in the hydrophone and also at the terminals of the power amplifier. An inductor in series with the transducer was used to neutralize, approximately, the capacitance of the transducer. The rise time in these photographs is longer than it would be under final conditions partly because it was not convenient to adjust the inductor and the amplifier impedance taps and partly because the 24-foot reflector arrangement has a tendency to broaden out the response in the manner suggested in Figure 6.

Figure 17 shows also an oscillogram of the hydrophone output when the transducer was cavitating. The intensity modulations on the sinusoidal waves are caused by the bursting of bubbles at much higher frequencies than 420 cps.

After the transducer (without castor oil) was calibrated successfully with voltages up to 5,000 volts rms (corresponding to an electric field of 10 KV/CM rms in the piezo-ceramic), an additional power test was conducted. This test was to be a continuous (CS) duty cycle at 2,000 volts rms. As expected, the current began to rise, presumably, toward a steady state level. After 10 minutes of operation, the current began to rise at a faster rate to the degree that it was necessary to turn it off at the end of 20 minutes. Investigation revealed that the ohmmeter reading was low and small globules of discolored fluid were discovered in the oil about the stack. A very small water leak is presumed to be the cause. This probably would not have occurred if the outer boot and castor oil were in place.

CONCLUSIONS

The performance of the 420 cps transducer-reflector combination has more than justified our confidence in the basic design approach. When one considers the comparatively short period of time and limited funds which were available for this effort, these final test results are even more impressive.

In reviewing the transducer design after the tests at Lake Pend Oreille and based on additional research at North American Aviation, it is apparent that several minor design changes could considerably improve its performance. These would include wider bandwidth, better cavitation suppression and improved electromechanical coupling.

SUMMARY OF REPRESENTATIVE MEASUREMENTS

420 cps Transducer, Lake Pend Oreille - 11-14 May 1964

I. RUBBER-BOOT ENCLOSURE AND CASTOR OIL FILL

Resonance frequency	420 cps
Depth	23.71 meters (77.7 ft.)
One (1) 10 KW Driver	

Acoustic Power	Source Level	
	1.0 volt rms	32.2 db//ubar 1 yd.
3.0 KW	4,000 volts rms - 10% duty cycle	106.5 ubar 1 yd.
3.0 KW	3,500 volts rms - 10% duty cycle (2 hour run)	106.6 ubar 1 yd.
3.5 KW	4,500 volts rms - Max. source level	107.0 ubar 1 yd.

II. WITHOUT CASTOR OIL

Resonance frequency 420 cps

Acoustic Power	Max. Source Level (See Figure 15)	
	For 1.0 volts rms	37.5 db//ubar 1 yd.
1.4 KW	At depth of 23.97 meters	103.9 db//ubar 1 yd.
4.3 KW	At depth of 43.97 meters	107.9 db//ubar 1 yd.
7.8 KW	At depth of 73.97 meters	110.5 db//ubar 1 yd.

CW or Continuous Operation (i.e., nonpulsing) 20 minutes duration at 2,000 volts rms and source level of 104.0 db//ubar 1 yd.

Combined Source Level - Transducer-Reflector: Add 15 db for DI of Reflector (approx.)

Transducer weight in air without castor oil	300 pounds
Transducer weight in air with castor oil	600 pounds
Transducer weight in water with castor oil	290 pounds

NOTE: The acoustic output and source level at the Florida Straits site are likely to be 1-2 db greater with castor oil as a result of the warmer temperature compared to 39^{o}F in Lake Pend Oreille and partly because repositioning within the reflector may improve the output of the transducer.

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

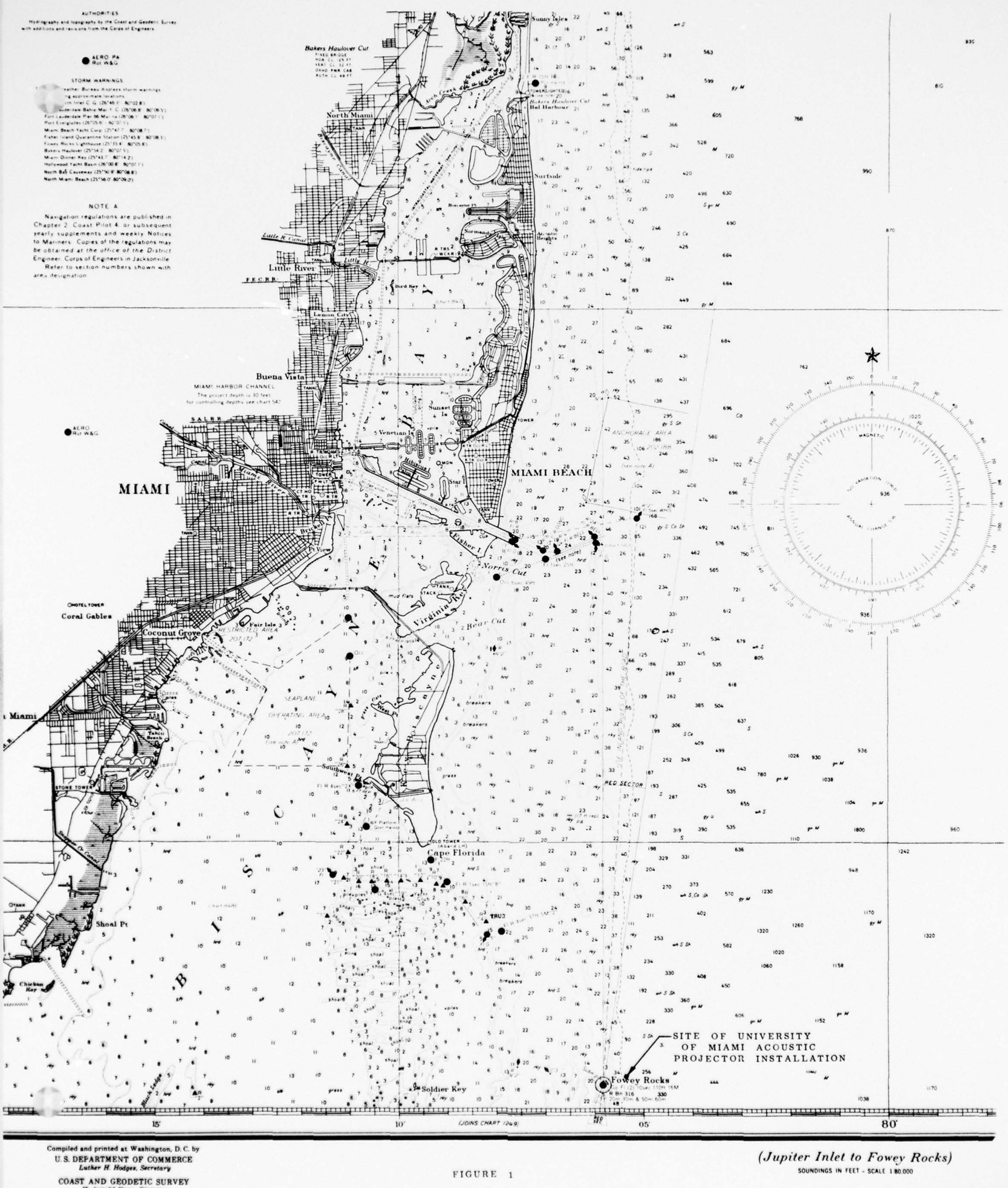
AUTHORITIES
Hydrography and topography by the Coast and Geodetic Survey with additions and revisions from the Corps of Engineers.
AERO PA
Rot W&G
STORM WARNINGS
NOTE A
Navigation regulations are published in Chapter 2, Coast Pilot 4, or subsequent yearly supplements and weekly Notices to Mariners. Copies of the regulations may be obtained at the office of the District Engineer, Corps of Engineers in Jacksonville.
Refer to section numbers shown with area designation.
Sunny Isles
Bakers Haulover Cut
Bal Harbour
North Miami
Surfside
Little River
Lemon City
Buena Vista
MIAMI HARBOR CHANNEL
The project depth is 30 feet; for controlling depths see chart 542
MIAMI
MIAMI BEACH
Venetian Is
Sunset Is
Star I
Fisher I
Norris Cut
Virginia Key
Bear Cut
Coral Gables
Coconut Grove
Fair Isle
RESTRICTED AREA 207.172
SEAPLANE OPERATING AREA 207.172
ANCHORAGE AREA
RED SECTOR
Southwest Pt
West Pt
Cape Florida
Shoal Pt
Chicken Key
Soldier Key
Fowey Rocks
SITE OF UNIVERSITY OF MIAMI ACOUSTIC PROJECTOR INSTALLATION
MAGNETIC
15'
10'
(JOINS CHART 1249)
05'
80°
Compiled and printed at Washington, D. C. by
U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, Secretary
COAST AND GEODETIC SURVEY
H. Arnold Karo, Director
(Jupiter Inlet to Fowey Rocks)
SOUNDINGS IN FEET - SCALE 1:80,000

FIGURE 1

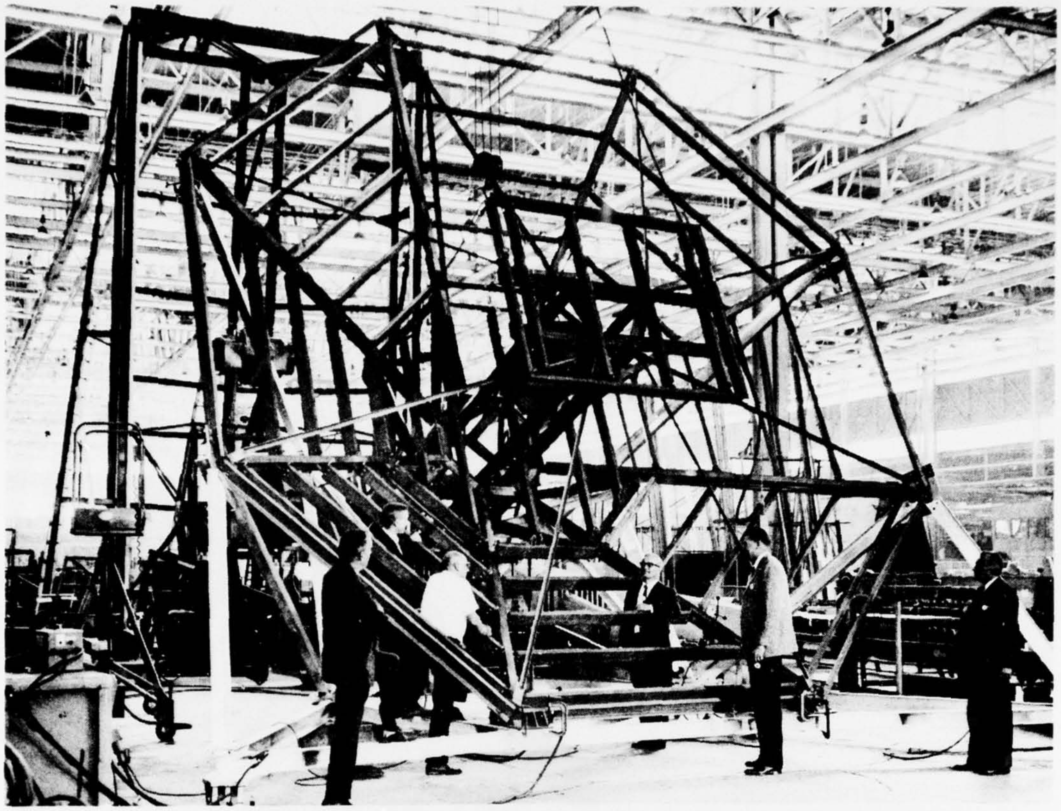

Figure 2. NAA-Columbus 24-foot Compliant Tube Reflector, Flextensional Transducer at Focus, 6' x 6' Secondary Reflector, and Associated NAA Personnel

Figure 3. Close-up View of Transducer in the Parabolic Reflector

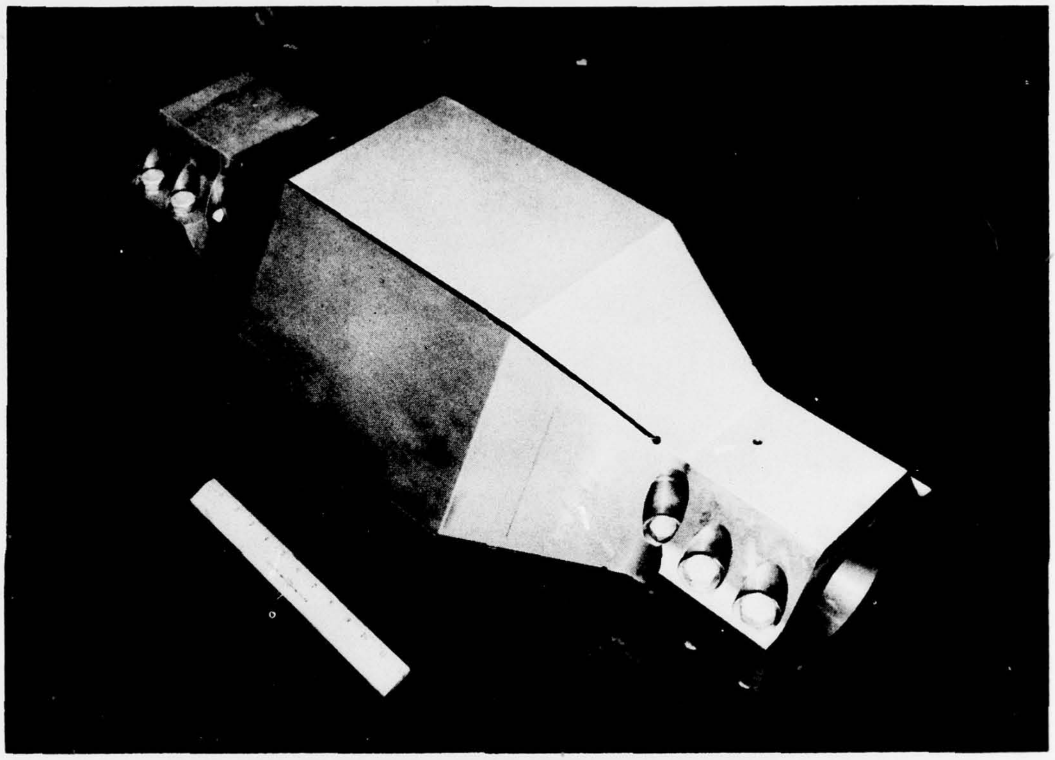

Figure 4.   Flextensional Transducer

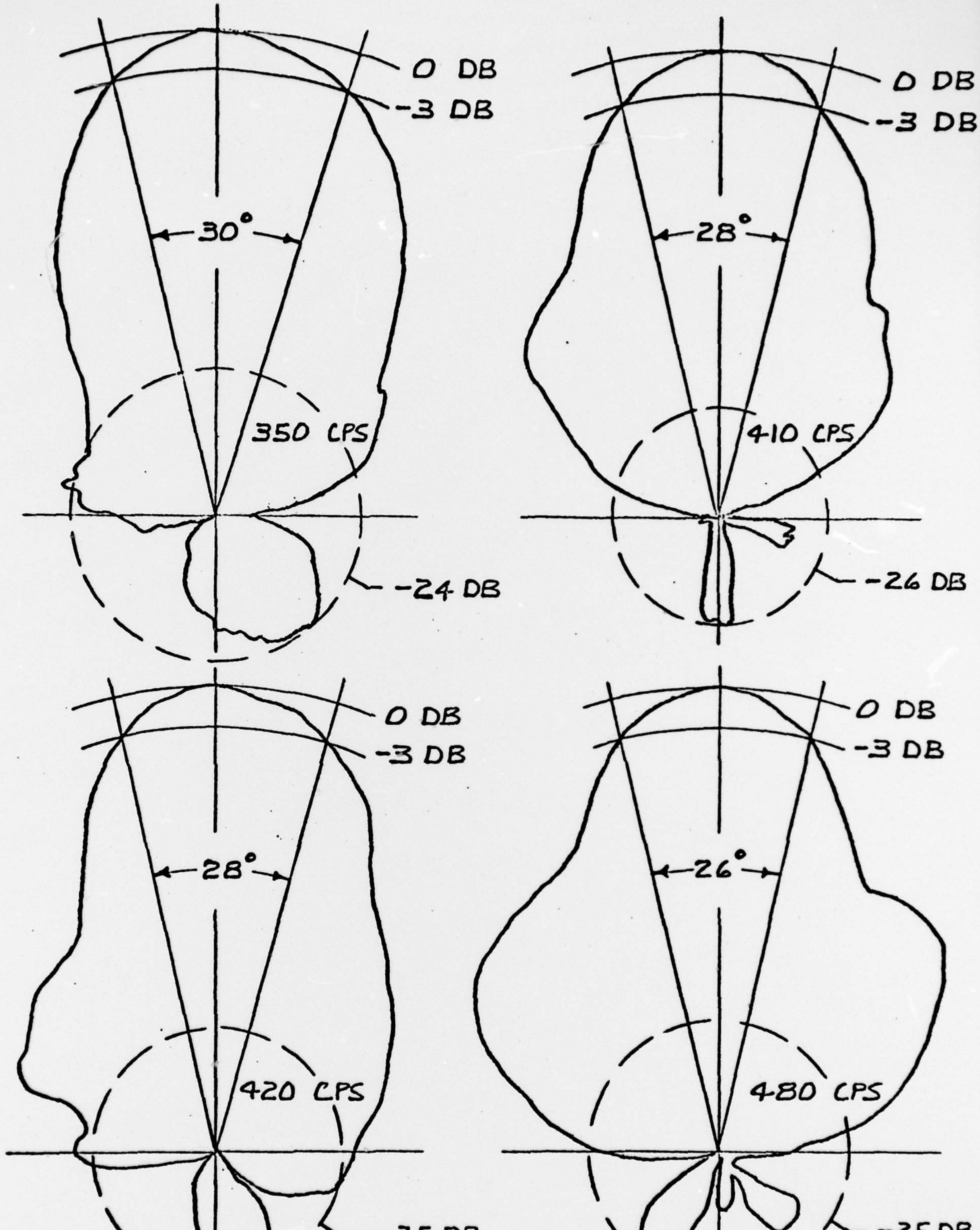

FIGURE 5

Polar Patterns of Transducer-Reflector Combination at 350, 410, 420 and 480 cps

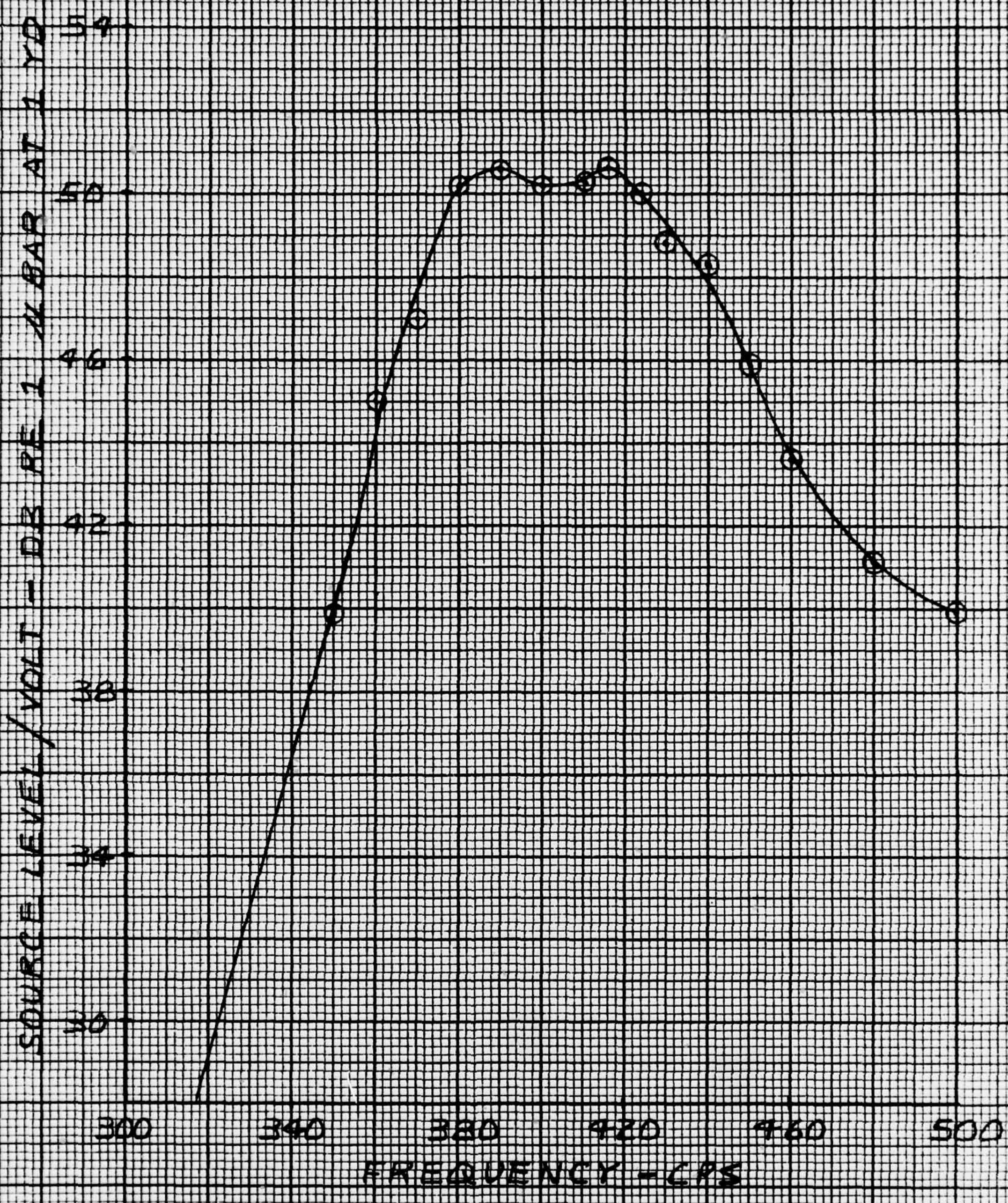

FIGURE 6

Transmitting Frequency Response of Transducer-Reflector Combination from Sound-Pressure Measurements in 123 Feet of Water

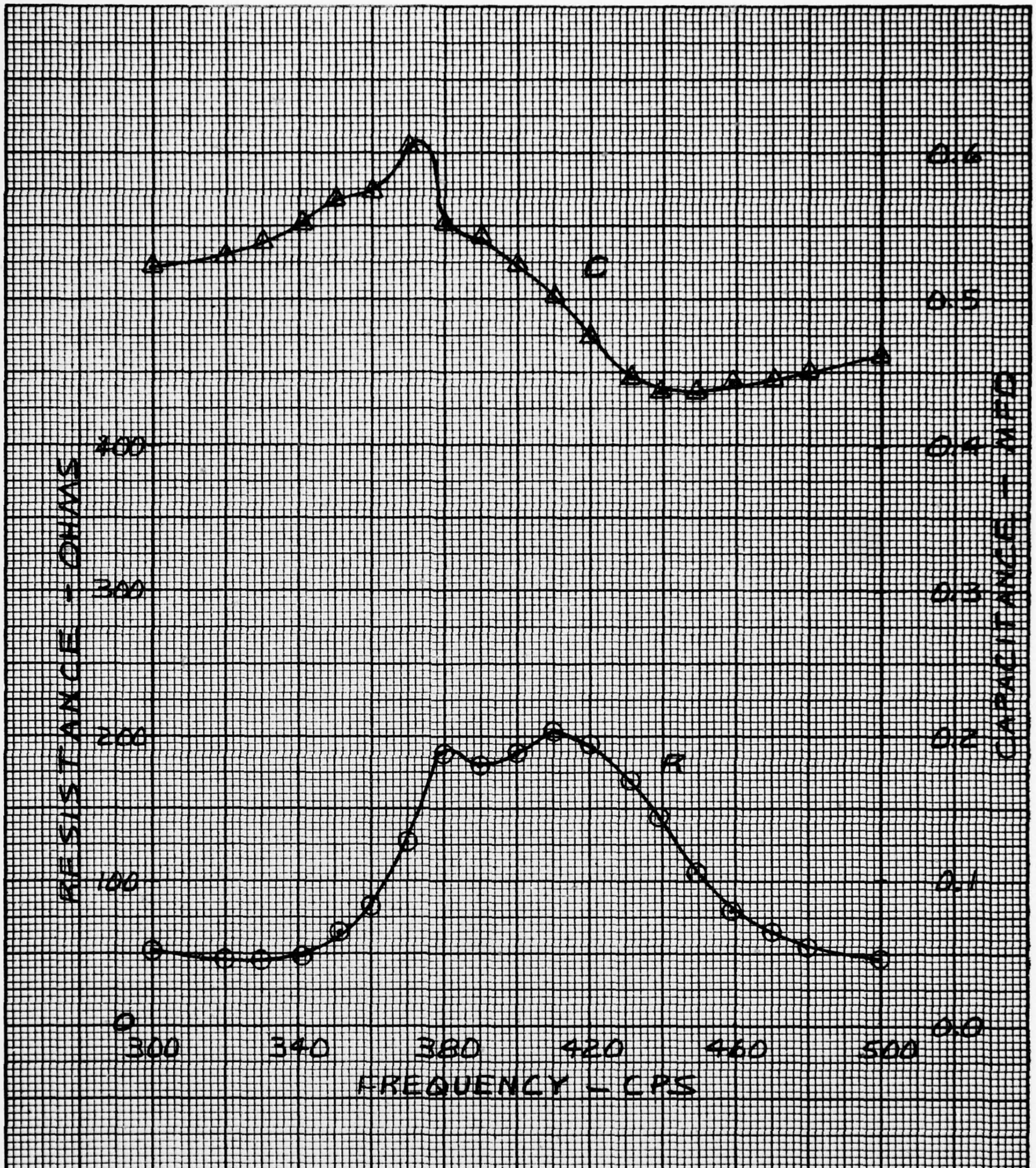

FIGURE 7

Impedance Bridge Measurements of Transducer While at Focal Position in Parabolic Reflector

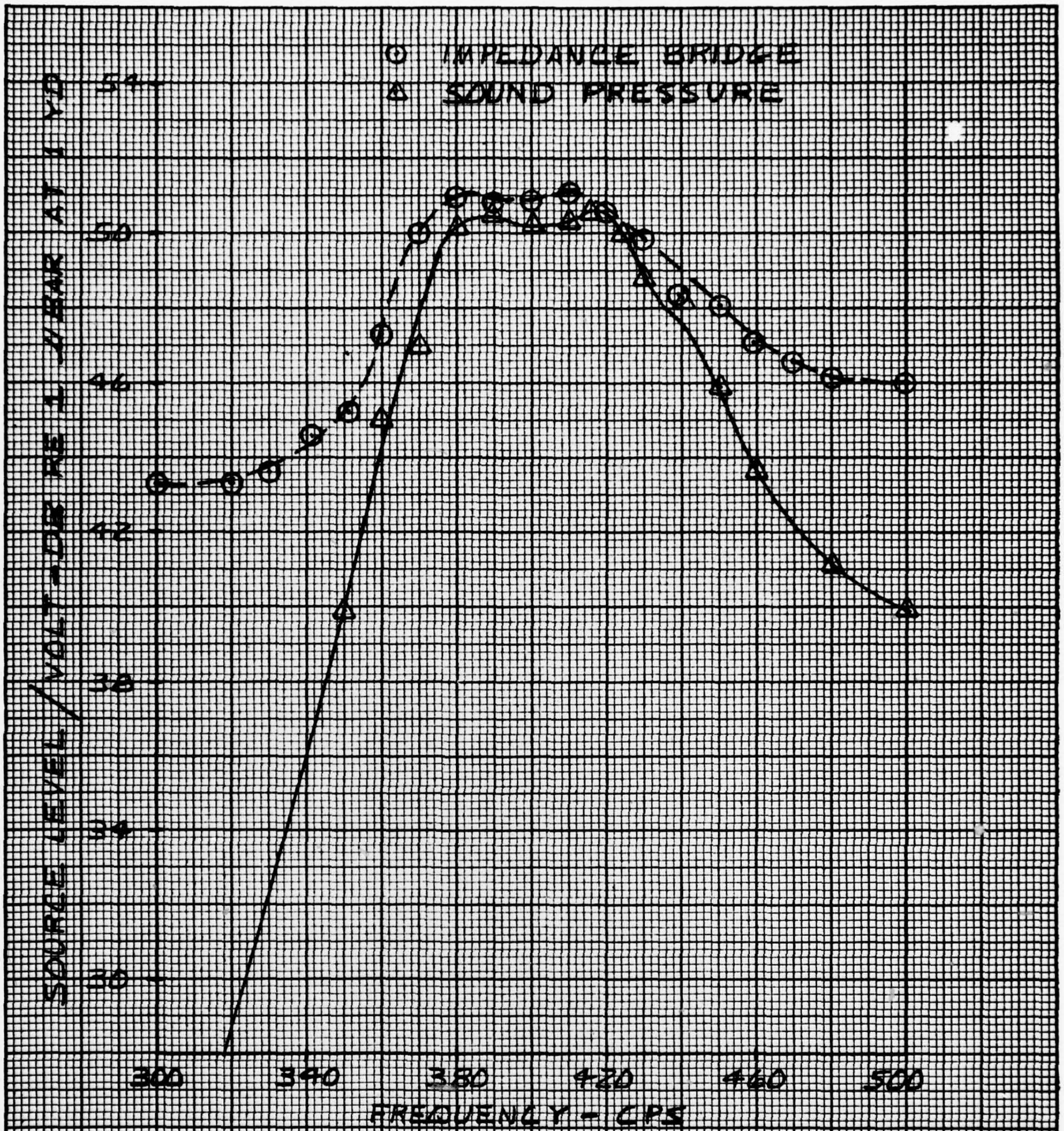

FIGURE 8

Comparison of Transmitting Frequency Response of Transducer-Reflector Combination in Terms of Impedance Bridge and Sound Pressure Measurements

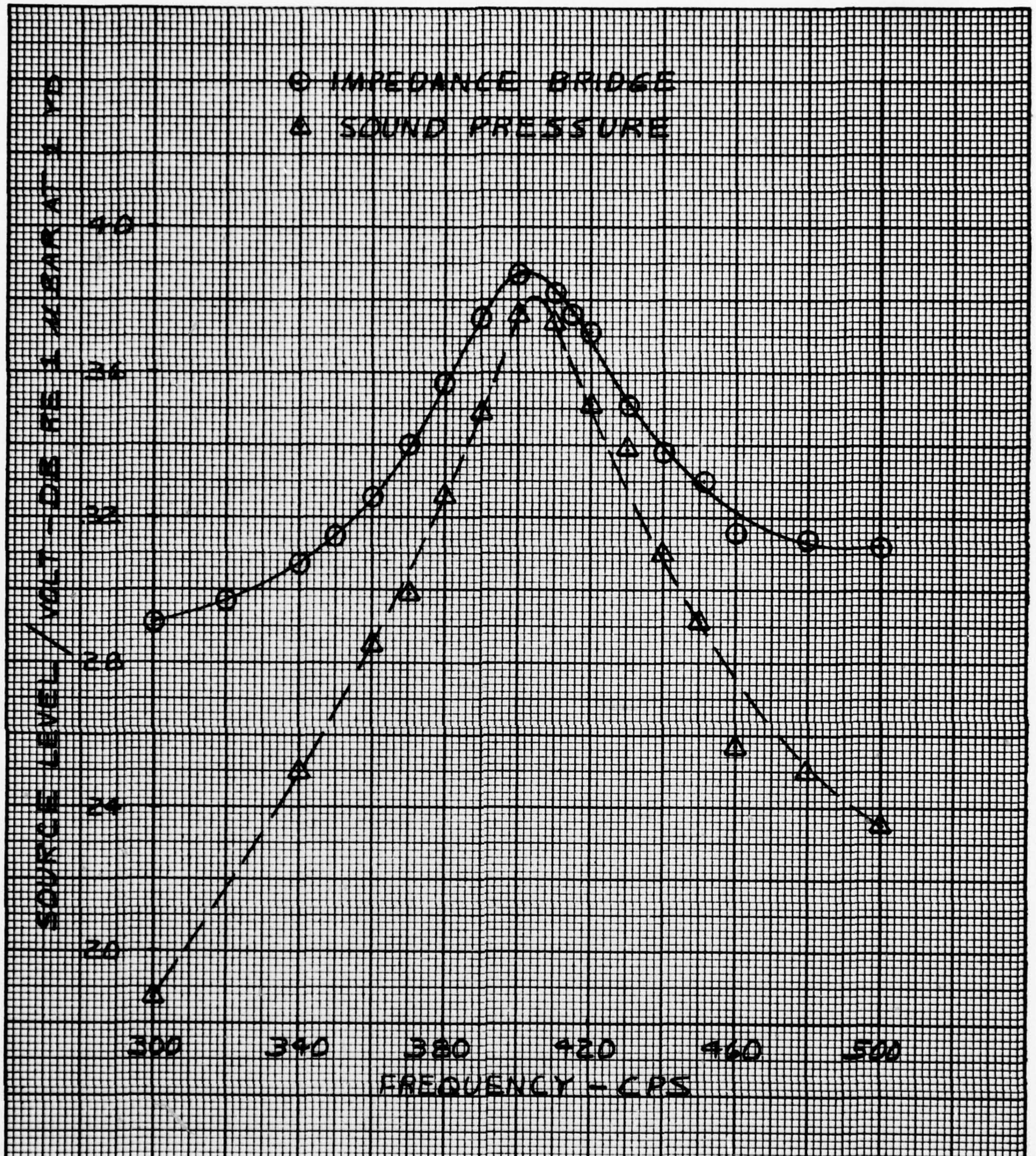

FIGURE 9

Comparison of Transmitting Frequency Response of Flextensional Transducer (alone in 33 feet of water) in Terms of Impedance Bridge and Sound-Pressure Measurements

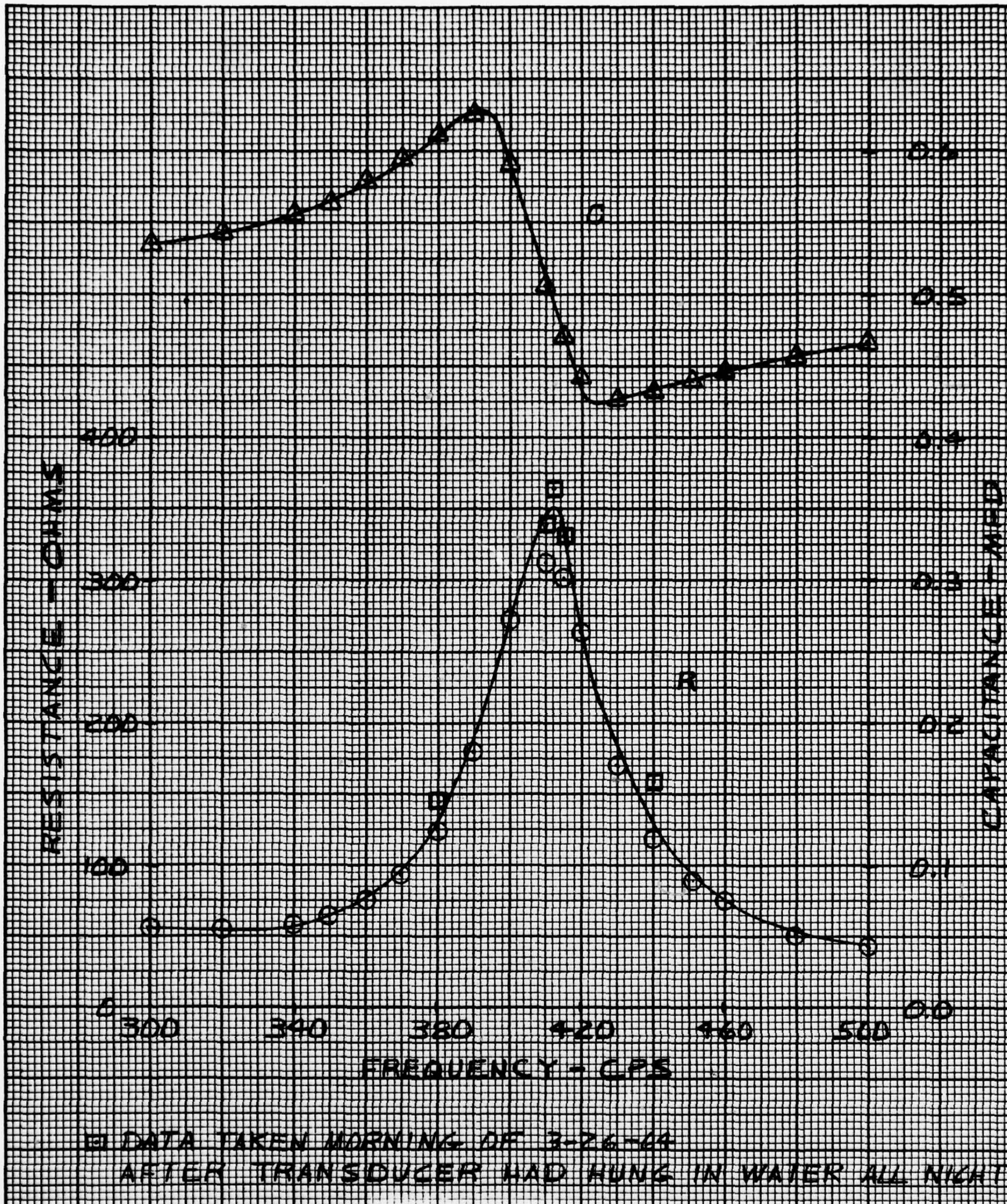

FIGURE 10

Impedance Bridge Measurements of Flex-
tensional Transducer without Reflector

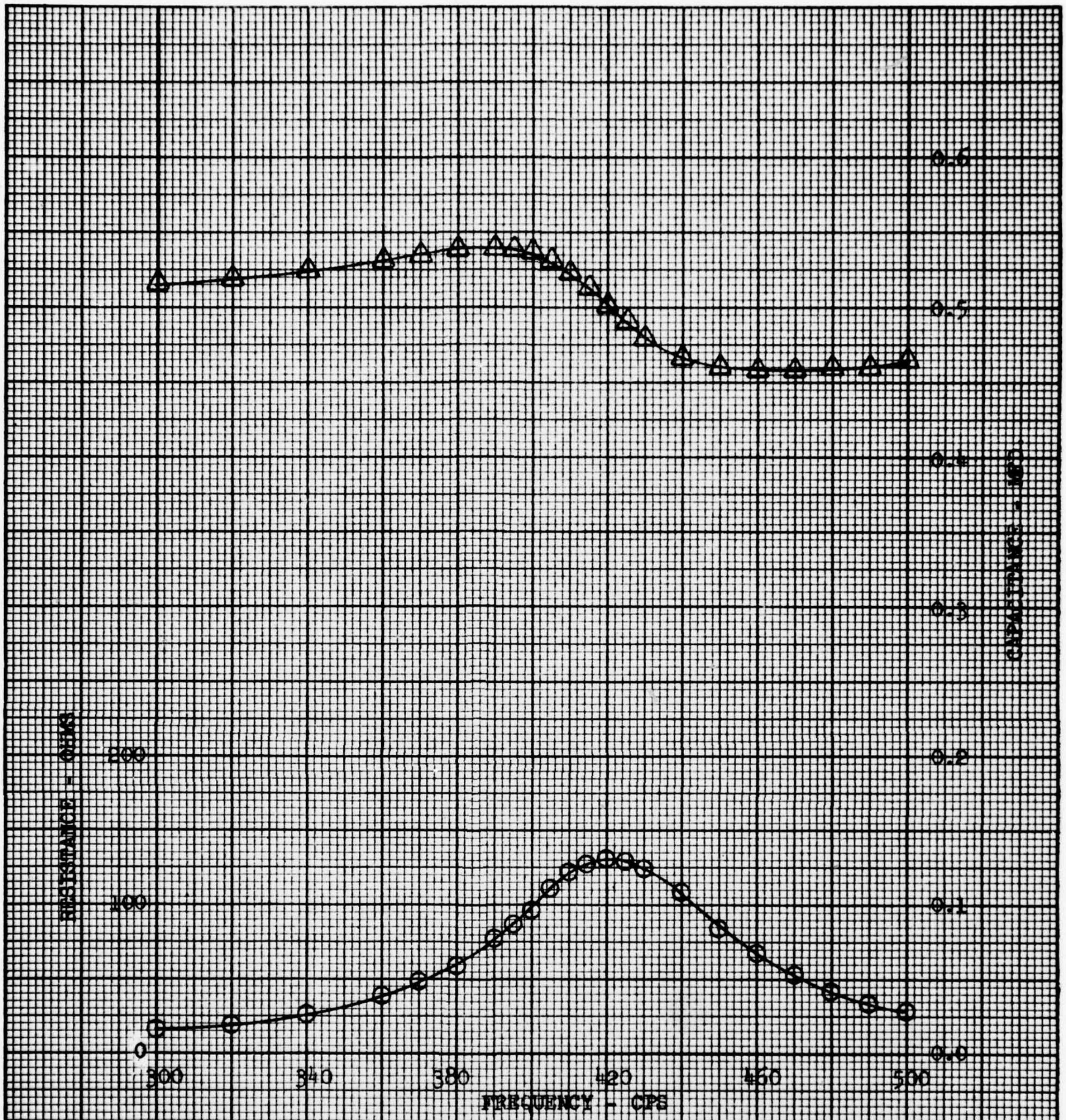

FIGURE 11

IMPEDANCE BRIDGE MEASUREMENTS
OF FLEXTENSIONAL TRANSDUCER
WITH CASTOR OIL AT 23.71
METERS DEPTH

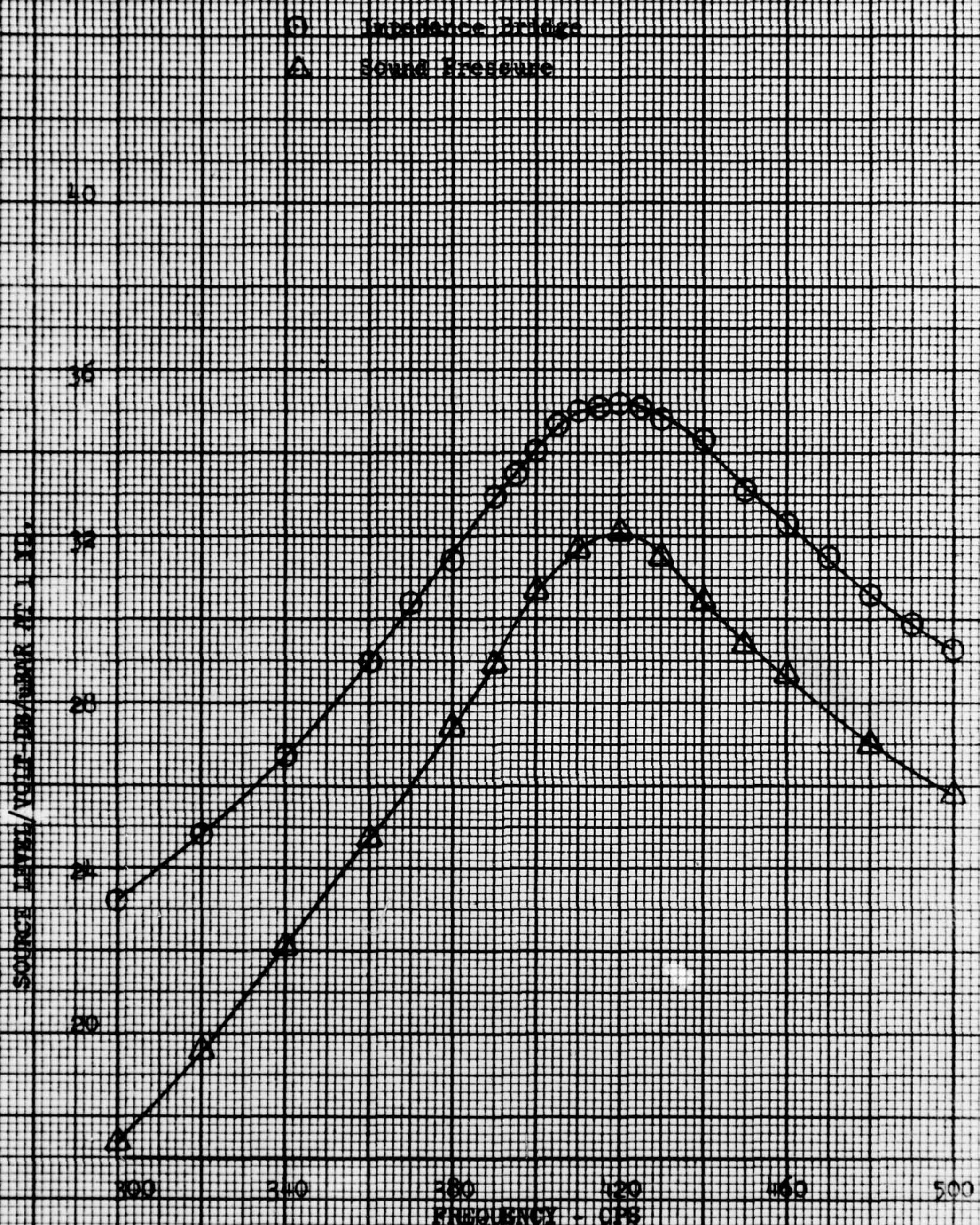

FIGURE 12

COMPARISON OF TRANSMITTING FREQUENCY RESPONSE OF FLEXTENSIONAL TRANSDUCER (WITH CASTOR OIL AT 23.71 METERS DEPTH) IN TERMS OF IMPEDANCE BRIDGE AND SOUND-PRESSURE MEASUREMENTS

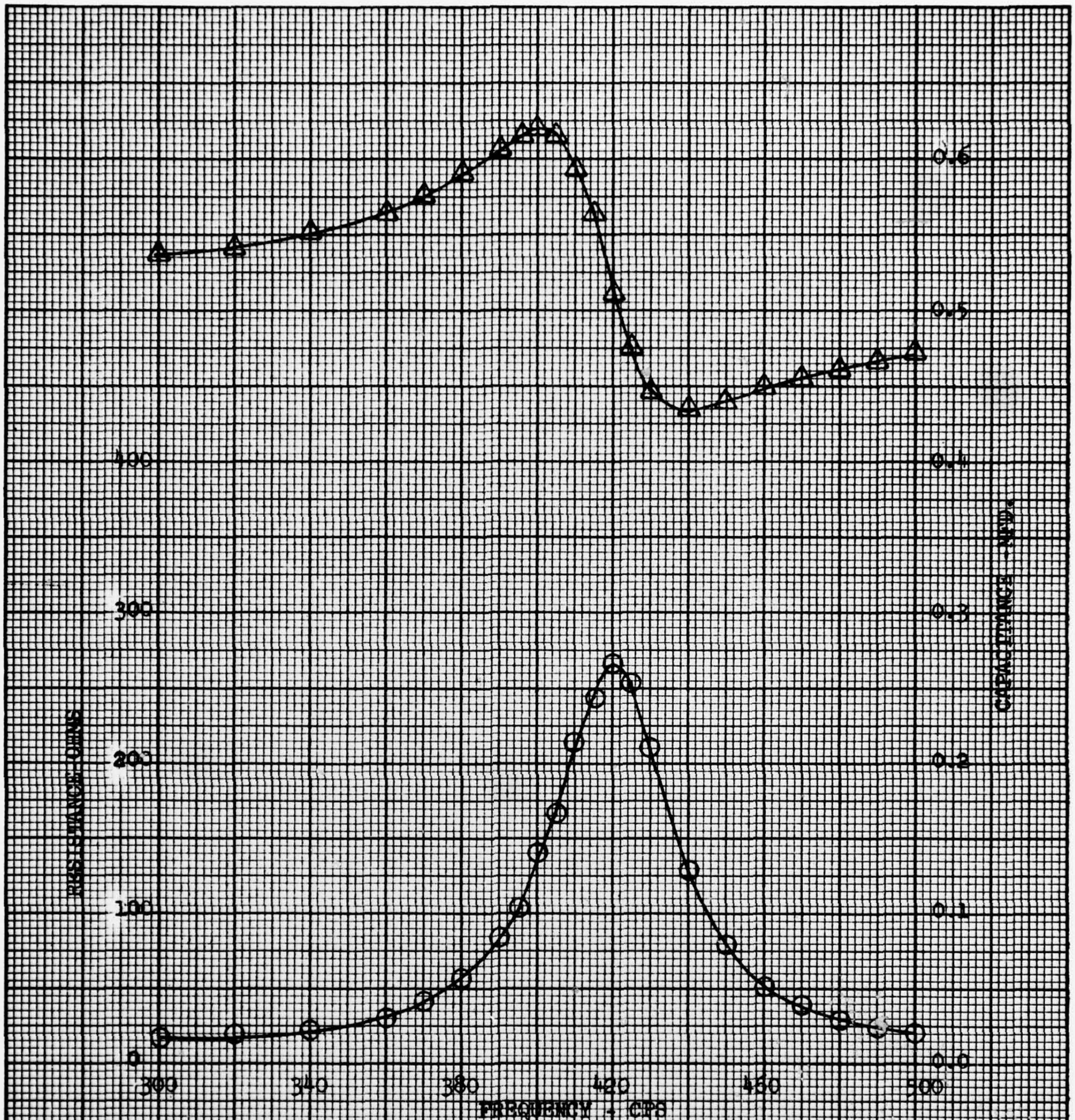

FIGURE 13

IMPEDANCE BRIDGE MEASUREMENTS OF FLEXTENSIONAL TRANSDUCER WITHOUT CASTOR OIL AT 23.97 METERS DEPTH

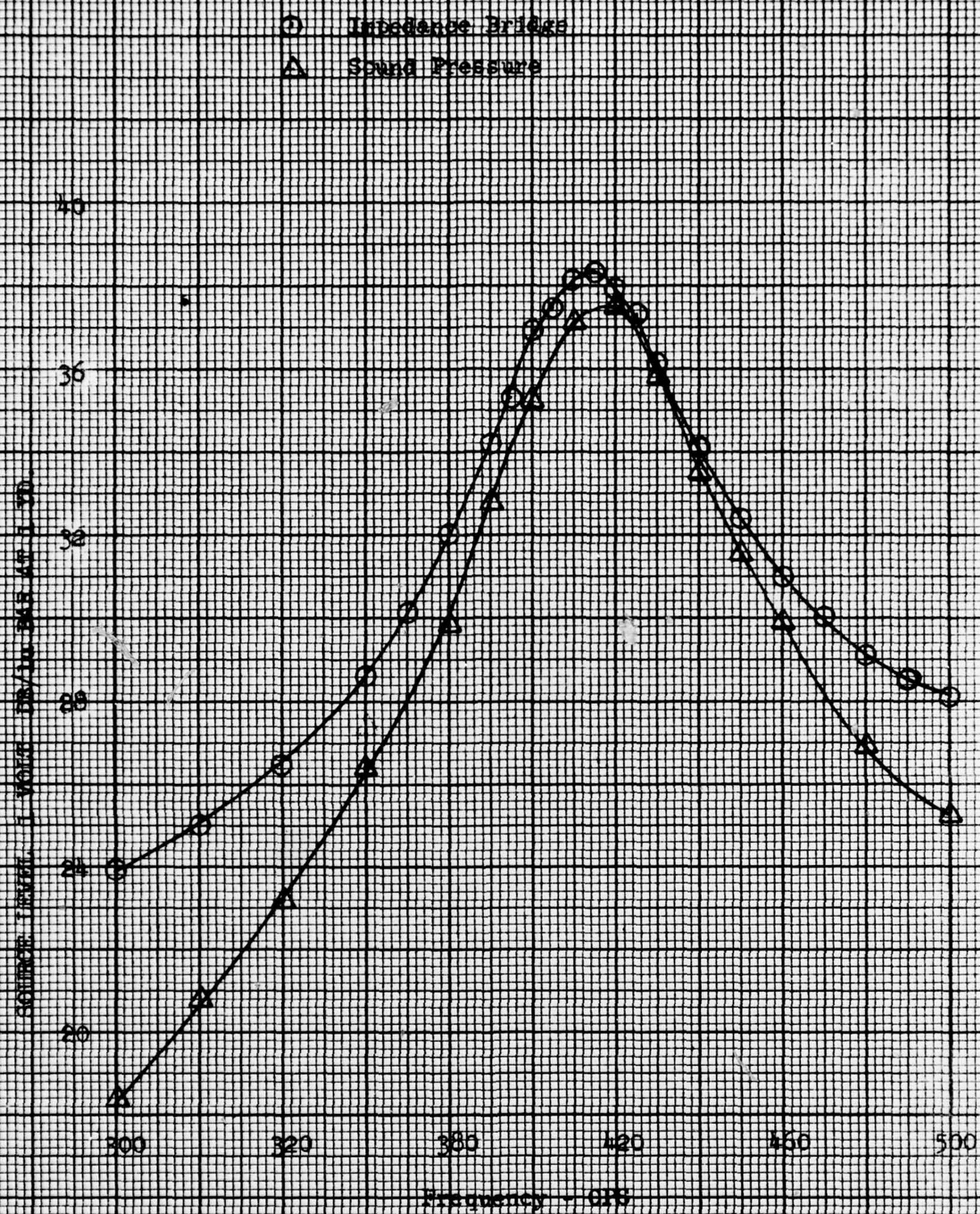

FIGURE 14

COMPARISON OF TRANSMITTING FREQUENCY RESPONSE OF FLEXTENSIONAL TRANSDUCER (WITHOUT CASTOR OIL AT 23.97 METERS DEPTH) IN TERMS OF IMPEDANCE BRIDGE AND SOUND-PRESSURE MEASUREMENTS

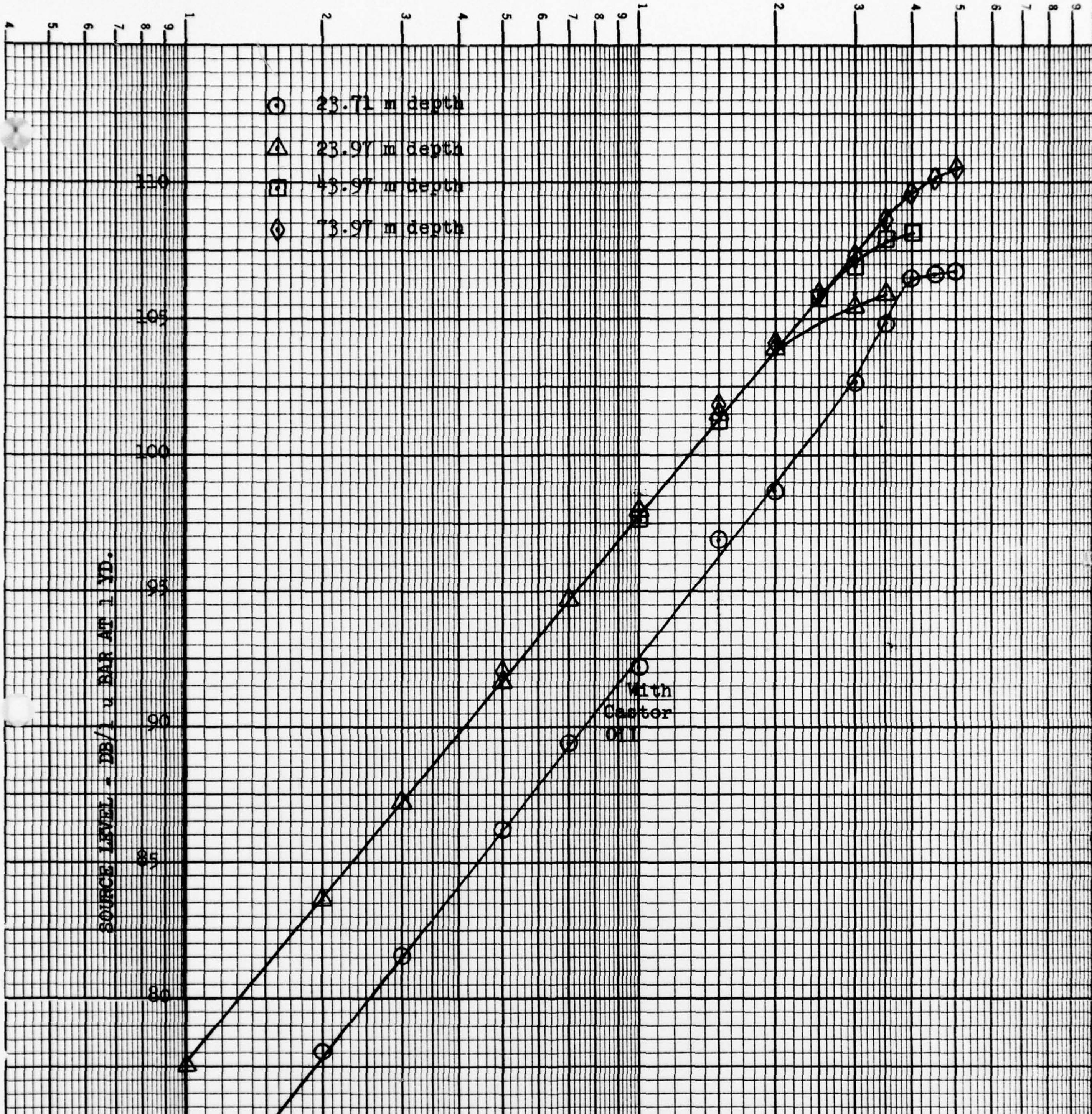

FIGURE 15
SOURCE LEVEL MEASUREMENTS OF
FLEXTENSIONAL TRANSDUCER WITH
AND WITHOUT CASTOR OIL AT
420 CPS

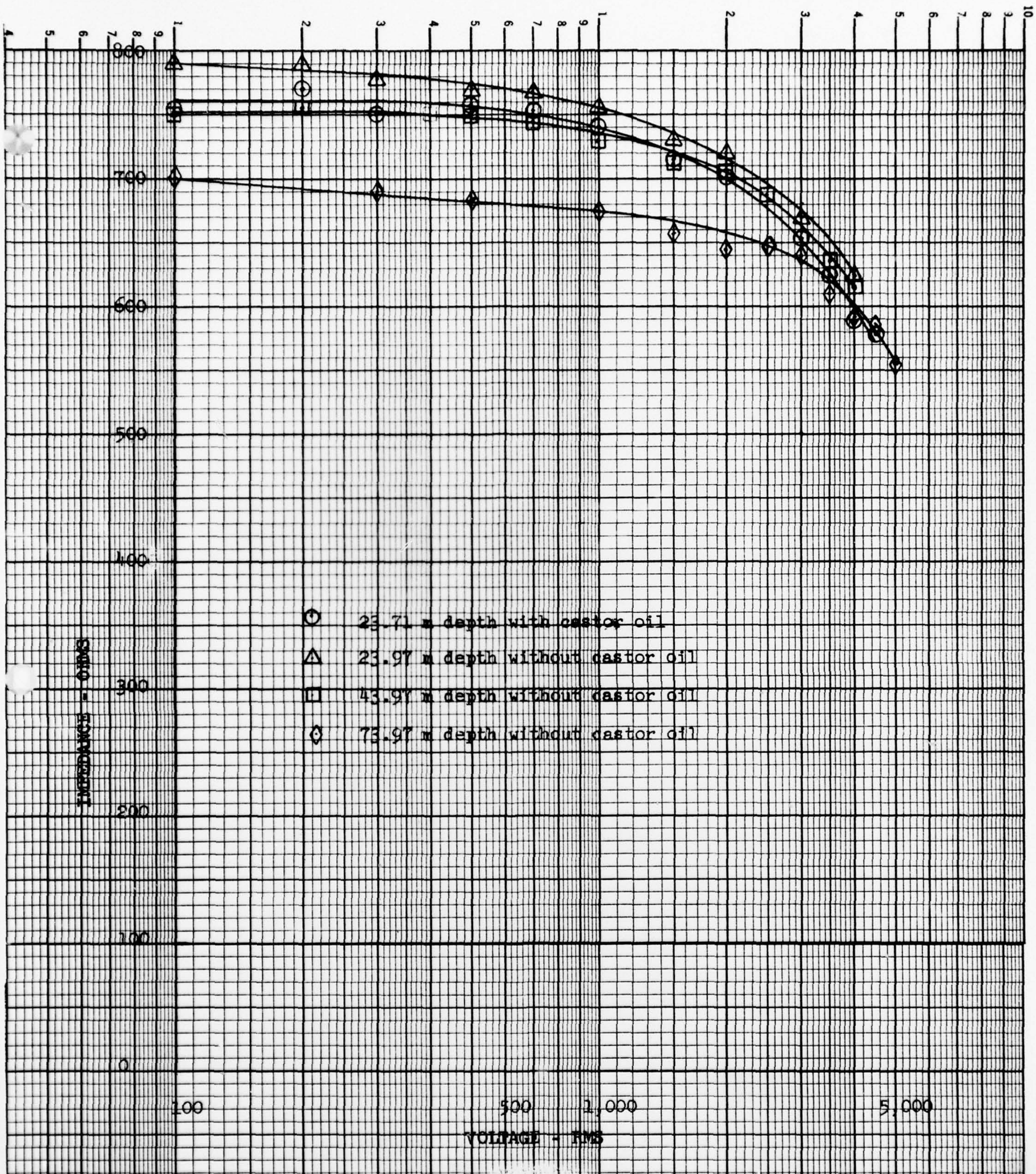

FIGURE 16
IMPEDANCE MEASUREMENTS OF
FLEXTENSIONAL TRANSDUCER
WITH AND WITHOUT CASTOR OIL
AT 420 CPS

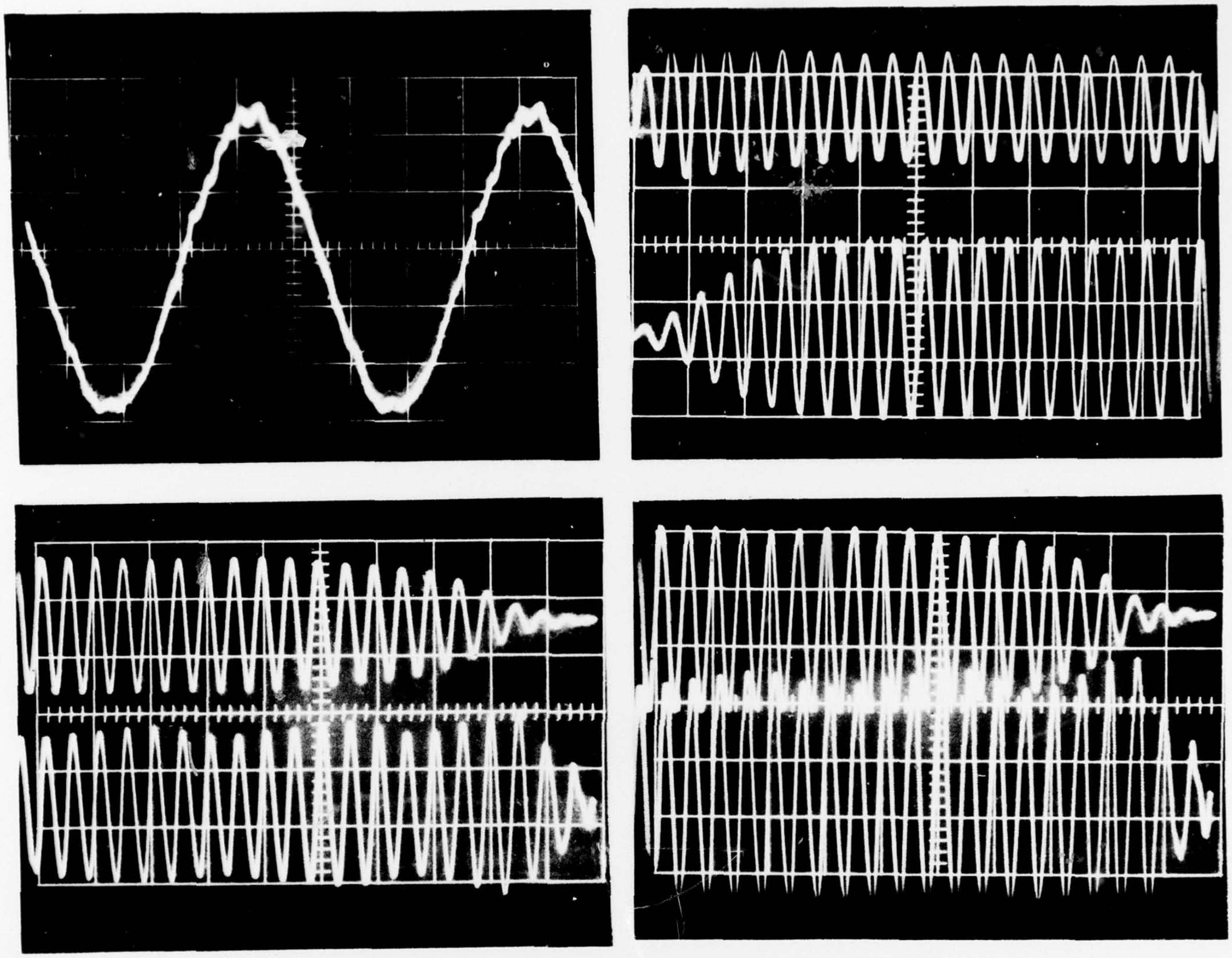

FIGURE 17
PULSE RISE TIME

SYMPTOMS OF CAVITATION ON HYDROPHONE SIGNAL (UPPER LEFT)

ONE AMPLIFIER WITH 145 OHM WINDING AND 4.0 KV ON TRANSDUCER
(UPPER RIGHT)

FOUR AMPLIFIERS WITH UNCERTAIN WINDING COMBINATIONS AT 4.0
AND 4.5 KV (BELOW)