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Dear Sir:

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The present letter is intended to constitute Quarterly Progress Report No. 15 covering the period 1 October 1964 through 31 December 1964.

Pressures on Ring Baffles.

Tests for determining pressure distributions on a single solid ring baffle have been completed, and the data from these tests are in the final stages of being reduced to an appropriate form for presentation.

Preliminary plots of this data show that the peak pressure (at the first liquid resonance, in the plane of excitation) varies almost linearly with the excitation amplitude. When plotted against depth of submergence d_s, the peak pressure has a maximum for the baffle located just above the liquid surface ($d_s/R \simeq 0$), a minimum for $d_s/R \simeq 0.10$, and a second maximum for $d_s/R \simeq 0.50$. Agreement between measured pressures across the baffle in the plane of excitation and a theory based on measurements of slosh height and resonance frequency, appears to be excellent.

The variation of pressure amplitude with the radial coordinate $x = (R - r)/w$ and the angle θ around the baffle has not been established as yet in detail. There are indications, however, that a simple cosine distribution

$$p(x,\theta,t) = p_0 \sqrt{1-x^2} \cos\theta \cos(\omega t+\varphi) \qquad (1)$$

where φ is the phase angle between the pressure and the excitation $X(t) = X_o \cos(wt)$, fits the data with reasonable accuracy.

The experimental apparatus consisted of an upright cylindrical tank of radius $R = 5.75$ in, filled to an average depth of $h/R \simeq 2$ with water, and fitted with a single, horizontal, solid (non-perforated) ring baffle of width $w/R = 0.157$. The vertical position of the ring baffle (relative to the liquid surface) was adjustable in steps of approximately 0.15 in. The tank was driven horizontally in steady harmonic motion at the first liquid resonance frequency, and the signals from various pressure - and force - transducers attached to the ring baffle were recorded on an oscillograph.

Records from the following transducers are relevant to the present discussion:

1. Average pressure amplitude p_1 on a small beam element located in the plane of excitation ($\theta = 0$) at the inside radius ($0.66 < x < 1.00$) of the ring baffle.

2. Average pressure amplitude p_2 on a small beam element located in the plane of excitation ($\theta = 0$) near the outside radius ($0.66 < x < 1.00$) of the ring baffle.

3. Average pressure amplitude p_3 on a small beam element located $\theta = 30°$ off the plane of excitation near the outside radius ($0.22 < x < 0.66$) of the ring baffle.

4. Total force amplitude F_6 on a half-ring baffle at a station in line with the excitation. The average peak pressure p_6 can be calculated from F_6, using the assumed cosine distribution, by the following formula:

$$p_6 = F_t / w(2R-w) \int_0^{\pi/2} \cos^2\theta \, d\theta = (4/\pi) F_t / w(2R-w) \tag{2}$$

A theory has been derived* for predicting the peak pressure in terms of the slosh height ξ and the liquid resonance frequency ω. In dimensionless form the appropriate equation can be written as

$$p/\rho n g R = 2\left(\frac{w}{R}\right)\left(\frac{\omega^2 R}{ng}\right)\left(\frac{\xi}{R}\right) f \tag{3}$$

where

$$\left.\begin{aligned} \hat{f} &= \exp(-1.84\, d_s/R) \\ \text{and} \quad \omega^2 R/ng &\simeq 1.84 \end{aligned}\right\} \; h/R > 1 \tag{4}$$

In essence, this theory relates the peak pressure across a ring baffle with the maximum vertical accelerations $\dot{U}$ of the liquid in the vicinity of the baffle. Comparisons of calculations involving Eq. (3) with dynamic pressures ($\rho U^2/2$) calculated on the basis of maximum liquid velocities U, show the former to be the better theory.

The following discussion pertains to the graphs included with this report. Figure 1 presents measured values of slosh height and liquid resonance frequency versus depth of submergence for two excitation amplitudes. Theoretical pressures, as calculated from Eq. (3) using values of ξ/R and $\omega^2 R/ng$ obtained from these curves, are shown plotted in Figure 3.

Figure 2 presents the pressure amplitudes p_1, p_2, p_3, p_6, as defined above, versus depth of submergence for two excitation amplitudes. We see that p_2 is the largest, with p_1 and then p_3 next largest, as can be expected from the locations of the various pressure transducers. The pressure p_6 calculated from the total force on the baffle at $\theta = 0$ (using Eq. (2)) practically coincides with the values of p_3. Future tests involving perforated baffles will make use of only p_6 for measuring peak pressures.

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* Liu, Frank C., "Pressure on Baffle Rings Due to Fuel Sloshing in a Cylindrical Tank," Aero-Astrodynamics Internal Note 4-64, GCMSFC, January 1964.

Since the values of $p/\rho ng R$ appear to be proportional to the excitation amplitude X_o/R, it was decided that better correlation could be obtained by plotting $p/\rho ng X_o$ instead of $p/\rho ng R$. Figure 3 shows $p_1/\rho ng X_o$ and $p_2/\rho ng X_o$ plotted against d_s/R for the values of X_o/R. These values are seen to agree quite closely with the theoretical pressures calculated from Eq. (3).

It should be noted that tests involving single ring baffles profide conservative estimates of peak pressures on multiple-baffle configurations; that is, the maximum peak pressure to be encountered on a multiple-ring-baffle system will always be less than for the corresponding case of a single ring baffle.

Damping Coefficients for Mechanical Models.

The experimental apparatus devised for measuring torque, as well as the phase angle between torque and displacement, in a pitching cylindrical tank has now been essentially completed. The maximum pitching angle with this arrangement has been measured to be approximately 5°, double amplitude, with no lateral motion. The exciting unit is a 25 lb. electrodynamic shaker. Calibration of the entire system and the associated electronic equipment is now in progress.

General.

Both portions of the present work appear to be proceeding satisfactorily. The work on ring baffle pressures, as discussed previously in this report, has been carried to the point where much additional data will be collected during the coming weeks. Immediately upon completion of the calibration program on the new apparatus of measuring damping coefficients, the experimental work will proceed.

It is our expectation that MSFC technical personnel will visit SwRI for purposes of witnessing some of these experiments some time in the relatively near future.

Respectfully submitted,

H. Norman Abramson, Director
Department of Mechanical Sciences

HNA/ddn
Attachments: (9) cc's

cc: NASA HQ
Mr. A. C. Hulen, SwRI—w/(2) cc's

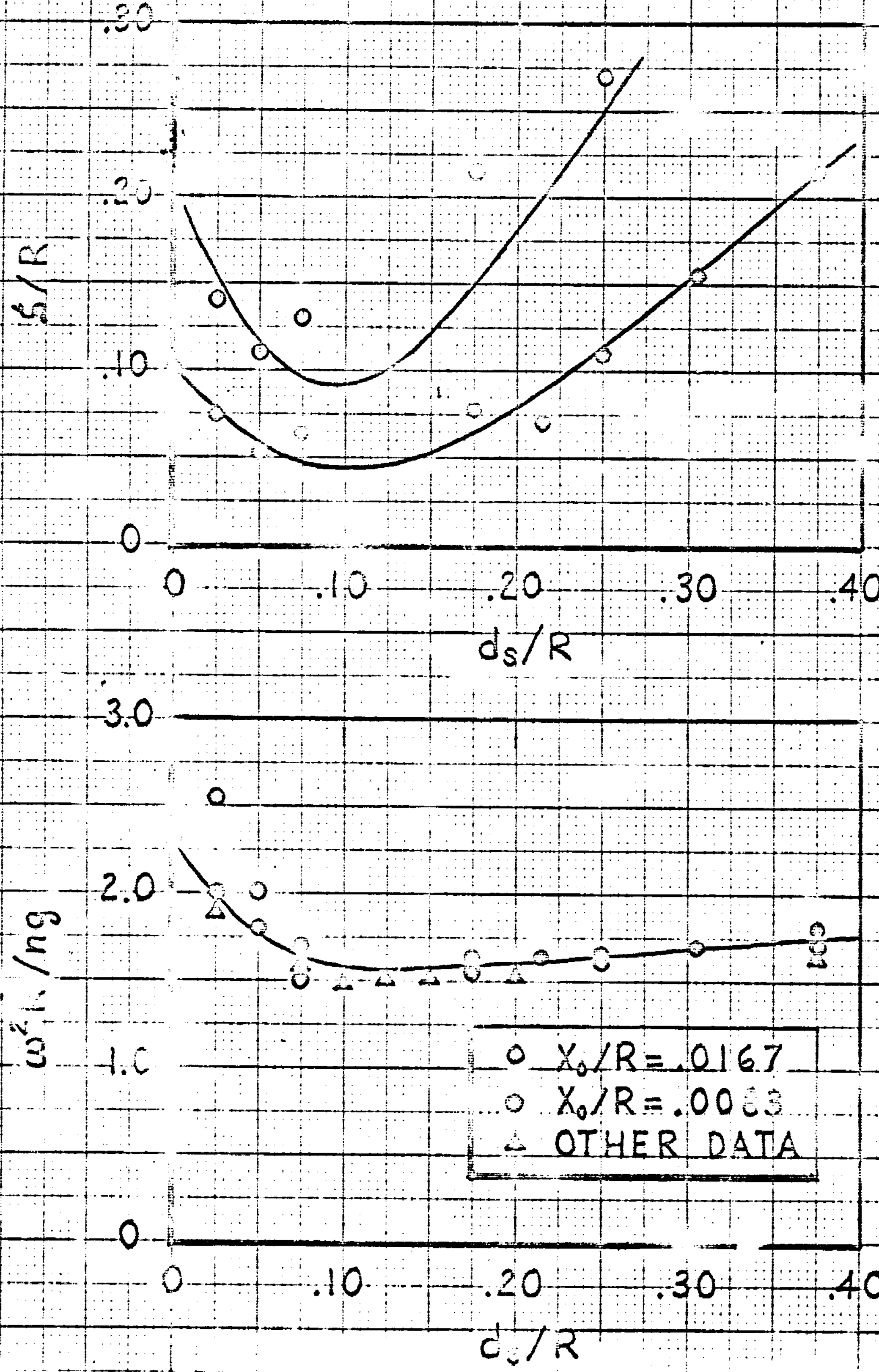

FIGURE 1. SLOSH HEIGHT AND RESONANCE FREQUENCY VS. DEPTH OF SUBMERGENCE

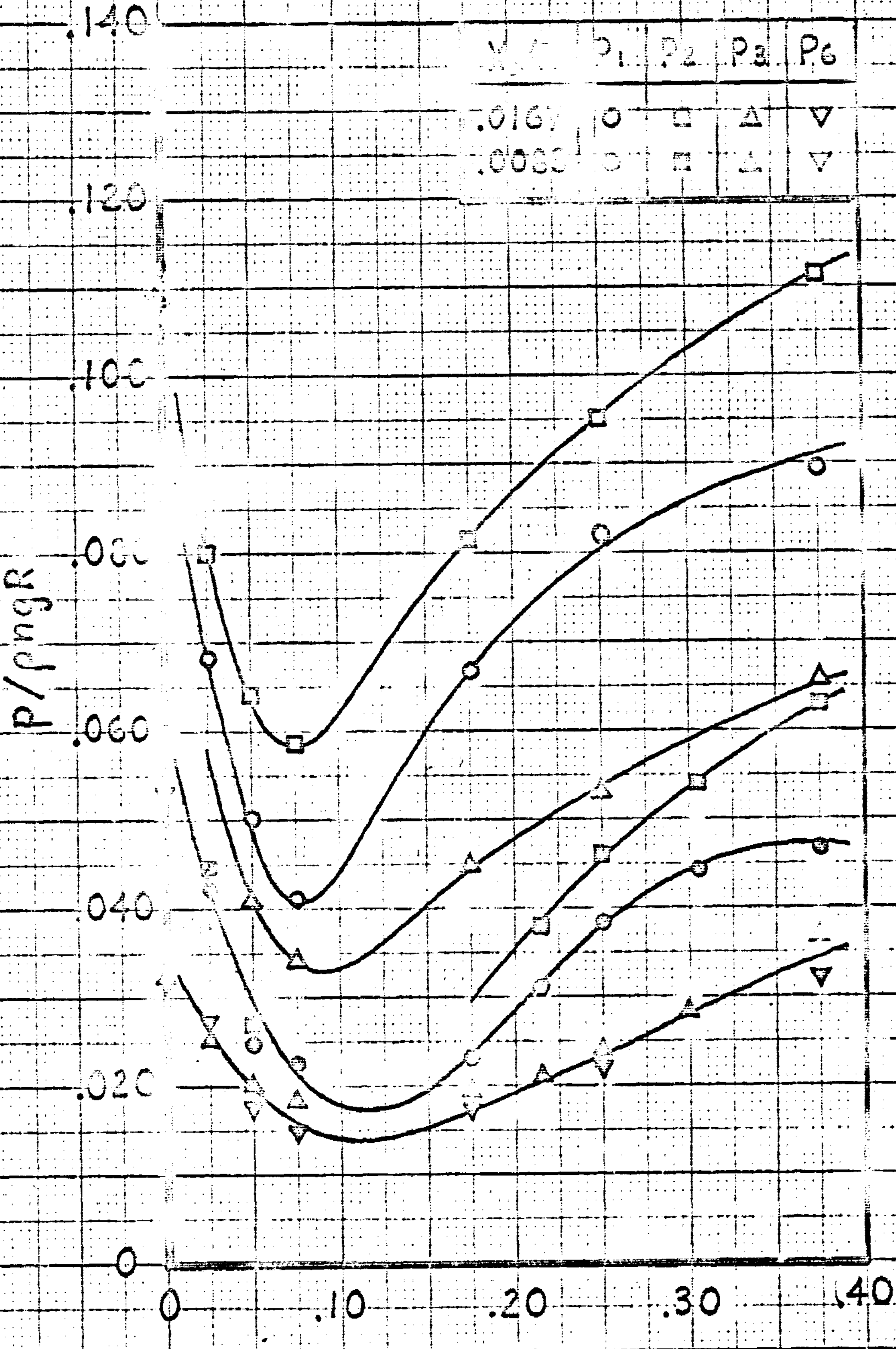

FIGURE 2. PRESSURE AMPLITUDES AS RECORDED FROM VARIOUS TRANSDUCERS

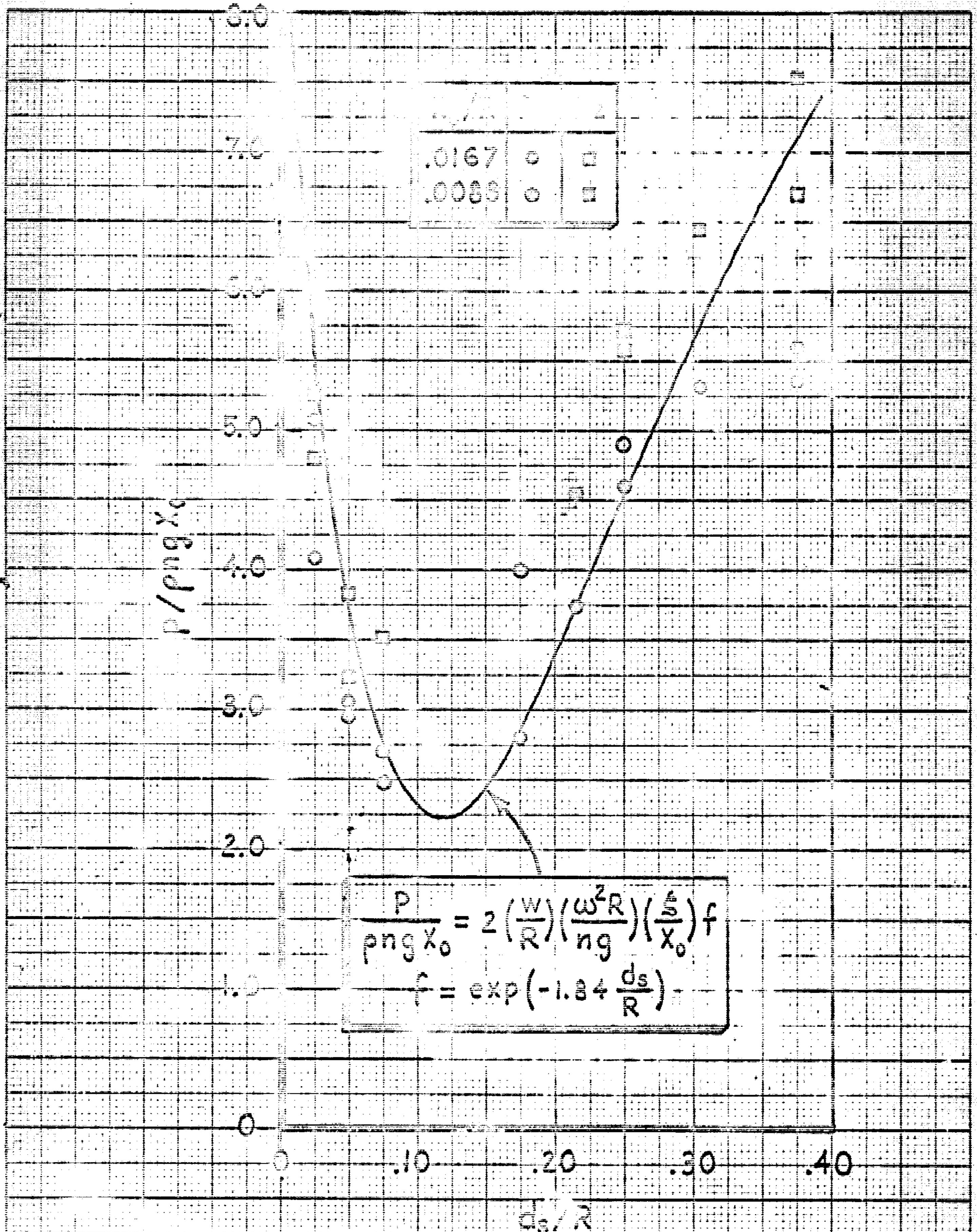

FIGURE 13. EXPERIMENTAL AND THEORETICAL DETERMINATIONS OF PRESSURE AMPLITUDES