SOUTHWEST RESEARCH INSTITUTE
8500 CULEBRA ROAD SAN ANTONIO, TEXAS 78206

April 5, 1965

Director
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Purchasing Office
Huntsville, Alabama 35812

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

Attention: PR-EC

Reference: Contract No. NAS8-1555
SwRI Project No. 02-1072
Quarterly Progress Report No. 16

Dear Sir:

The present letter is intended to constitute Quarterly Progress Report No. 16 covering the period 1 January 1965 through 31 March 1965.

Pressures on Ring Baffles

A harmonic analysis of the pressure data is now in progress. Pressure data reduced by the peak amplitude measurement method yielded good results only for the ring section normal to the excitation amplitude. The erratic pressures at other ring sections are the results of the data taken for peak pressure-force measurements. At frequencies corresponding to the peak pressure-force measurements, the liquid motion is comprised of a combination of the first anti-symmetric and symmetrical sloshing modes. The harmonic analysis results also indicate that these two modes are the dominant harmonics.

Experimental force measurements for solid and perforated ring baffles have been completed and the data reduced. Preliminary results indicate that the experimental force measurements on a solid ring baffle are in a range bounded by two different theoretical force computations. Figure 1 presents the experimental non-dimensional force measurement vs. baffle submergence d_s/R for three values of translation amplitude. Included in this plot are the

FACILITY FORM 602

N66-16715 (ACCESSION NUMBER)
(THRU)
12 (PAGES)
1 (CODE)
CR 70021 (NASA CR OR TMX OR AD NUMBER)
12 (CATEGORY)

D/35615-K

average theoretical values calculated from the NASA-MSFC Aero-Astrodynamics Internal Note 4-64 by Frank C. Liu and the average values obtained from the Handbook of Astronautical Engineering, "Propellant Sloshing", Section 14.14/15, pp. 14-14 to 14-27. Experimental slosh heights and resonant frequencies were used in the theoretical computations.

Figure 2 presents a comparison of the baffle forces for a solid ring baffle and various perforated ring baffles. The force results for all the baffles studied in Technical Report No. 5, Southwest Research Institute, will be presented ultimately in a new technical report covering the present work.

Damping Coefficients for Mechanical Models of LIQUID SLOSHING

The object of this program is to determine the significance of the moment of inertia damping proposed in H. F. Bauer's mechanical model for lateral sloshing (NASA TR R-187). This term arises only when the tank is excited in pitching motion. If the moment of inertia damping is not included, the moment response of the equivalent mechanical model can be written as $I_{fluid}\ddot{\varphi}$ + terms caused by free surface sloshing (including damping) where I_{fluid} is the effective moment of inertia of the fluid in a closed container. According to Bauer, however, the moment response should be

$$\left[I_{rigid} - I_D\left(\frac{I_D^2}{I_D^2+C_D^2}\right)\right]\ddot{\varphi} + C_D\left(\frac{I_D^2}{I_D^2+C_D^2}\right)\dot{\varphi}$$

+ terms caused by free surface sloshing (including damping) where I_{rigid} is the moment of inertia of a rigid body of the same mass and shape as the fluid, I_D is the moment of inertia of a massless, oscillating disc located at the liquid c.g., and C_D is the damping coefficient of the viscous damper attached to the disc. If the damping is zero, this equation reduces to

$$\left(I_{rigid} - I_D\right)\ddot{\varphi} \quad + \text{ sloshing terms}$$

so that $I_D = I_{rigid} - I_{fluid}$ and both models are equivalent. C_D can be determined approximately by measuring the damping of the fluid in a closed container (no sloshing) which is excited in a pitching motion.

We had originally planned to determine C_D by pitching a closed tank in steady state motion, and then measuring the moment response and the phase angle of the moment with respect to the excitation. The inertia of the system without fluid was compensated by electrical means; hence, these measurements should have been sufficient to determine the actual fluid moment of inertia and the damping. However, the damping was so small that the inherent noise in the system completely invalidated the experimental data. After trying a number of corrective procedures, all to no avail, it was decided to abandon this method.

A schematic of the new apparatus developed to measure both the liquid moment of inertia and damping for the capped rigid tank case is shown in Fig. 3. The liquid is contained in a 7.71 inch diameter tank which is supported on two sides by sharp pivot points near the top of the tank; the sharp pivot points produce very low inherent damping in the system. Four springs are attached to the tank near the bottom, so that the entire tank forms a single-degree-of-freedom, spring-mass system. The natural frequency of the system can be varied by changing the attachment point of the springs relative to the pivot point.

The liquid moment of inertia is determined by first measuring the natural frequency of the tank with liquid, and then without liquid. The difference in natural frequencies allows the liquid moment of inertia to be calculated about the pivot point. The liquid moment of inertia about the c.g. is then found by the transfer theorem. (It was decided to pivot the tank near the top, rather than at the c.g., since the natural frequency change from empty tank to full tank is considerably greater about a pivot point near the top. This, of course, helps reduce the experimental error.) Tentative data indicate the liquid moment of inertia about its c.g. to be about 0.19 to 0.20 of the same mass of frozen liquid; this agrees with theory.

Damping of the liquid is being measured by oscillating the system at the natural frequency and then shutting off the excitation and observing the decaying response. The logarithmic decrement of liquid damping is taken as the difference of the logarithmic decrement of the tank with liquid and that for the empty tank weighted with an amount of lead equal to the weight of the water. Hence, the damping measurements are made at the same amplitudes and frequencies for both the full and empty tank.

Tentative data show the empty tank damping to be about δ = 0.00270. The full unbaffled tank damping values are slightly greater than this at all frequency values which have been measured between 2 cps and 5 cps. The log decrements due to the liquid alone obtained by taking the difference of these two values are about δ = 0.00066, which, of course, is very small indeed. In fact, it may be questioned whether this is within the experimental accuracy of the system, except that the damping values with liquid are always greater than those for the empty tank.

Preliminary data for the damping of the liquid when one ring baffle is located at the mid-plane of the tank indicate that the damping is substantially larger than for the unbaffled tank. Testing is continuing with the baffled tank.

General

Both portions of the present work appear to be proceeding satisfactorily. The work on ring baffle pressures, as discussed above, has been carried quite far and therefore we feel that preparation of a comprehensive technical report covering this work can be initiated shortly.

We trust that MSFC technical personnel will visit SwRI in the near future for detailed discussions of this work. It is also our hope that this general program of research can be continued for an additional year and that discussions on specific aspects of this continuation might be carried out at the same time.

Respectfully submitted,

H. Norman Abramson, Director
Department of Mechanical Sciences

HNA:ac

Attachments: (9) ccs.
3 figures

cc: NASA HQ

Mr. A. C. Hulen, SwRI-w/encls.(2)cc

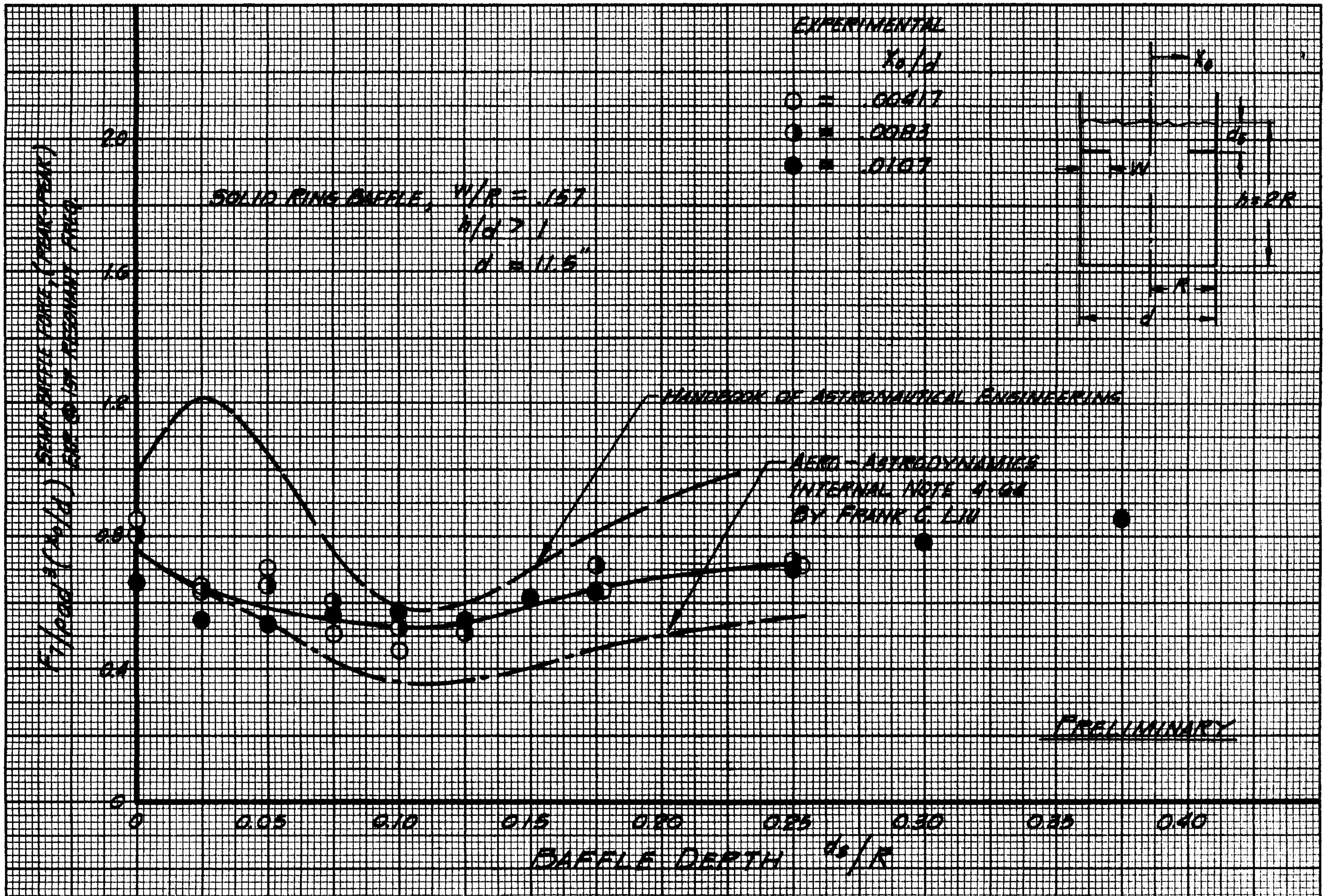
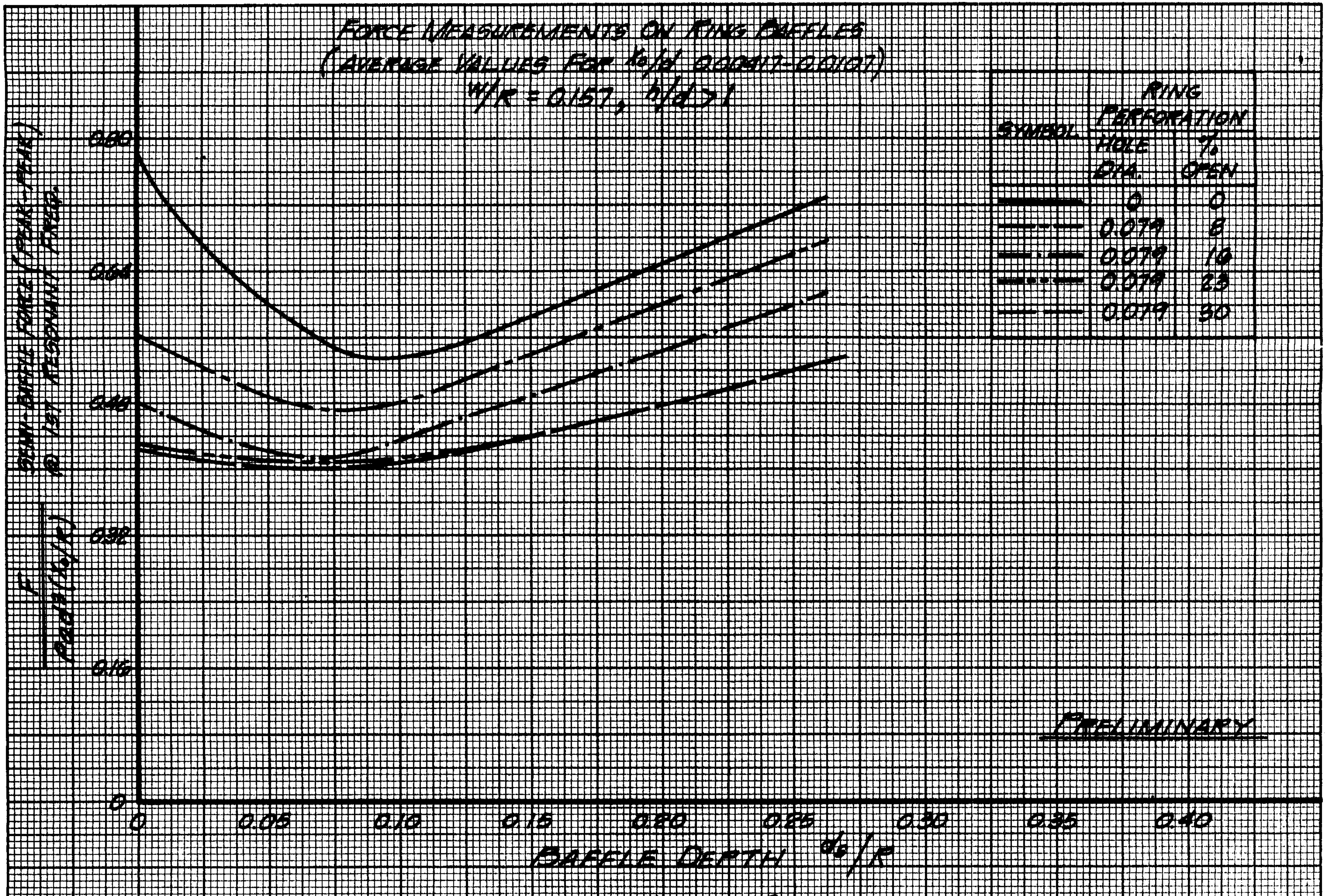

EXPERIMENTAL
X_0/d
○ = .00417
◐ = .0083
● = .0107
X_0
d_s
W
h ≥ 2R
R
d
SOLID RING BAFFLE, W/R = .157
h/d > 1
d = 11.5"
HANDBOOK OF ASTRONAUTICAL ENGINEERING
AERO - ASTRODYNAMICS
INTERNAL NOTE 4-64
BY FRANK C. LIU
PRELIMINARY
$F_1/\rho g d^3 (X_0/d)$ SEMI-BAFFLE FORCE, (PEAK-PEAK)
EXP. @ 1ST RESONANT FREQ.
2.0
1.6
1.2
0.8
0.4
0
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
BAFFLE DEPTH d_s/R

FIGURE 1



FORCE MEASUREMENTS ON RING BAFFLES
(AVERAGE VALUES FOR x_0/d 0.00817-0.0107)
$W/R = 0.157$, $h/d > 1$

FIGURE 2

SOUTHWEST RESEARCH INSTITUTE
DATA SHEET

SHEET NO. ____ OF ____ SHEETS

SUBJECT ____________________

PROJECT ____________________

DATE ____________________

BY ____________________

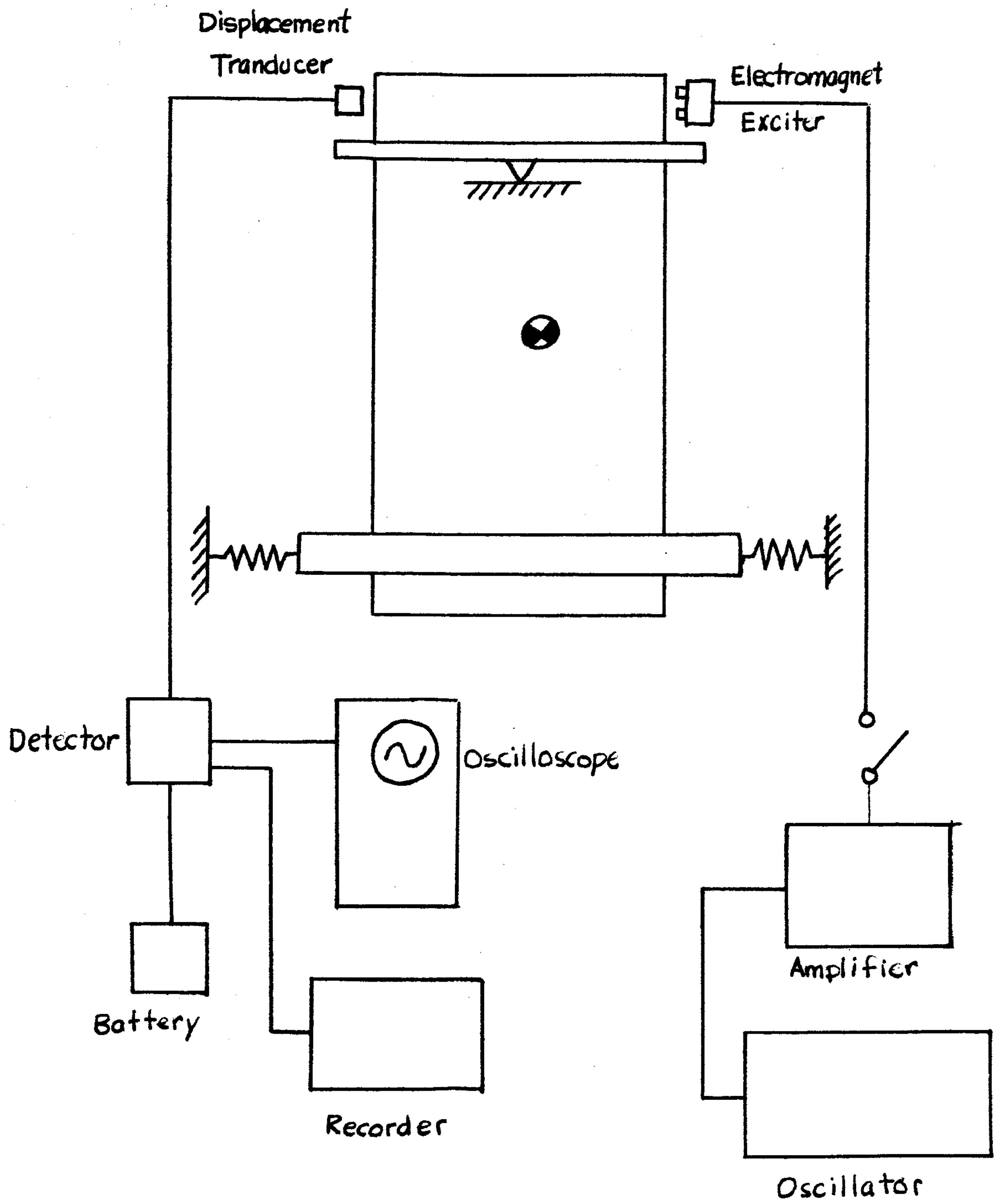


FIG.3 SIMPLIFIED SCHEMATIC OF TEST APPARATUS