TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 501

LANDING-SHOCK RECORDER

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SUMMARY

A description of a special type of seismograph, called a "landing-shock recorder," to be used for measuring the acceleration during impacts such as are experienced in airplane landings, is given. The theory, together with the assumptions made, is discussed in its relation to calculating the acceleration experienced in impact. Calculations are given from records obtained for two impacts of known acceleration. In one case the impact was very severe and in the other it was only moderately severe.

INTRODUCTION

At the time the development of the landing-shock recorder was started it was believed that the change in magnitude of acceleration experienced in the landing of an airplane was too rapid to be accurately recorded by an ordinary accelerometer having a frequency of 60 vibrations per second. Also, as the accelerometer responds to structural vibrations, it often gives records which are almost unreadable. It was believed that an instrument giving a time-displacement record during the impact due to landing would give valuable information not only about the character of the landing, but also about the reliability of the accelerometers in use. Accordingly, the National Advisory Committee for Aeronautics developed the design of the present landing-shock recorder, which is an instrument that furnishes a time-displacement history of movement in a given direction.

DESCRIPTION OF THE INSTRUMENT

A diagrammatic sketch of the landing-shock recorder is given in figure 1. The essential parts are a weight, a supporting spring, and a recording mechanism. The weight is restricted to movement in a given direction by an enclosing cylinder and is made relatively frictionless by six ball bearings which aline it in the cylinder. The spring, which supplies the necessary restoring force to the weight, is so chosen that the combination has a natural frequency of about 1.5 vibrations per second. The connection between spring and weight is so arranged that the movement of the weight relative to the base causes a mirror to rotate; the mirror thereby reflects a beam of light onto a moving film to give a time history of the movement of the weight. Figure 2 shows the original instrument as it was arranged for experimental purposes. The base, film drum, and motor drive are those of a standard N.A.C.A. recording instrument.

THEORY

The equation describing the relation between the response of a loaded spring and an imposed acceleration varying as $\frac{d^2x_1}{dt^2}$ is

$$M\,\frac{d^2x}{dt^2} + Df\left(\frac{dx}{dt}\right) + Kx = M\,\frac{d^2x_1}{dt^2} \qquad (1)$$

where M is the active mass on the spring

D is the damping coefficient

K is the constant of the spring

x is the displacement of the weight from the neutral position

x_1 is the displacement (from some fixed point) of the instrument base in a direction parallel to the axis of the cylinder

t is the time

The instrument has been made relatively frictionless, so the damping $Df\left(\frac{dx}{dt}\right)$ can be neglected.

Equation (1) can thus be rewritten

$$\frac{d^2x}{dt^2} + \frac{K}{M}x = \frac{d^2x_1}{dt^2} \qquad (2)$$

The two terms on the left of equation (2) account for the imposed acceleration; the term $\frac{K}{M}x$ gives the acceleration accounted for by the restoring force of the spring, and is the acceleration given by the conventional-type accelerometer where $\frac{d^2x}{dt^2}$ is assumed to be zero. However, when spring-weight systems of very low frequency are subjected to accelerations of short duration, the part $\frac{d^2x}{dt^2}$ may be predominant. The landing-shock recorder was designed to work under this latter condition. Here the term $\frac{d^2x}{dt^2}$ accounts for the predominant part of the acceleration during impact and, due to the low value for $\frac{K}{M}$, the term $\frac{K}{M}x$ is usually more in the order of a correction. It is of interest to note the fact that conventional accelerometers always give readings in error by the amount of $\frac{d^2x}{dt^2}$. However, x is made very small in the conventional instrument, thus justifying its neglect in all cases except those in which t becomes so small that the term $\frac{d^2x}{dt^2}$ becomes appreciable. It is conceivable that in sharp impact this latter possibility may be realized. It is also of interest to note that the true acceleration can be found in any case by taking into account both terms on the left side of equation (2).

RESULTS

In order to check the performance of the instrument and determine the accuracy of computing the acceleration, the instrument was subjected to known accelerations simulating impact conditions as nearly as possible.

These known accelerations were induced by a beam supported at each end, deflected at the midpoint between the supports, and released by a trigger. With the landing-shock recorder located at the midpoint of the beam, the trigger was released so as to give a series of impulses to the instrument. The deflection of the beam at the start of the initial impulse being known and simple harmonic vibration being assumed, the corresponding acceleration, a, is given by the relation

$$a = 4\,\pi^2 f^2 d \cos 2\pi ft$$

where f is the frequency of vibration of the beam and d is the deflection of the beam from the rest position. At zero time $\cos 2\pi\, ft = 1$, giving an initial acceleration of $a = 4\pi^2 f^2 d$. The assumption of simple harmonic vibration is reasonable, as the deflection was limited to less than 3 inches with a beam 10 feet long and the beam supports allowed no vertical movement at the end.

As an illustration of the results obtained with the landing-shock recorder, a record is reproduced as figure 3. The film speed for this record was about 1.25 inches per second. Time on the record is given at 1-second intervals by the white dots along the bottom of the film. A sample sheet of calculations is given in table I. Figure 4 gives the curves for displacement, first difference $\frac{dx}{dt}$. The values determining the curve of $\frac{dx}{dt}$ against time could not be found with sufficient accuracy to justify drawing a curve more definite than a straight line, as drawing a straight line involves averaging over the part of the cycle during which the acceleration varies least. The second difference is constant, having a value of 3,400 in./sec.^{2} This value corresponds to 8.8 g for $\frac{d^2x}{dt^2}$; adding a value of 1.0 g for $\frac{K}{M}x$ (see fig. 7), the total acceleration is 9.8 g. This value compares with the value 9.56 g, calculated from the displacement of the beam. The beam had a frequency of 5.64 vibrations per second and was given a deflection of 2.65 inches. These values give an acceleration of 8.6 g, which, with 1.0 g due to the acceleration of gravity, gives a total acceleration of 9.6 g. This is only one of several records that were computed. All the records gave results within 10 percent of the computed acceleration, which is about the degree of accuracy to be expected. Refinements contemplated in the instrument for general use will probably reduce this error to about ±5 percent.

Figure 5 gives the record of an airplane landing, 5(a) being the record from the landing-shock recorder and 5(b) the record from an accelerometer. The accelerometer had a frequency of 60 vibrations per second and was about critically damped. The complete results from the landing-shock recorder for the same landing are given in table II and figure 6. In figure 6 are given the displacement curve for the weight on the spring, its velocity $\frac{dx}{dt}$, its acceleration $\frac{d^2x}{dt^2}$, and its total acceleration $\frac{d^2x}{dt^2} + \frac{K}{M}x$. All quantities except the total acceleration, which is given in multiples of g, are given in inches and seconds. The results from record 5(a) give an acceleration of 3.05 g at time 1.815 seconds, and the readings from record 5(b) give an acceleration of 3.14 g at time 1.85 seconds.

CONCLUSIONS

Tests of the landing-shock recorder have indicated its value for determining the performance of accelerometers under doubtful conditions and for making measurements to determine the accelerations under impact conditions. It can also be used to advantage on landing tests where excessive vibration occurs, owing to its lack of resonance to airplane vibrations.

A further valuable result of this development has been the increase in confidence in the standard N.A.C.A. recording accelerometer. Airplane landings have been shown to be of less sharp impact than was formerly believed and comparison of records has shown that the accelerometer has a sufficiently rapid response to record the maximum acceleration reliably, even with a small a-amount of overdamping.

It is worth mentioning that, although evaluation of the records entails considerable computation and graphical differentiation, the proper region of the record for analysis is readily recognized after a little experience, and the calculations can be quite easily made.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 13, 1934.

TABLE I

Time sec.	Deflection from the record in.	Deflection of the weight in.	$\frac{dx}{dt}$ in./sec.	$\frac{d^2x}{dt^2}$ in./sec.^{2}	$\frac{\frac{d^2x}{dt^2}}{g}$	$\frac{\frac{d^2x}{dt^2} + \frac{K}{M}x}{g}$
0.0025	0.000	0.000	11.0	3400	8.8	9.8
.005	.009	.054	16.0	3400	8.8	9.8
.0075	---	---	21.0	3400	8.8	9.8
.010	.024	.144	31.0	3400	8.8	9.8
.0125	.043	.258	45.0	3400	8.8	9.8
.0150	.064	.334	---	3400	8.8	9.8
.0175	.091	.546	---	3400	8.8	9.8
.01875	---	---	68.0	3400	8.8	9.8
.0200	.119	.714	---	3400	8.8	9.8
.02125	---	---	71.0	3400	8.8	9.8

TABLE II

Time sec.	Deflection from the record in.	Deflection of the weight in.	$\frac{dx}{dt}$ in./sec.	$\frac{d^2x}{dt^2}$ in./sec.^{2}	$\frac{d^2x}{dt^2}$ g	$\frac{d^2x}{dt^2} + \frac{K}{M}x$ g
1.76	0.000	0.000	0.00	350	0.90	1.90
1.77	.002	.012	3.75	350	.90	1.90
1.78	.013	.078	7.3	350	.90	1.90
1.79	.029	.174	11.2	372	.96	2.00
1.80	.047	.282	15.8	450	1.16	2.30
1.81	.079	.474	21.2	668	1.72	2.85
1.815	---	---	---	720	1.86	3.05
1.82	.112	.672	28.5	665	1.72	2.95
1.83	.167	1.000	34.2	457	1.18	2.47
1.84	.221	1.326	37.5	232	.60	2.05
1.85	.301	1.806	39.5	150		
1.86	.364	2.184	40.8	122		
1.87	.443	2.658	42.0	110		
1.88	.515	3.090	43.0	110		

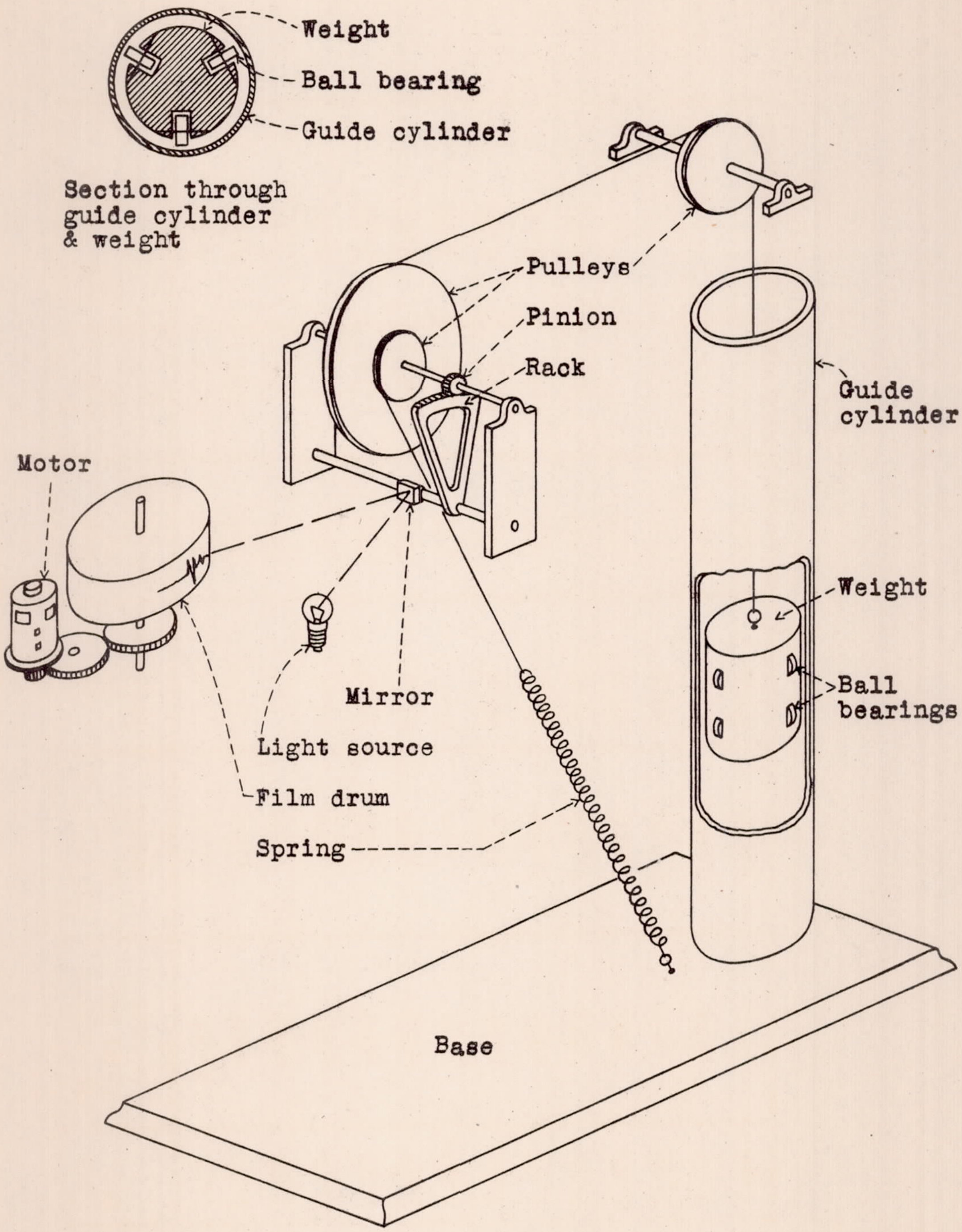


Figure 1.- Diagrammatic sketch of landing-shock recorder.

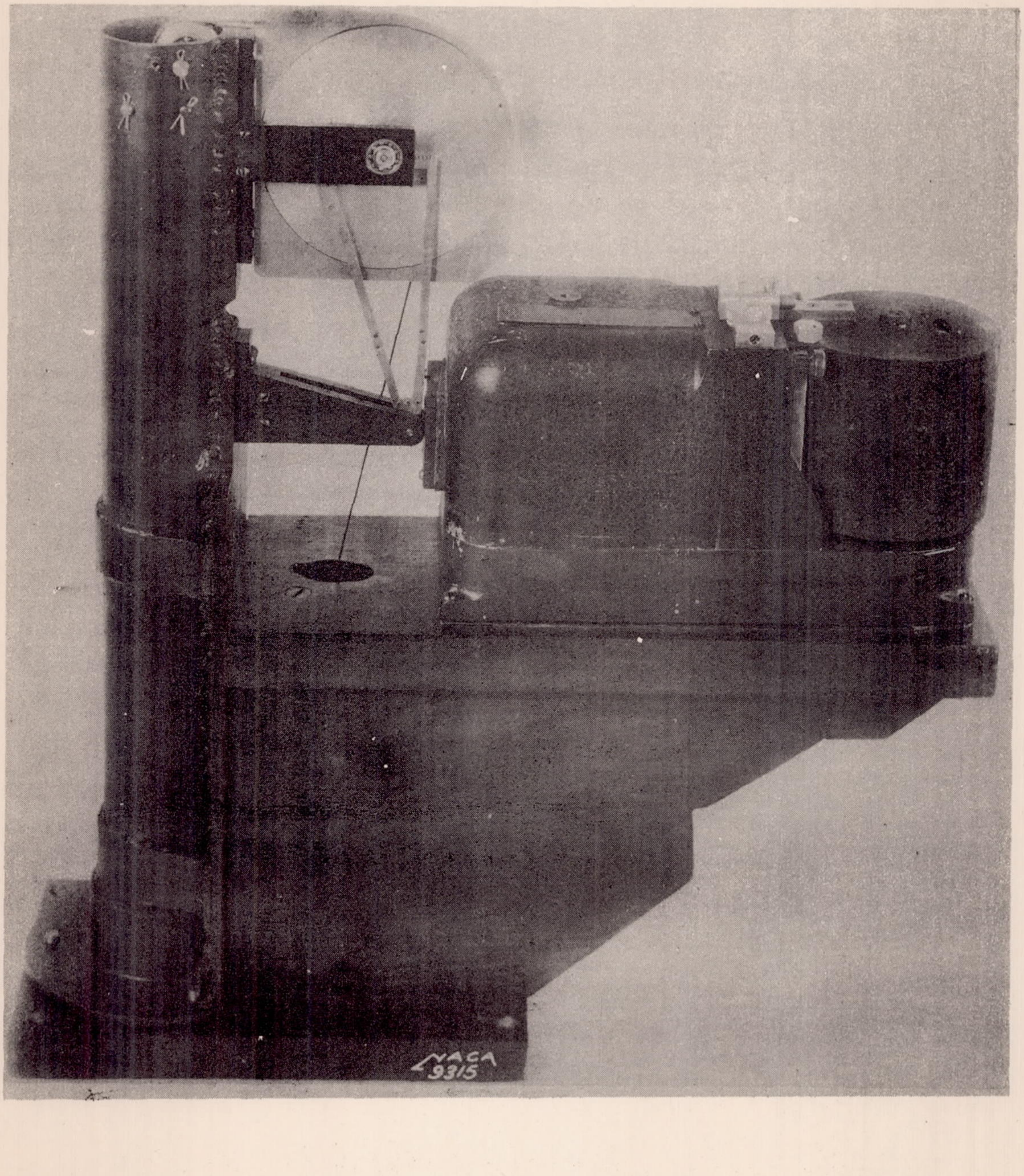
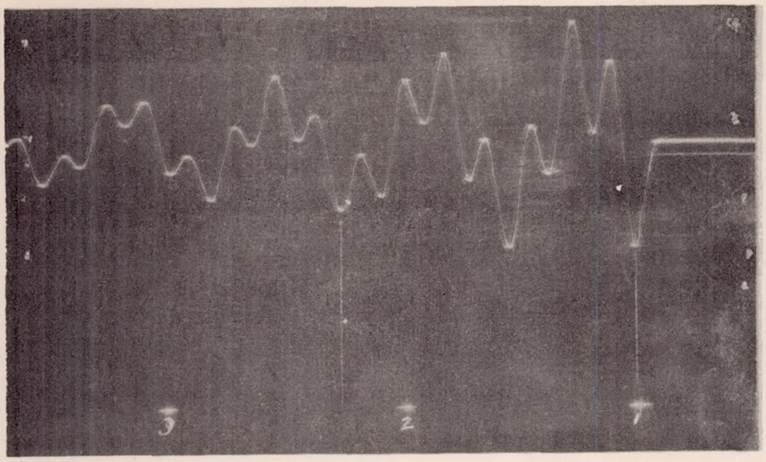
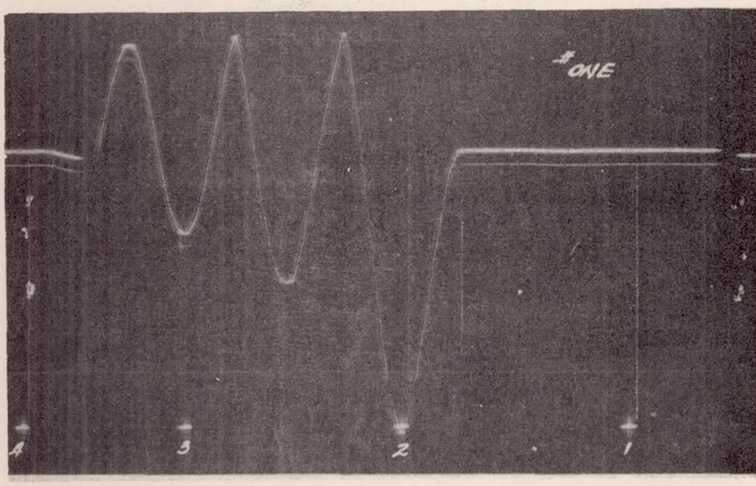


Figure 2.- Landing-shock recorder



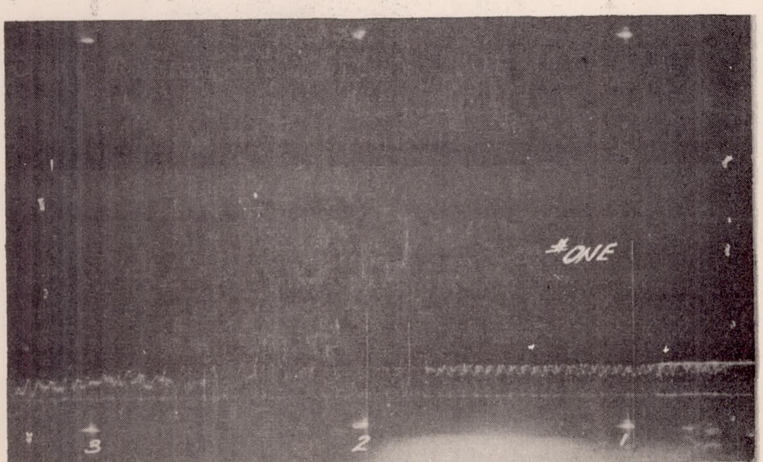
Film motion ⟶

Figure 3.- Landing-shock-recorder record of vibrating beam.



Film motion ⟶

Figure 5a.- Airplane landing. Landing-shock-recorder record.



Film motion ⟶

Figure 5b.- Airplane landing. Standard accelerometer record

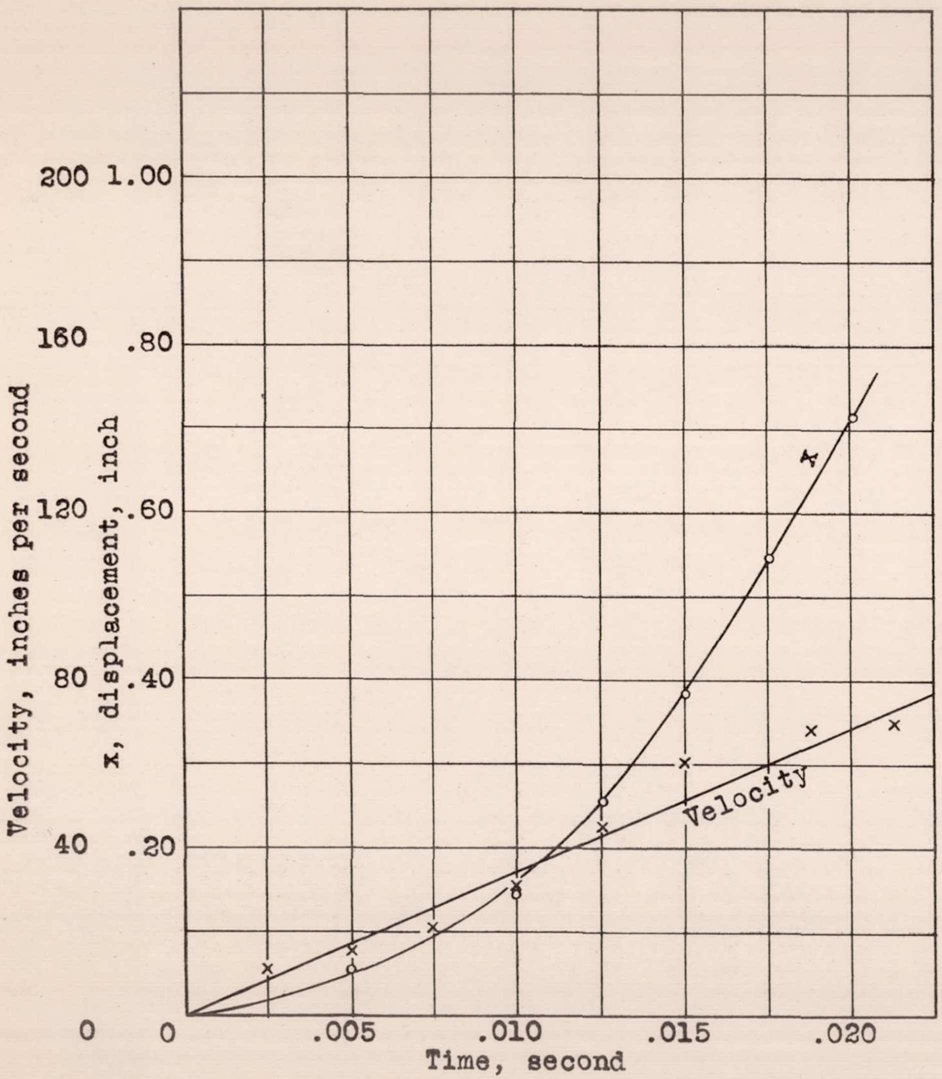


Figure 4.- Calculated curves from record of figure 3.

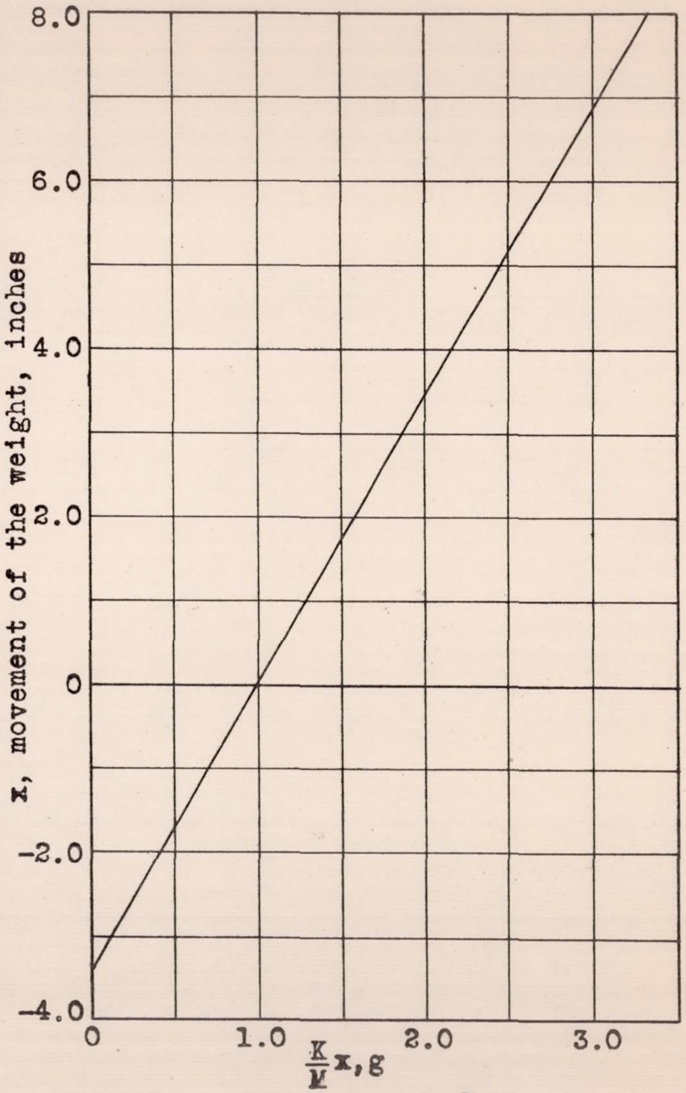


Figure 7.- Variation of $\frac{K}{M}x$ with x.

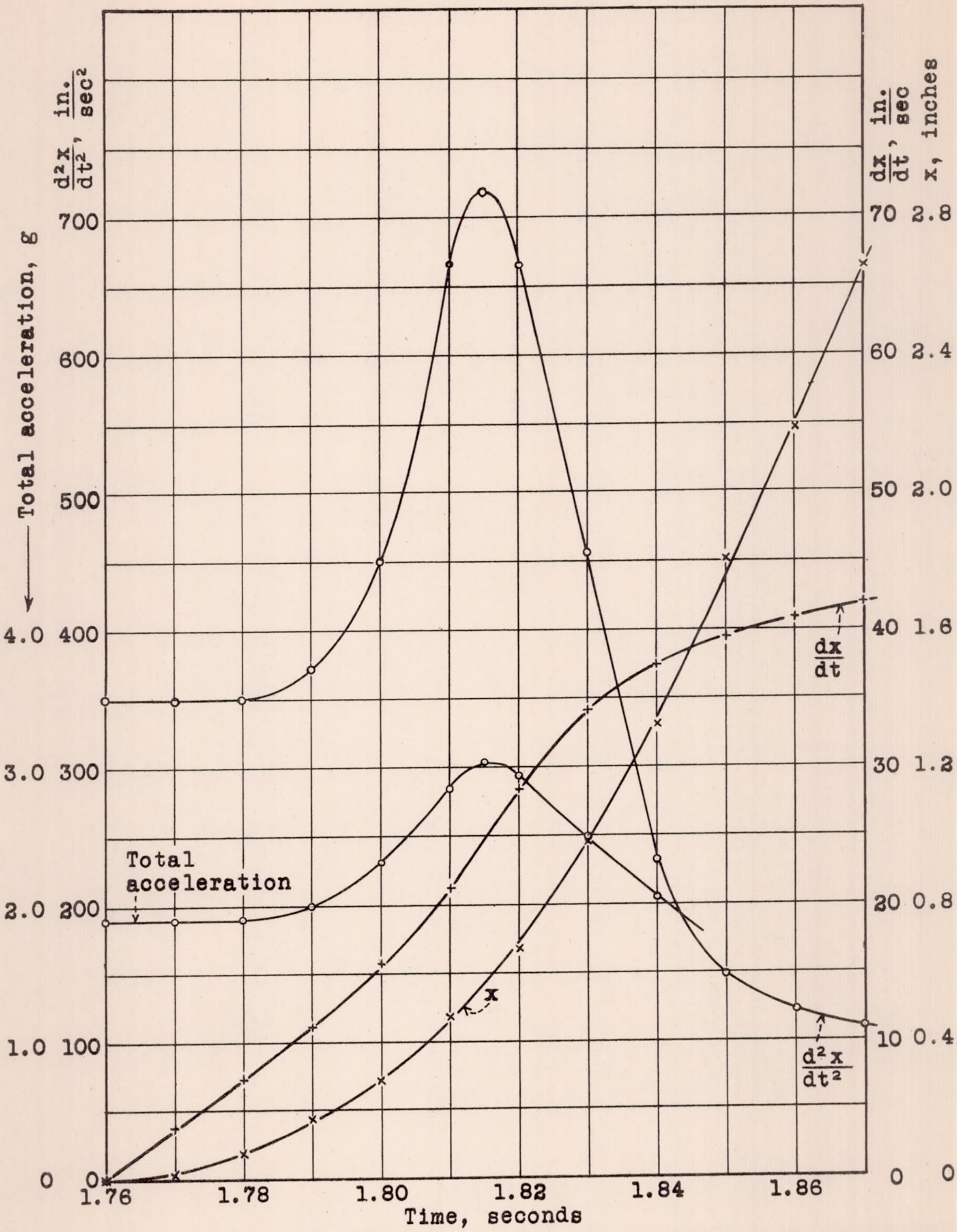


Figure 6.- Calculated curves from record of figure 5a