TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

———————

No. 501

———————

LANDING-SHOCK RECORDER

By M. J. Brevoort
Langley Memorial Aeronautical Laboratory

———————

Washington
July 1934

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 501

LANDING-SHOCK RECORDER

By M. J. Brevoort

SUMMARY

A description of a special type of seismograph,
called a "landing-shock recorder," to be used for measur-
ing 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 cal-
culating the acceleration experienced in impact. Calcu-
lations 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 re-
corder 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 vibra-
tions 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 reliabil-
ity 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 nat-
ural 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 in-
strument as it was arranged for experimental purposes.
The base, film drum, and motor drive are those of a stand-
ard N.A.C.A. recording instrument.

THEORY

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

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

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 $Df\left(\dfrac{dx}{dt}\right)$ 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 simu-
lating 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 land-
ing-shock recorder located at the midpoint of the beam,
the trigger was released so as to give a series of im-
pulses 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 ac-
celeration, 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 vi-
bration 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 in-
tervals by the white dots along the bottom of the film.
A sample sheet of calculations is given in table I. Fig-
ure 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
$\frac{d^2 x}{dt^2}$; 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 acceler-
ation 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 $\frac{d^2 x}{dt^2}$, and its total acceleration $\frac{d^2 x}{dt^2} + \frac{K}{M} x$. 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 graphic-

al 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.	$\dfrac{dx}{dt}$ in./sec.	$\dfrac{d^2x}{dt^2}$ in./sec.^{2}	$\dfrac{d^2x}{dt^2}$ g	$\dfrac{d^2x}{dt^2} + \dfrac{K}{M}x$ 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.	$\dfrac{dx}{dt}$ in./sec.	$\dfrac{d^2 x}{dt^2}$ in./sec.^{2}	$\dfrac{d^2 x}{dt^2}$ g	$\dfrac{d^2 x}{dt^2} + \dfrac{K}{M} x$ 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		
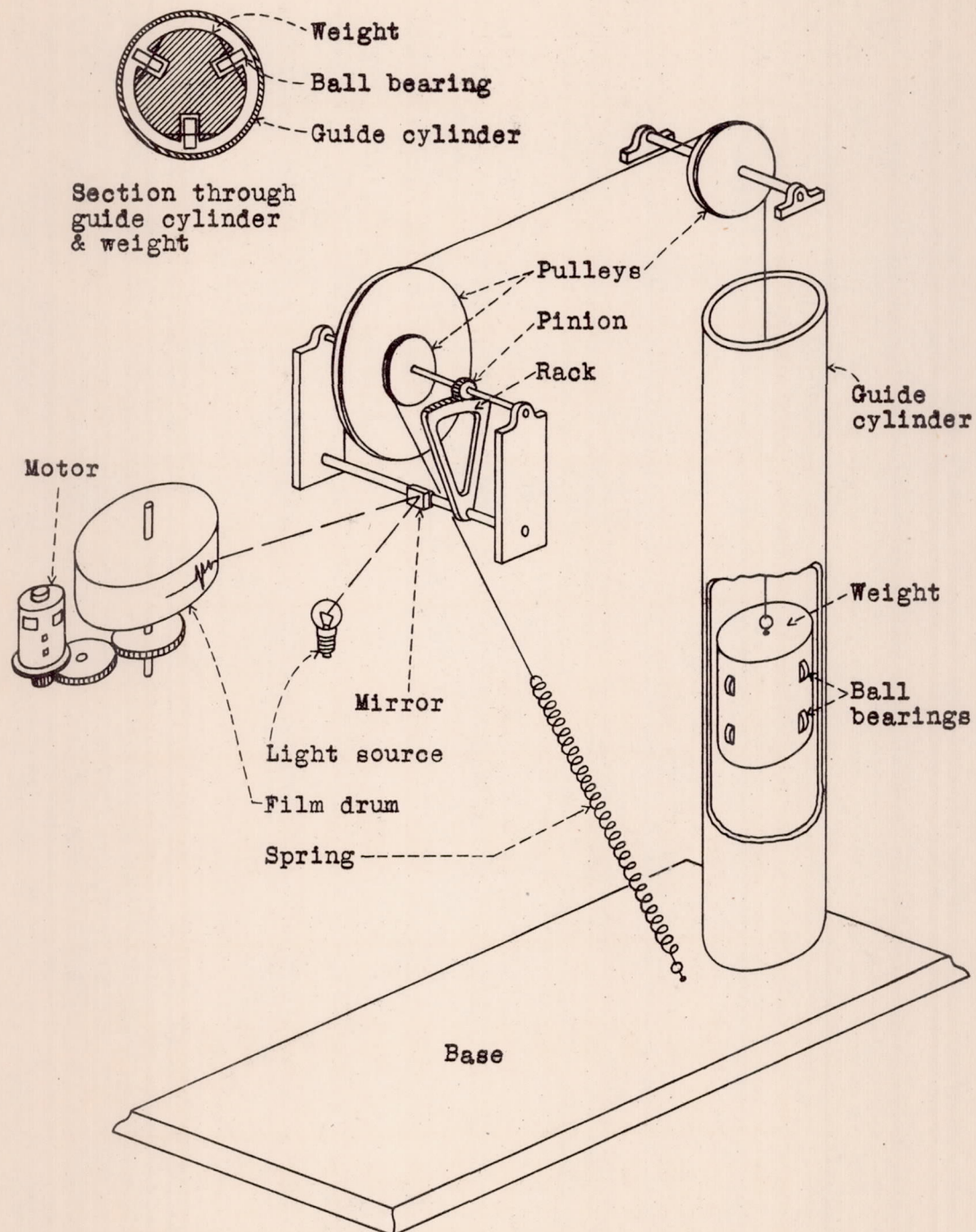
Figure 1.- Diagrammatic sketch of landing-shock recorder.
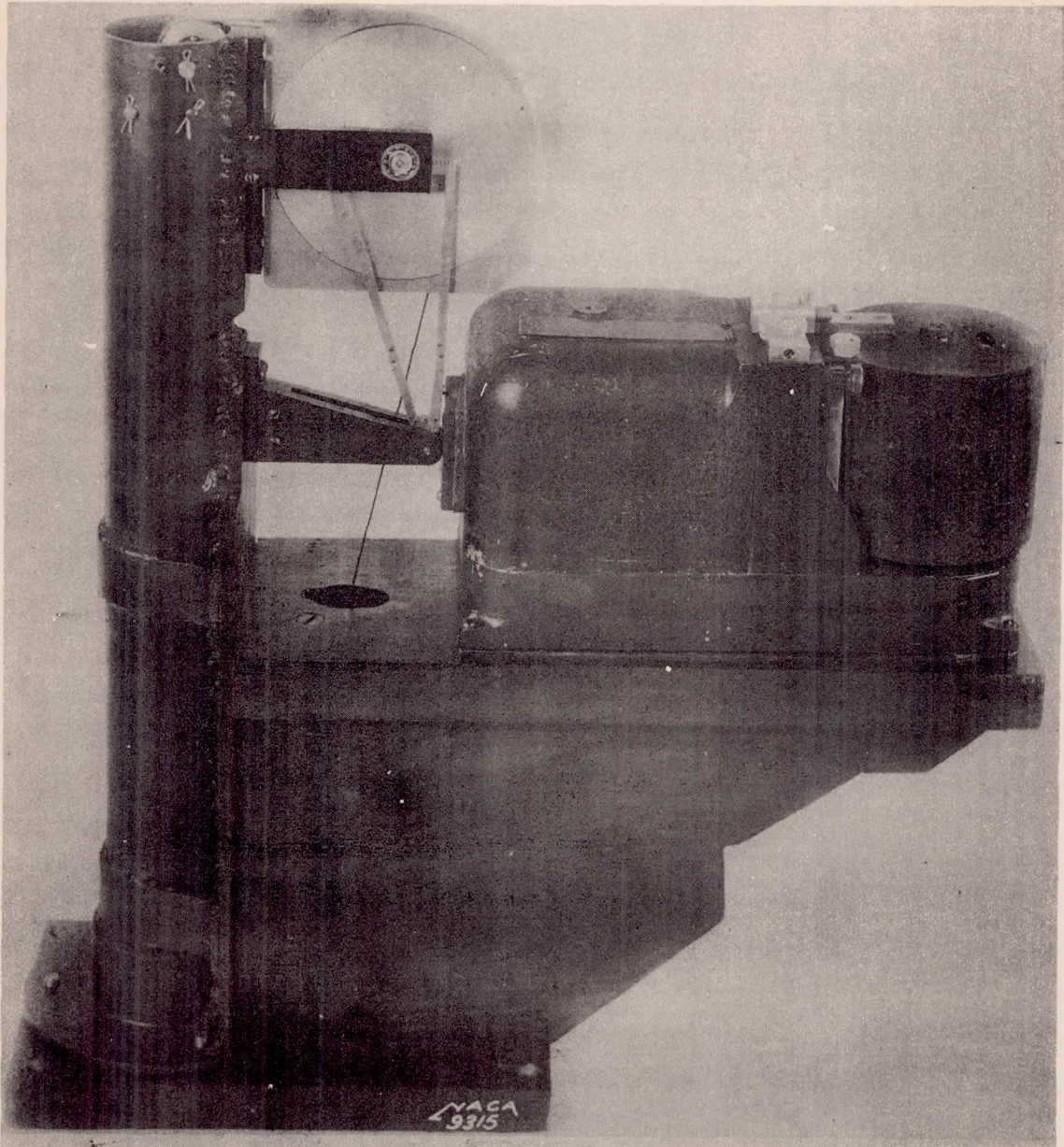
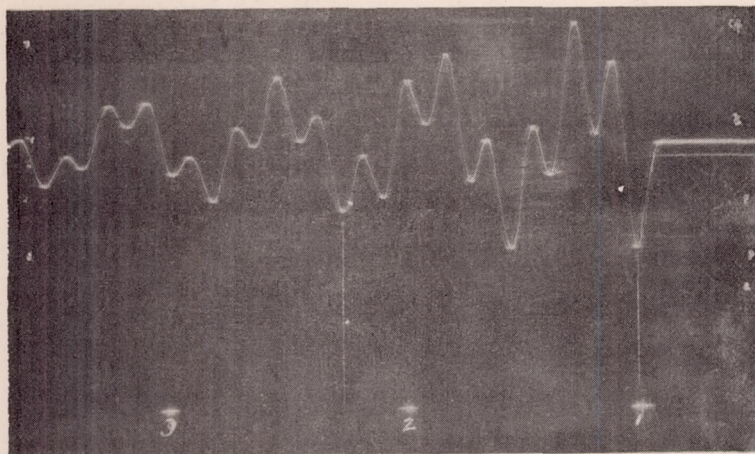Figure 2.- Landing-shock recorder

Figure 3.-

Landing-
shock-
recorder
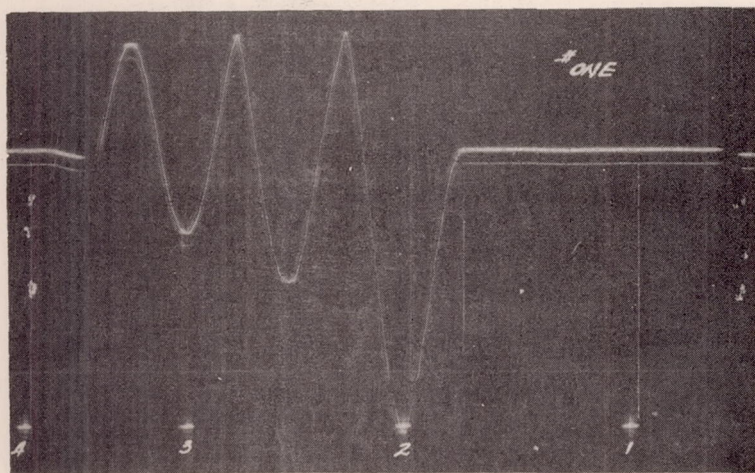record
of vibrat-
ing beam.

Film motion ⟶

Figure 5a.-

Airplane
landing.

Landing-
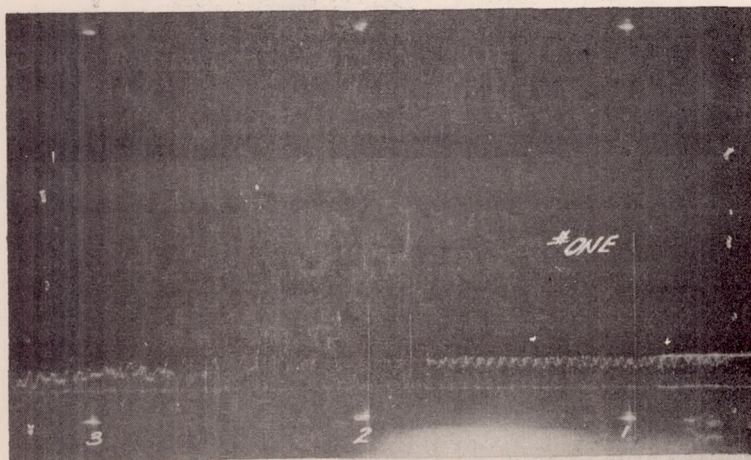shock-
recorder
record.

Film motion ⟶

Figure 5b.-

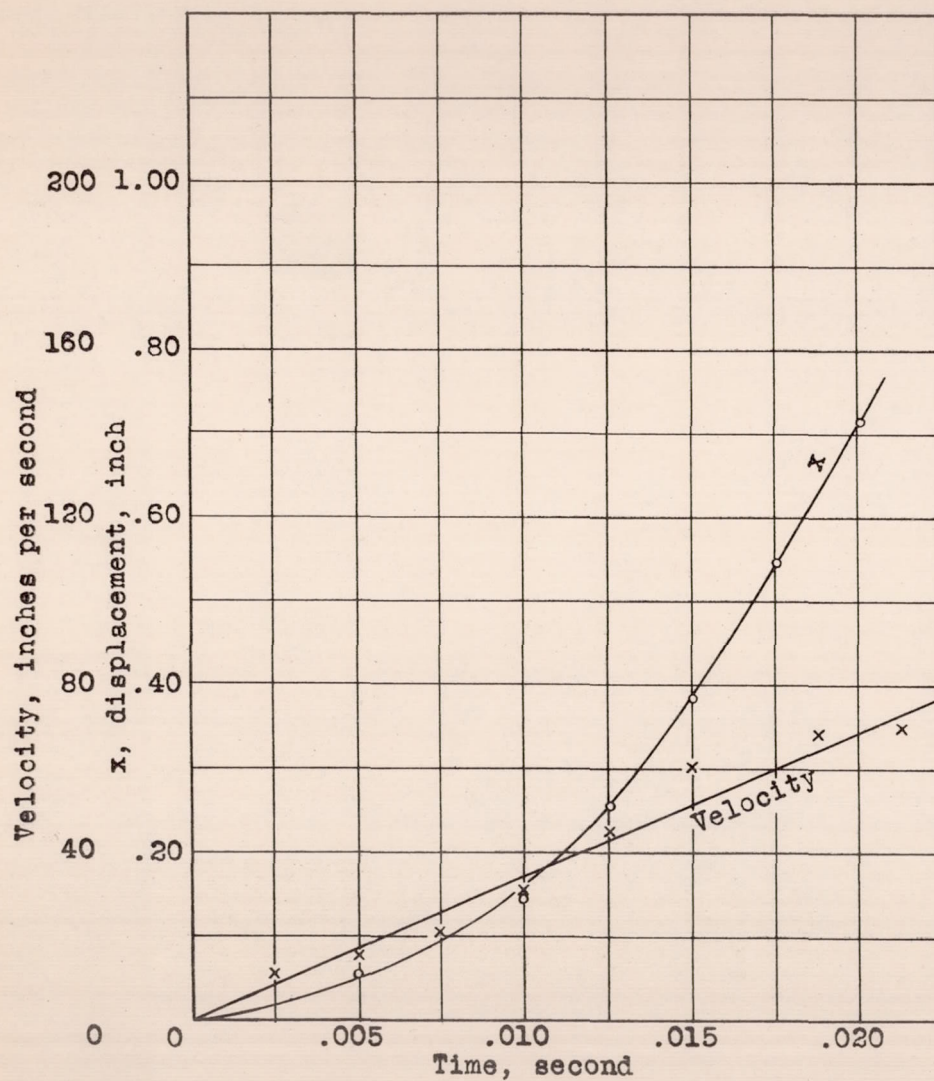Airplane
landing.

Standard
acceler-
ometer
record

Film motion ⟶

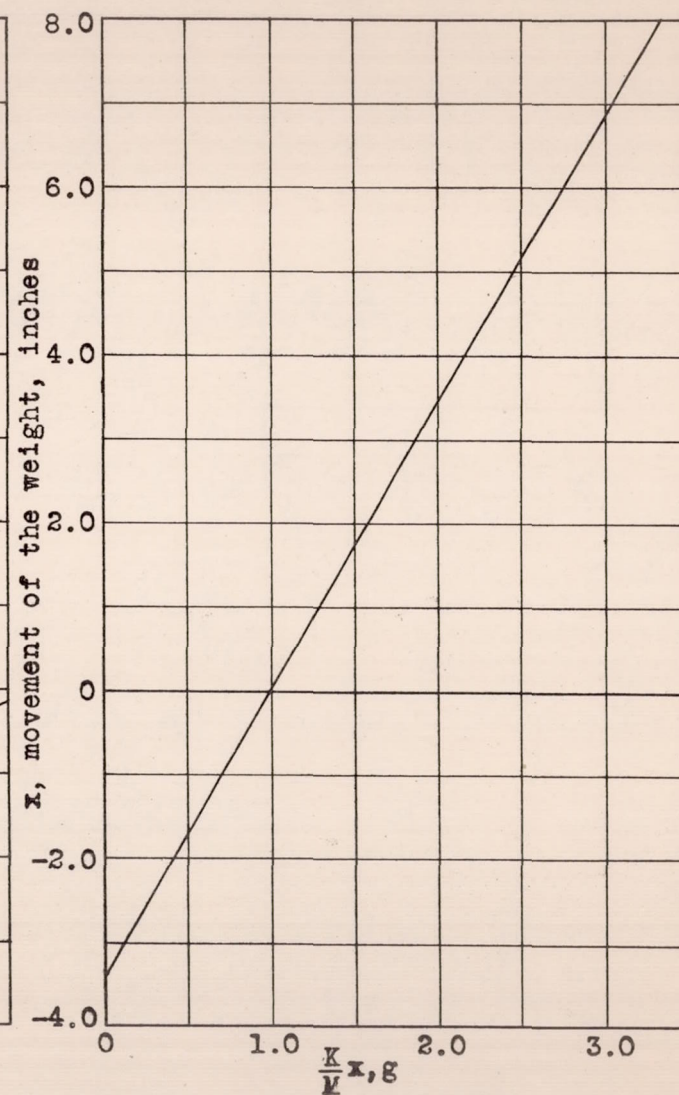Figure 4.— Calculated curves from record of figure 3.
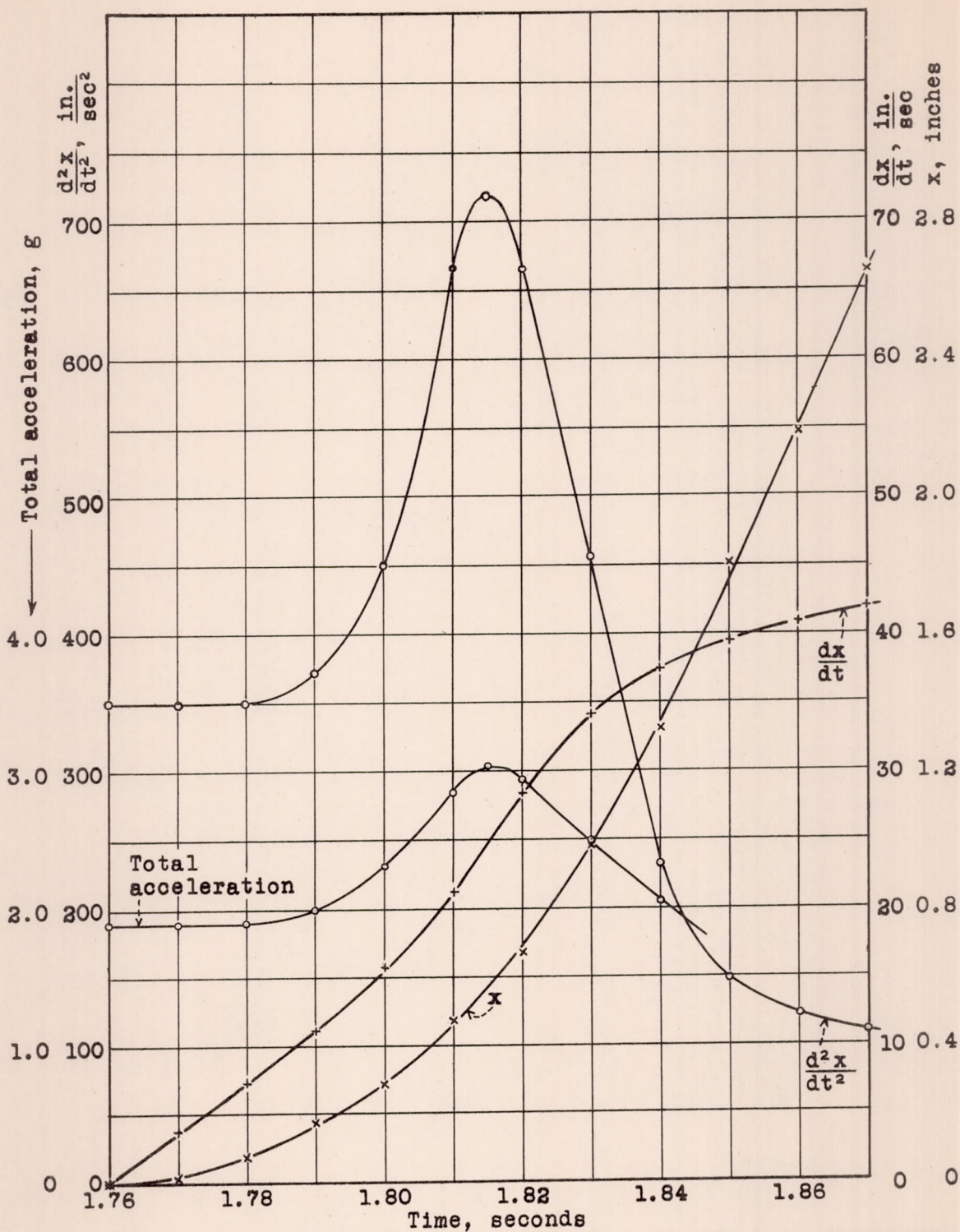
Figure 7.— Variation of $\frac{K}{M}x$ with x.

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