DEVELOPMENT OF AN AUTOMATIC COUNTING ACCELEROMETER

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SUMMARY

This report describes an automatic counting accelerometer for recording and classifying the accelerations to which various preselected parts of an airplane are subjected This device was developed by the Civil Aeronautics Administration Technical Development and Evaluation Center

The instrument consists of a small pickup unit and a counting unit The pickup unit contains five accelerometer elements which may be adjusted to any value from 0 to 5 times the acceleration gravity (g) ± 0 1 g Each element is constructed to produce an electrical impulse each time an acceleration greater than its preset value is reached These impulses are transmitted to the counting unit where they are classified and recorded The pickup unit is connected electrically to the counting unit by a five-conductor shielded cable The operating power is supplied by dry cell batteries which are contained in the counting unit The total weight of the accelerometer is 18 77 pounds

Laboratory and flight tests conducted under various conditions indicate that the instrument is suitable for use in aircraft to obtain statistical data concerning the number and severity of acceleration shocks experienced

INTRODUCTION

An instrument that would obtain an immediately readable record of the number and magnitude of accelerations experienced by various aircraft components has long been needed. It could arm the designer with valuable information Another application of such a device is its use as a training instrument. It could be used to check the performance of a pilot while landing, on take-off runs, and in flight Thus, a measure of his normal piloting skill could be obtained To be practical this instrument must be of simple design, light in weight, easy to install and maintain, and must record a large number of accelerations such as would be experienced during several days or weeks of flight operations

In order to obtain data on the magnitude and frequency of occurrence of the accelerations experienced by aircraft, the TDEC developed an automatic counting accelerometer which was described by Albert London in a previous publication.[1]

As a result of experience gained in the use of this earlier model and through the analysis of a large number of landing and taxiing shock data, it was deemed desirable to undertake the development of an improved model which would classify and count such accelerations Specifications of this instrument included the following features The automatic counting accelerometer shall include a pickup unit and a counter unit, both of which shall be as small and light as possible They shall be capable of being readily mounted in the airplane and constructed to protect the elements from rain, dust, or inadvertent damage They shall function properly under the extremes of acceleration, pressure, and vibration ordinarily expected in aircraft, and under variations in temperature from 0 to 90° F

1 The pickup unit shall include five single-element type accelerometers, each of which shall
   a Be capable of an accuracy of ± 0 1 g under conditions such as exist during a landing impact
   b Incorporate a rotating adjustment, with adequate locking means, and be so constructed that a rotation of not less than five degrees of the adjustment will correspond to 1 0 g change in the triggering acceleration of the element
   c Provide for the adjustment of each element to measure accelerations in the range 0 5 to 5 0 g
2 The counting unit shall include
   a Five time-delay relays
   b Five counters
   c. Dry cell batteries of sufficient capacity for counting the accelerations experienced during 1,000 shock impulses

The improved automatic counting accelerometer described in this report was developed through contract with the American Instrument Company, Silver Spring, Md Subsequent laboratory and flight tests were conducted at the CAA TDEC, Indianapolis, Ind.

[1]London, Albert, "Development of an Automatic Recording Accelerometer," CAA Technical Development Report No 48, February 1945

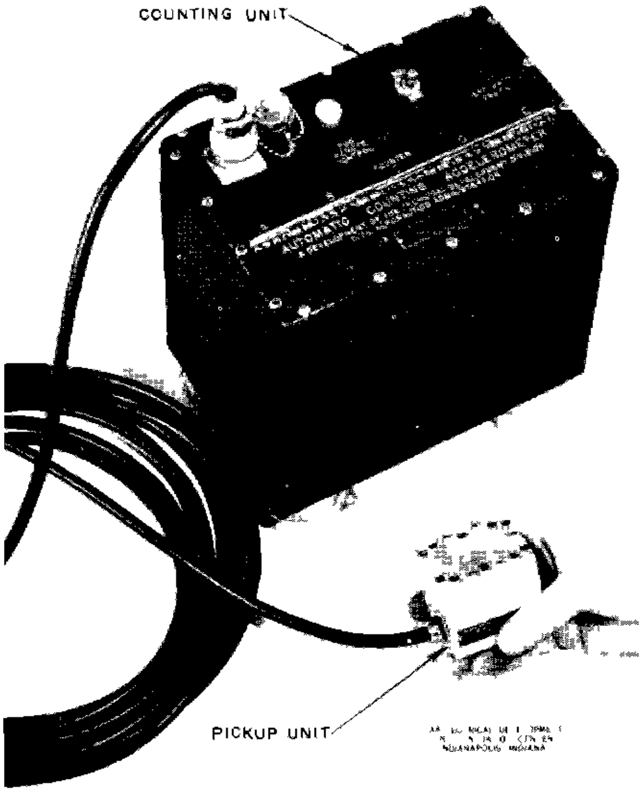


Fig. 1 Automatic Counting Accelerometer Showing Components

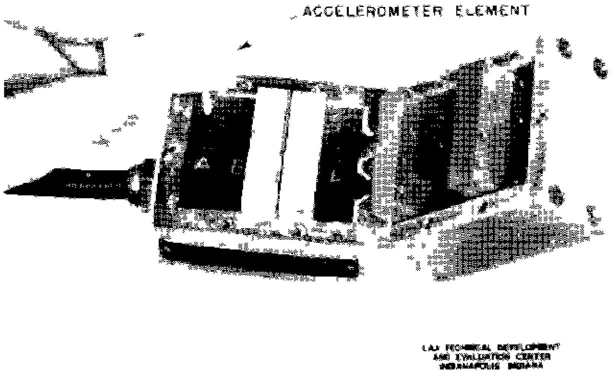


Fig. 2 Pickup Unit of Accelerometer Pickup

DESCRIPTION

The automatic counting accelerometer consists of a pickup unit, a counting unit, and a connecting cable, as shown in Fig. 1 The total weight is 18 77 pounds

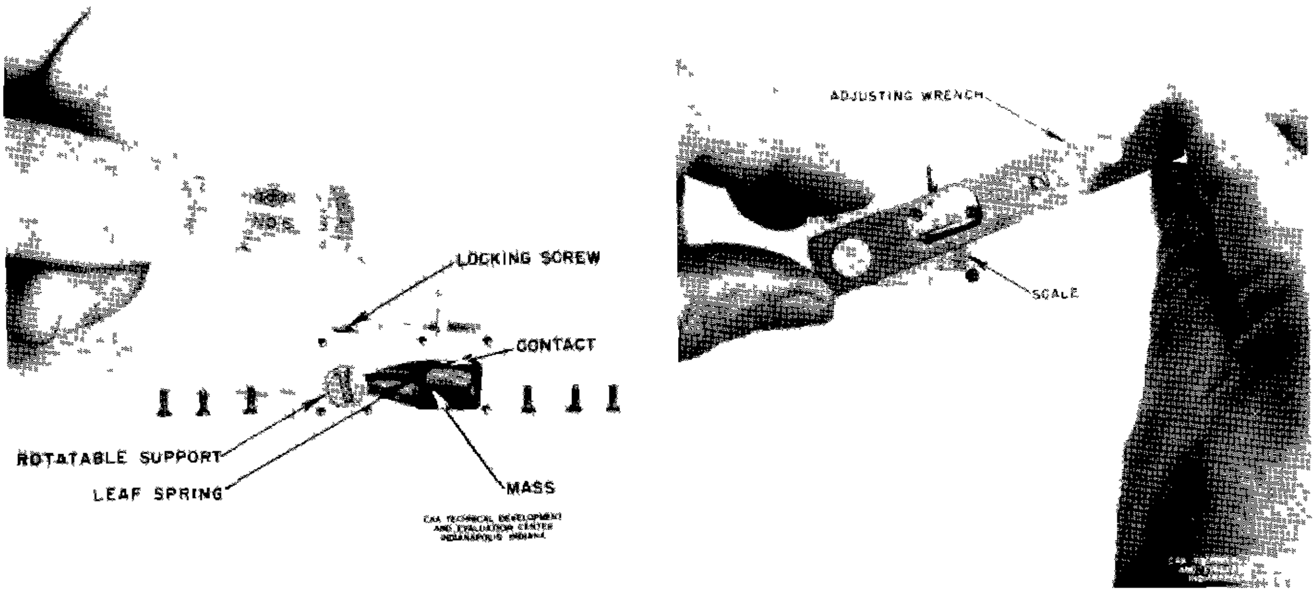
The pickup unit contains five accelerometer elements any of which may be inverted with respect to the pickup unit to allow recording of accelerations in opposite directions See Fig 2 By using five such elements in one pickup unit, a range of accelerations may be counted in stepped values The unit is 2 3/8 by 1 7/8 by 2 1/8 inches and weighs 0 77 pound

Each accelerometer element, Fig 3A, includes a leaf spring supporting a mass, a rotative spring support, a locking screw, an electrical contact, and a cover plate with a scale inscribed thereon

The position of the wrench with respect to the cover-plate scale indicates the acceleration in terms of g to which the element is adjusted This is shown in Fig 3B Moving the wrench rotates the spring support so that the force with which the mass is held against the contact is adjusted An electrical circuit between the mass and the contact is normally closed, and the circuit is broken as a result of an acceleration acting upon the spring-supported mass By adjustment of the rotative support, the element may be set to break contact for values of acceleration over the range of 0 to 5 g

The counting unit, shown in Fig 4, is 6 by 9 by 10 1/4 inches and weighs 18 pounds complete with batteries The unit contains five counters, five copper slug time-delay relays, and six 6-volt dry cell batteries This unit is connected to the pickup unit by means of a five-conductor shielded cable Cables up to 25 feet in length may be used for remote location of the pickup unit

When any of the five accelerometer elements experiences an acceleration greater than its preset triggering value (and of a duration equal to or greater than its preset time response) the element circuit is broken, allowing the time-delay relay to close the counter circuit See Fig 5 This causes a count to be registered by the corresponding counter The time delay can be adjusted to prevent the recording of short-duration or high-frequency accelerations and fixes a minimum time that must exist between successive shocks Since five acceleration values may be selected, the instrument records the number of times that each of



A. Components of Element

B Making g Setting of Element

Fig 3 Accelerometer Element

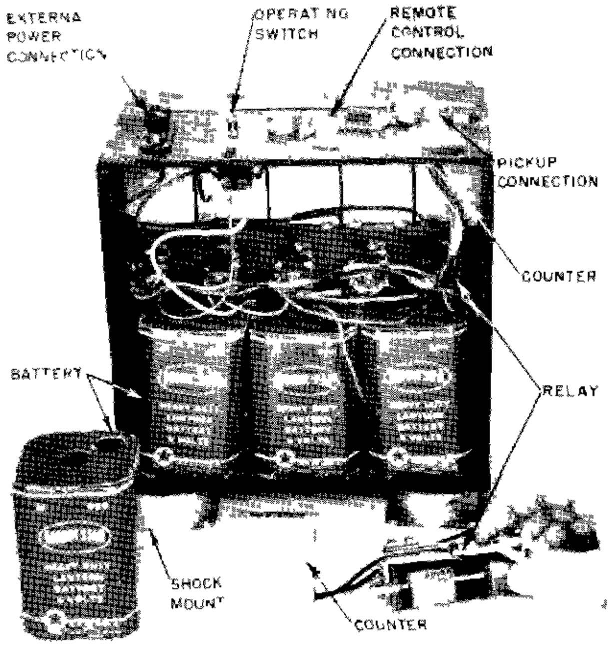


Fig 4 Accelerometer Counter Unit With Cover Removed

five values has been exceeded Thus, when the pickup unit is subjected to an acceleration greater than the maximum preselected value, all counters register a count An instantaneous total of the number of times that any one of the five acceleration values has been exceeded is continuously visible

Since the maximum current drain is only 0 05 ampere, many hours of intermittent or continuous service may be obtained before replacement of the batteries becomes necessary External binding posts are provided on the counting unit to permit operation of the instrument, if desired, from an external 28-volt to 36-volt dc source

The only control necessary for operation is an on-off switch located on the counter unit In addition provision has been made for remote control so that either air or ground shocks can automatically be excluded from the records

LABORATORY TESTS

Tests were conducted in the laboratory to determine the operating characteristics of the pickup unit and the counter unit The operational effects of various controlled conditions and the operational range limits,

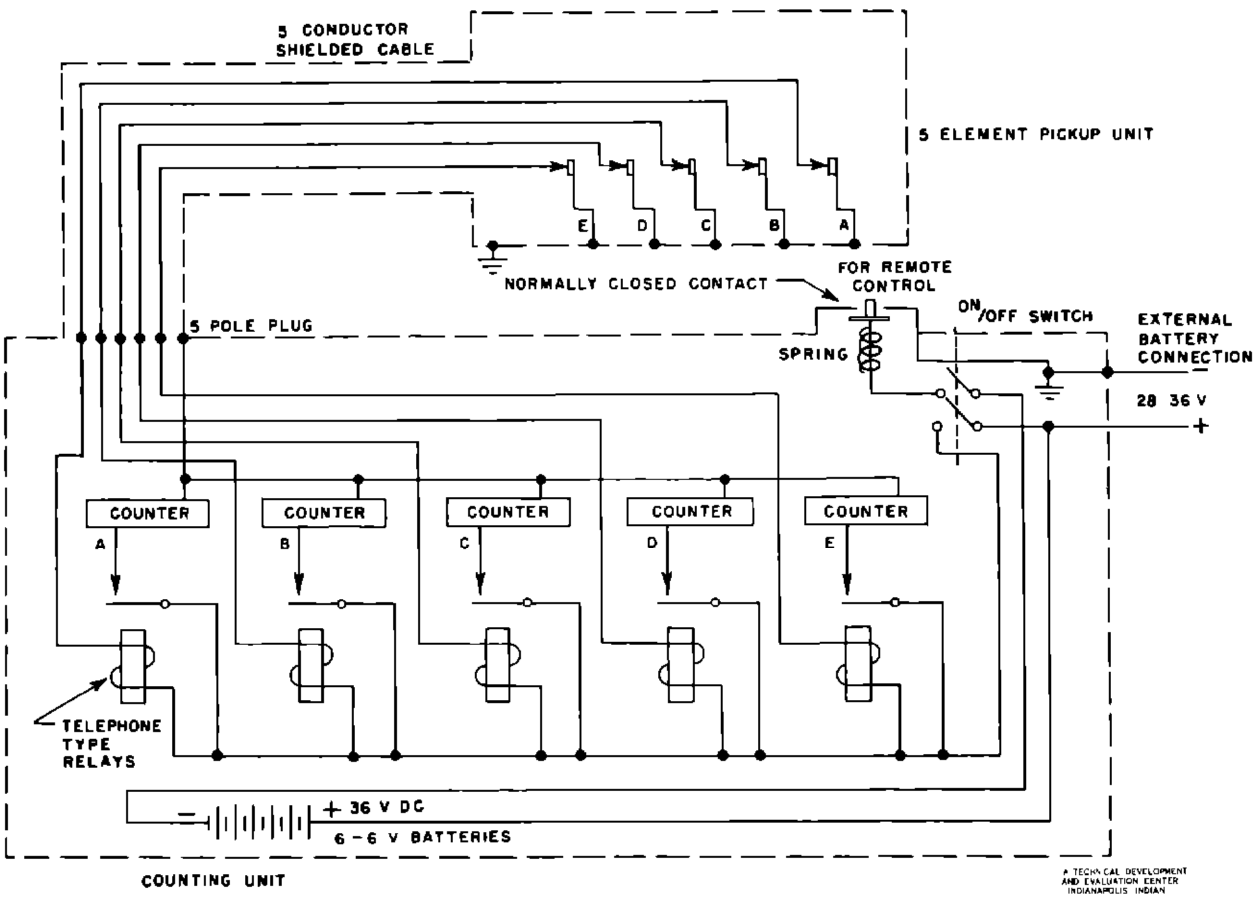


Fig 5 Schematic Diagram of Automatic Counting Accelerometer

accuracy limits, and battery life were also determined by tests conducted in the laboratory

Element Calibration

Prior to any tests, the instrument was calibrated in the laboratory on a rotating table and an oscillating table

1 Rotating Table Tests

The accelerometer element to be calibrated was mounted on a turntable, as shown in Fig 6, and subjected to centripetal accelerations The magnitude of acceleration was computed from the speed of rotation and the distance of the element from the axis of rotation This is expressed in terms of g by

$$\frac{a}{g} = \frac{4\pi^2 f^2 R}{32\ 2} \qquad (1)$$

where

a = acceleration in feet per second per second

g = acceleration in gravitational units

$$f = \frac{rpm}{60}$$

R = distance of the element from the axis of rotation in feet

In order to reduce the effect of any error that might arise due to misplacement of the gravitational center of the spring-supported mass in securing the element to the table, the distance R from the axis of rotation to the gravitational center of the mass was purposely made large A large value of R also reduces the probability of error in determining the operational stability of the mass and leaf spring If the distance from the axis of rotation to the mass is relatively small, error could arise because there is an increase in R as the contacts open

The turntable was provided with slip rings, which were connected to the element case and terminal The counter served to indicate the breaking of the element contacts The turntable speed of rotation was varied, and the opening accelerations for 1, 2, 3, 4, and 5 g settings of each accelerometer

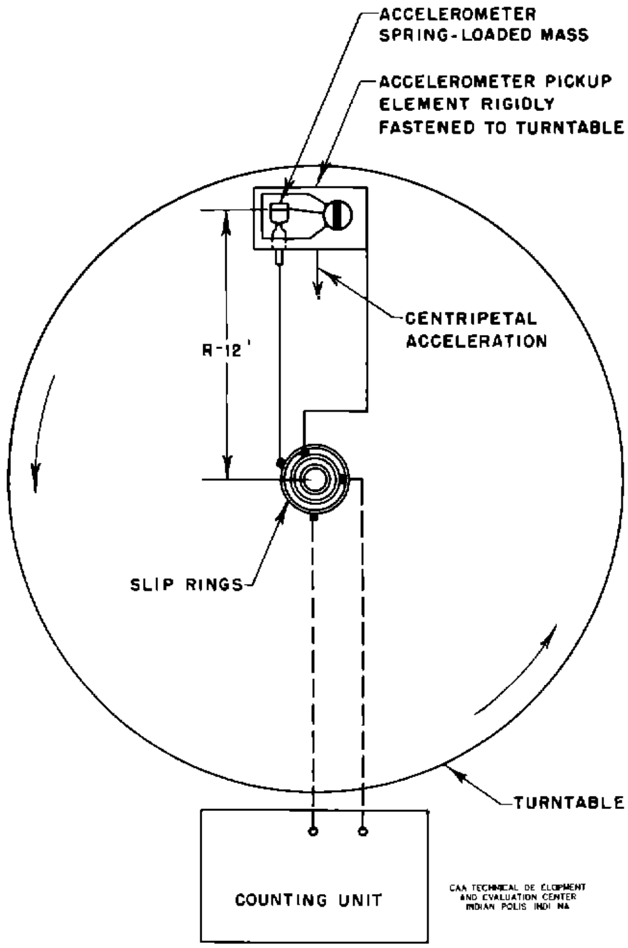


Fig 6 Calibrating Accelerometer Element Using Rotating Table

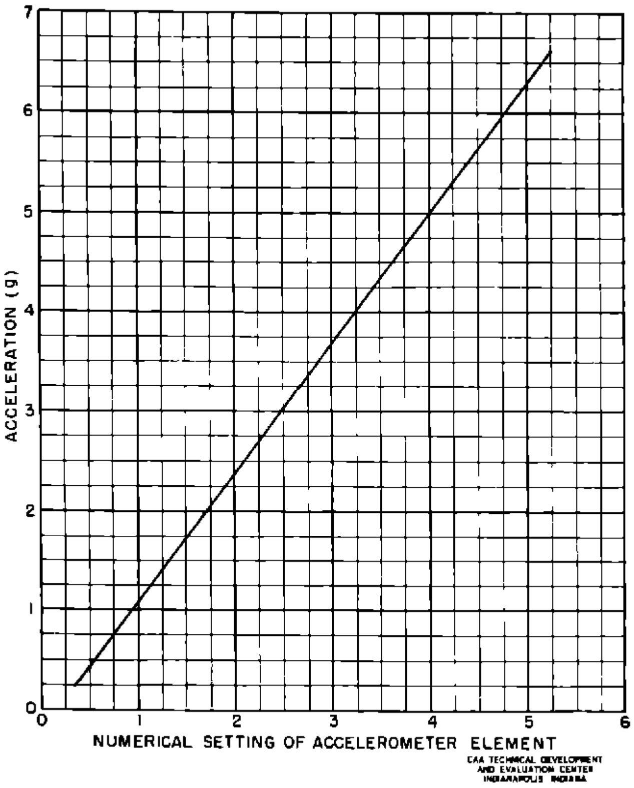


Fig 7 Typical Calibration Curve For Accelerometer Element

element were noted Plotting accelerometer settings versus the acceleration at which the contacts opened resulted, for each element, in a calibration curve similar to that shown in Fig 7

Since the element was placed in such a way that its mass moved in a horizontal plane, the earth's gravity was not a factor If it is placed in other positions, the effect of gravity must be accounted for when interpreting the indications

The elements were found to be very stable in their operational characteristics, that is, the contacts closed for accelerations equal to those for which they opened

2 Oscillating Table Tests

The rotating table was suitable for applying long-duration accelerations, but to apply accurately measurable short-duration accelerations, it was necessary to use another mechanism For this purpose, a vibration calibrator shown in Fig 8 was used

This machine produces essentially sinusoidal vibrations the amplitude and frequency of which may be controlled accurately Tables which oscillate both horizontally and vertically are available for the mounting of equipment to be tested.

The elements were secured to the vertically oscillating table of the calibrator and subjected to sinusoidal oscillations of controlled amplitude and frequency The counting unit was employed as a means of indicating when the elements triggered at accelerations of 1, 2, 3, 4, and 5 g To allow for the earth's gravity, however, the elements were set at 2, 3, 4, 5, and 6 g Thus, the instrument was calibrated as a unit incorporating the performance of the various components Since the time-delay relays were adjusted to limit their response to shock durations of not less than 0 02 second, the acceleration peaks imposed by the oscillating motion were not counted Instead, the instrument counted the number of times the preselected accelerations persisted for more than 0 02 second The maximum acceleration which persisted for more than 0 02 second was computed from the frequency and displacement amplitude of the table oscillation This is expressed in

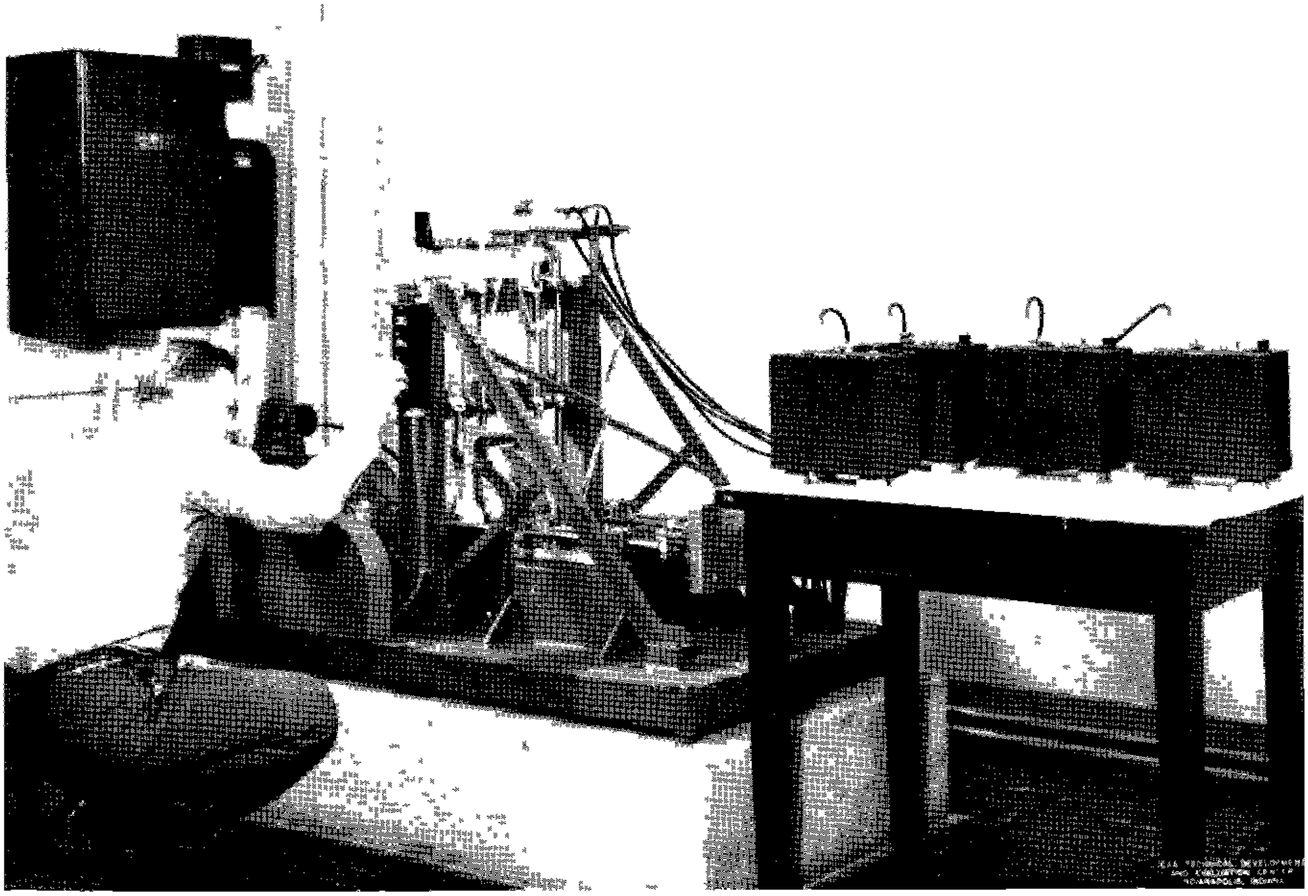


Fig 8 Vibration Calibrator Used in Laboratory Testing of Automatic Counting Accelerometer

terms of g by the equation

$$\frac{a}{g} = \frac{4\pi^2 fA}{32.2} \cos 0.02\,\pi f \qquad (2)$$

where

A is the amplitude in feet of one-half of the total excursion, and f is cycles per second, or the number of complete excursions of table oscillation per second.

The results of these tests corresponded closely with the calibration data obtained through use of the rotating table

Element Resonant Frequency Effect

An important advantage in using a preloaded element that triggers the counter when an electrical contact is open, arises from the fact that no motion of the mass relative to the element case occurs until the exciting force reaches a magnitude which overcomes the preloading of the element Therefore, it is possible to record short-duration accelerations without errors that could result from the dynamics of a moving mass

To determine the effect of vibration frequency upon the response of the element, an accelerometer element was rigidly mounted on the horizontally oscillating plate of the vibration calibrator and subjected to controlled vibrations of known frequencies and amplitudes An oscilloscope was used to indicate the opening of the contacts of the element The amplitude and frequency of the vibrations were varied.

When allowed to oscillate freely, the resonant frequency of the cantilever-mounted mass and spring was measured at 10 cycles per second (cps) When restrained by preloading and subjected to a wide range of frequencies, no error attributable to the resonant frequency of the element appeared over the design operating range of the instrument

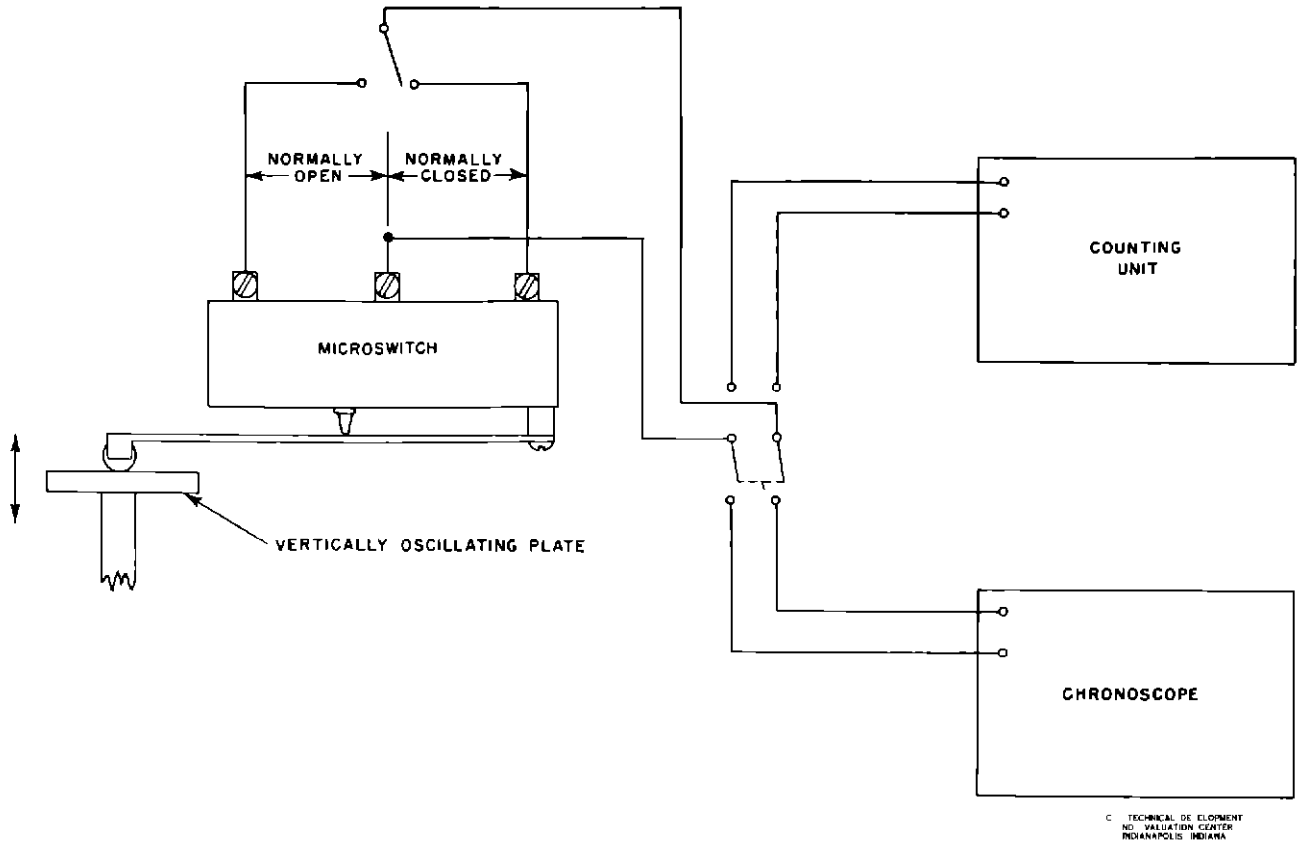


Fig. 9 Schematic Diagram For Time Measurements

Time Response

1 Counting Unit

The time-delay relay and counter arrangement were adjusted to record accelerations having durations equal to, or greater than, 0 02 second The minimum response time of 0 02 second of shock duration was adopted to eliminate structural vibrations from the records.

Tests were conducted to determine actual time response characteristics of the instrument under varying voltages and varying shock durations and frequencies The following method was used to conduct these tests

A microswitch was located at various distances above the vertically oscillating table of the vibration calibrator This allowed the length of time, which the circuit remained open or closed, to be controlled independently The length of time was measured with a chronoscope capable of measuring time intervals from 1 second down to 10^{-5} second A schematic diagram of the arrangement used is presented in Fig 9 By means of the double-pole, double-throw switch, the circuit timing provided by the microswitch was observed by either the chronoscope or the five counter circuits of the counting unit one at a time

Since the three variables (shock duration, shock frequency, and battery voltage) could be controlled individually, it was possible to measure the time response of each of the counter circuits as affected by those variables The measurements included

a The effect of varying voltage and pulse frequency on the pulse duration response of the counter circuits

b The effect of varying voltage and pulse durations on the pulse frequency response of the counter circuits

It was found that the pulse duration response became slower with decreasing voltage Below 24 5 volts, the counting circuit was inoperative At that voltage, a pulse duration of 0 03 second was required to obtain a count However, a minimum pulse frequency of 8 1/3 pulses per second (pps) was required to operate the counter at that voltage At full battery voltage (36 volts) a pulse duration of 0.01 second would operate the counter, provided that the pulse frequency did not exceed 10 pps At potentials between 28 and 36 volts, pulse durations of 0 02 second or longer would operate the counters if the time between pulses was equal to, or greater than, 0 12 second Battery potentials of less than 28 volts can result in unreliable operation of the accelerometer. Variations in the response of the counter circuits, when subjected to repeated impulses of identical durations and frequencies, were found to be within ± 0 001 second

A maximum shock frequency response of 8 1/3 impulses per second is considered adequate, since the records are statistical in nature Significant information on air and ground accelerations is obtained even though shocks which might occur at higher frequencies are not counted

2 Elements

Tests were conducted to determine the time response of the pickup elements For this purpose, a pickup unit was mounted on the vertically oscillating table of the vibration calibrator, and a switch was arranged to make contact when the table was at the extreme limit of its travel.

With the calibrator adjusted to provide an amplitude of 1 inch (total excursion equals 2 inches) and with the elements of the pickup unit adjusted to trigger at accelerations of 1, 2, 3, 4, and 5 g, the frequency of the calibrator was increased until the peak acceleration so obtained exceeded each element setting The time for opening and closing, together with the time at which the table reached the end of its travel, were recorded through use of a pen tracing oscillograph The effect of the earth's gravitational field was considered in interpreting the results of this test

Since the motion of the calibrator table is essentially sinusoidal and may be precisely controlled, it was possible to determine the time at which its acceleration exceeded and returned to the setting of each element The trace made by the oscillograph determined the opening and closing time of the element contacts

From these tests, it was determined that the maximum time between the preset time and the contact opening time was approximately 0 0001 second.

Accelerometer Accuracy Limits — Element Adjustment

The accuracy limits for setting the accelerometer elements, with respect to the counts registered by the counting unit, were determined by mounting the pickup unit on the vertically oscillating table of the vibration calibrator. This was connected to the counting unit in the usual manner The elements then were adjusted to trigger at 1, 2, 3, 4, and 5 g, and the response of the instrument was determined The elements were adjusted again and the tests repeated This procedure was repeated several times before and after flight testing the instrument It was found that the accuracy limit for setting the elements was ± 0 1 g

Temperature Effect — Instrument Operation

The effect of temperature on the operation of the automatic counting accelerometer and on the voltage supplied by its batteries over a period of time was determined by subjecting it to two tests It was first placed in an oven in which the temperature was maintained at the specified maximum value of 90° F In the second test, it was placed in a cold chamber in which the temperature was maintained at the specified minimum value of 0° F.

In each test new batteries were installed, and the temperature of the automatic counting accelerometer was permitted to attain the level of its ambient temperature When the temperatures stabilized the operating switch was closed, and frequent readings of battery voltage were obtained The pickup unit was subjected to accelerations by manually shaking it each time the battery voltage was measured

It was found that at 90° F the battery voltage, with the operating switch closed, dropped from 35 volts at the start to 28 volts in 62 hours The accelerometer operated successfully throughout the test At 0° F, the battery voltage dropped from 32 5 volts at the start to 28 volts in 10 hours In this case, the accelerometer also operated successfully throughout the test

Tests of Flight Instrumentation

Laboratory performance tests were conducted on the flight test instrumentation to determine its suitability for flight testing the automatic counting accelerometer The basic instrumentation used for measuring flight and ground shocks experienced by the pickup unit consisted of a strain-gage type accelerometer, an amplifier, and a recording oscillograph. The sensing unit was a Fredric Flader, Inc , Type ASD-40 The amplifier was a Hathaway Instrument Company Type MRC-12 The oscillograph was a Hathaway Type S8B, calibrated to insure that it operated accurately The test arrangement used is shown in Fig 10

The pickup unit of the automatic counting accelerometer was rigidly fastened to the Flader sensing unit with sensitive axes

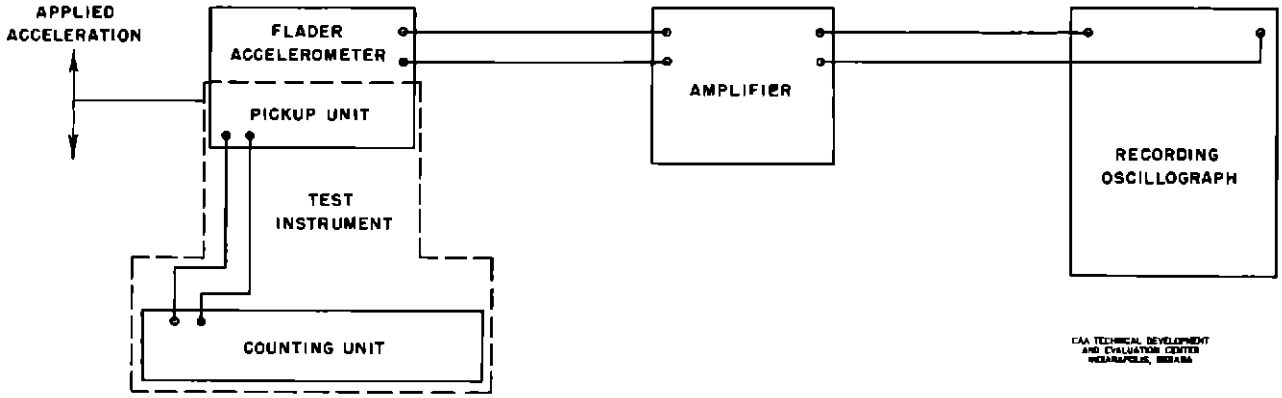


Fig 10 Schematic Diagram For Determining Performance of Automatic Counting Accelerometer

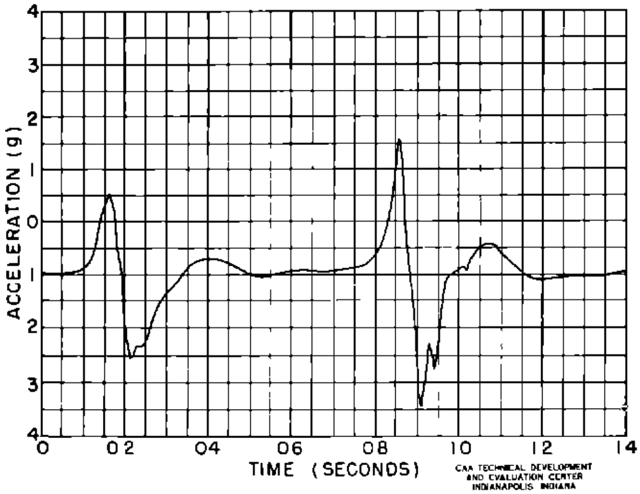


Fig 11 Portion of Oscillograph Trace Showing Accelerations Obtained During Laboratory Tests of Flight Instrumentation

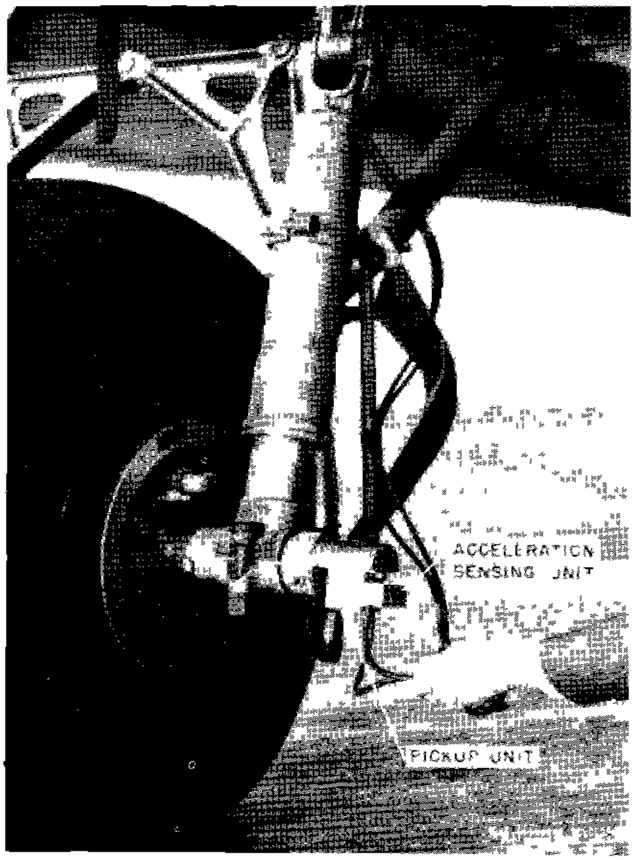


Fig 12 Method of Mounting Sensing Units on Axle

parallel The combined units were then subjected to accelerations by manually shaking, and the counts registered by the counting unit were compared with the traces recorded by the oscillograph A portion of an oscillograph trace obtained during these tests is reproduced in Fig 11 The results of the tests are listed in Table I It will be observed that the automatic counting accelerometer counted all of the accelerations that persisted for 0 02 second or longer and some that persisted less than 0 02 second

FLIGHT TESTS

A number of flight tests were conducted in the Center's DC-3 airplane N-182, using the instrumentation previously described The accelerometer elements were set for 2, 2 5, 3, 4, and 5 g The combined pickup and acceleration sensing units were mounted on the landing gear axle, as shown in Fig 12 This mounting

TABLE I

LABORATORY PERFORMANCE TESTS

Automatic Counting Accelerometer			Oscillograph Record		
Pickup Unit					
Element	g Setting	Count	No of Accelerations of Duration Greater Than 0 02 Second and of Magnitude Greater Than Element Setting	No. of Accelerations of Duration Between 0 01 and 0 02 Second and of Magnitude Greater Than Element Setting	Total Number of Accelerations
A	2 0	6	6	0	6
B	2 5	6	5	1	6
C	3 0	3	2	1	3
D	3 5	1	1	0	1
E	4 0	1	0	1	1

Note Battery voltage greater than 28 volts
Intervals between accelerations were greater than 0 12 second

location was used since the severity, duration, and frequency of accelerations so obtained were considered to represent a severe test of the response characteristics of the automatic counting accelerometer The two multiconductor cables were brought through the wing to the recording instruments inside the airplane Fig 13 shows the automatic counter unit, the recording oscillograph, and the amplifier secured to the bench inside the airplane A switching arrangement capable of activating the two instruments simultaneously was installed in order to coordinate the counts obtained by the automatic counting accelerometer with the oscillograph traces

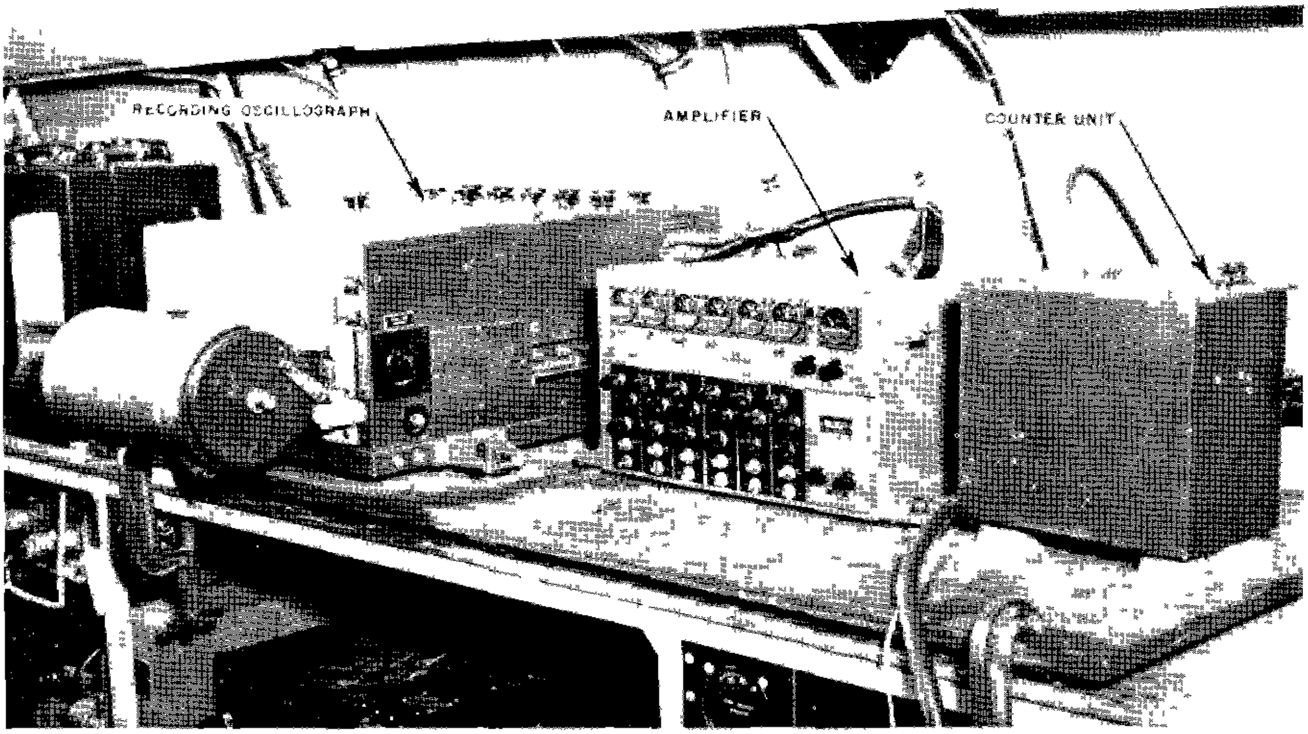


Fig 13 Recording Equipment Used in Airplane To Secure Data From Accelerometers

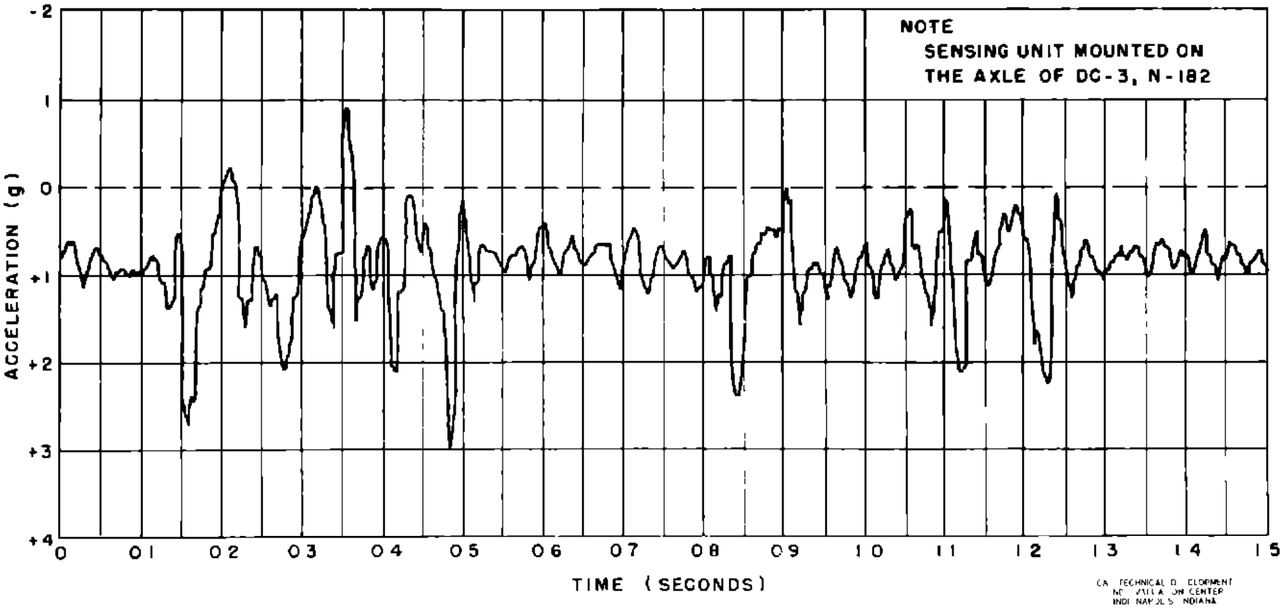


Fig. 14 Portion of Oscillograph Record Showing Typical Landing Shocks

While warming up the engines of the DC-3 prior to take-off, the instrumentation was activated No recording by the counter unit occurred from the engine excitation. While engine excitation is not recorded by the instrument, the actual recorded accelerations during landings may have resulted from addition of both the engine excitation and the landing accelerations This is considered desirable since the combined accelerations could prove significant from a structural standpoint

The maximum acceleration experienced during landings with the pickup unit mounted on the axle was about 5 g, including the effect of gravity Maximum accelerations between 2 0 and 2 5 g were recorded when the sensing units were mounted inside the airplane near the center of gravity

A reproduction of a portion of an oscillograph trace obtained during a landing with the pickup unit and acceleration sensing element secured to the landing gear axle is shown in Fig 14 It will be noted that a 0 02 second minimum duration response of the automatic counting accelerometer could result in the counting of shocks of less than their peak value or in the failure to count very short duration shocks Since the elements will respond to shocks having a duration as short as 0 0001 second and since the relays may be adjusted to provide a counting circuit response to shocks having a duration as short as 0 005 second, this instrument may be adjusted for faster operation if considered desirable

The results obtained by comparing the flight test records of the automatic counting accelerometer and the oscillograph are summarized in Table II From the table it will be seen that the instrument records all shocks having a duration equal to or greater than 0 02 second and counts many shocks having a duration as short as 0 01 second This is not a detriment to the practical use of the instrument and may be considered desirable, since the only purpose of having a time limit incorporated in the counter circuit is to eliminate the recording of engine and other high-frequency vibrations

CONCLUSIONS

1 The automatic counting accelerometer counts all accelerations of duration equal to or greater than 0 02 second, provided that the accelerations occurred at intervals equal to or greater than 0 12 second.

2 The automatic counting accelerometer may be adjusted to limit its time response to shocks lasting from 0 005 to 0 05 second, with corresponding shock frequency responses of 0 105 to 0 150 second or longer

3 The adjustment range of the pickup elements of the automatic counting accelerometer is from 0 to 5 g ± 0 1 g

4 The automatic counting accelerometer is suitable for use in aircraft to obtain sta-

TABLE II

RESULTS OF FLIGHT TESTS

Automatic Counting Accelerometer			Oscillograph Record		
Pickup Unit					
Element	g Setting	Count	No of Accelerations of Duration Greater Than 0 02 Second and of Magnitude Greater Than Element Setting	No of Accelerations of Duration Between 0 01 and 0 02 Second and of Magnitude Greater Than Element Setting	Total Number of Accelerations
A	2 0	35	27	8	35
B	2 5	24	18	6	24
C	3 0	6	4	5	9
D	4 0	3	1	2	3
E	5 0	1	0	1	1

Note Battery voltage greater than 28 volts.

tistical data concerning the number and severity of acceleration shocks experienced Engine and other vibrations experienced in flight had no adverse effect on the operation of the automatic counting accelerometer

5 The automatic counting accelerometer operates reliably at potentials from 28 to 36 volts dc and at temperatures between 0 and 90° F

6 The voltage of new batteries, as installed in the automatic counting accelerometer, dropped to 28 volts after operating continuously for a period of 62 hours at an ambient temperature of 90° F or after 10 hours at an ambient temperature of 0° F

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