THE DEVELOPMENT OF THE C.A.A.-N.R.C. FLIGHT RECORDER

by

Walter McKay

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INTRODUCTION

by

J. G. Jenkins
and
M. S. Viteles

A report of apparatus development conducted by the Instruments Section, Aeronautical Engineering Department, Massachusetts Institute of Technology, Cambridge, Massachusetts, by means of a grant-in-aid from the Civil Aeronautics Administration.

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Executive Subcommittee

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SUMMARY

This report describes in detail the development, construction, and preliminary testing of a graphic recorder, the C.A.A.-N.R.C. Flight Recorder. This recorder represents the outgrowth of extensive background research which revealed the deficiencies of the available commercial recorders and which aided in the identification of the characteristics required in an improved recorder.

The C.A.A.-N.R.C. Flight Recorder was developed by the Instruments Section, Aeronautical Engineering Department, Massachusetts Institute of Technology, in accordance with specifications set down by J. G. Jenkins and M. S. Viteles of the Executive Subcommittee of the National Research Council Committee on Selection and Training of Aircraft Pilots. These specifications, reflecting the experience gained through previous Committee research on graphic recorders, called for the development of a flight recorder which would find ready use in practical field situations by providing records of plane and pilot performance easily read and interpreted by direct inspection of the record.

The C.A.A.-N.R.C. Flight Recorder, as finally constructed, is 17 3/4 inches wide, 10 1/2 inches high, and 9 inches deep and weighs 35 pounds. Driven by a clock-work motor, the 15" wide wax paper chart provides a continuous record (for three hours recording) of the following elements:

1. Elevator position, operated by elevator control cable movement.

2. Aileron position, operated by aileron control cable movement.

3. Rudder position, operated by rudder control cable movement.

4. Airspeed, operated by static pressure from a pitot tube, recording airspeed over the range of 30 to 150 MPH.

5. Altitude, operated by aneroid capsules, recording over the range of 0 to 3,000 feet, with provision for adjusting to the zero point of the scale.

6. Lateral acceleration, operated by a damped pendulum moving laterally, recording over the range of -0.5g to +0.5g, and serving as a recording ball bank indicator.

7. Vertical acceleration, operated by a damped pendulum moving vertically, recording over the range of 1.0 to 2.0g.

In addition, an electro-magnet signal marker is provided, operated by a remote switch. Power for activating the signal marker and for heating the styli for wax-paper recording is supplied from dry cells yielding 7.5 volts.

Each of the recording elements has been given thorough bench tests in order to determine the accuracy of the recording and the correctness of the calibration. Preliminary flight tests, with the instrument installed in the bag-

gage compartment of a Luscombe airplane, were also made to check the elements under dynamic flight conditions. The results showed that the elements possess adequate sensitivity and provide accurate records of the desired functions.

To date, the instrument has not had an extensive field try-out. Further research is needed, designed to develop methods of analysis of the records so as to yield qualitative and quantitative indices of pilot proficiency and to study the reliability and validity of the indices.

The report also presents detailed instructions for installing, operating, and maintaining the instrument, as well as detailed photographs of the separate elements and graphs of the results of the bench and flight test.

INTRODUCTION

by

J. G. Jenkins
and
M. S. Viteles

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Much of the research of the National Research Council Committee on Selection and Training of Aircraft Pilots has been concerned with the development of objective measures of flight proficiency. In this connection, consideration has been given to the possibility that instruments which graphically record altitude, airspeed, control movements, and other items of pilot and plane performance can furnish data useful in the assessment of pilot proficiency. Early studies involving the use of existing commercial flight recorders have been summarized in a report by McFarland and Holway.[1] More recently, Viteles and Backstrom[2] have described a detailed analysis of graphic records obtained through the use of the R-S Ride Recorder made with the view of isolating possible qualitative and quantitative indices of pilot proficiency. In this report is also presented a discussion of the deficiencies of the R-S Ride Recorder which apply, in part, to other commercial instruments.

Experience with commercial recorders indicated that they were not quite suitable for use in Committee investigations on the selection and training of aircraft pilots. At the request of the Executive Subcommittee of the Committee on Selection and Training of Aircraft Pilots, the authors (with the assistance of Oscar Backstrom, Jr.) undertook to prepare recommendations for the design of an instrument that would better serve the immediate needs of the Committee in providing criteria of pilot proficiency.

In preparing these recommendations, it became apparent that it was necessary to distinguish between a recorder designed primarily for "quantitative research" and one designed primarily for "clinical" or "field" use. It was the opinion of the authors that the needs of the Committee could best be served by the construction of the latter type of instrument, designed primarily to supply unequivocal data on plane attitude and pilot performance useful to an instructor, inspector, or reviewing board in evaluating flight performance and progress during training, while providing refined quantitative data to only a limited extent. With this in mind, and with the approval of the Executive Subcommittee, the following specifications were presented to the Instruments Section, Aeronautical Engineering Department, Massachusetts Institute of Technology, as a guide for

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[1] McFarland, R. A. and Holway, A. H. The theory and measurement of flight performance. May, 1941. (A progress report on file in Committee files.)

[2] Viteles, M. S. and Backstrom, O., Jr. An analysis of graphic records of pilot proficiency obtained by means of the R-S Ride Recorder. Part I. Washington, D. C.: Civil Aeronautics Administration Division of Research, Report No. 23, November 1943.

Viteles, M. S. and Backstrom, O., Jr. An analysis of graphic records of pilot proficiency obtained by means of the R-S Ride Recorder. Part II. (Part II deals with quantitative indices of pilot proficiency. Copy in Committee files.)

the development and construction of a new recorder:

1. The instrument should be designed to provide a record which will enable an instructor or inspector to determine, by inspection, the attitude of the plane during various maneuvers and the control movements made by the pilot to achieve or correct the observed plane attitude. The instrument should be specifically designed for use in the Civilian Pilot Training Program and in connection with elementary instruction given in basic training courses of the Army and Navy. This implies that provisions for recording will be limited essentially to the more elementary training maneuvers and will not cover aerobatic maneuvers of the type employed in the intermediate and advanced Army and Navy training.

2. Since the instrument will, in general, be used in connection with standard flights, no elaborate means of identifying maneuvers need be incorporated, with the following exceptions:

   a. The instrument should include a signal marker to be operated electrically by the pilot or observer.

   b. If possible, it should include a trace showing automatically the beginning, direction, and end of each turn.

3. The instrument should record all traces on one chart to avoid the need of synchronizing charts. If possible, each of the recording styli and pens should maintain a uniform horizontal position on the chart to avoid the need of transparent scales or other devices for synchronizing traces on the same chart. Arcing error should be minimized, and if at all possible, excluded.

4. The instrument should give an immediately visible and interpretable record which may be examined immediately upon the conclusion of flight. The effects recorded should not require computation for interpretation in the field. It is acceptable that computations be employed in the case of such data as are to be used for quantitative purposes; but no computation whatsoever is acceptable for field use.

5. The cost of reproducing the instrument in large numbers for field use, convenience of installation, ease and cost of maintenance, etc., should be given every consideration in the design of the instrument and in the selection of its constituent units.

In addition to these general specifications, the following specific suggestions were made concerning various units in the instrument.

1. <u>Control Movements</u>. The instrument should provide three traces showing the number, extent, and direction of movements of each of the three controls, viz., stick (or wheel) right and left, stick (or wheel column) forward and back, rudder pedals (right and left).

2. <u>Signal Marker</u>. There should be included a solenoid signal marker, to be operated by the observer or pilot by means of an appropriate switch,

for use in indicating the beginning and end of each maneuver. This trace should be made by a double solenoid to facilitate use of a signal code in case it should seem desirable to identify and grade maneuvers by code signals.

3. Lateral Balance. The instrument should provide a trace (or traces) to record each slip and each skid during flight. The trace (or traces) may be obtained through the use of either (1) a recording ball bank indicator operating by electric contacts or (2) two pendulums free to swing only in the lateral plane of the airplane.

a. The recording ball bank indicator might consist essentially of a facsimile of the ball bank indicator or lateral inclinometer commonly used in airplanes, with the addition of electrical contacts placed at suitable intervals in the glass tube. The number and location of these contacts would be decided on the basis of advice from instructors and other qualified persons and on the basis of such experimental findings as may be useful in this connection. It is certain that the minimum number would be four; two on each side of the mid-position of the inclinometer. If only two were used, one would indicate a position of the ball corresponding to a "little imbalance"; the other would indicate "considerable imbalance" or mark the position corresponding to the amount of imbalance sufficient to endanger the airplane and its occupants.

The unit involving the two pendulums free to swing only in the lateral plane of the airplane could be that now used in the R-S Ride Recorder.

b. The final choice between the two units should be left to Professor Draper of Massachusetts Institute of Technology, who, however, may be interested in considering the relative advantages of each as outlined in the course of our discussion of the proposed recorder.[4] The advantages of the recording ball bank indicator appear as follows:

(1) It would provide a trace giving directly categorized information enabling the instructor to tell at a glance whether the student slipped or skidded "not at all," a "little," or to a "considerable or "dangerous" degree.

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[3] One of these pendulums would be free to swing only left of center, and the other would be free to swing only right of center; each would be stopped at its mid-position. The purpose of employing two pendulums each stopped at the mid-point instead of a single pendulum free to swing both right and left of center, is to minimize error due to limited damping. Such error would be excessive in an unstopped single pendulum. If a feasible means of damping (specifically, some means other than dry friction) exists, a single pendulum free to swing both right and left of center in the lateral plane might be employed.

[4] There was also made available to Professor Draper a copy of a Memorandum concerning projected graphic recorder, prepared by Oscar Backstrom, Jr., University of Pennsylvania and, later, of the Viteles-Backstrom report, op cit.

(2) Damping could easily be varied by a change of fluid in the glass tube.

(3) The recording ball bank indicator would probably possess a certain advantage over the lateral pendulums in that the lay instructor is familiar with the ball bank indicator. Although the ball and the pendulums are subject to the same effects in the same amounts, certain instructors might be reluctant to accept the lateral pendulums as substantially a ball bank indicator.

(4) Since the trace of this device would be to all intents and purposes a signal trace indicating certain ranges in which the ball has moved, the trace might be designed to take up less chart space than the trace of the lateral pendulums which record actual extent of deflection.

c. The advantages of the use of lateral pendulums may be summarized as follows:

(1) The pendulums provide traces of a continuous variable. From these traces, categorized information, such as the recording ball bank indicator will furnish, can be obtained, but in addition, other information can be derived. The chart can be marked with lines indicating the limits of the electric contacts proposed in the recording ball bank indicator, to furnish the data available for that instrument. In addition, since the trace records lateral imbalance continuously, more information on extent and pattern of lateral imbalance will also become available.

(2) The lateral pendulums represent a mechanical unit, as opposed to the recording ball bank as an electric unit. As such, the pendulums may possess certain advantages in field operation, in terms of the need of a source of electric power as well as possibly greater stability under constant use.

(3) In the present R-5 Ride Recorder, no damping is necessary for the pendulums if a suitable place of installation and suitable cushioning against engine shock are provided for the instrument. In the set of records made at Tulane University and examined at the University of Pennsylvania, no difficulty was experienced with vibration traces in the lateral imbalance lines. Such vibration traces are few, and where they occur, can easily be discounted. The fact that no damping was necessary probably resulted from the location of the instrument in the baggage compartment and from the type of pendulums, which employ a very short shaft, thereby minimizing the extent of damping motion.

In [illegible] chart space need be con- [illegible] as the [illegible] own if desired. [illegible] advantage that they are [illegible] of such units.

4. Airspeed. A sensitive trace of airspeed should be included in the graphic recorder.

5. Load Factor. The graphic recorder should provide a trace of load factor to supply information [illegible] turns in elementary maneuvers. The chart space [illegible] should be calibrated in a trigonometric scale of degrees [illegible] accordance with the approximate relation: load factor = g [illegible], i.e. the angle of "proper bank."[5]

6. Altimeter. The instrument should include a trace providing information on maintenance of altitude. Such information will ordinarily be used not to show the attainment and maintenance of any specific altitude in feet, but variations in altitude during prescribed maneuvers, i.e., to show whether the subject maintained a recorded altitude X ± n feet. This trace can probably be provided by a recording sensitive altimeter, with maximum reading not exceeding 4,000 feet.[6] The trace should be readable within the most refined limits of the instrument, i.e., the smallest quantity recorded accurately by the instrument should be easily derivable from the chart.[7]

7. Turn Indicator. It is highly desirable that the instrument include a unit indicating unequivocally the beginning, direction, and close of each turn about the Z axis. The trace indicating turn should only be included if the instrument is sufficiently sensitive to provide this information with respect to shallow turns since analogous information for medium and high turns can be derived from the traces of movements of the three controls.

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[5] It is to be recognized that this relation will not hold in those portions of a turn in which the angular extent of climbing or diving, or slipping or skidding is great. Units 3 and 4 will provide a rough indication of whether these conditions exist. Furthermore, the greatest error in the relation occurs when the above conditions exist in the case of shallow banks. Viteles, M. S., and Backstrom, O., Jr., op cit., pp. 160-168.

[6] If such an altimeter were provided with a means of adjustment to "0" feet at ground level, it might also be used to show whether the subject attained and maintained a specific altitude. The only deterrent to such a use would be the fact that reliance would have to be placed on the instructor or other field personnel for making this adjustment for each flight, whereas, whether the adjustment to "0" feet is correct or not, the instrument can always show variations in feet from any unknown altitude.

[7] A recording rate-of-climb device is not recommended because of the existence of an undesirable lag in such an instrument. Moreover, the extent of this lag is variable from time to time and situation to situation.

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THE DEVELOPMENT OF THE C.A.A.-N.R.C. FLIGHT RECORDER

Under a grant from the National Research Council Committee on Selection and Training of Aircraft Pilots, the Instruments Section, Aeronautical Engineering Department, Massachusetts Institute of Technology undertook the development of an improved flight recorder in accordance with specifications prepared by John G. Jenkins and Morris S. Viteles, dated December 12, 1941. In approaching this task, the following general considerations were formulated.[8]

1. The flight recorder should be designed to give the desired records with a minimum of field attention and maintenance. All components must withstand the ordinary rigors of flight service as well as the ministrations of well-meaning but instrumentally inept personnel. Each component-sensitive element should, insofar as possible, be sensitive to only the function which it is supposedly measuring. The design of the recorder should permit simple installation and convenient operation. It should be self-contained as regards power sources required for the operation of any of the recorder components. External connections must be made simply and calibration procedures should be straightforward. Recorder components should be replaceable without necessitating extensive disassembly. Paper handling should be carried out expeditiously. Traces must be clear, sharp, and free from airplane vibration and other erratic effects caused by instrument deficiencies. Given such a flight recorder, failure to obtain criterion data could be attributed only to the choice of functions measured.

2. In practice, certain compromises must be made with the above ideal requirements. It is generally desired to obtain a sensitive trace of a given function over a wide range in that function. These are opposing tendencies in practical instrument design since high sensitivity and wide range each make for large trace amplitude and, in combination, cause trace amplitude to become prohibitively large. Benefits derived from temperature compensation must be weighted against the sometimes inordinately great effort required to provide such compensation. Elimination of arcing can introduce sufficient friction in the mechanisms to re-act on the sensitive elements and thus produce erroneous indications. An expanded time scale involving higher paper speed

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[8]These considerations as well as other problems involved in the construction of the instrument are more fully discussed in: McKay, Walter. <u>Factors governing the design of a flight recorder</u>. January, 1942. (Copy in Committee files.)

results in unwieldy lengths of record. Reduction of any residual instrument errors to one-tenth of their values, whatever they may be, would be much more than ten times more difficult and costly. Considerations such as these always confront the instrument designer. Successful instruments are those in which such conflicting elements have been rationalized for greatest practical use.

On the basis of the specifications furnished by the National Research Council Committee on Selection and Training of Aircraft Pilots and of the general considerations outlined above, the Instruments Section, Aeronautical Engineering Department, Massachusetts Institute of Technology developed and constructed a pilot model of a graphic flight recorder now known as the C.A.A.-N.R.C. Flight Recorder. In this report are found a detailed description of this recorder, results of the preliminary bench and flight tests made prior to the delivery of the recorder to the National Research Council Committee on Selection and Training of Aircraft Pilots, instructions for the use of the recorder, and suggestions for further research with this instrument.

DESCRIPTION OF THE C.A.A.-N.R.C. FLIGHT RECORDER

A. General Description

The recorder is designed to provide a graphic record of the following flight functions:

1. Aileron, elevator, and rudder control positions.

2. Airspeed from 30 to 150 mph, operated from a pitot tube.

3. Altitude from 0 to 3,000 feet including a zero adjustment covering a barometric range of from 28" Hg. to 31" Hg.

4. Lateral acceleration from -0.5 to +0.5 g.

5. Vertical acceleration from 1.0 to 2.0 g.

6. Signal marker.

The graphic records are produced on waxed paper 15 inches wide, spooled in 50-foot lengths. The paper speed is approximately 3 inches per minute and is driven by a mechanically governed clockwork motor requiring reloading every 16 feet of record which corresponds to 3 hours of recording time. The chart paper is printed with time divisions 5 seconds apart and with suitable scales for reading the various function values, making unnecessary the use of transparent scales for transcribing data.

The recorder is 17-3/4 inches wide, 10-1/2 inches high, and 9 inches deep and weighs 35 pounds complete. It is installed in the airplane in an upright position with the 17-3/4 inches dimension parallel to the lateral axis of the airplane and with the chart side forward. The chart can be viewed during actual recording through the transparent window in the cover, as shown in Figure 1, Appendix A.

The entire recorder is supported on anti-vibration mountings carried by two horizontal plates along the 9-inch dimension and must be tied to the airplane at these plates.

No remote power is required since the instrument includes dry cells supplying 7.5 volts. A remote switch enables the instructor to operate the signal marker unit for coding the record. The only external connection required are three cable lines to the control wires and tubing to the pitot-static tube.

B. Detailed Description

Following is a detailed description of the instrument and its elements. Photographs, detailed drawings, and calibration curves presented in the appendices should be referred to in connection with these descriptions.[9]

1. Main Frame. The recorder elements are mounted on a main frame shown in Appendix A, Figures 9, 10, and 11. The frame consists of a cast aluminum inverted T-section with end plates. All the chart drive equipment is mounted on the front or chart side of the main vertical member, including the clockwork motor, clockwork governor unit, drive roll and writing table, chart feed, and take-up rolls. The lateral accelerometer element is also mounted in a housing attached to the front of the main vertical member. All the other recorder elements are mounted on the back side of this member. Each of these elements is contained in a separate housing in order to facilitate maintenance.

The main frame is cut out wherever possible in order to reduce its weight. A cover plate, attached to the underside of the frame and the recorder cover, is secured to the frame, making the entire unit dust-tight.

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[9]Appendix A presents photographs of the recorder and chart paper. Detailed blueprint drawings of the various elements are on file in the Committee files. Appendix B presents the results of the calibration tests and photographs of the recorder as installed in a plane.

2. Chart Drive.[10] The chart is driven by an Esterline-Angus clockwork motor containing three heavy springs, one of which drives the chart take-up roll. The motor, wound by means of a crank clipped to the bottom cover plate, is directly geared to the chart drive roll.

A centrifugal governor, driven through step-up gearing, holds the chart speed constant at approximately 3 inches per minute within 1 per cent, under normal operating conditions. This unit was chosen in preference to others because of its unusually large spring capacity, giving satisfactory driving torque and long running time. The motor will run for more than three hours before rewinding. Since the length of chart carried in the recorder is 50 feet, corresponding to approximately three hours in time, the motor need be rewound only when changing paper.

The chart drive is started electrically by a magnet-operated wiper on a gear in the governor train. This magnet is actuated by turning on the main recorder switch mounted on the right end of the recorder as viewed from the front.

3. Chart and Method of Recording.[11] The chart paper is 15 inches wide. The surface of the paper is waxed and the record is obtained by scribing the wax away with the recording styli thus revealing the red paper beneath. The styli are heated electrically. This melts the wax and lubricates the stylus to paper contact, reducing friction materially. The power consumption per stylus is 0.2 watt and all eight styli are heated, requiring a total power consumption of 1.6 watts. A separate switch mounted behind the chart feed roll turns the stylus heaters on and off.

The chart paper is printed in order to provide time lines and function values, thus making unnecessary the use of auxiliary transparent scales for transcribing data. The time lines spaced approximately $\frac{1}{4}$ inch apart, represent 5-second intervals and are arced so that time synchronization can be easily accomplished. The radius of the stylus arcs is 6 inches for all traces with the exception of the signal marker.

4. Control Position Elements.[12] Three control position elements are included for recording aileron, elevator, and rudder positions. The chart width for the elevator and rudder recording is 1-$\frac{1}{2}$ inches for each and for the aileron, 2 inches. Except for this difference, which involves the design of the cam described below, all three control position units are identical.

The elements are simple, spring loaded, take-up drums, connected mechanically to the appropriate control cables by means of fine flexible cable or cord. Adjustments for making the proper initial settings are provided on the left side of the main frame where the cords emerge. It will be noticed in studying the chart paper that the ordinates are laid out in fractions of full control positions. The external gears on the elements determine the amount of linear control

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[10] See Figure 11, Appendix A.

[11] See Figure 23, Appendix A.

[12] See Figures 12, 13, and 14, Appendix A.

cable motion which produces full scale deflection of the styli. The gears provided are based on a total cable motion of two inches either side of zero. Other amounts of cable motion can be accommodated by replacing this set of gears with a set having a different ratio. As set up at present, the records will give the fraction of two inches that each of the control cables is displaced from zero. It will also be noticed that the pen deflections are non-linear. The first 0.2 of the control motion either side of neutral occupies 0.8 of the available chart width. The remainder of the control motion is included in the outer [illegible] [illegible]lable chart width. This was done in order to get greater sensitivity in recording small control movements in the vicinity of neutral.

It is essential that the cord used for the connections from the control cables to the recorder should not stretch appreciably and that it should be flexible enough to lie closely around the pulleys. Closely woven linen line is supplied with the recorder, having been found to be satisfactory in those respects. Stretch of the string appears on the record in failure of the control trace to return to zero when the control cable is moved to the neutral position. Since pulley friction is responsible for the force stretching the string, ball-bearing pulleys were used throughout the connection system in order to reduce friction to a minimum.

5. __Airspeed Element__.[13] The airspeed recorder element consists of a spring restrained sylphon bellows, to the interior of which dynamic pressure from the pitot tube is admitted, and suitable levers for converting the motion of the free end of the bellows to stylus travel. The response of the bellows is linear with pressure which means that if a linear lever system is used, the pen deflection will be parabolic with airspeed. Such an element was first designed and constructed and is shown in Figure 17, Appendix A. The range of this unit was from zero to 150 miles per hour and the total stylus travel for this range was one inch.

After inspection of the entire recorder, the Committee requested revision of the airspeed element to give linear record deflection rather than one which is parabolic with airspeed.[24] Accordingly a cam was designed and inserted in the indicating system which would modify the output so as to give linear spacing between each airspeed scale division. Also, the lower limit of the range was raised from 0 to 30 miles per hour. The final airspeed element is shown in Figures 15 and 16.

It is appreciated that the static pressure from the pitot tube should be communicated to the element in such a way as to cause the element to respond to the difference between dynamic and static pressure. In view of the fact that the recorder is to be used on training planes it was decided that the added complications of doing this would not be worth while. In such a plane there should be very little difference between cabin pressure and static pres-

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[13] See Figures 15, 16, and 17, Appendix A.

[24] Communication from M.S. Viteles, Chairman of the Committee on Selection [illegible] of Aircraft Pilots, to [illegible], January 25, 194[illegible]

[illegible] pilot [illegible] it will be necessary to use either an optical diaphragm method for obtaining a measure of this pressure difference or an air tight case which would make the problem of bringing the stylus shaft out of the case very difficult.

6 Altitude Element.[15] The sensitive element of the altitude recorder consists of a gang of ten aneroid capsules in series, each of which is evacuated to a very low pressure level, resulting in a relatively large deflection for a given altitude change.[16] The scale sensitivity is 1000 feet per inch of stylus travel and the instrument is linear within 2 per cent over the range. The range of recording is from 0 to 3000 feet, limited by the scale sensitivity requirement. Thus the total chart width is three inches for the altimeter.

Provision is made for adjusting the zero of the instrument to account for changes in barometric pressure over the range 29 to 31 inches of Hg. This zero resetting is effected by moving the fixed end of the capsule assembly by means of a spring loaded screw operated by turning the knurled wheel accessible through the back of the recorder case. Temperature errors are negligible when the instrument is properly set to zero. Details of the altimeter are shown in Appendix A, Figures 18 and 19

7- Lateral Accelerometer.[17] The lateral accelerometer consists of a mass suspended on springs so arranged that motion of the mass with respect to the frame is lateral and is transmitted to the stylus arm through a lever system. The motion of this mass relative to the frame is damped to the extent required to prevent oscillations of the stylus and to give minimum dynamic errors. Functionally, this instrument serves the purpose of a recording ball bank indicator.

The range covered by this accelerometer is from -0.5 g to +0.5 g and the chart is laid out in 5 equal scale divisions either side of zero covering a total chart width of two inches. The element consists of a mass supported between a pair of sylphon bellows which serve as the accelerometer springs. These bellows are rigidly held at their outside ends. The motion of the central mass is transmitted to the stylus shaft through suitable links. Damping, the proper amount of which is essential in good accelerometer design, is accomplished pneumatically. As the mass moves relative to the fixed ends, air is pumped through a small orifice into or out of one of the sealed bellows interiors depending upon which way the mass moves. This is a simple and ef-

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[15] See Figures 18, 19, and 20, Appendix A.

[16] It was originally intended to use a single sylphon bellows instead of the ganged capsules. Several models were constructed, one of which is shown in Figure 20, Appendix A. These were found to be unsatisfactory due to snap action of the convolutions of the thin-walled bellows when gradually compressed. Also non-uniformity of wall thickness caused the top convolutions to remain open when the bottom convolutions were completely closed. It was concluded that bellows at present available were unsuited for this type of service.

[17] See Figure 21, Appendix A.

[illegible] damping means. A photograph of the element is shown in Figure 21, Appendix A. Its location in the recorder is shown in Figure 11 where the [illegible] element will be seen just under the chart drive roll at the right center of the photograph.

8. Vertical (Normal) Accelerometer.[18] The vertical accelerometer, housed in the same unit with the lateral accelerometer, is similar in design to the lateral accelerometer element except that the direction of the motion of the mass is perpendicular [illegible] recorder and the range is from [illegible] to 2.0g. This [illegible] indicate angle of bank so long as the airplane is not slipping, skidding, or changing altitude. In other words, if the lateral accelerometer trace reads zero, and if the altitude remains constant, the vertical accelerometer can be used to measure angle of bank. In the presence of lateral accelerations other than zero, and under conditions of changing altitude, the angle of bank can be found by more involved computations. The chart width for this trace is one inch. Due to the trigonometric relationship between angle of bank and vertical acceleration the chart space per angle of bank is greater for the steeper than for the shallower angles of bank.[19]

9. Signal Marker.[20] The signal marker comprises an electro-magnet arranged to operate a short stylus arm. The signal marker is controlled by a remote push button switch operated by the instructor when coding the record.

10. The Wiring System.[21] The three components requiring electrical power are:

a. Chart drive starting magnet, energized whenever the main switch is turned on. This magnet consumes 0.05 watt.

b. Signal marker unit, operated by the remote switch.

c. Stylus heaters, operated by a seperate switch. If this switch is in the "on" position, the heaters will be turned on when the main switch is turned on; with this switch in the "off" position, the stylus heaters are inoperative. This switch should always be "on" when the recorder is operating.

Power for operating these components is obtained from the 7.5 volt battery included in the recorder. This battery is made up of two single cells connected in parallel. The life of a set of cells is approximately 50 hours of continuous operation.

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[18] See Figure 21, Appendix A.

[19] This relationship and the effect of other factors upon the vertical acceleration trace are discussed in greater detail in Viteles, Backstrom, op. cit., pp. 158-68.

[20] See Figure 22, Appendix A.

[21] A wiring diagram is presented in Figure 24, Appendix A.

BENCH AND FLIGHT TESTS OF THE RECORDER

A. Bench Test Results

Each recorder element was tested for scale errors by means of an appropriate bench test:

1. The control position elements were tested by applying known displacements to the control cable connections and reading the corresponding stylus deflections. The results of these tests are given in Appendix B, Figure 25.

2. The airspeed and altitude elements were tested by subjecting the elements to known pressures corresponding to the airspeeds and altitudes, within the range, and measuring the stylus deflections. The airspeed unit calibration is given in Fig. 26 and the altimeter calibration is given in Figure 27, Appendix B.

3. Both accelerometer elements were checked for scale errors. The lateral element was calibrated by tilting the unit to various angles from the horizontal, introducing a portion of the acceleration of gravity along the line of action of the accelerometer. This caused a deflection of the seismic element and hence of the stylus. The data obtained are plotted in Figure 28, Appendix B. The vertical accelerometer could not be calibrated in this manner because the range of the instrument is in excess of 1 g. Therefore, this element was calibrated by suspending weights from the seismic element. When the suspended weight became equal to the weight of the seismic element, the imposed acceleration was 2 g. Results of this procedure are given in Figure 29, Appendix B.

The correct damping was determined for both accelerometers by means of a dynamic test. A straight track was constructed, along which a cart was propelled by means of a cable attached to falling weights, the amount of weights determining the magnitude of the acceleration. The seismic element was mounted on the cart with a special indicating system which recorded the deflection of the seismic element as a function of time. The cart was then released and accelerated along the track for a distance of 16 feet. A braking system then brought the cart to rest. Study of the record of accelerometer response to this suddenly-applied, constant acceleration made it possible to choose the optimum damping. This is approximately the value required to just keep the instrument from over-shooting when an acceleration is suddenly impressed on the system, giving minimum time of response. Careful control of damping is necessary when using a relatively low natural frequency (11 cycles per second), required in order to get the necessary sensitivity.

B. Flight Test Results

Flight tests were made with the recorder installed in a Luscombe airplane. The installation location chosen was the baggage compartment which was revised in order to accommodate the instrument. This compartment is directly behind the side-by-side seats making it possible for an observer to watch the action of the recorder in flight.

The elevator and rudder control cables pass directly beneath the recorder and the connections were made to the corresponding recorder units over ball bearing pulleys. The aileron control cable passes across the top of the recplane windshield, and connection to the recorder was made by ball-bearing pulleys. The airspeed unit was connected by installing a tee in the pitot line and running a length of rubber tubing from this tee to the connection provided on the recorder. Photographs of the installation are shown in Appendix B, Figures 30, 31, and 32.

Flight tests made on the recorder include tests on the airspeed element, altimeter element, and both accelerometer elements.

1. The speed range of the airplane was not sufficient to check the operation of the airspeed unit over the entire range. However, checks were made by comparison with a calibrated airspeed indicator.[22]

2. Altitude recordings were checked against readings of a sensitive altimeter installed for the purpose. Results of this comparison are given in Figure 27, Appendix B. Good agreement was found.

3. The lateral accelerometer was checked in flight by making skidding turns at attempted constant altitude. The airplane wings were maintained as closely as possible to horizontal and the airplane was flown at various rates and times of turn in order to establish known values of lateral acceleration. Results of these tests are given in Figure 28, Appendix B. Agreement of the flight test results with the static calibration is only fair due to inability to maintain altitude and horizontal attitude during skidding turns, making it difficult to determine the true acceleration acting during these turns.

4. The vertical accelerometer was checked in flight by making properly banked turns at constant altitude and at varying rates and times of turn in order to establish known values of the resultant normal (vertical) acceleration. Results of these tests are given in Appendix B, Figure 29. As in the case of the lateral accelerometer, the flight check points are scattered due to inability to maintain altitude in tight turns. All the flight check points are for angles of bank greater than 30°.[23]

INSTRUCTIONS FOR USE OF THE RECORDER

A. Installation

1. Recorder. The recorder must be installed in the airplane with its long dimension parallel to the lateral axis of the airplane, since mounting in the opposite direction would cause the lateral acceleration unit to measure longitudinal acceleration. The recorder should be installed with the chart side forward. The "left" and "right" chart designations for the lateral acceleration record are based on installation in this manner.

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[22] Figure 26, Appendix B, presents the results of both the bench and the flight tests of the airspeed element and shows good agreement.

[23] Angles of bank smaller than 30° result in normal accelerations not much greater than 1.0 g. which is the lower limit of the range of this unit. An airplane with more power than was available would be required to obtain more accurate values.

The mounting plates, running fore and aft along each side of the recorder, should be rigidly attached to the airplane frame. The simplest method of doing this is to build up supports from the structure underneath the recorder. The recorder should be levelled in the airplane. If either left or right side is higher than the other, the lateral accelerometer will not read zero when the airplane is level. This adjustment is conveniently carried out by shimming the low side until the lateral accelerometer reading agrees with that of the ball bank indicator on the instrument panel.

2. Control Position Element Connections. The cords operating the control position units must be suitably attached to the airplane control cables. With the recorder mounted in the fuselage behind the seats, the elevator and rudder cables are readily accessible. In order to tie to the aileron cable it will be necessary to bring a line forward. For all three elements, ball bearing pulleys must be installed where necessary. This must be done in a workmanlike manner if dependable records are to be obtained. The runs should be kept as short as practical and care must be taken to locate the connecting lines so as to prevent fouling over full range and so as to minimize the chance of the lines being damaged or broken in routine operations. Closely woven linen line should be used in order to prevent stretch.

After the cord connections from the control cables to the control position elements are made up, the length of the connections must be adjusted so that the styli will record zero on the chart when the controls are neutral. This adjustment is carried out by means of the three screws projecting through the left side of the recorder, adjacent to the cord pulleys. If one of these adjusting screws comes to the end of its travel it will be necessary to back off that screw and change the length of the cord. In making this adjustment there are two possible zeros, one of which is incorrect and occurs on the return of the cam. This incorrect zero may be identified by moving the external connections a small amount either side of zero. If the stylus moves rapidly all the way to the extreme position without slowing up near the extremes, the cam is operating on its return position. If this is the case, the connections should be slacked away or taken up enough to reach the true zero position.

As delivered, the control position elements accommodate a total control cable motion of 4 inches. Should it be desired to adapt the recorder to a total motion different from 4 inches, it will be necessary to change the external gears on the control position elements. The gear ratio supplied is 1.1, each gear having a pitch diameter of .9375 inch and 60 teeth (64 pitch). Using this same diametral pitch, any gear combination which will have a total number of 120 teeth on both gears can be used.

3. The Airspeed Element. The airspeed indicator unit must be connected to the pitot side of the pitot-static tube. The tube to which this connection is made projects through the right side of the recorder. Rubber tubing will be satisfactory for this line. No provision is made for a static line connection to the recorder because of the low speeds encountered in the use of this recorder.

D. Operation

1. Loading Chart Paper.[24] Mount one of the spools of chart paper on the feed roll holders at the bottom rear of the chart side of the recorder. The paper should feed off from the top of the feed roll. The paper should then come forward from the feed roll, over the first guiding roller, then up and over the second guiding roller. From here the chart continues under the chart drive roll and writing table, around and over the writing table, over the chart drive roll and finally down to the take-up roll at the bottom.

Wind the spring motor using the crank provided for this purpose. From fully run down, 150 turns of the crank are required to wind all three springs up tight. Winding will be required only whenever a new chart is installed. Since the motor cannot be wound with the chart paper mounted, the practice must be adopted of winding the motor tight each time the chart is changed. Approximately 45 turns will be required. In threading the chart, care should be taken to center the chart with respect to the spacing collars. If this is not done, the chart will shift laterally, making all chart readings incorrect.

2. Adjusting Stylus Zeros. After proper installation of the recorder, the only zero adjustment required will be that provided with the altimeter element. The knurled wheel, accessible when the flap on the back of the cover is opened, is used to zero the altitude trace.[25] Before take-off this wheel should be turned until the altitude stylus is lined up with the zero altitude chart line. The element is then adjusted to read zero at the existing barometric pressure. If the barometric pressure changes it will be necessary to reset the zero. The instrument should be tapped lightly when setting the zero in order to remove friction. If it should be required to adjust the altitude trace in flight, the wheel can be turned until the altimeter reads the same altitude as that indicated by a properly set sensitive altimeter.

In the event that the stylus positions for the airspeed and the two accelerometer elements do not coincide with the chart zero lines, the adjusting screws on the [illegible] of the stylus arms can be used to correct this.

For coinciding the [illegible] position chart zeros with neutral control positions, the adjusting screws on the left side of the recorder must be used. If the stylus arm adjusting screws are used for this purpose, the relation of the arms to the [illegible] will be disturbed.

3. [illegible] To operate the recorder it is only necessary to turn the [illegible] which starts the paper feeding. The remote [illegible] operates the [illegible]. The stylus heaters may be turned on or off

[24]See Figure [illegible] Appendix

[25]See Figure [illegible] and 5, [illegible]

[illegible] of the switch mounted under the right end of [illegible] roll. [illegible] this switch [illegible]

4. Removal of Record. Printed on the chart paper is an indication of the amount remaining on the roll, in terms of minutes to run. At the appropriate time the used roll may be removed by moving the take-up roll slightly to the right. The chart roll can then be slid off the end of the wooden take-up roll. The spring motor should then be wound and a new chart installed as described above.

C. Maintenance

The following practices are recommended in order to insure trouble-free operation.

1. Keep the recorder covered at all times. Dust and dirt will prevent proper working of the units.

2. Change the dry cells when required (approximately every 50 hours). This can be detected by failure of the recorder to start when the main switch is thrown on.

3. Refrain from doing any work on the recorder without proper tools and reasonable skill.

FURTHER RESEARCH

Research with the C.A.A.-N.R.C. Flight Recorder to date has been limited to the calibration of the elements and to checking the accuracy of recording of the various flight functions. The next step in the evaluation of the instrument will be the development of methods of analysis of the records so as to yield qualitative and quantitative indices of pilot proficiency. This should then be followed by an experimental determination of the value of these indices for use as criterion data and as diagnostic information for flight instruction in the field.

SUMMARY

This report describes in detail an improved flight recorder developed at Massachusetts Institute of Technology for the Committee on Selection and Training of Aircraft Pilots of the National Research Council. It was designed as a field instrument for use in obtaining criterion data for evaluating pilot performance during flight. It is hoped that this unit will serve as a prototype for a recorder which will find extensive use in pilot training, subsequent to the establishment of valid criteria.

The recorder traces on waxed paper 15" wide a continuous record of the following functions:

1. Elevator position — control cable motion

2. Aileron position — control cable motion

3. Rudder position — control cable motion

4. Airspeed — 30 to 150 m.p.h.

5. Altitude — 0 to 3000 feet

6. Lateral acceleration — -0.5 to +0.5 g.

7. Normal acceleration (bank angle) 1.0 to 2.0 g.

The instrument is designed for use in training airplanes, weighs 35 pounds, and requires no external power. External connections required are cord lines to the control cables and tubing from a pitot head for the airspeed element. The entire unit is mounted on shock mounts in order to eliminate the effect of vibration.

In developing this recorder an attempt was made to develop elements having both sufficient sensitivity and operating force great enough to drive recording styli without excessive stylus friction errors. Bench and flight tests show that this has been satisfactorily accomplished. Given intelligent handling in the field, accurate quantitative records of the various functions will be readily obtained. Further research is needed in order to develop methods of analysis of the records so as to provide criteria of pilot proficiency.

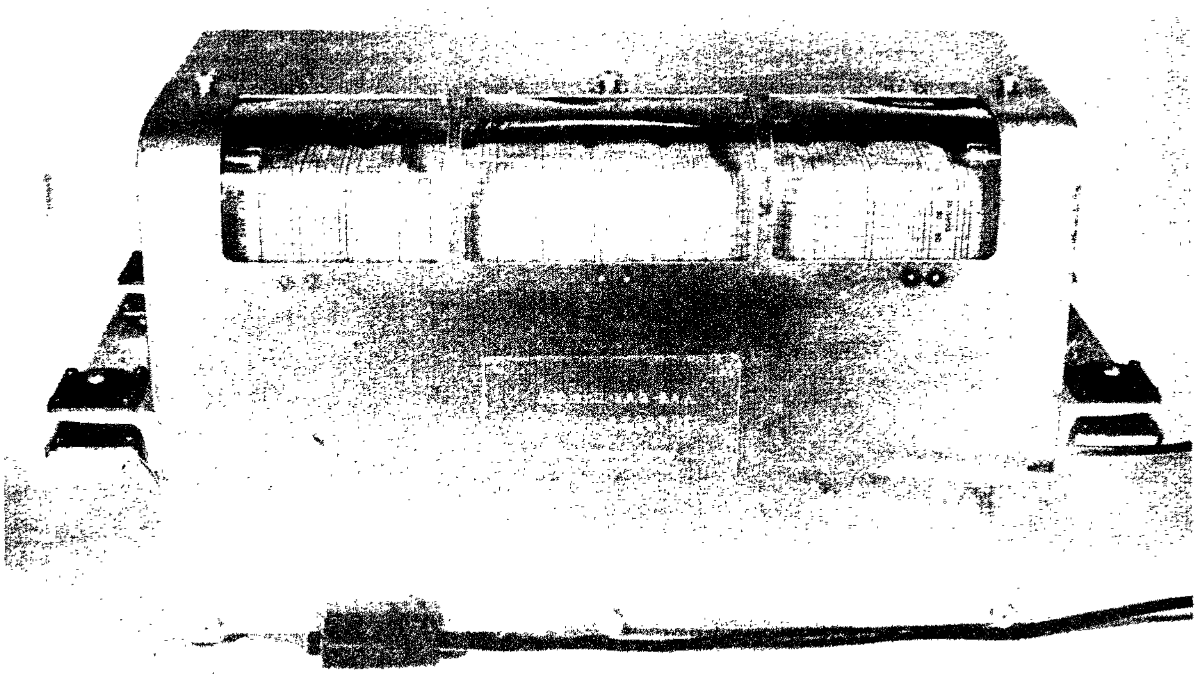


FIGURE 1
Top Front View

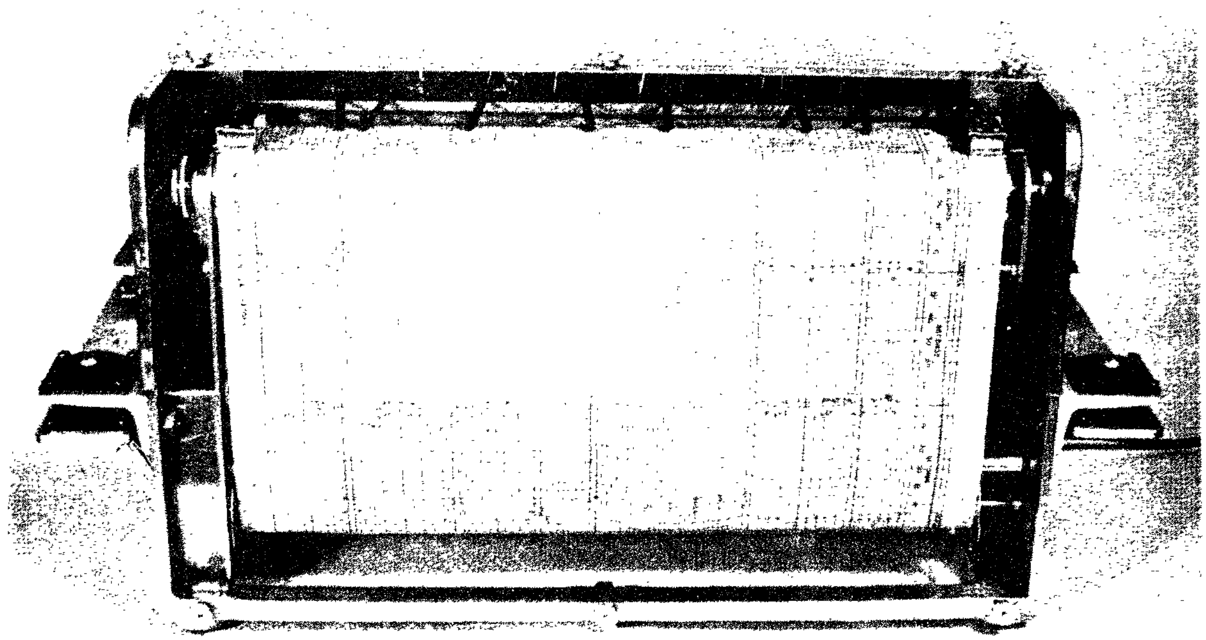


FIGURE 2
Top Front View - Front Cover Off

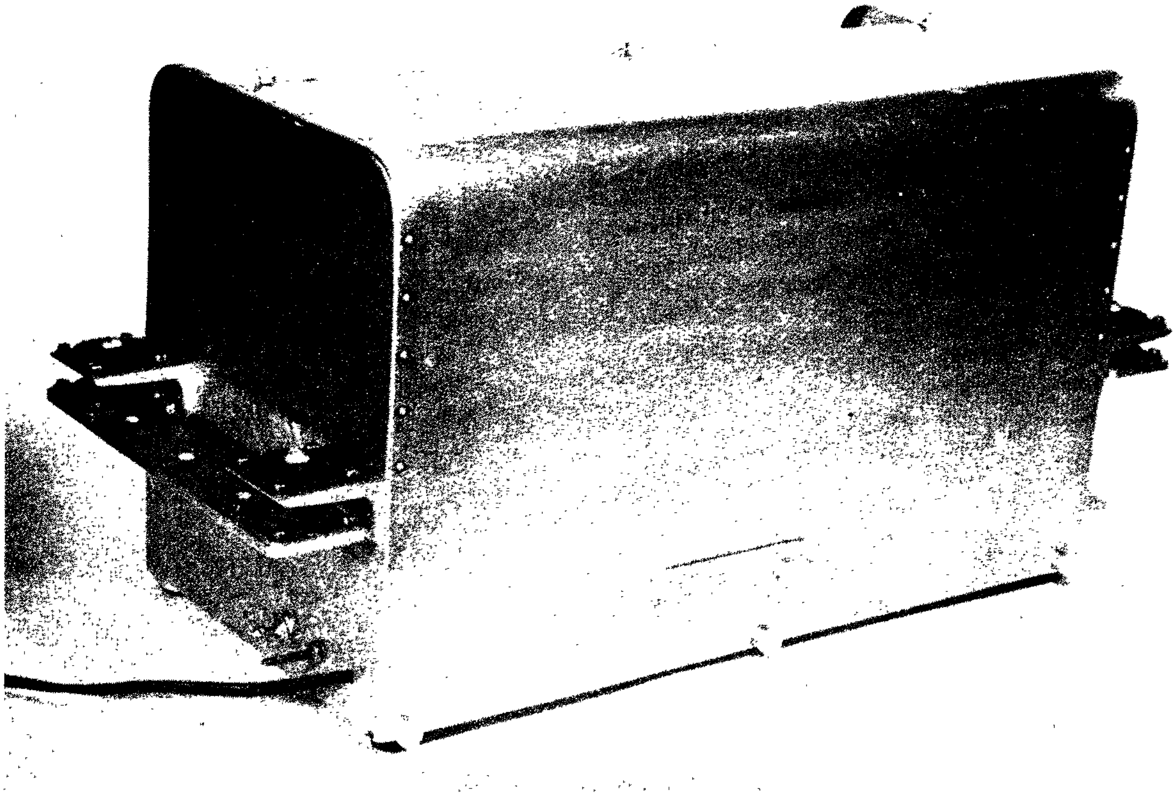


FIGURE 3
Rear View

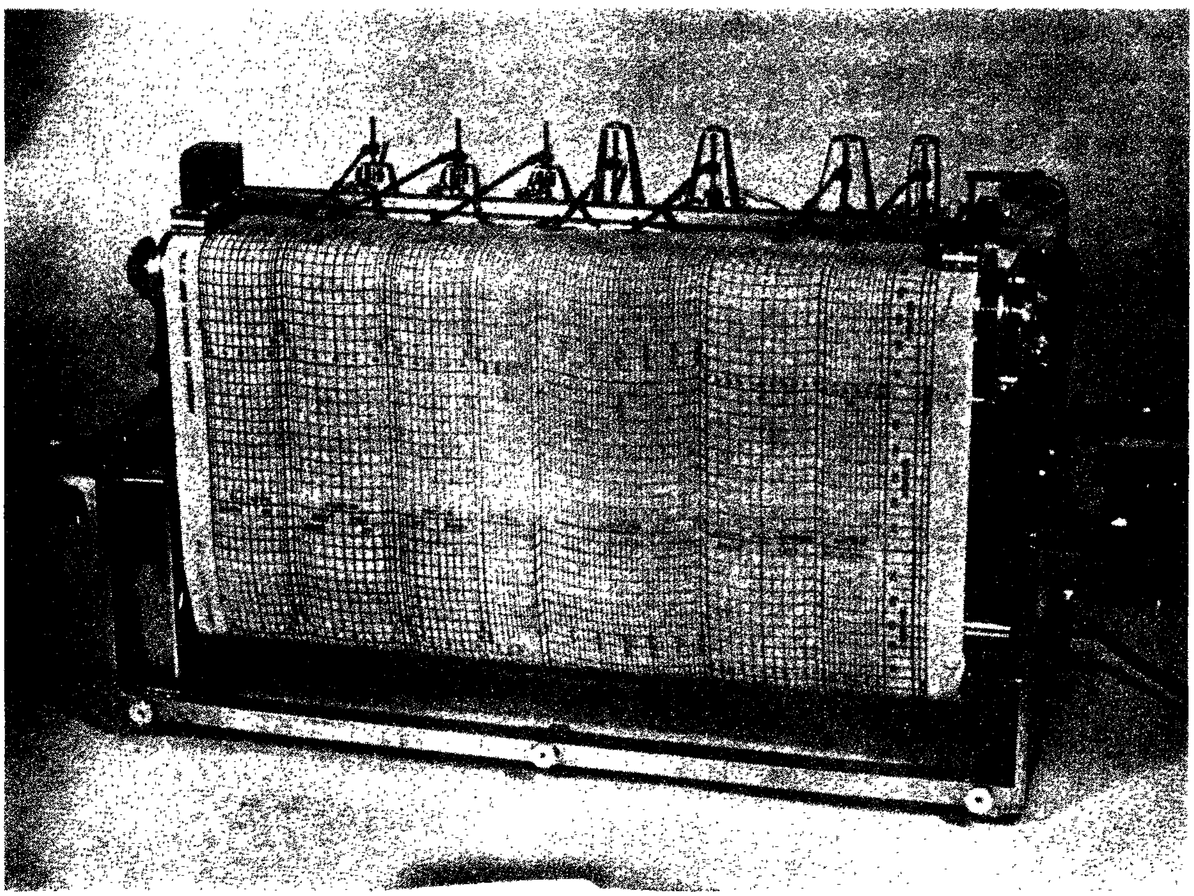


FIGURE 4
Top Front View - Cover Off

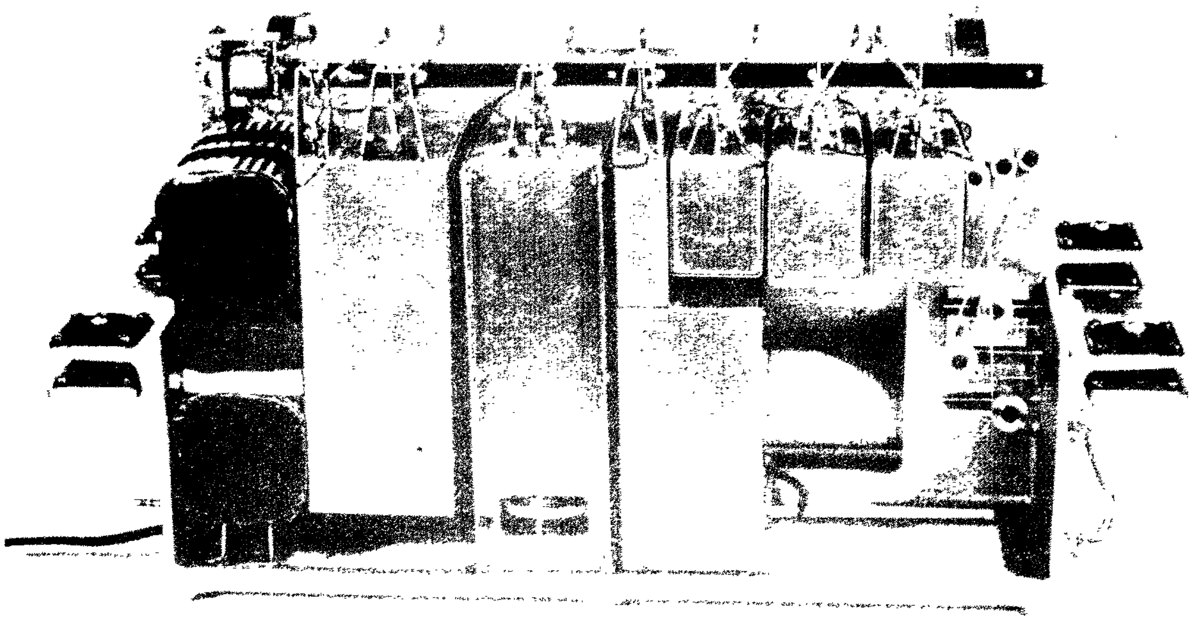


FIGURE 5
Top Rear View - Cover Off

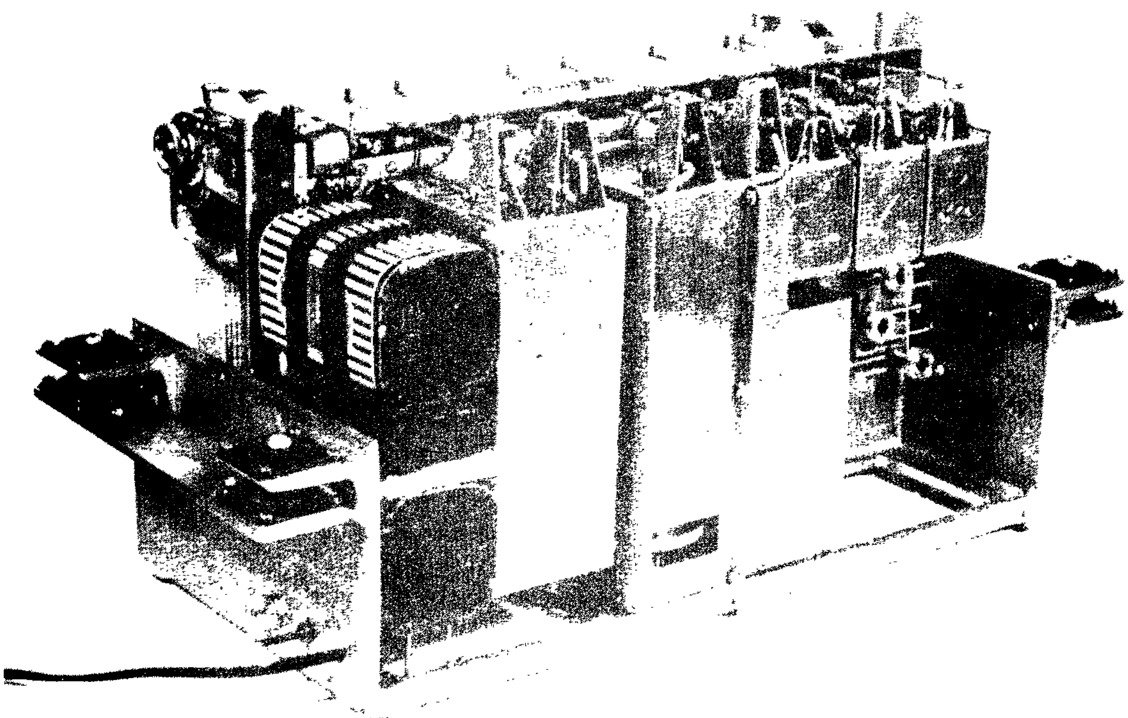


FIGURE 6
Right Rear View - Cover Off

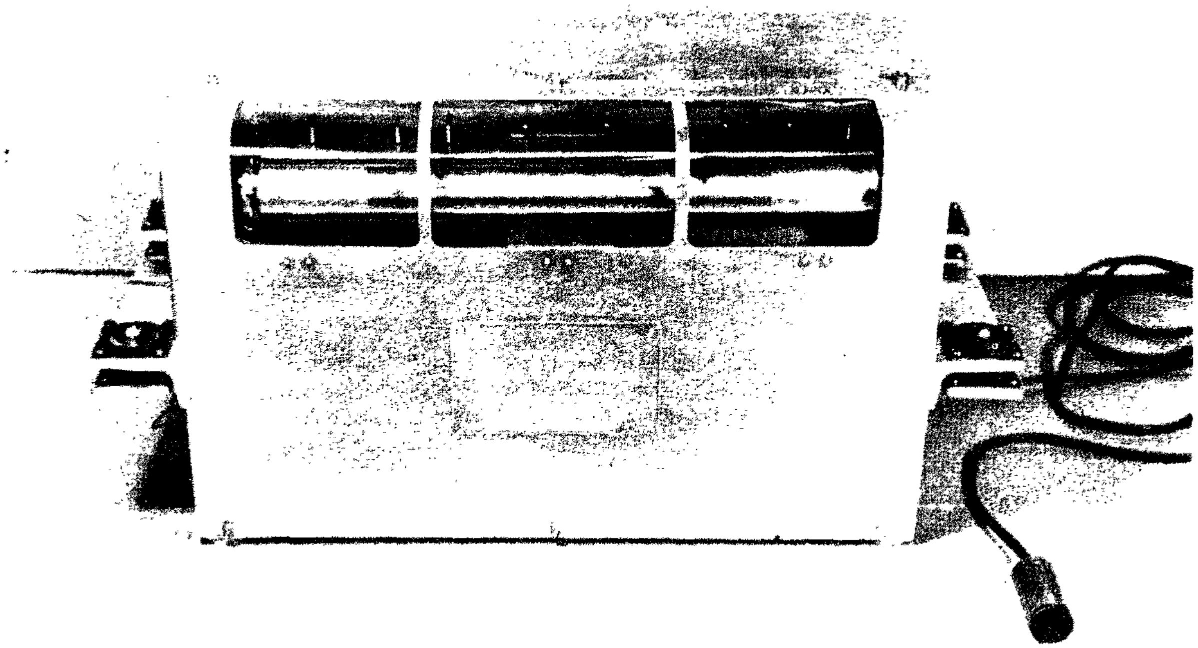


FIGURE 7
Top Front View - No Chart Paper

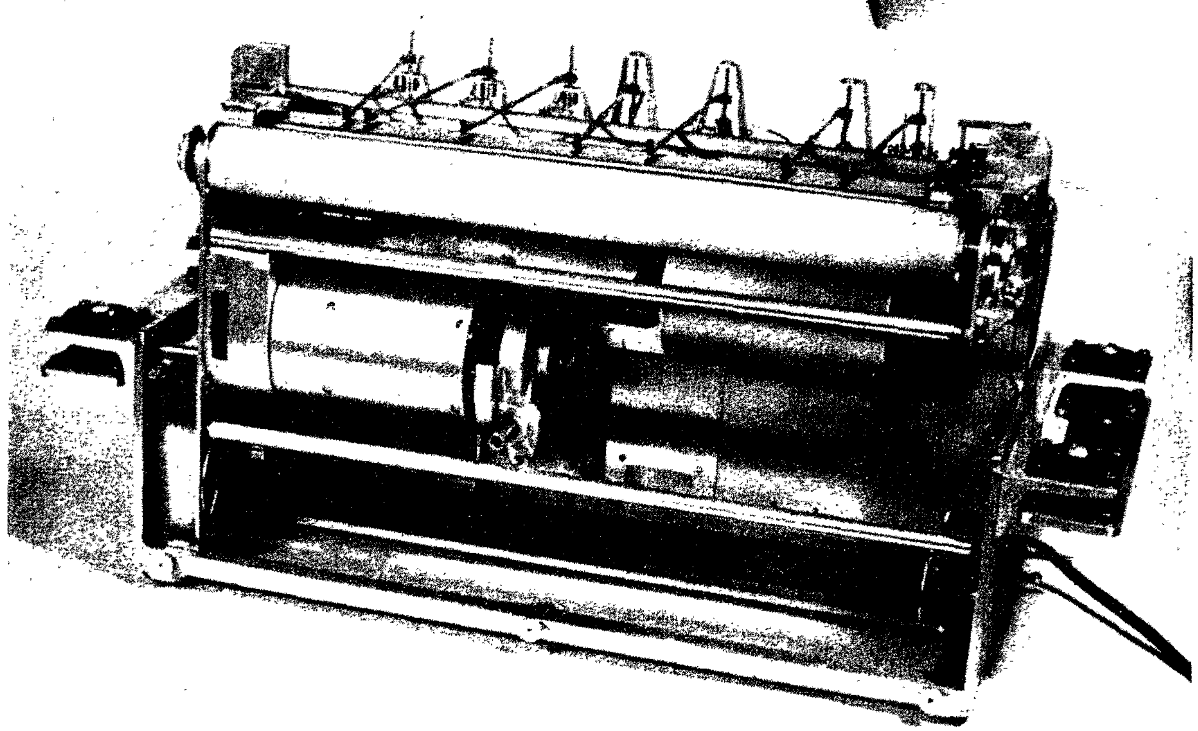


FIGURE 8
Top Front View - No Chart Paper And Cover Off

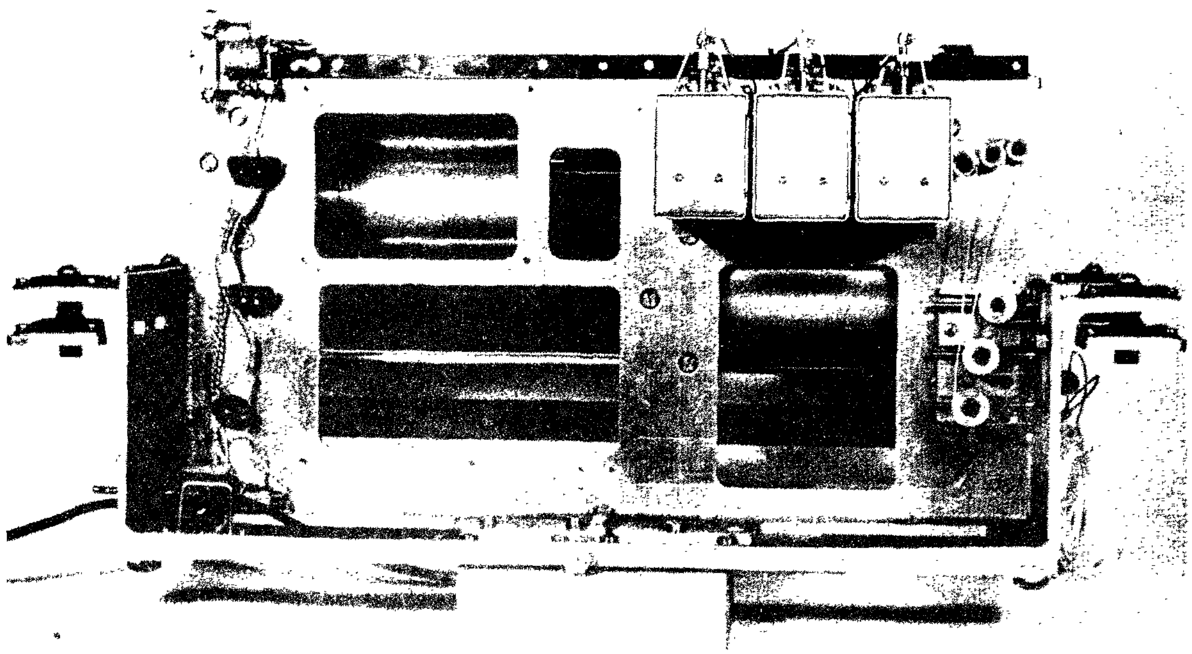


FIGURE 9
Rear View Of Frame Showing Control Position Elements

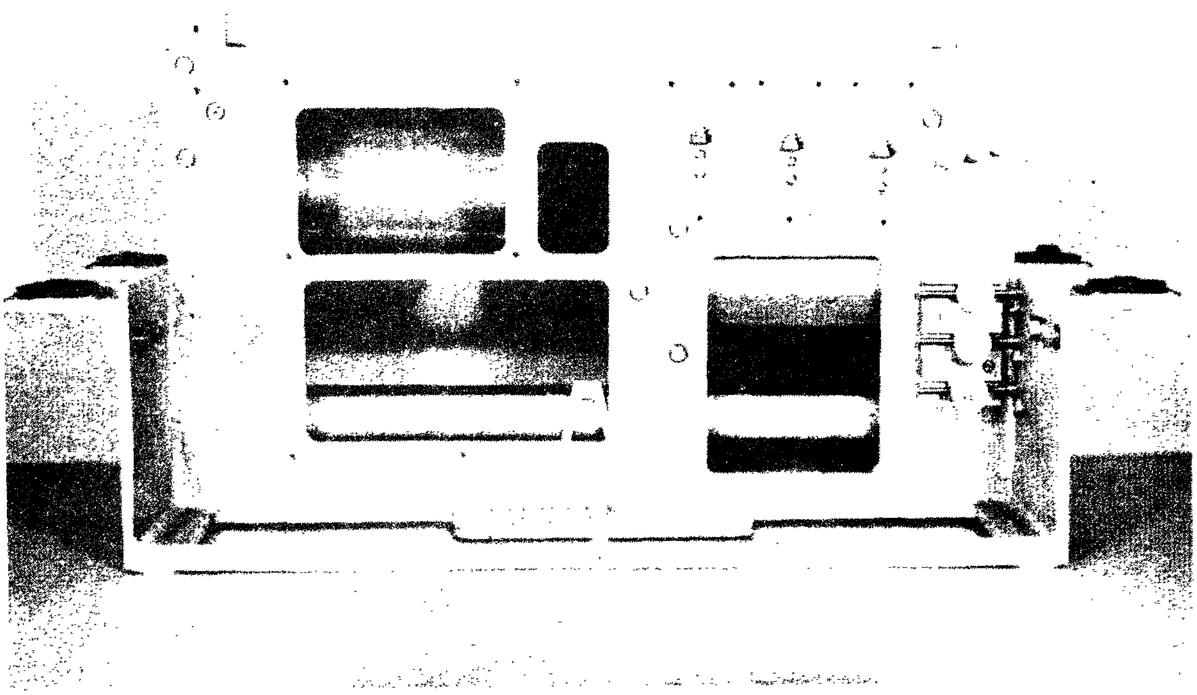


FIGURE 10
Rear View Of Frame

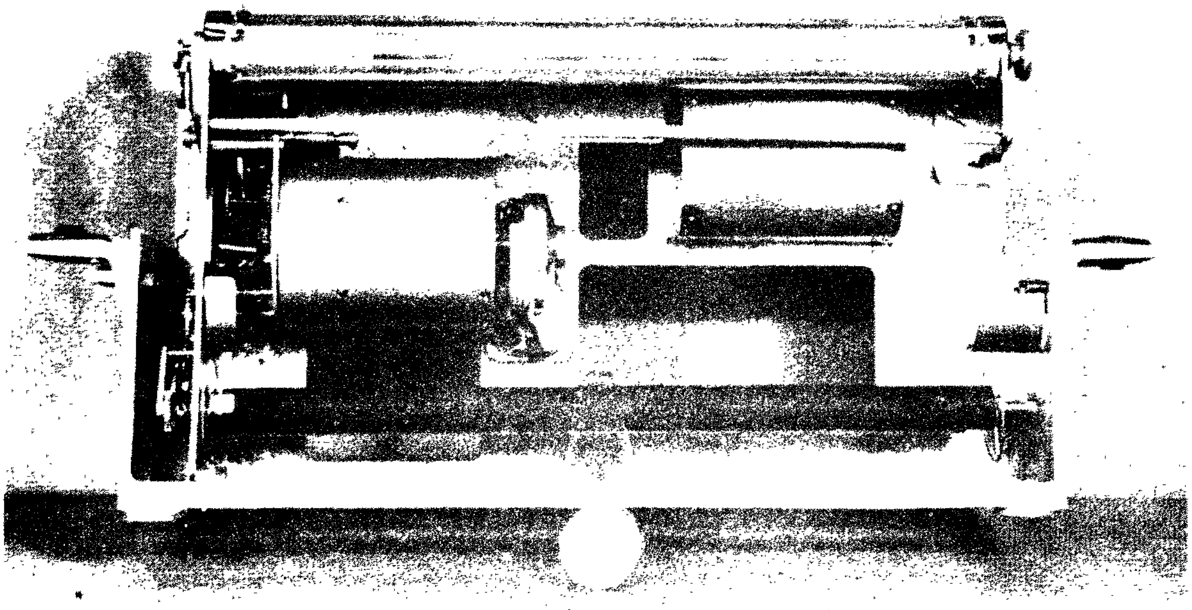


FIGURE 11
Front View Of Frame Showing Clockwork Governor Train

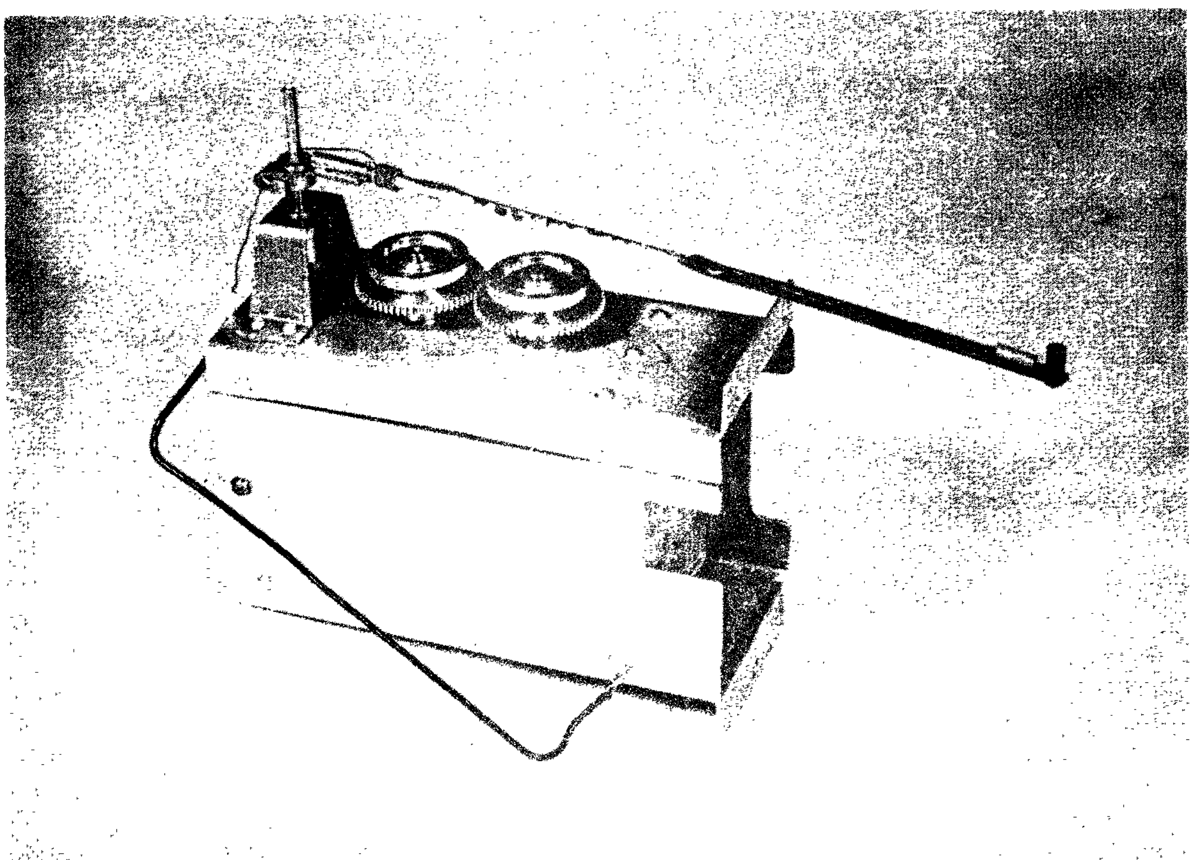


FIGURE 12
Control Position Element

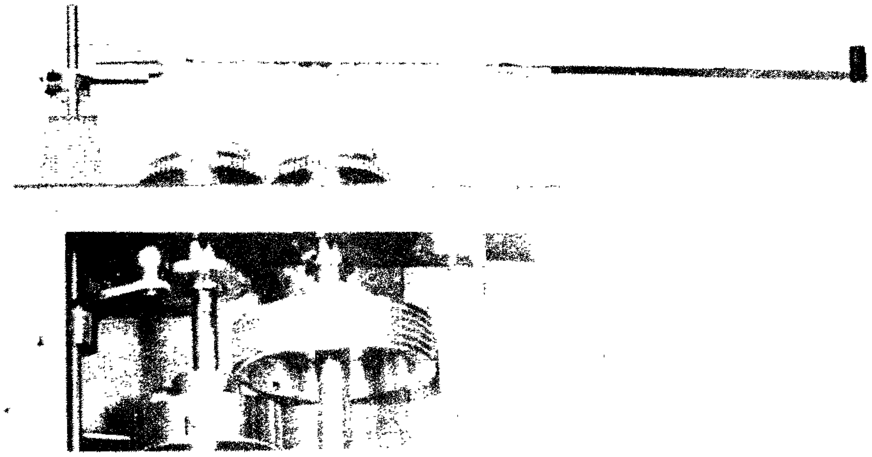


FIGURE 13
Control Position Element Showing Cam And Follower,
Spring Barrel And Take-up Drum

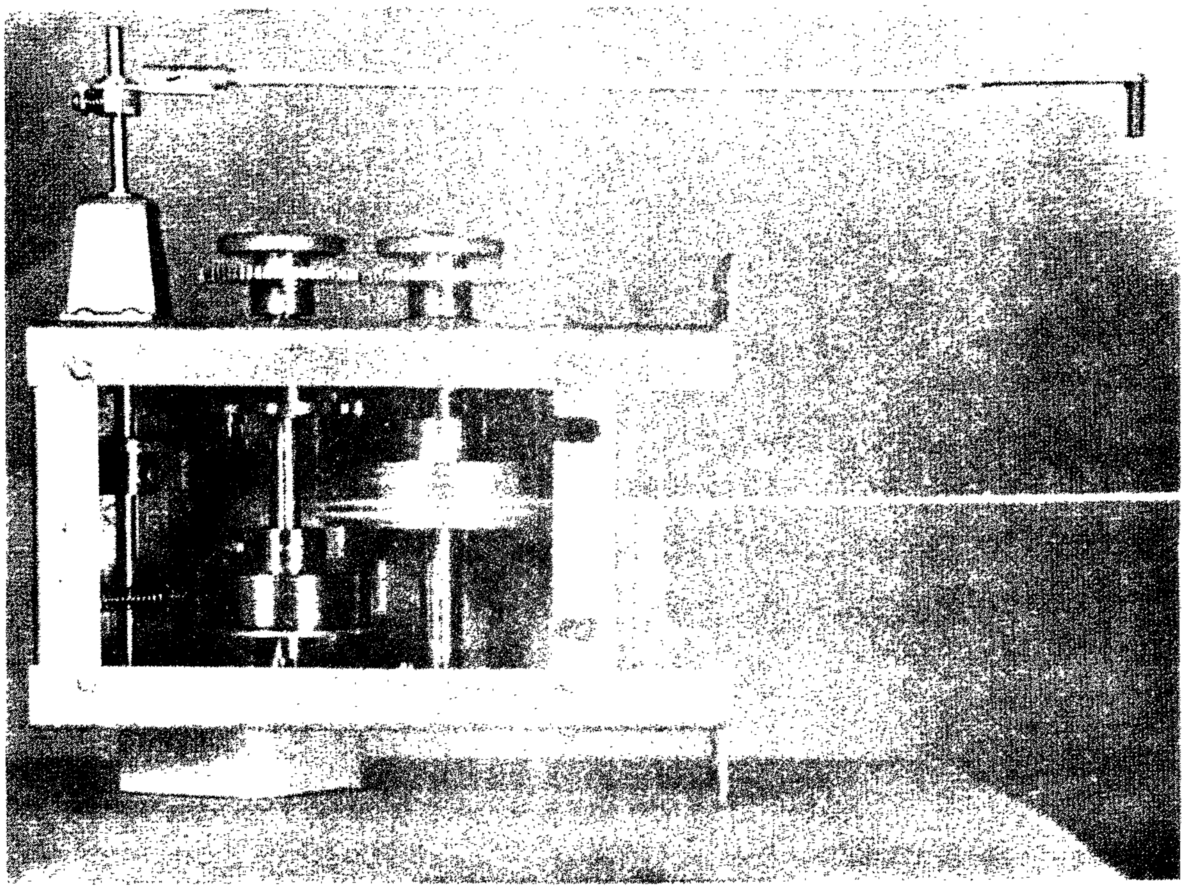


FIGURE 14
Control Position Element Showing Cam And Follower,
Spring Barrel And Take-up Drum

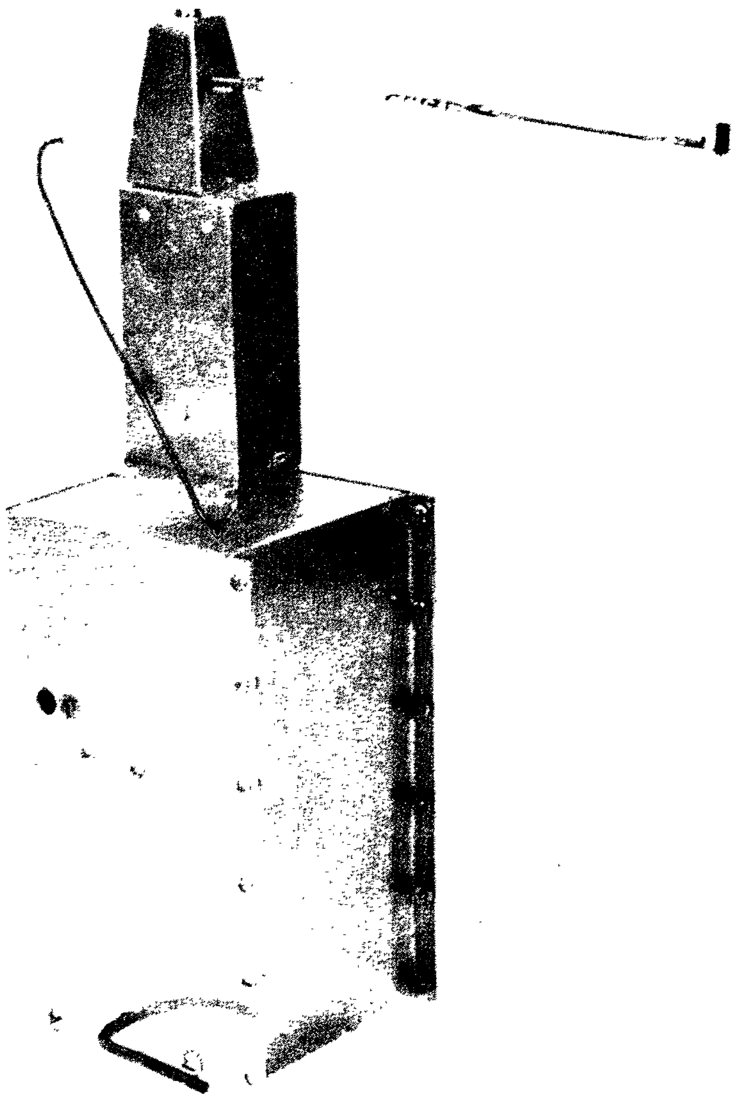


FIGURE 15
Airspeed Element

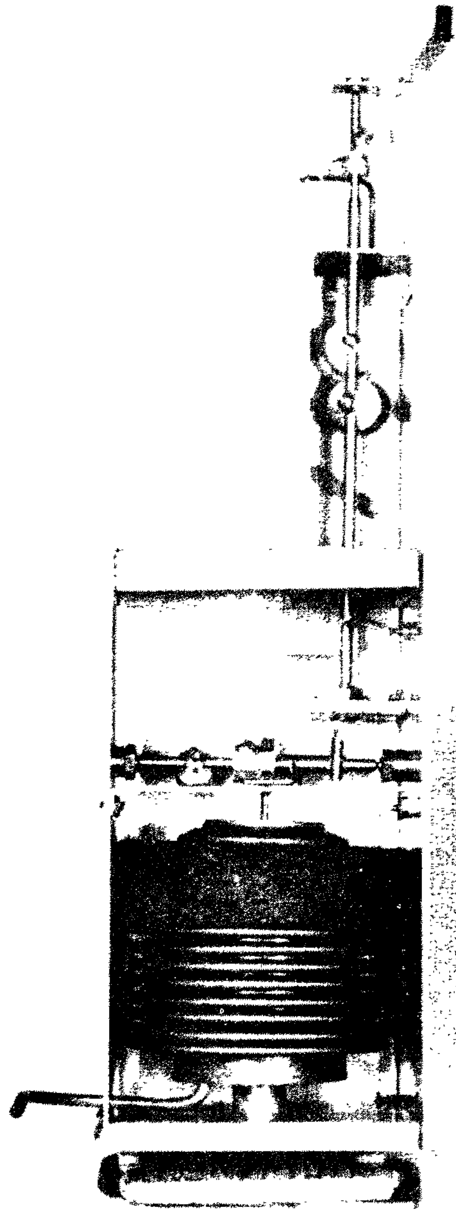


FIGURE 16
Airspeed Element Showing Actuating Bellows
And Non-linear Indicating System

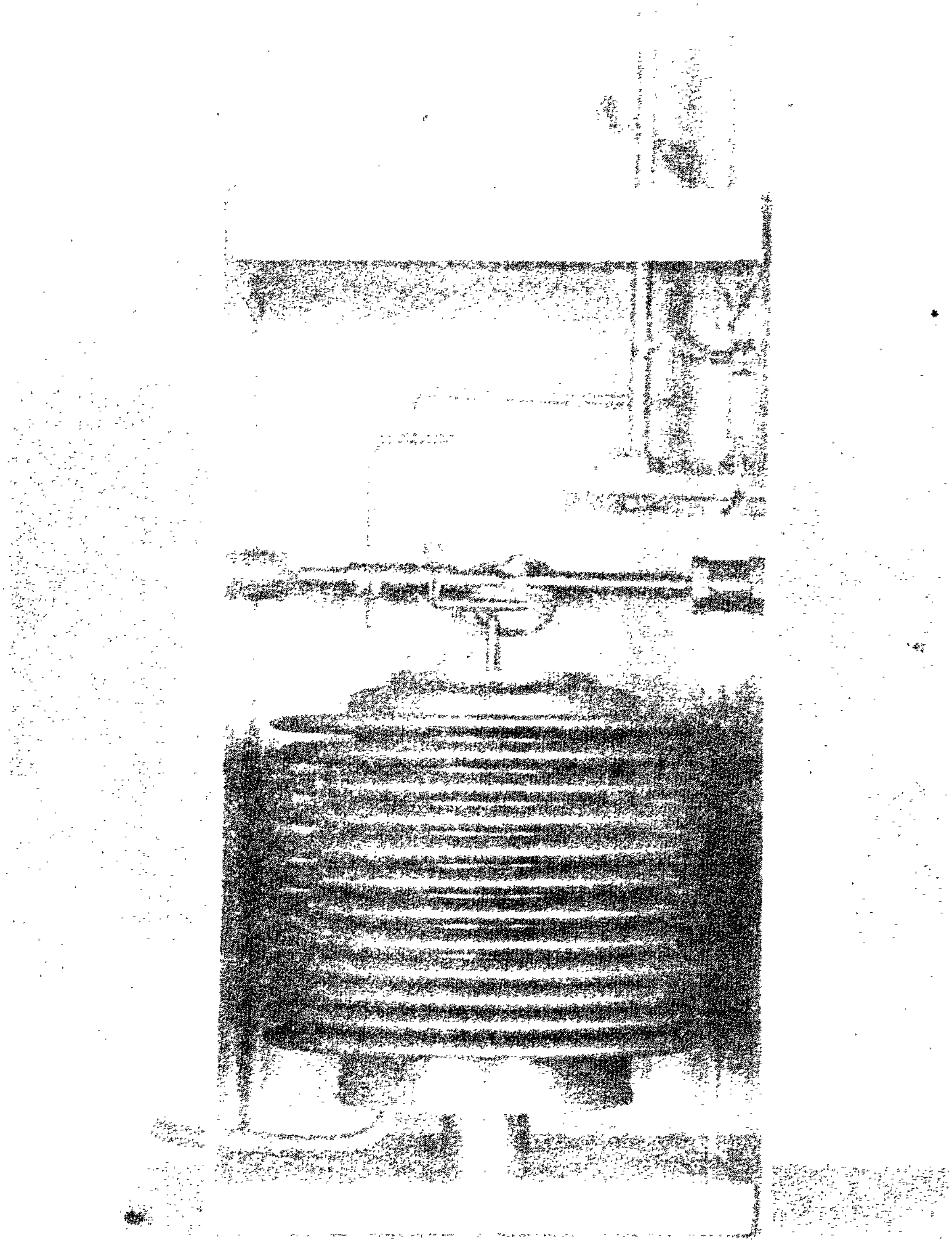


FIGURE 17
Original Airspeed Element With Linear Indicating System

FIGURE 18
Altitude Element Showing Barometric Adjustment Wheel

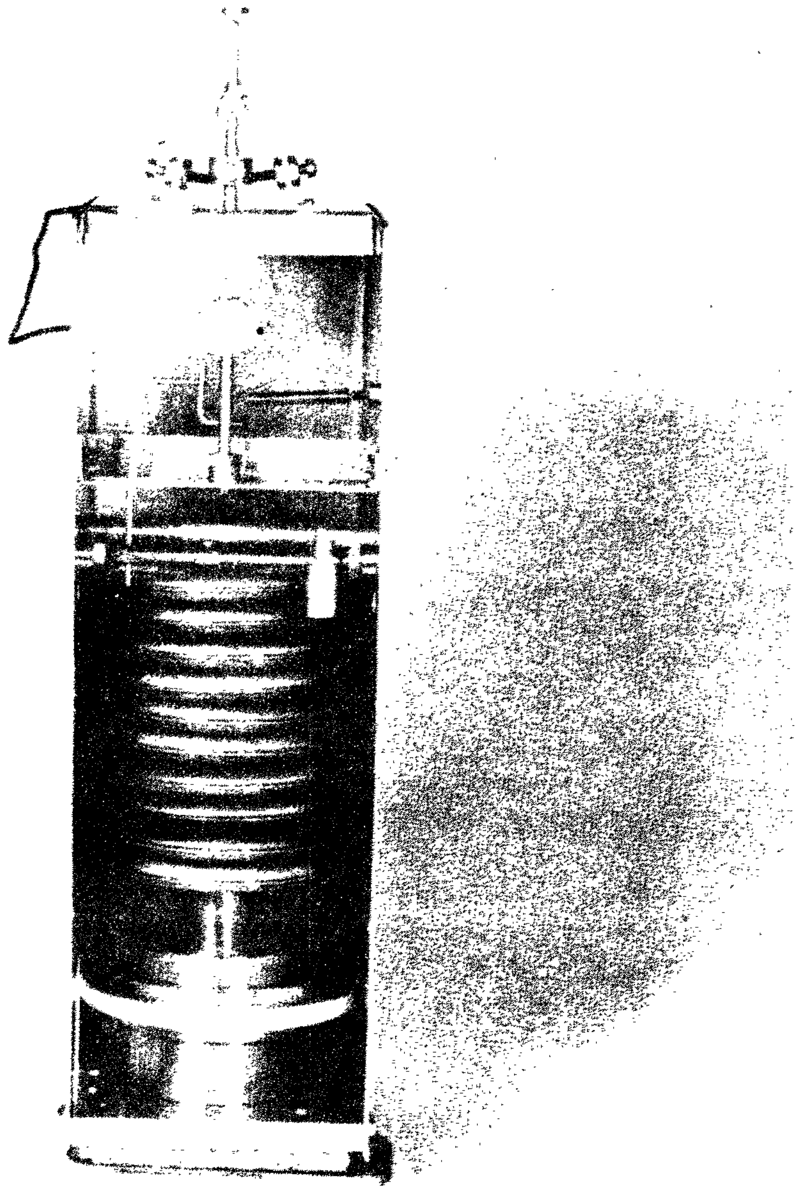


FIGURE 19
Altitude Element Showing Actuating Capsules And Indicating System

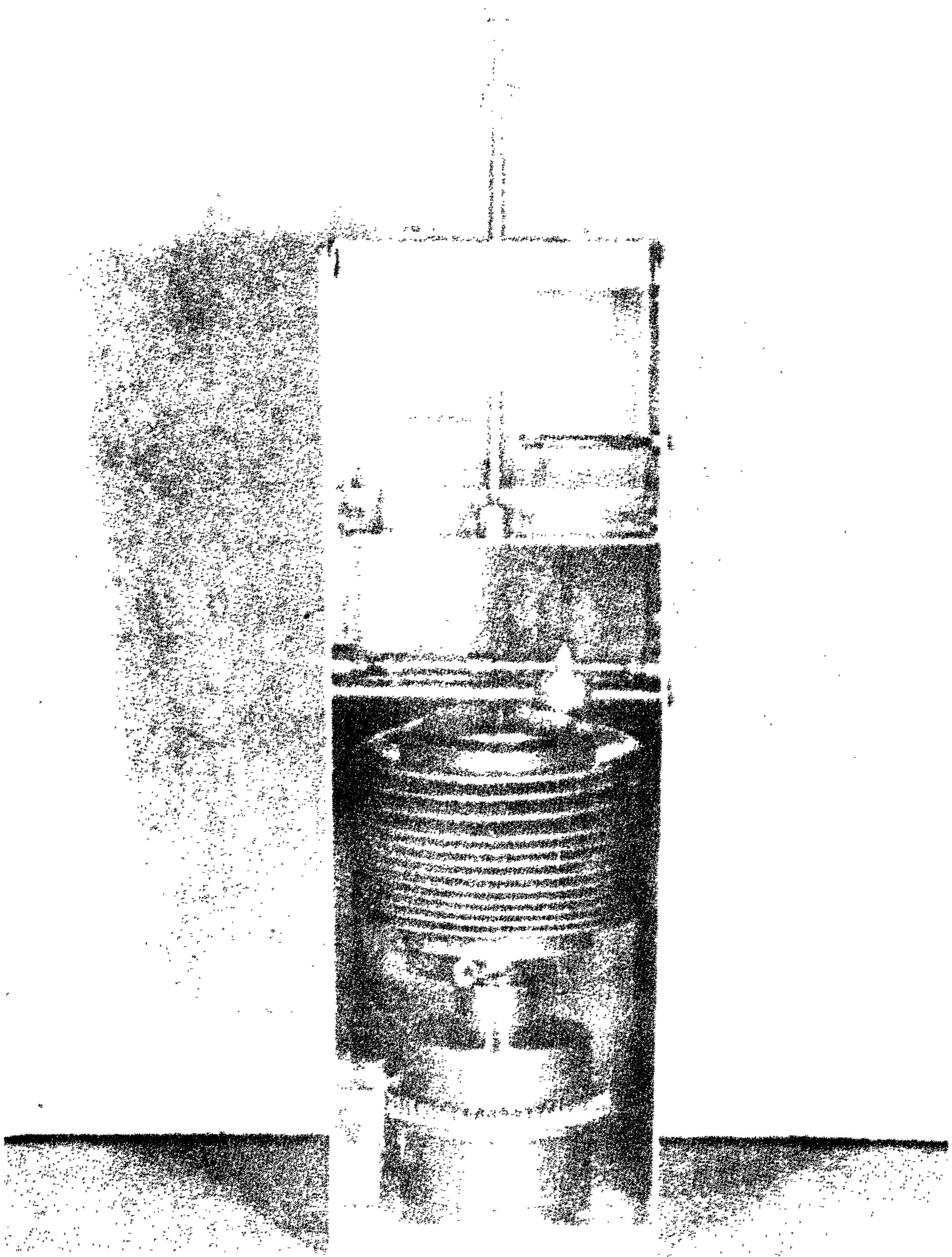


FIGURE 20
Original Altitude Element Showing Actuating Bellows
And Worm Drive Barometric Adjustment

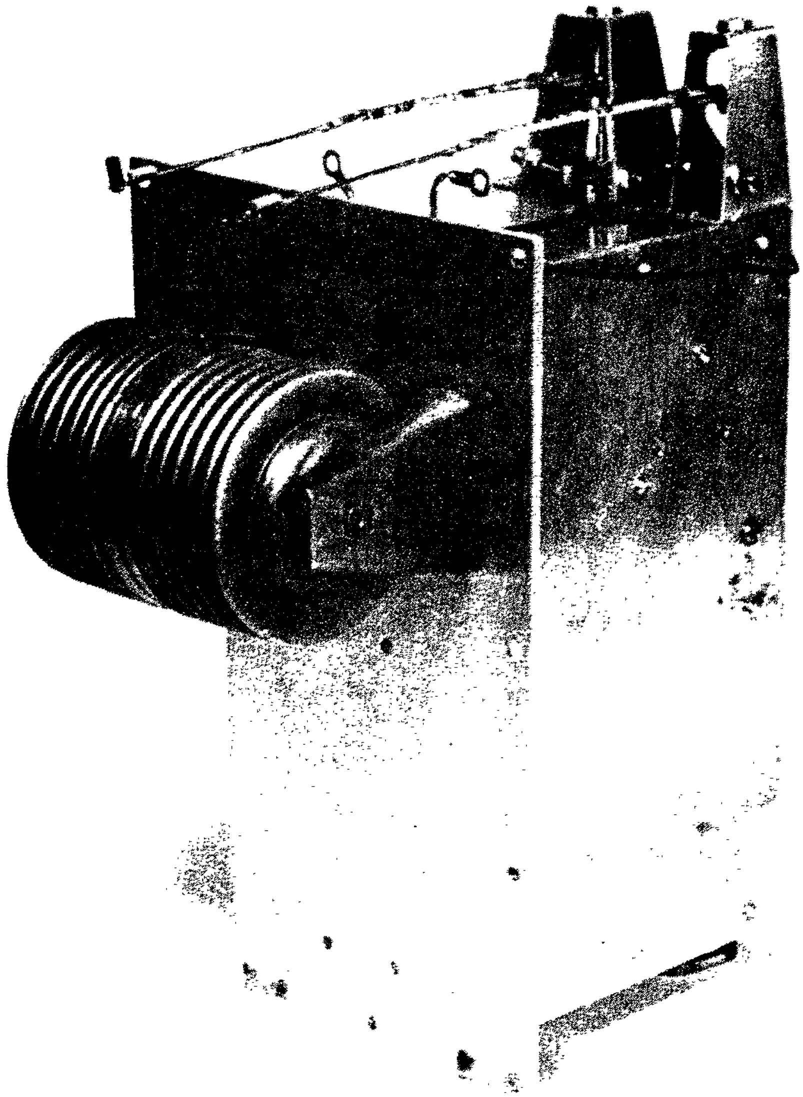


FIGURE 21
Lateral And Normal Acceleration Elements Showing
Lateral Seismic System

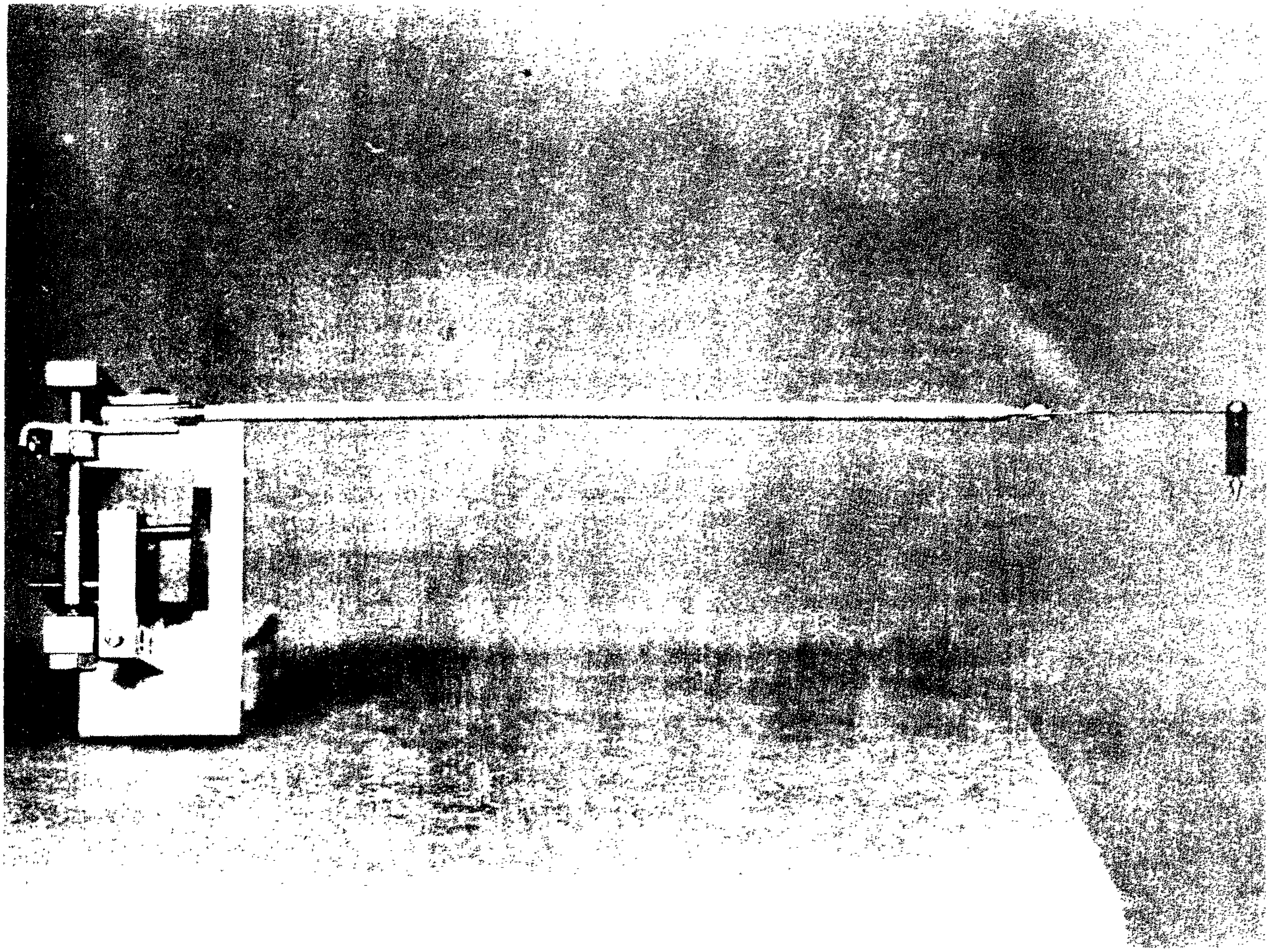


FIGURE 22
Signal Marker Unit

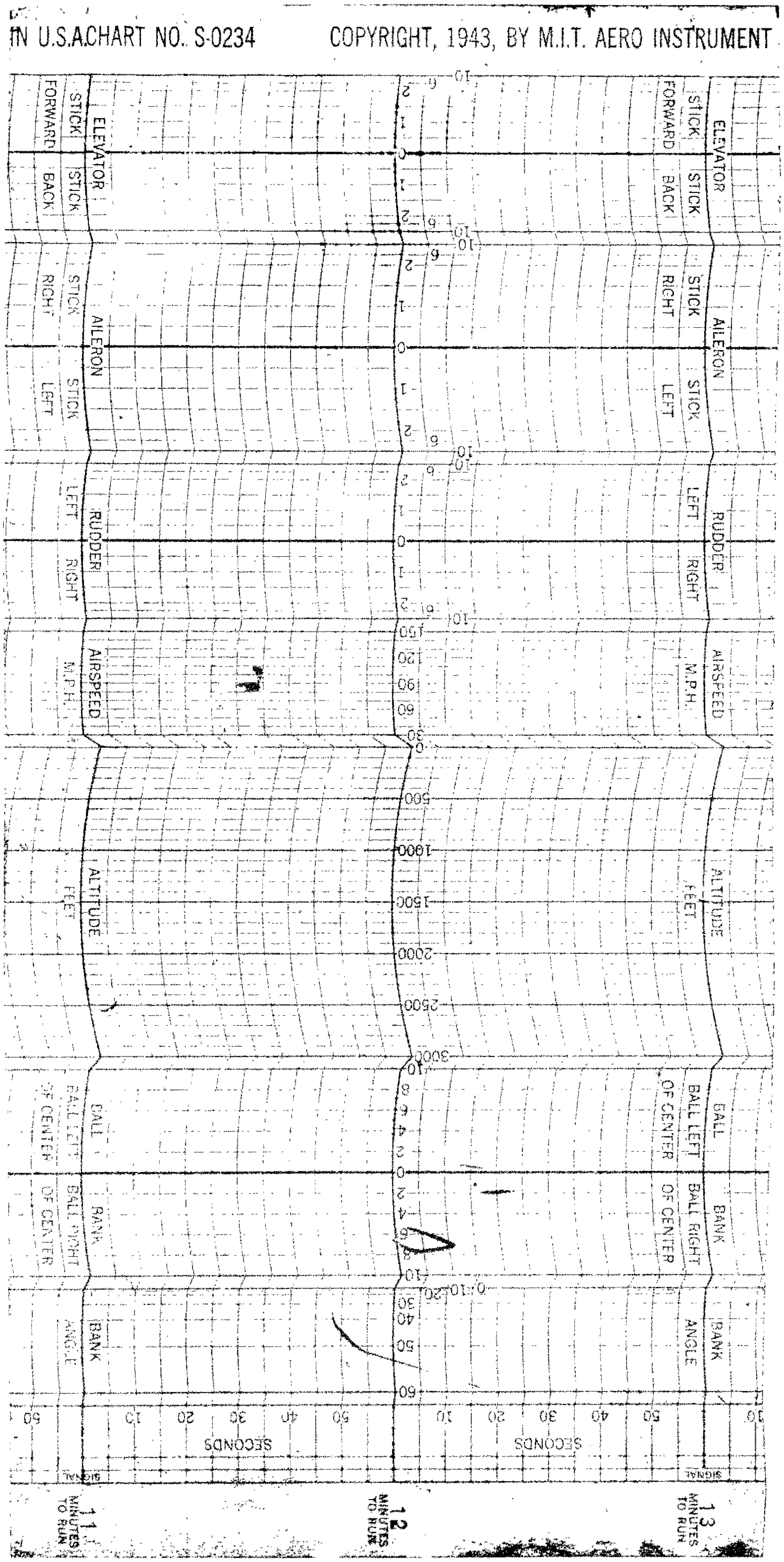
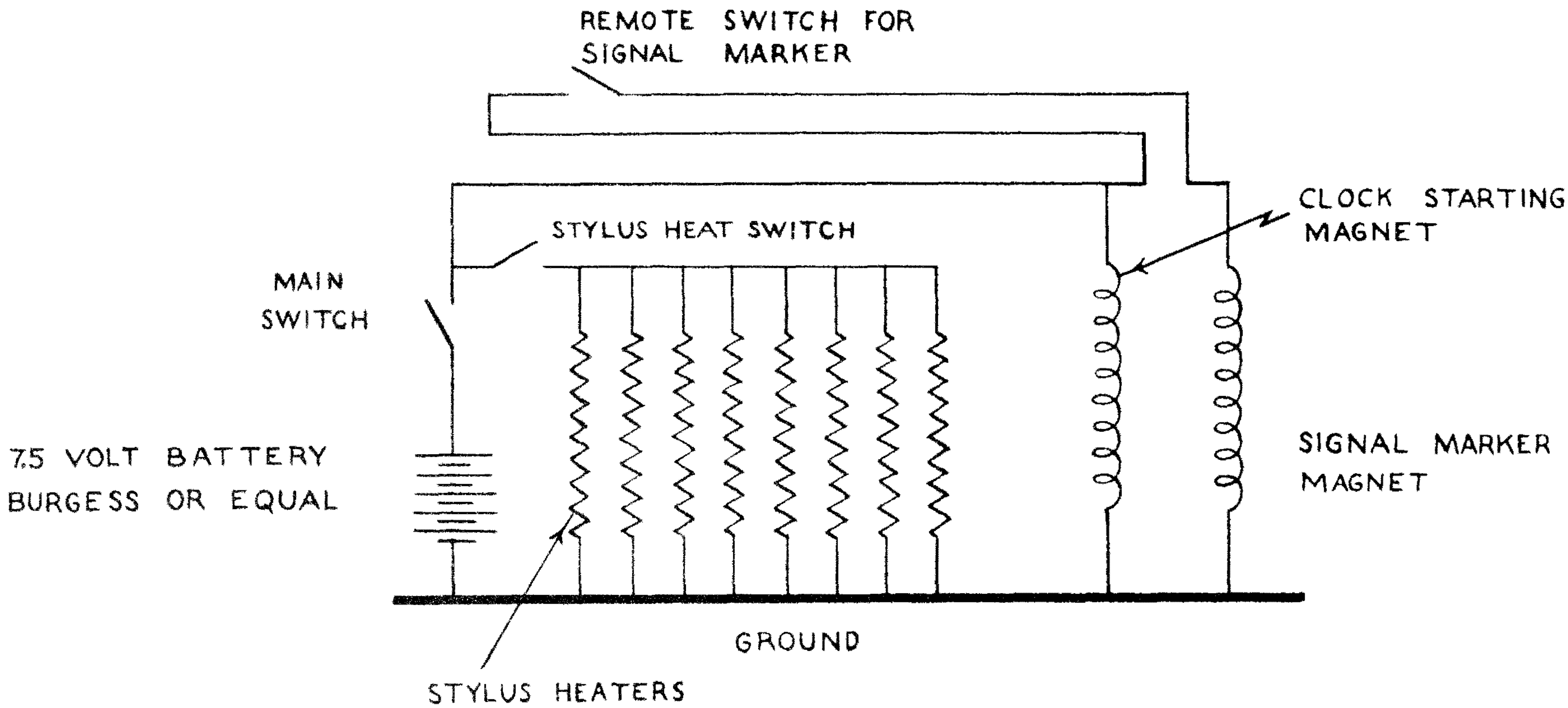


FIGURE 23
Final Chart Paper Sample



NOTE: ALL OTHER DECI. DIM.
ALL OTHER FRAC. DIM.
ALL OTHER RADII
ALL OTHER ANGLES

				SCALE	MATERIAL
				SPEC. NO.	SIZE
				FINISH	NUMBER REQUIRED
DATE	CHANGE	BY	APP'D		

WIRING DIAGRAM

FIG 24

INSTRUMENT LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASS.

JP — DRAWN — 6/23/43 DATE
NRC RECORDER — FOR
CHECKED — DATE
W. McK 6-23-43 — APPROVED — DATE

B-055
DRAWING NUMBER

APPENDIX A

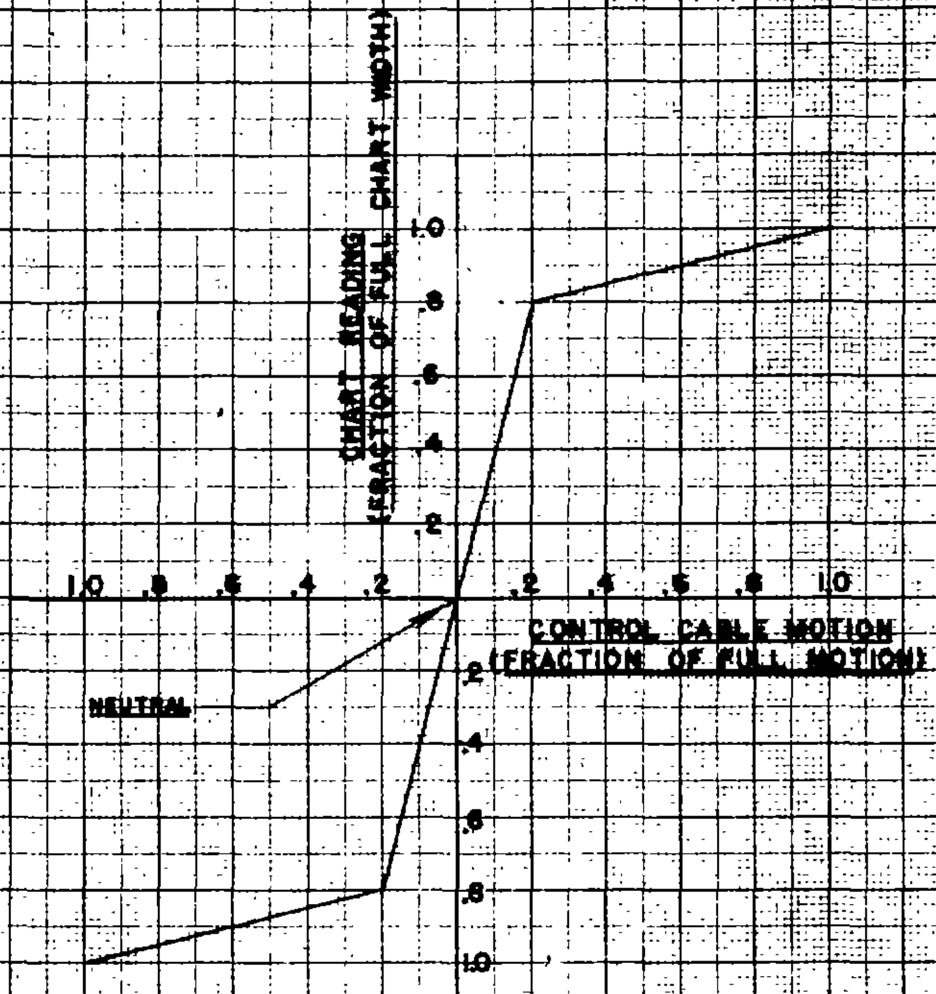
PHOTOGRAPHS AND DRAWINGS OF THE C.A.A.-N.R.C. FLIGHT RECORDER AND CHART PAPER

APPENDIX B

GRAPHS OF THE BENCH AND FLIGHT TEST RESULTS
AND
PHOTOGRAPHS OF THE INSTALLATION OF THE RECORDER

FIG. 25

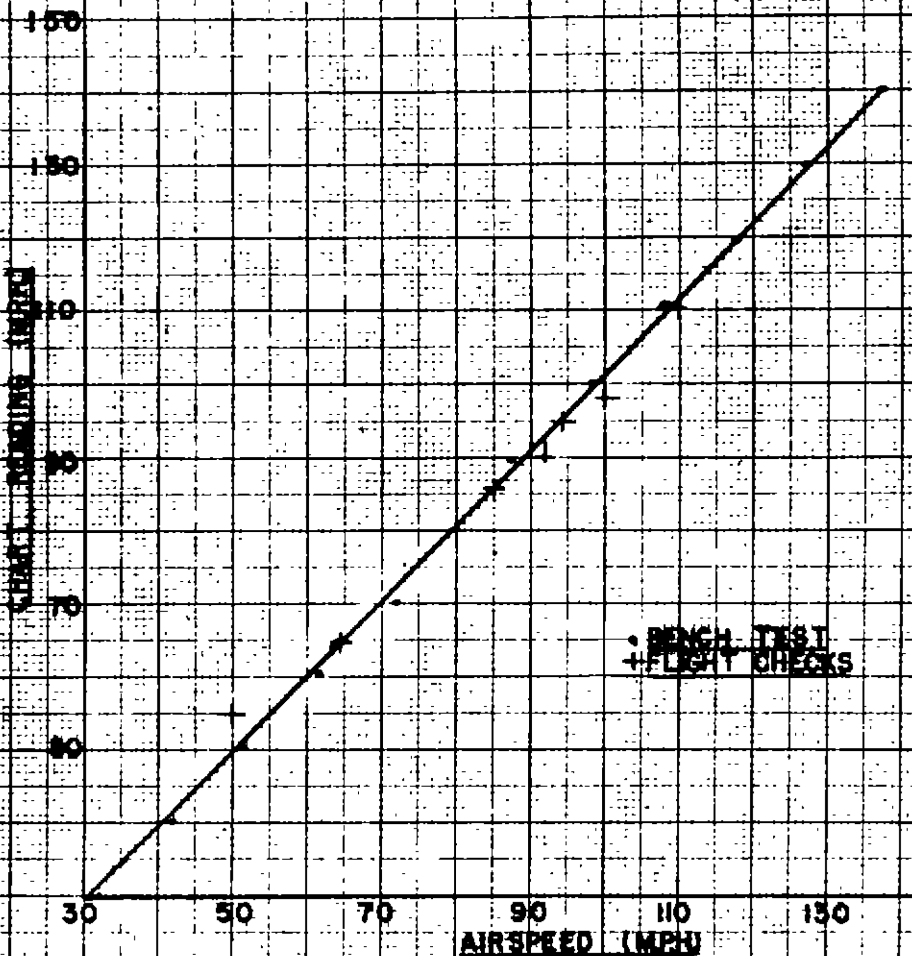
CONTROL POSITION ELEMENT CALIBRATION



M.I.T. AERO INST. LAB.
6-24-43 W.M. JR

FIG. 26

AIRSPEED ELEMENT CALIBRATION



M.I.T. AERO. INST. LAB.
6-24-43 WM JP

FIG. 27

ALTITUDE ELEMENT CALIBRATION

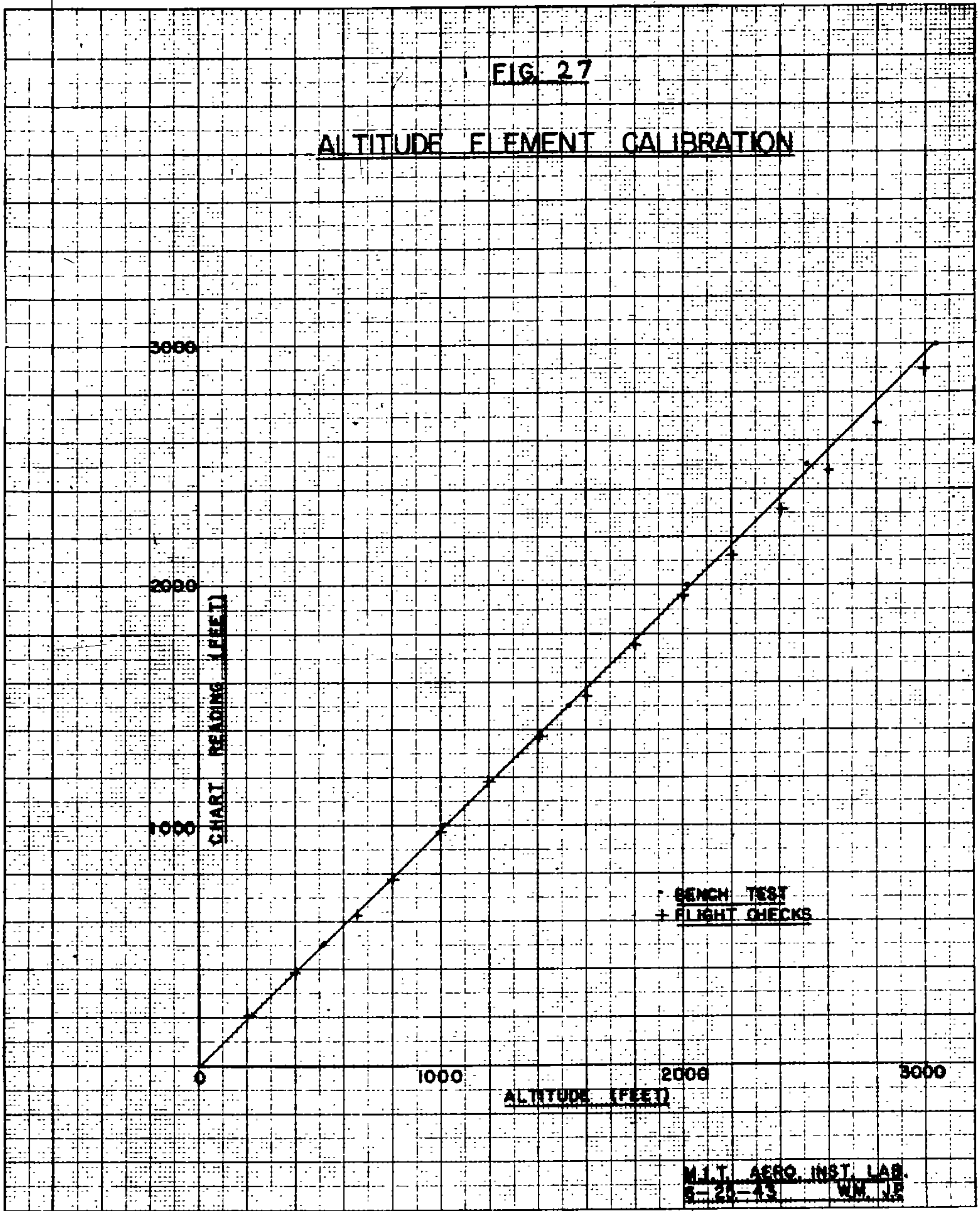
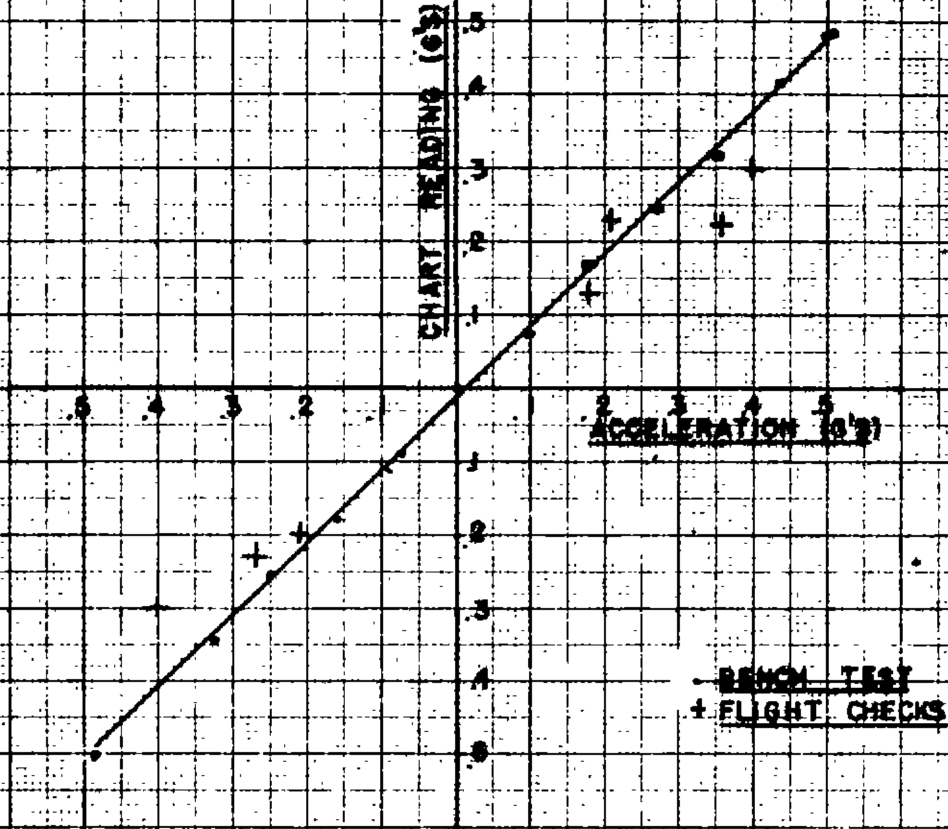


FIG. 28

LATERAL ACCELERATION ELEMENT CALIBRATION



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8-24-43 W.M. JR

FIG. 29

NORMAL ACCELERATION ELEMENT CALIBRATION

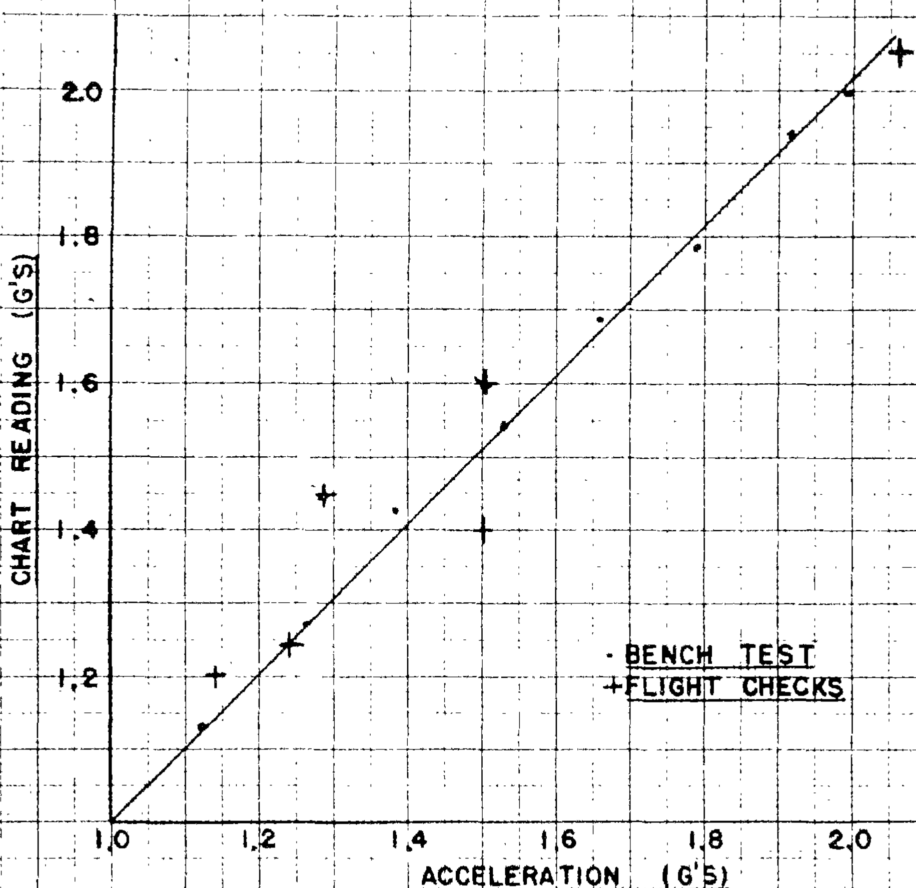

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FIGURE 30
Installation In Luscombe NC 23065

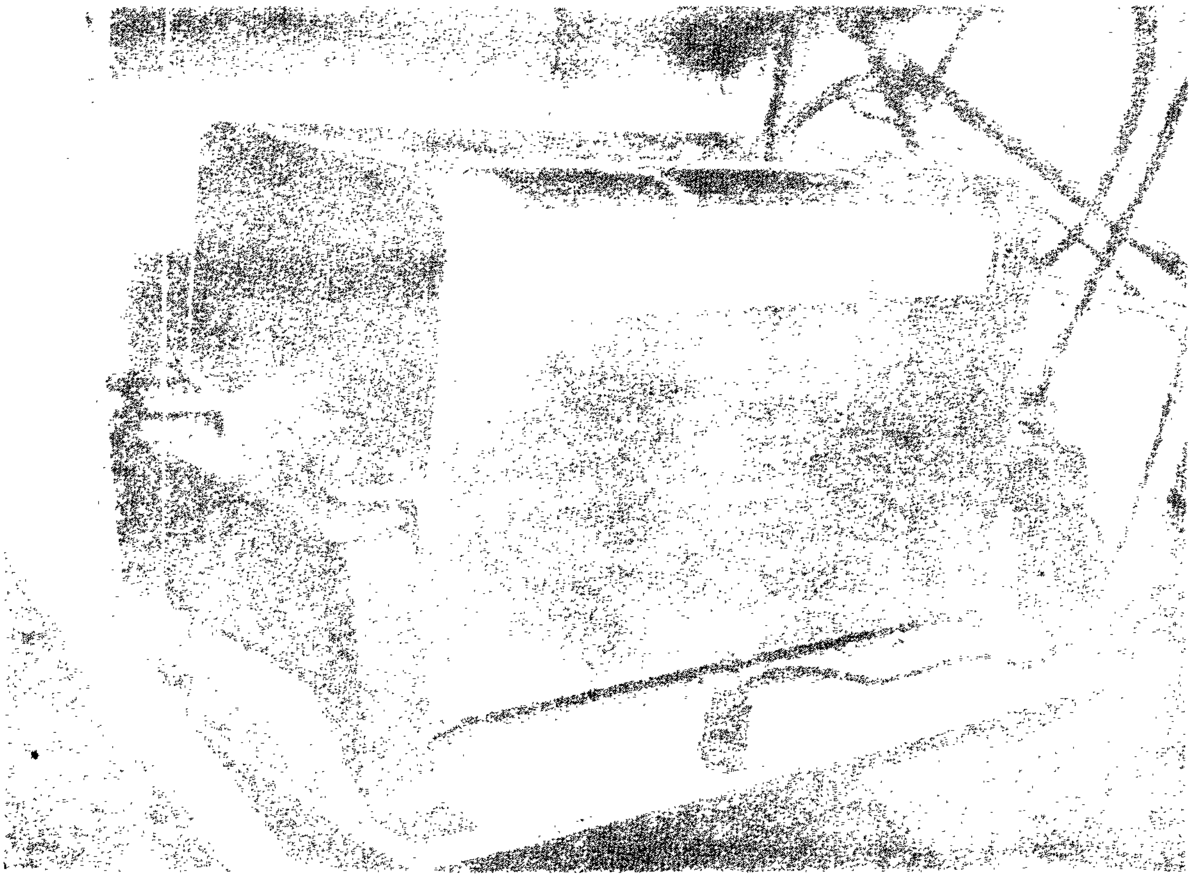

FIGURE 31
Installation In Luscombe NC 23065

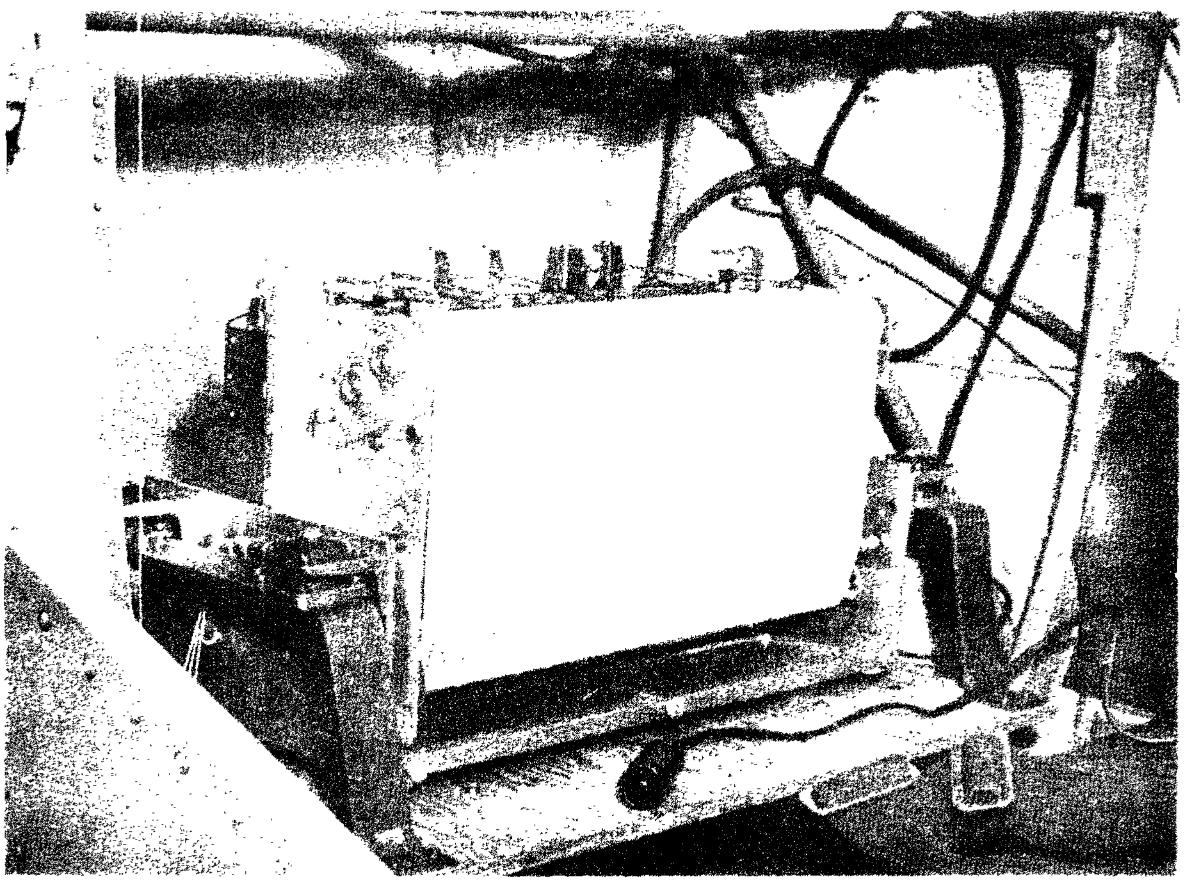

FIGURE 32
Installation In Luscombe NC 23065 - Cover Off