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THE RADIOTELEMETER AND ITS IMPORTANCE TO AVIATION

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FOREWORD

The author wishes to acknowledge the able assistance and cooperation of Blue Hills Observatory (Harvard University), the Feiber Instrument Company, and the U. S. Department of Agriculture, Weather Bureau, in the preparation of this report.

THE RADIOTELEMETER & ITS IMPORTANCE TO AVIATION

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SUMMARY

This report gives a brief history leading up to present developments of the various methods employed in the procurement of aerological data in the free or upper air, which is beyond the range of surface recording instruments.

It emphasizes the importance to aviation of accurate weather forecasting, and recounts the work which has been done in this science.

The radiotelemeter is a device which is carried into the stratosphere by a free balloon and consists of instruments to register temperature, humidity and pressure, and which, by means of an automatic ultra-high frequency radio transmitter, emits signals which carry such aerological data to the recording station on the ground.

The present radiotelemeter is the result of experimentation in the United States and in Europe. In this country several leading universities and institutions have contributed to its development. The National Bureau of Standards was responsible for much of the technical perfection of the instruments.

A detailed description of the "radiotelemeter", with its component units, its use in obtaining aerological data, the method of operation, and its usefulness, are discussed. Illustrations are included for purposes of clarification and ready reference.

The use of teletype circuits for transmission of weather data is briefly covered. The limitations of the instrument and the trend of development as well as the U. S. Weather Bureau program pertaining to aerological observations are discussed.

This latest method in the study of aerology, although it has not yet reached a stage of perfection, has proved its value and its practicability for a definite place in future programs.

INTRODUCTION

Safety in aviation is very largely dependent upon accurate weather reports and reliable forecasts. Weather data are provided hourly from points along the airways by trained observers. Since meteorological changes may take place in a very few hours, advance information as to such changes becomes highly important.

The Civil Aeronautics Authority is particularly interested in weather from the standpoint of air safety and this study was made to determine the present status of aerology.

This report is submitted for the purpose of acquainting those interested in aviation with the latest methods for the procurement of aerological data upon which to base forecasts. The information is disseminated with a view to coordinating the work being done and to assist in the correlation of further experimentation in this field.

The study of upper air conditions is sometimes called "meteorology of the free atmosphere", but more generally it is termed "aerology". It consists of the various methods of exploring and obtaining data pertinent to the upper atmosphere or upper strata, including the stratosphere, where topographical conditions have little or no effect.

The importance of accurate weather forecasting to aviation can hardly be overemphasized. Methods of weather forecasting have been improved from year to year, and much credit for this progress is due the United States Weather Bureau and cooperating agencies including the U. S. Army Air Corps, the U. S. Navy, the National Bureau of Standards, the air carriers, and the leading universities of the country.

It should be realized that the subjects of meteorology and forecasting have been studied in all their phases by specialists for many years. Not very many years ago it was learned that weather travels. It was also found that characteristic types of clouds indicated certain types of weather, and that areas of high and low pressure moved in characteristic fashion. The causes of various kinds of precipitation, and other fundamental principles of meteorological phenomena were discovered, but little was known about the unexplored upper regions, including the stratosphere, and their influence on weather.

Progress in the science of weather study was greatly accelerated with the advent of telegraphy, followed by the teletype. Then came the manned balloon, the kite with instruments attached, the sounding balloon, followed by the airplane, and more recently the radiotelemeter.

The coming of the airplane not only speeded up the study of aerology by its use in making upper air soundings at altitudes of up to 17,000 feet, but it also increased the demand for more accurate weather forecasting in the interest of safety.

The Civil Aeronautics Authority has developed more than 23,000 miles of lighted and radio-equipped airways and teletype communication systems for transmission of weather reports between stations. When it is realized that scheduled air transports fly in excess of 50 million miles annually, and that military services and miscellaneous commercial and private flying augment this by much more than an equal number of miles each year, the vital importance of accurate weather forecasting by the U. S. Weather Bureau and affiliated agencies can be appreciated.

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The backbone of a comprehensive meteorological service is communications. The extensive network of teletype circuits that crisscross the nation, supplies this need adequately. Nearly one-third (215) of the more than 700 weather reporting stations in this country are being operated by the personnel of the Civil Aeronautics Authority (formerly by the Bureau of Air Commerce) in conjunction with their regular communications activities. The close cooperation of the Weather Bureau and the Bureau of Air Commerce made this system possible.

The Civil Aeronautics Authority recognizes the importance of greater safety in aviation through intelligent long range planning, and is lending every support and assistance possible to encourage the further development of aerology.

BRIEF HISTORY OF UPPER AIR SOUNDINGS

The need for information concerning conditions in the upper air has long been recognized. Work, in this connection, prior to 1916, was conducted by means of kites, manned balloons, captive balloons, and sounding balloons. The facts disclosed by these methods were somewhat meager.

During the World War, a British flying officer while in France, became interested in the possibilities of meteorological observations from aircraft. He made notes of his observations that stratus clouds were most frequent in anti-cyclones; a temperature inversion existed immediately above the stratus layer; the lowest temperature of a cloud formation was near its upper surface; and definite heights of cumuli were necessary for thunderstorm development.

Other observations followed, and in 1918 - 1919, a total of 550 airplane observations of temperature and humidity was made in France by British meteorologists, the data being used in current forecasting.

This type of free-air investigation continued in Great Britain and in other European countries for a while. In the summers of 1924 and 1925, the records of soundings to heights of between 15,000 - 21,000 feet, obtained in Belgium, were presented in a report by M. Jaumotte, Director of the Belgium Meteorological Institute. He sustained the Bjerknes Theory that "the end result of the juxtaposition of two air masses of different temperature was a superposition of the tropical air over the polar air with mixing of negligible importance", as opposed to the Exner Theory that the end result was a complete mixing of the two masses. This is merely cited to indicate how recent have been the discoveries of upper air phenomena, which prove or disprove various theories of many years standing.

The first meteorological airplane observations in the United States were conducted by the U. S. Signal Corps in cooperation with the U. S. Weather Bureau at Aberdeen Proving Grounds in 1918. The results, although useful, were not entirely successful, due to the difficulties encountered in mounting the recording instruments on the airplane in such a way as to provide good ventilation, and at the same time to avoid excessive vibration.

During 1923, the Weather Bureau, cooperating with the U. S. Army Air Corps at Bolling Field, Washington, D. C., arranged a number of flights for the purpose of examining the dust content of the air to determine the relation between dustiness and visibility.

Flights were also made by the Bureau of Aeronautics, Navy Department, in cooperation with the Weather Bureau in April, 1925, at the Naval Air Station, Anacostia, D. C. These flights were made to an altitude of 10,000 feet, and marked the beginning of the use of obtained aerological data in current forecasting.

The adoption of a definite program of airplane weather observations marked the first step in bringing about a decided change in free-air exploration. It was then realized that the use of kites would eventually be abandoned. The practical method appeared to be a cooperative arrangement by the War and Navy Departments for regular flights conducted at strategically located fields over the entire country. The data obtained would be of immediate benefit to aviation and would increase the accuracy of general weather forecasting. This plan did not become a reality, however, until July, 1934.

In July, 1931, the Weather Bureau abandoned all but two upper air soundings by means of kites, and contracted for daily air-

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plane weather flights at Omaha, Cleveland, Chicago, and Dallas. The data obtained were supplemented by similar data secured in airplane flights of Naval Air Stations along the Pacific Coast. The two remaining Weather Bureau stations using kites for observations discontinued their use in 1933.

The following arrangements were made: Meteorological instruments (Aerometeorographs), which recorded the desired information, were fastened to the struts of the airplane. Upon returning to the ground, the data were evaluated, and the aerological information thus obtained was dispatched to the Weather Bureau at Washington, and to other forecast centers. This plan of upper air soundings is still in effect.

Valuable work was done by the Massachusetts Institute of Technology during the winter of 1930 - 1931, by investigating records of about 1300 soundings made by means of kites and airplanes. This resulted in an improved method for the greater utilization of upper air soundings. At Boston, the Army Air Corps cooperated by furnishing an airplane and pilot for daily observations throughout each school year, which continued until December, 1937. This work by M.I.T. and, later the work of the California Institute of Technology, and others, in utilizing airplane soundings for air mass analysis, have been of immeasurable value.

On July 1, 1934, the U. S. Weather Bureau increased the number of airplane observation stations to six. The Army maintained seven, the National Guard one, and the Navy's cooperation brought the total number to 23 stations.

The Bureau of Air Commerce cooperated and the Civil Aeronautics Authority continues to do so. It supplies airway radio and teletype circuits for the transmission of the data, beginning each morning at 7:10 E.S.T., which makes it available to all District and Airway Forecast Centers in the United States for the preparation of morning forecasts.

In addition to the use of box kites, since discontinued, and aircraft with meteorological instruments attached, pilot balloons were, and still are, being released daily, when visibility permits, at nearly 70 airport stations and offices of the Weather Bureau to obtain information as to the direction and velocity of winds at various altitudes. They also serve to give the height of the ceiling (distance from ground to lower cloud level or fog bank). This information is secured through the use of a theodolite. The operator sights the balloon through the instrument, makes notes of the angular readings, and then computes the data by triangulation.

Research work is now being conducted on a radio pilot balloon, for use during periods of low ceilings and poor visibility, which holds great promise. This will be discussed briefly in a later chapter.

RECENT DEVELOPMENT

From time to time sounding balloons were sent aloft by the Weather Bureau to obtain data from heights greater than those possible through the use of kites or airplanes. Beginning in 1926, the

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Fergusson Balloon Meteorograph was used, but was later discontinued. These balloons, filled with hydrogen, varied in size from less than one, to several meters in diameter. The plan generally used was to seal the balloon and send it aloft. As it continued to expand, due to the thinning atmosphere, it would eventually burst. The recording instruments (meteorographs) then floated to earth by means of a small parachute. Radio was not then available and, while some instruments became lost, approximately 85 per cent of them were returned in some areas for a small reward. The chief disadvantage of this system is that the meteorograph records are frequently not available until days, weeks, and sometimes months afterward (and in one case 23 years later) which render them useless for forecasting purposes.

Radio sounding balloons first underwent experimentation in France. This work was conducted by Capt. Robert Bureau, of the French Meteorological Office. A light, short-wave radio-telegraphic transmitter was suspended from the sounding balloon. It was designed to give indications of the pressure and temperature elements of aerological instruments "even after the latter has entered the stratosphere".

The first radio balloon sounding for temperature was made on January 17, 1929, and was followed by several others.

Leading universities of this country, as well as those abroad, have been working for years to perfect an instrument for the automatic transmission of aerological data by radio which would have a reasonable amount of dependability.

The recent development of ultra-high frequency radio of simple design and inexpensive construction, together with the improvement and simplification of meteorological instruments of light weight, have brought us to the era of the radiotelemeter for upper air soundings.

Prominent among the American educational institutions in this work have been the Blue Hill Observatory of Harvard University, the Massachusetts Institute of Technology, and the California Institute of Technology. The Army and Navy have carried on independent research, and also have collaborated with these institutions, and with the National Bureau of Standards and the U. S. Weather Bureau who have been ready at all times with every possible assistance.

In December, 1936, the Blue Hill Observatory, using its Harvard instruments, conducted the first regular schedule of radio soundings with free balloons in the United States.

From February to April, 1937, Massachusetts Institute of Technology and Blue Hill Observatory jointly conducted 31 radio soundings with Harvard radiotelemeters (then called radiometeorographs), proving their practicability in nearly all types of weather.

On September 1 and October 1, 1937 the U. S. Weather Bureau began daily radio soundings at three stations including

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Boston, where the Harvard instrument was employed, thereby giving the observatory further opportunity to improve equipment and technique.

An ultra-high frequency radio transmitter, and aerological instruments denoting pressure, temperature, and humidity had been improved. For example, the clock movement rotating the helix was found to operate longer when lubricated with graphite than with oil. It became apparent that the more simple each unit was designed, within limits, the better it performed its work.

RADIOTELEMETER ADVANTAGES

Just as the airplane replaced the kite in aerology, so is the radiotelemeter probably destined to supplant the airplane at least to a great extent.

The advantages of this small instrument over any other method of aerology yet devised are significant, and are limited only by the ability of experts to perfect further the mechanism.

Listed below are a few of the outstanding advantages of the radiotelemeter in comparison with aircraft for upper air soundings

1. Ability to go aloft regardless of weather conditions.
2. Ability to reach the stratosphere.
3. Instantaneous transmission of aerological data by radio.
4. The obtaining of information pertaining to icing conditions, without risk.
5. Relative low cost when built in quantity production.
6. Elimination of all hazards to equipment and personnel.
7. Greater coverage (more observations) due to probable decreased cost.

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At the present time, the instruments, while having occasional failures, are quite accurate and dependable.

DESCRIPTION OF APPARATUS

Radiotelemeters of other manufacture using the Olland type principle, are quite similar to those of Harvard, but a lengthy technical discussion is unnecessary for the purposes of this report. The following chapters will briefly describe that instrument, step by step.

Definitions

The instrument which is used for upper air observations is known either as a "Radiometeorograph" or a "Radiotelemeter". The entire observation is, in reality, a radiometeorograph observation including recordings and evaluations on the ground. Since the instrument itself has no graph the U. S. Weather Bureau terms it the latter, which designation will be used in this report. The three meteorological instruments which measure pressure, temperature, and humidity will be termed "Pressure Element", "Temperature Element", and "Humidity Element". These three elements combined will be termed "Instrument", and the electrical device which transmits the information will be termed "Transmitter". The entire unit will be called "Radiotelemeter".

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Housing

The housing of the latest Harvard unit consists of a balsa-wood box having outside dimensions of 7½" x 3 3/8" x 2½", with a wall thickness of one-half inch. It weighs less than 3 ounces, yet is sturdy enough to withstand normal handling without injury to the equipment.

The side on which the aerological instruments are mounted, as well as both ends, are painted white in order to provide shielding against false temperature recordings which would otherwise be caused by absorption of radiation from the sun in the upper atmosphere. The balance of the box is painted black to absorb warmth for the benefit of the clock mechanism, battery, and transmitter. A thin aluminum shielding with open ends is built around the instruments on the 3 3/8" x 7½" side of the box on which they are mounted to guard against false temperature readings by preventing actual contact of the solar rays with the bimetal thermometer, and to protect all of the elements.

The opposite side of the box opens by a slide door and allows easy access to the transmitter. (Fig. 1)

Clock

One of the most difficult problems encountered was the drive mechanism which converts the deflections of the instrumental elements into time signals. The observatory experimented with standard clock movements, special imported clock movements, fan

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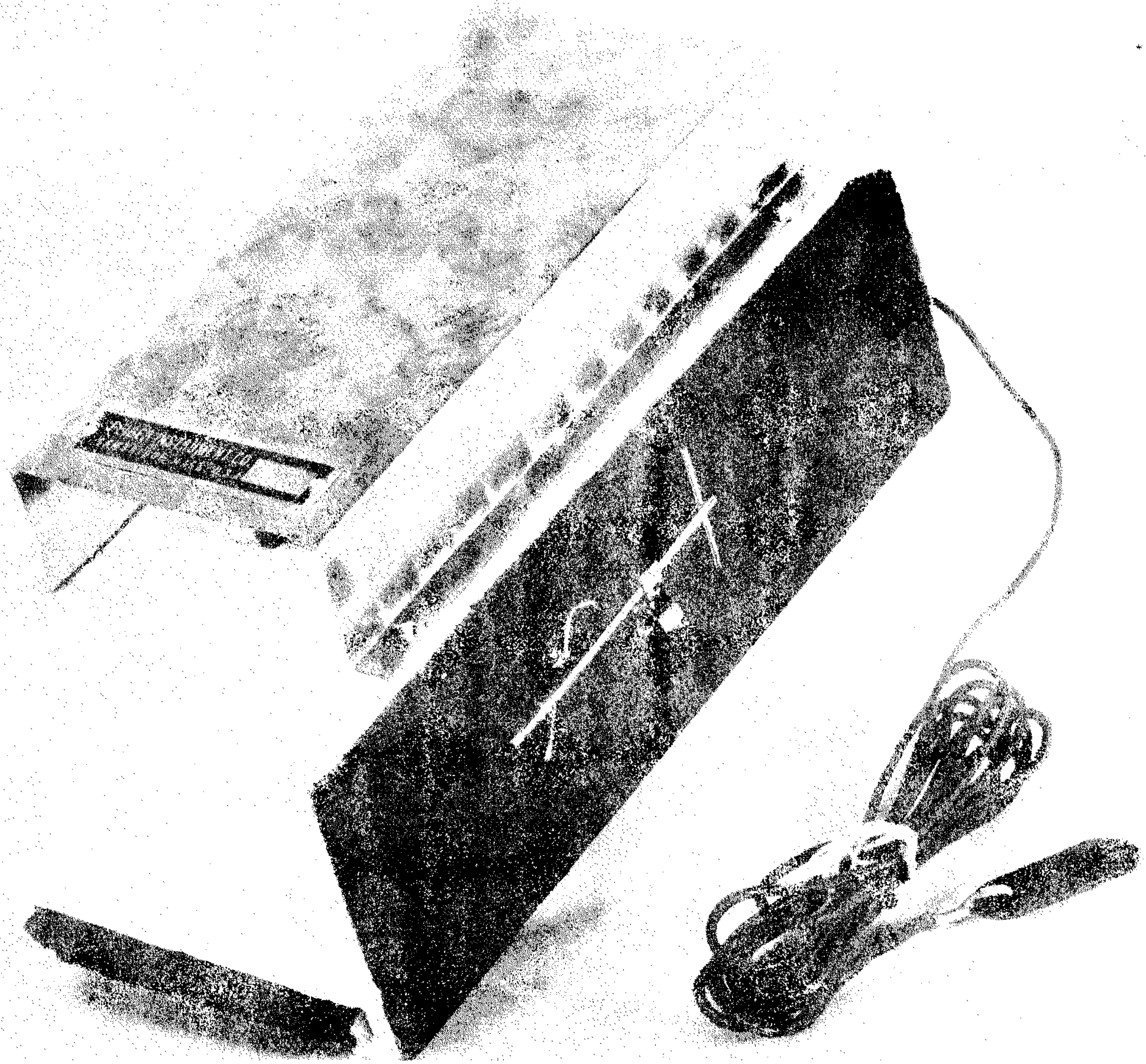

Fig. 1

The Harvard Radiotelemeter with antenna attached. Box, painted black and white houses the transmitter and clock. The key is for winding the clock. The aluminum shield covers the aerological instruments. Sliding door (on bottom) is for access to transmitter. Total weight 1.8 pounds.

(About two-thirds actual size)

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drives, governors, gravity drives, and small electric motors.

For all practical purposes, the watch or small clock movement was found to be the most satisfactory answer to the problem. It was necessary to redesign the mechanism, however, to double-quick time. In other words, the movement used is a twelve hour watch instead of a twenty-four, and the drive shaft which would ordinarily actuate the second hand at the rate of one revolution per minute, drives the helix two revolutions per minute. The movement is equipped with an escapement of 600 beats per minute. The mechanism used is that of an ordinary $1.50 watch of reliable manufacture.

Helix

The helix is a small shaft of about 1/8" in diameter and 1" long. It is made of insulated material, which is non-conductive to electricity. It is wound spirally from top to bottom three times by silver wire, which is countersunk in the insulation and turned down by a tiny lathe, so that the entire surface is smooth and even. The silver wire is electrically connected to the transmitter. The four pens (reference, pressure, temperature, and humidity) are likewise wired, and each time one of the pens slides over the silver wire of the helix a contact is made which bridges the grid leak of the transmitter. The circuit is then completed and the sequence signal is omitted by the transmitter to the observing station. The measurement of time between the reference pen and each of the other element

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pens (twice each minute), is the reading desired.

The helix shaft has two bearings - one in the clock and the other in the bakelite rain shield or housing. The housing is cast integrally with the base to which the clock is attached on the inside, and the instruments on the outside of the box. This bakelite shielding, or housing, encloses only about two-thirds of the helix, the open space being allowed for the pens to make their contacts (Fig. 2).

Reference Pen

The reference pen is fastened to the common bakelite base and comes in contact with the lower portion (part nearest the clock) of the helix. The pen is a fixed point and does not move, thus it comes in contact with the helix each time at exactly the same point and with the same time interval.

Measurements of pressure, temperature, and humidity are always made in relation to the reference pen. Just as altitudes are measured above or below sea level, the aerological readings are measured from this common datum point.

Pressure Element

The barometer is of the aneroid type, which is evacuated, and hermetically sealed. In common with the other elements, it is fastened to the bakelite base. This type of barometer is used extensively in measuring pressures. (Fig. 2)

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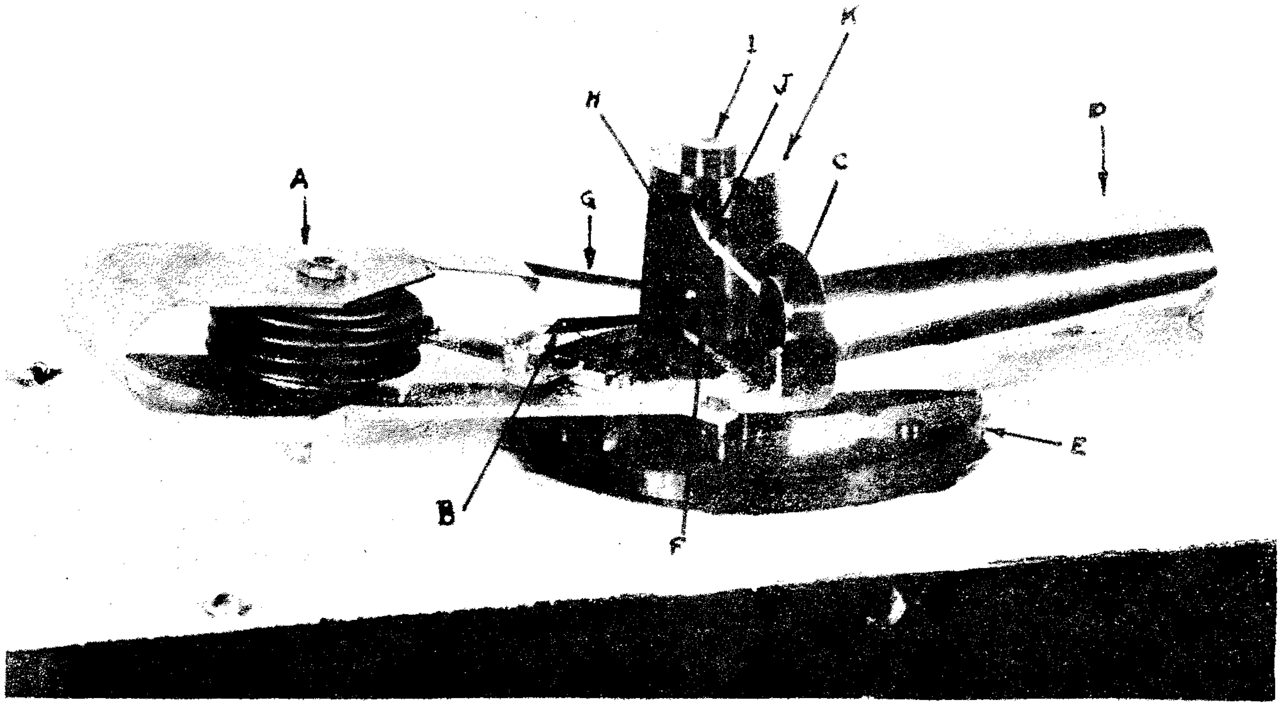

(About actual size)

Fig. 2

A. Aneroid barometer with 4 cells
B. Hygrometer showing hairs and pen
C. Temperature element
D. Shield for temperature element
E. Bakelite base
F. Reference pen
G. Pressure pen
H. Helix
I. Upper bearing for helix
J. Temperature pen
K. Rain shield around helix

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Outside pressure changes cause the expansion or contraction of the cell. When carried to higher altitudes, where pressures become less, the cell expands and the pressure pen, in contact with the helix, moves up or out, contacting the silver wire of the helix at a different time interval with respect to the reference pen. Conversely, when descending to lower altitudes, the atmospheric pressure increases, and causes contraction. The pressure pen in this case moves down, or in, toward the base of the helix. Differentials of pressure between the atmosphere and the inside of the cell control the movement of the pressure pen.

Temperature Element

The temperature element is of the bimetal thermometer type. It is mounted on the common bakelite base, with its pen coming in contact with the helix at the top, or near the outer end of the shaft. (Fig. 2)

The temperature element is shielded by a thin, light-weight metal cylinder or shell, two inches long and 3/4" in diameter, with both ends open. Shielding is necessary in order to obtain true temperature readings by preventing actual contact of the element with the sun's rays, and also for protection in handling, particularly after calibration.

The temperature element itself, mounted inside the shield, is about 3/4" long, curved cylindrically around 250° with a diameter of 5/16". It is fastened by two metal pins at each corner of the

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lower open side to the same base as that of the shield. To the upper outer corner of the other open side the temperature pen is fastened, which contacts the helix.

The metal used in the temperature element is extremely sensitive to temperature changes. As the instrument rises and the temperature falls, the curved element contracts, or tends to curl up and close the gap of its open end, thereby drawing the pen which is in contact with the helix to the direction of the reference pen.

Conversely, as the instrument descends by parachute into higher temperatures, the element expands, or tends to uncurl, pulling the pen away from the reference pen. This is all told in graphic form at the observing station on the automatic recorder, in the same fashion as the pressure element always in direct relationship to the reference pen recordings.

Temperature readings of this element have been quite accurate from sea level to the stratosphere, where they remain constant. Such information is useful to the Weather Bureau in preparing forecasts.

Humidity Element

Accurate hygrometric measurements of the radiotelemeter are of utmost importance, but they are made difficult by the lack of a hygrometer which reacts quickly at low temperatures.

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At the present time the hair hygrometer is used. It has five strands of human hair, each $1\frac{1}{2}$" long, stretched up and over the humidity pen which in turn contacts the helix. As the humidity of the air increases, the hairs lengthen. This causes the pen, which has a slight spring tension, to move out, or away from the base of the helix and the reference pen. As the humidity decreases, the hairs contract or tighten, and thus pull the pen down, or in the direction of the base of the helix, and closer to the reference pen. The humidity readings, like the others, are evaluated with respect to the reference pen.

The hygrometer is attached to the common base along with the other elements, and is located halfway between the pressure and temperature elements. (Fig. 2)

Humidity data are now reliable only to altitudes of approximately 15,000 feet, due to lag and to the inability of the instrument to react favorably in extremely low temperatures, which cause the hairs to freeze, and render accurate calculation of relative humidity almost impossible.

Diligent work is now being carried on by the National Bureau of Standards and other organizations to perfect a more accurate and sensitive instrument to replace the human hair for humidity measurement. Encouraging results have been produced to date.

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Calibration

All of the elements, or instruments, must be carefully calibrated before being used, otherwise such errors would exist as to make the record of readings valueless.

The work of calibration requires about two hours and is done in a special chamber designed for that purpose (Fig. 3). The chamber is a box about the size of a large, old-fashioned hamper, well-built and insulated, which accommodates seven instruments at one time. The recorder, on a continuous chain, and located adjacent to the calibration chamber, automatically makes records of each of the elements, determined by their distances to marks made by the reference pen. A relay trips a recording pen each time that contacts are made, by an instrument, or element, with the helix. These pens are attached vertically to the endless chain and are carried across the paper at such a rate that they return to the starting edge after each revolution of the helix. If an element pen should move, contact will be made either sooner or later than its previous position. The variation in time is a measure of the change in the element actuating that pen. Contacts must be positive and sharp at "make" or "break", otherwise the measured distances will be inaccurate. The traits or peculiarities of each element are thus definitely known.

The same type of recorder, although mechanically different in some respects, is used for recording data during actual soundings.

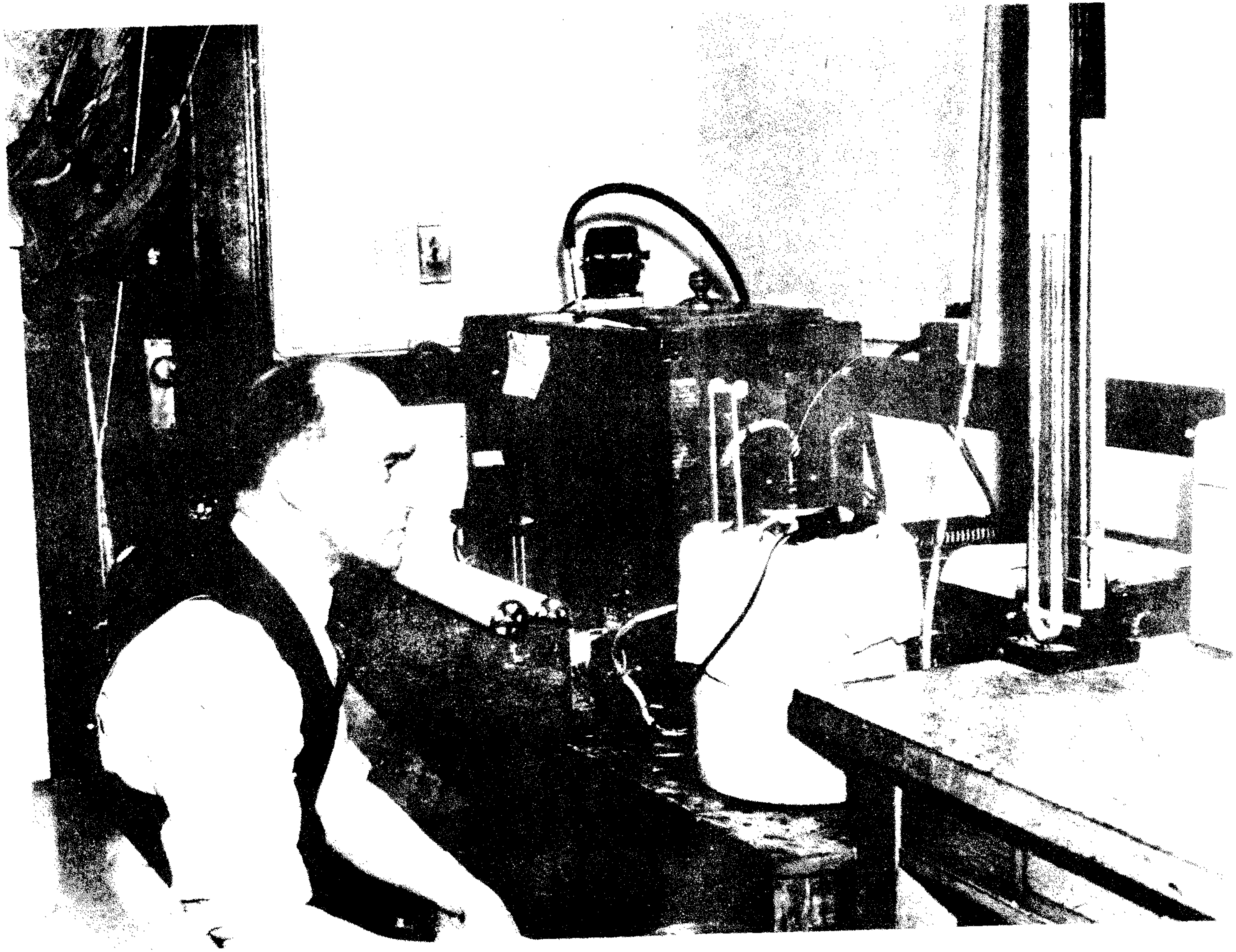

Fig. 3

Calibration chamber, during humidity calibration (Moist test). Recorder at right.

The methods employed in simulating comparable conditions to those found in the stratosphere for calibration purposes are interesting and somewhat ingenious. Dry ice and alcohol are used to obtain lower temperatures and they are circulated by a pump to induce temperatures to below -50° C. All stages of temperature and pressure are used from those found in the room to the extremes to be found 15 miles above the ground. The humidity element is likewise calibrated by inducing various degrees of humidity within the chamber.

The equipment at Boston is located in the Airport Weather Office. After calibration, the instruments are handled carefully and as little as possible, so that the delicate elements will not be disturbed.

Transmitter

The transmitter is located inside the housing or box. In comparison with other transmitters, it might be considered a miniature, since it is so small and light that it could easily be slipped in one's coat pocket without notice. (Fig. 4)

The radio transmitter operates on a fixed frequency of 68 megacycles. This frequency is high enough to avoid most of the congestion on the radio spectrum. It is favorable for transmission over great distances with a minimum of power; moreover the short antenna measuring seven feet used for this frequency simplifies the launching problems.

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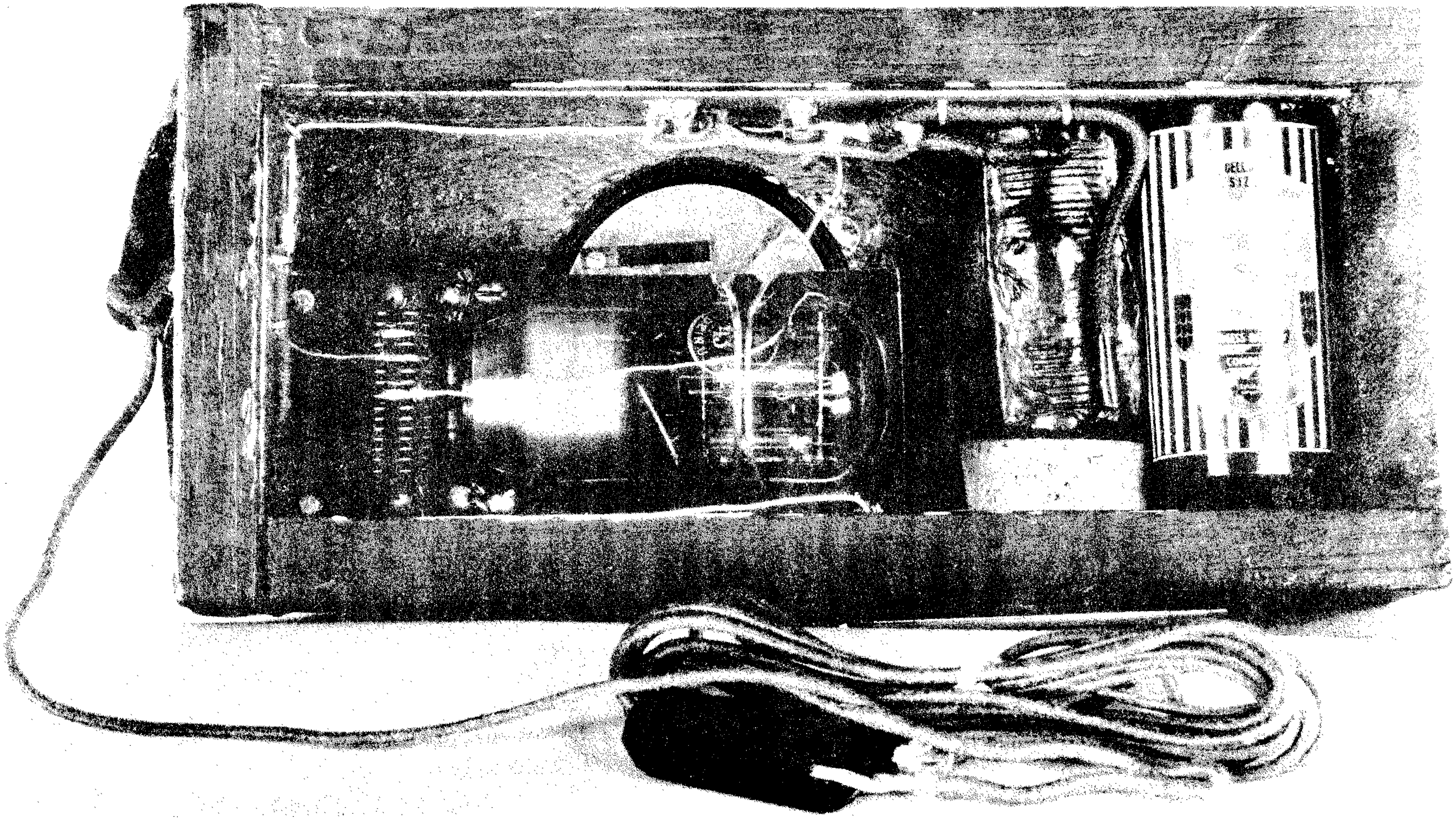

(Actual size)

Fig. 4

Complete transmitter used in the Harvard instrument. The clock is located behind the tube.

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The single tube used is, in reality, two in one, as it serves a dual purpose. It is a low filament current twin-triode tube, in a push-pull tuned oscillator circuit, which does the work of the two tubes formerly used.

Attached near the base of the tube is the coiled tuning inductance.

At the other end of the box there is located a uni-cell dry battery, no larger than an ordinary flashlight cell, which supplies the filament current. Another battery, even smaller, supplies the plate current of 45 volts.

There is ample space left for the insertion of a water container and the light packing used to delay the penetration of the extreme cold to the batteries, clock, and transmitter.

Signals are emitted each time the circuit is closed - four times every 30 seconds. This is done as each of the four pens contact the silver wire of the helix, which makes a complete revolution every 30 seconds.

Radiotelemeter Unit

The entire unit, comprising the housing, aerological instruments, transmitter, clock, water container, and packing, ready for ascension weighs 800 grams, or about 1.8 pounds. It is wrapped in a very fine, soft crepe paper, as an additional precaution against the intense cold. The open ended shield covering the aerological instruments, however, is left uncovered so that actual conditions of the upper air will be reported as found.

DESCRIPTION OF OPERATION

Launching

The launching can probably be best understood from a description of an actual ascent made at the Weather Bureau airport office, Boston, at 4:15 AM, March 10, 1938. The stages of technique involved were: routine tests, assembly, launching, recording, evaluation and dispatch of the data to Washington.

The radiotelemeter unit had been previously assembled with calibrated instruments, transmitter and a seven foot antenna. The water container was placed within the box, the clock was started, and the assembly was carefully packed and wrapped. It was then carried to the instrument shelter where it remained for about 10 minutes in order to acquire a steady state in the proper environment. While there, the radio receiver and recorder in the Weather Office were tuned in, and the signals were observed as the contacts were made. A standby radiotelemeter was ready for service in case of malfunctioning. Everything functioned properly, however, and preparations continued for the launching.

The balloon used was of cast latex rubber. It weighed only 350 grams (2/3 of a pound) and when inflated with hydrogen to a diameter of 5 feet, this type would usually soar with its burden to altitudes of ten to fifteen miles before expanding to the bursting point. The inflation of hydrogen from the cylindrical container

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was done with care to prevent any chance of fire. Weights were attached to the bottom of the balloon, and when it was capable of lifting a little more than two pounds, the diameter of the balloon was about five feet. It was then tied tightly with cord at the neck to prevent any escape of the gas, and was carried outside. (Fig. 5)

A heavy string about six feet long was attached to the neck of the balloon and to this string was tied an envelope containing a warning of the fire hazard should the balloon be found intact. The finder was requested to read the enclosures and was offered a reward of one dollar for the return of the instruments. The enclosures consisted of a franked sticker, self-addressed to the Weather Bureau Airport Station at Boston, a "VERY FRAGILE" sticker, a self-addressed franked postcard giving mailing instructions, a questionnaire for details of the discovery, information regarding its original release, purpose thereof, etc.

To the lower end of the string was attached the parachute made of plain red, silk cloth, with shroud strings two feet long. These were attached to a ring of two twisted reeds, which in turn was tied to another heavy string ten feet in length. Eight rubber cords tied at the top and bottom of this string allowed slack, to guard against undue shock to the instruments while in turbulent air. To the lower end of the string was tied the seven foot aerial attached to the radiotelemeter.

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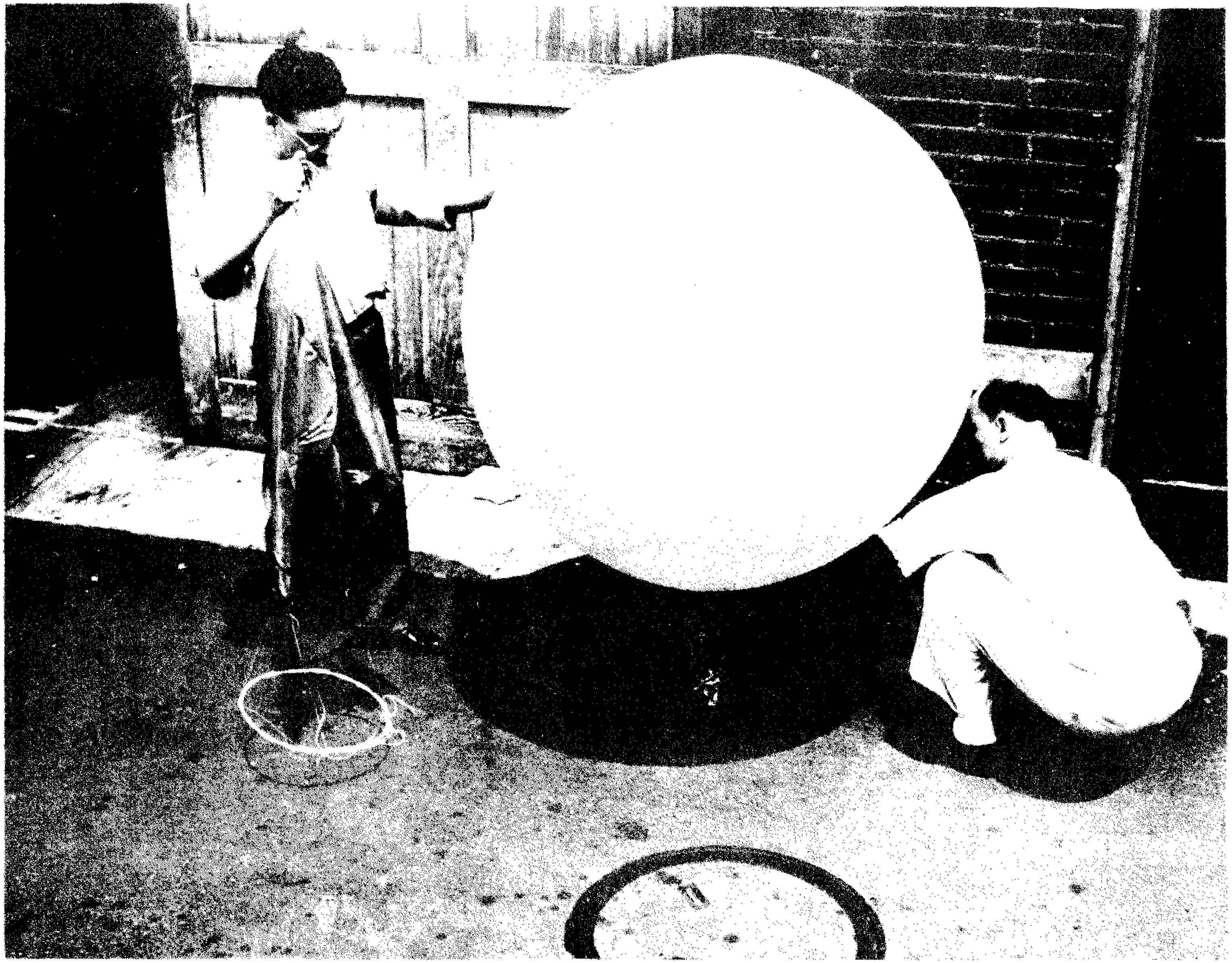

Fig. 5

Inflating the balloon. Note the weights under balloon. It is inflated until capable of lifting more than 2 lbs. Operater at left is holding parachute ready to be attached in the final assembly.

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With this done, the entire assembly comprising (from top to bottom) the balloon, string with envelope attached, parachute with rigging, string with rubber shock cords, aerial, and radio-telemeter was then ready for release. (Fig. 6)

Signals were being emitted several minutes prior to the actual launching. The radio receiver was tuned in. The recorder was in operation, and the signal impulses made their four marks every thirty seconds on the margin-guide-perforated recording paper, which moved at a very slow but constant rate from its roll out on to the table. (Fig. 7)

The balloon with its cargo was released at precisely 5 27 AM and began its ascent at the rate of approximately 700 feet per minute. The observers proceeded to the weather office immediately to keep the radio tuned, to see that the recording equipment continued functioning, and to perform the important work of evaluating rapidly the recorded signals for synoptic purposes.

Soundings, Recordings, and Evaluations

Evaluation began within a very few minutes after the instrument was launched.

The reference line of dots or small dashes made by contacts of the reference pen was easily discernible by the comparatively straight course it followed across the paper. A colored line was drawn across these contacts as they progressed, and from this line the other measurements were taken. Contacts made by the temperature element were quickly identified, as this line had a

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Fig. 6

The sounding equipment is sent aloft. One of the numerous experimental flights, differing in some respects from that described, but similar in operation.

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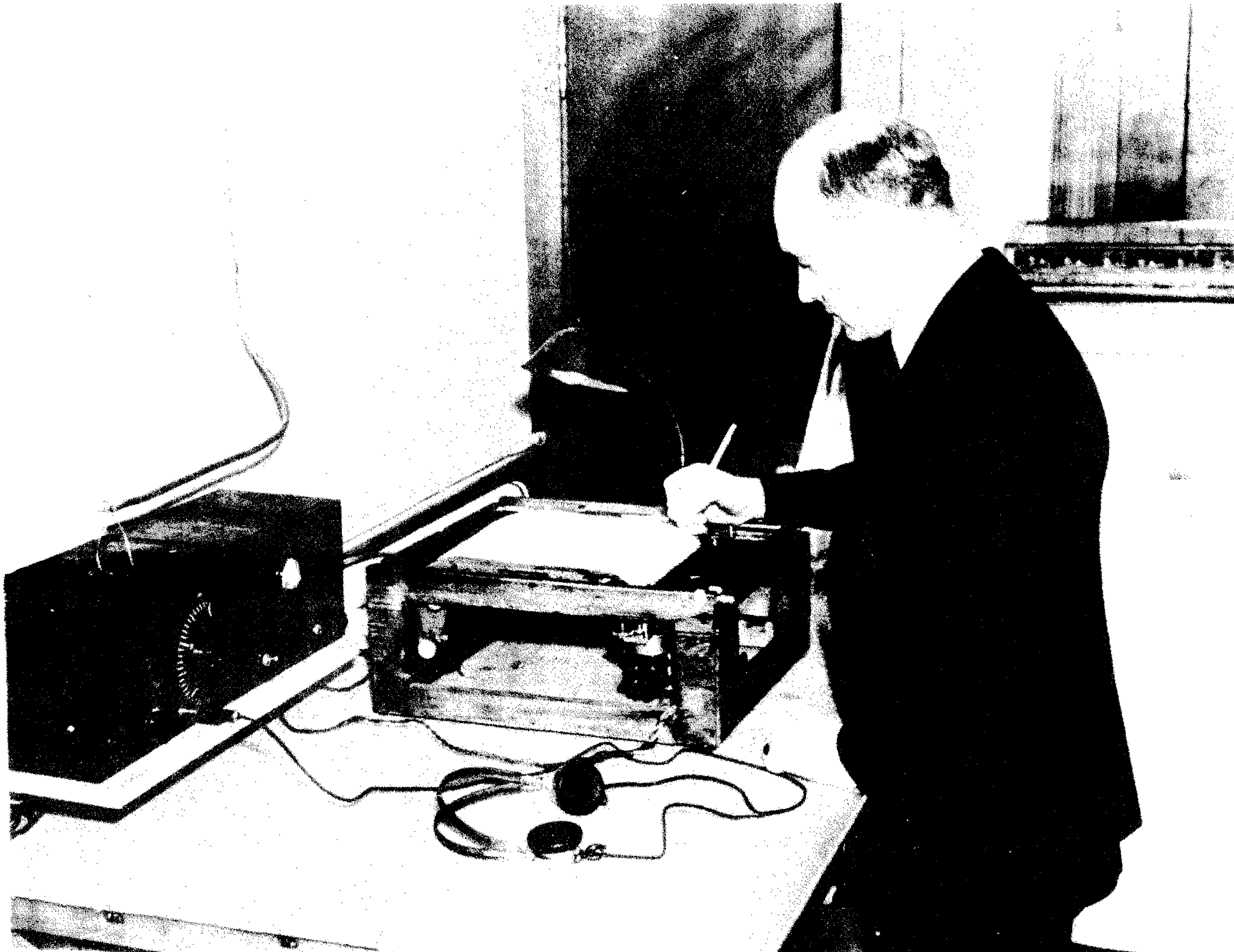

Fig. 7

Recorder in operation. Operator is drawing lines connecting signal impulse marks for each element, for later measurement and evaluation. Radio receiver (left) with earphones for tuning.

definite and rather steady trend to the right, indicating falling temperatures. A differently colored line was drawn through this series of contact marks. The pressure contacts formed a line veering to the left, denoting decreased pressure, as did the humidity line which meandered, indicating various degrees of moisture in the air. Each of these lines was given its individual color, and thus the four tracks were followed without doubt or confusion. (Fig.8)

Significant, or progressive points, were selected and numbered in corresponding positions on the four lines or tracks. To determine the value of an element at a given point, the distance was measured from the reference line to the same point on the element line by a pair of dividers. (Fig. 9) The same distance was set off on the calibration curve, and the value was then read off the scale, then plotted on the Adiabatic Chart. This routine of measurement was repeated over and over for each of the elements, and as the balloon continued to rise with its ticking, transmitting, data-finding cargo, it was only a matter of a few moments until the altitude, temperature and humidity encountered on the wandering course were known.

Below is a greatly abbreviated record of the sounding. It will be noted that humidity evaluations were omitted after passing above the 10,000 foot level due to lag, largely induced by the hairs of the hygrometer freezing and stiffening, and the rapid rate of ascent.

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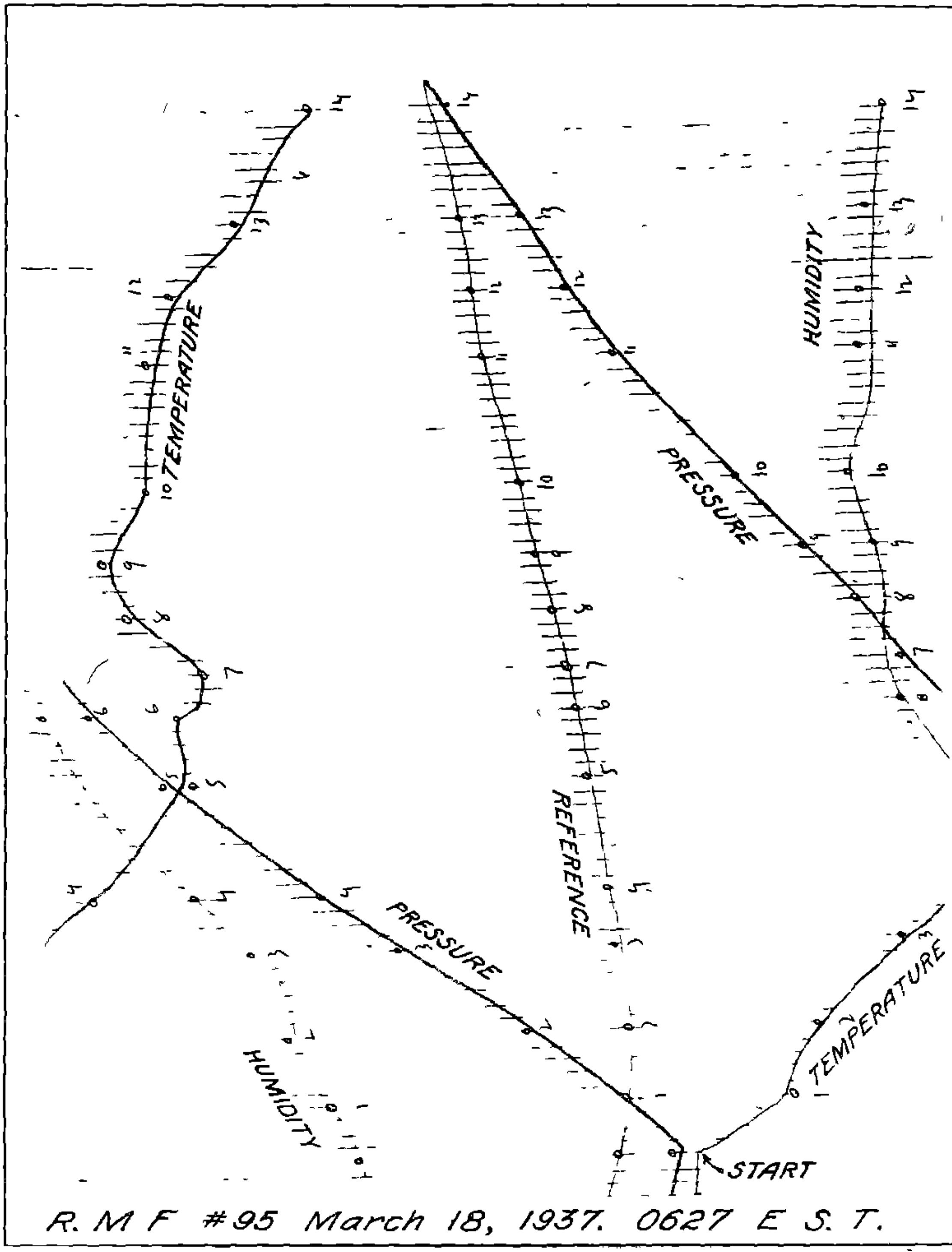

Fig. 8

A typical recording. Note comparatively straight reference line, also temperature inversions, fluctuating humidity and steady fall of pressure, the latter denoting increasing altitude. The temperature recording was picked up (lower left) where it ran off paper (lower right). Likewise the pressure recording was picked up (center right) where it ran off paper (center left). Numbers denote corresponding positions. They are written in as the recording progresses to obtain correct measurements. For example, measurement from the reference line at station "10" would be to station "10" of the other recordings.

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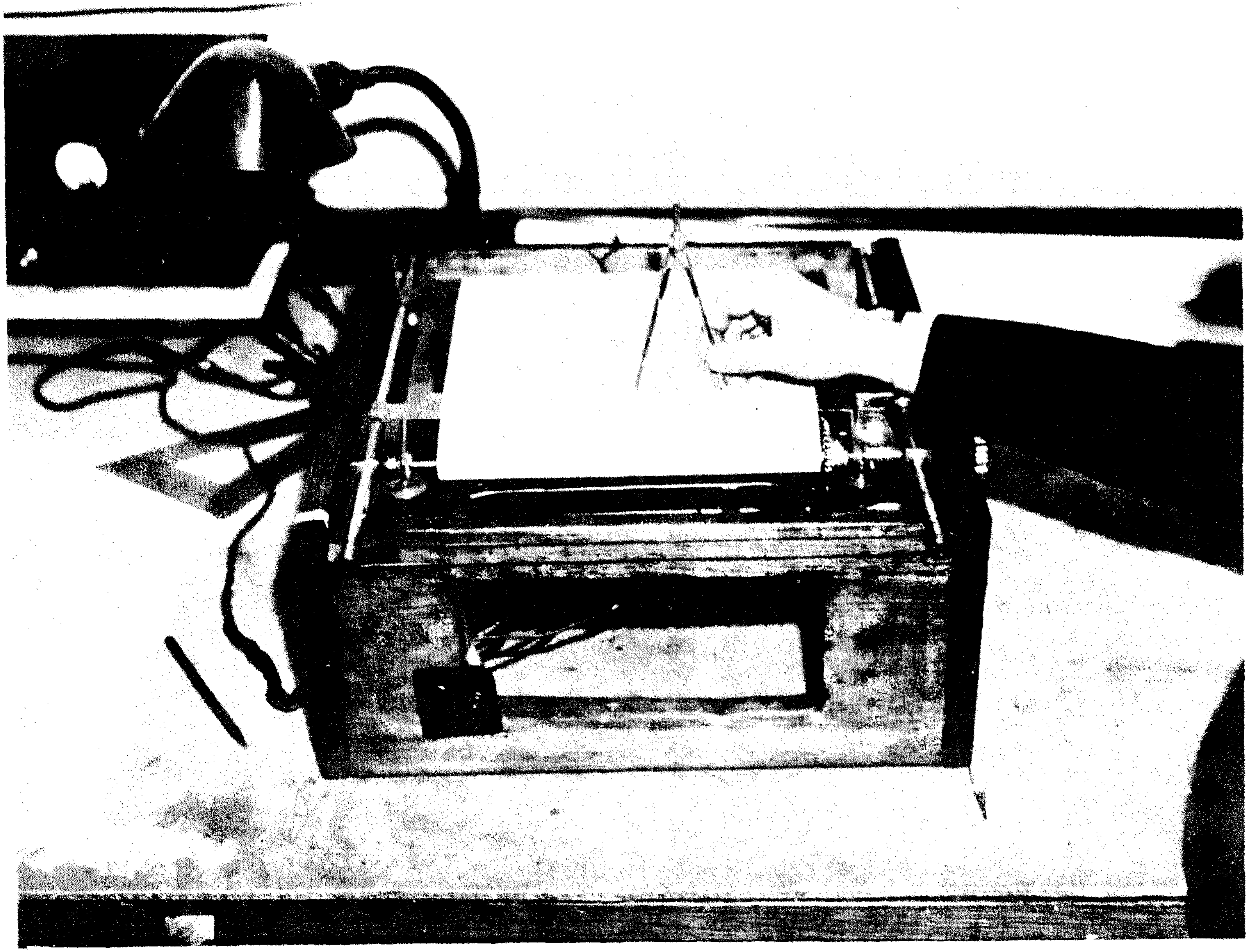

Fig. 9

The recorder. Operator is measuring distances from the reference line to the other lines with a divider. He then sets off the same distance on the calibration curve, reads the value from the scale, then plots the data on the adiabatic chart.

Altitude	Temperature	Humidity
2,000 feet	19° (F)	71
4,000 "	12° "	70
6,000 "	17° "	69
8,000 "	13° "	63
10,000 "	8° "	64
14,000 "	-2° "	-
37,900 "	-68° " (-55° C)	-
43,000 "	-52° " (-46.5 C)	-
72,200 "	-49° " (-45 C)	-

The equipment went to an altitude of 72,200 feet, nearly 14 miles high. It reached this altitude at 7.04 AM, in one hour and 37 minutes after the launching. It was noticed that the pressure element contact marks swung sharply to the right at this point, indicating increased pressure which, undoubtedly, was caused by the bursting of the balloon, followed by the opening of the parachute and the beginning of the trip back to earth. The signals continued for six minutes and then ceased at 7:10 AM, probably due to stoppage of the clock mechanism because of extreme cold, or from an unknown cause.

The transmission of signals had continued for one hour, 43 minutes, and the sounding at Boston for March 10th was considered successful.

While the flight was in progress, the data had been recorded, evaluated, and graphed. Conditions were known up to the stratosphere. It was learned, for instance, that at about a mile high there existed a temperature inversion, the temperature being 5° (F) higher at 6,000 feet than at 4,000 feet. It was found that the coldest temperature recorded was 68° (F) below zero at 37,900

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feet, and that another temperature inversion existed at 43,000 feet, where it rose to -52° (F). It continued to warm up gradually to -49° (F) at 72,200 feet, remaining quite steady for the last 30,000 feet.

Communications

Fully as important as accumulating the aerological data is the prompt dispatch of the information to the forecasters of the U. S. Weather Bureau at Washington, D. C., and other forecast centers, prior to the synoptic hour, 7:30 AM E.S.T.

The Civil Aeronautics Authority maintains teletype circuits, augmented by point to point radio which provide a network of communications facilities covering the airways of the country. Through a cooperative arrangement, the U. S. Weather Bureau utilizes this equipment for the transmission of weather data. Consequently, information concerning weather conditions to be found on any civil airway within the hour is available on bulletin boards to pilots and others. The Authority broadcasts such information by radio at periodic intervals during each hour for the benefit of airmen in flight. (Fig. 10)

At Boston, as at many other important stations, the U. S. Weather Bureau and the Airways Operations Division of the Civil Aeronautics Authority share adjacent offices where all facilities are available. When an operator types a message on the teletypewriter, the same message is reproduced instantaneously along that particular circuit. There are relay or clearing house stations, called principal

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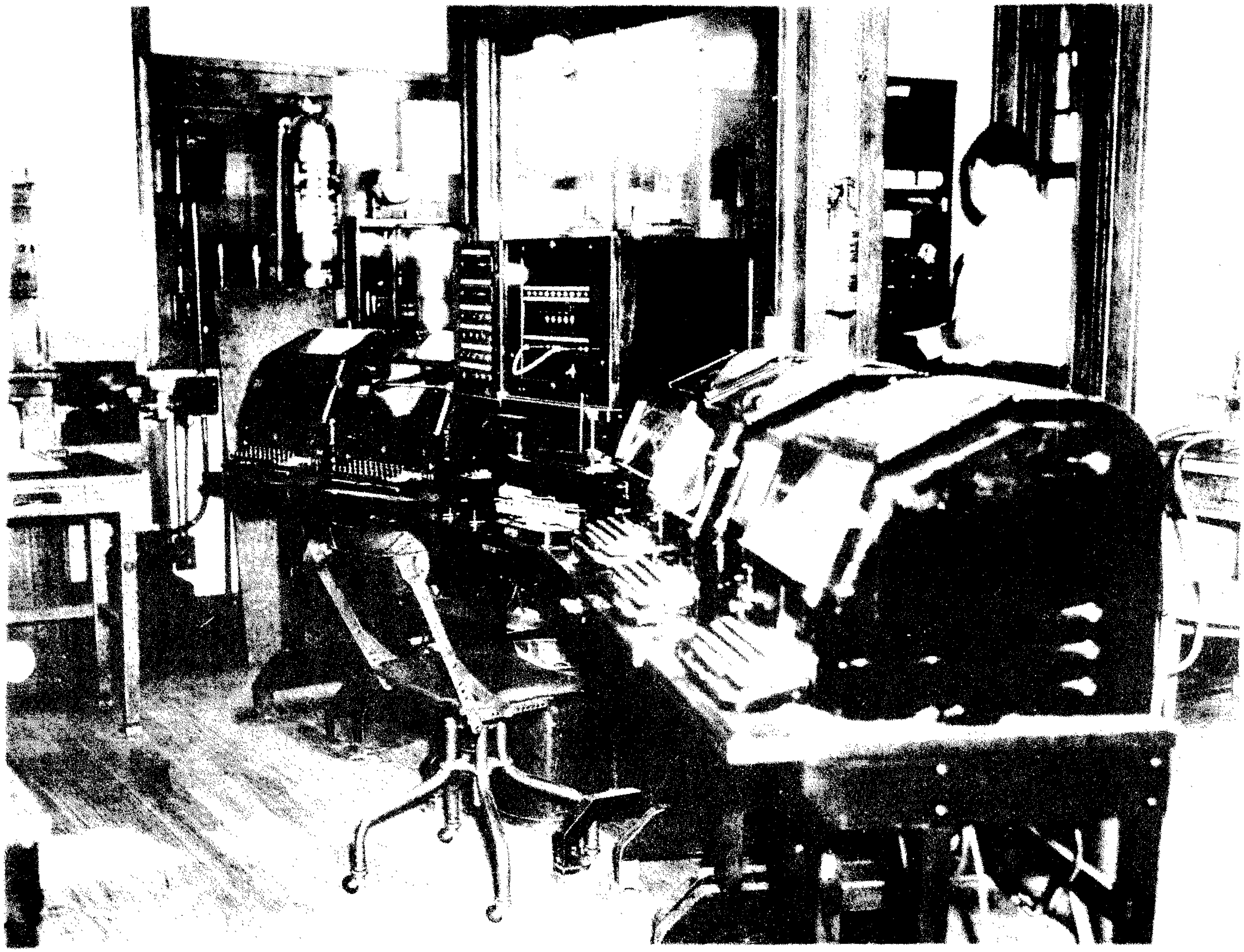

Fig. 10

Interior of a Civil Aeronautics Authority airways teletype station showing teletypewriter machines and radio broadcast booth. The radio operator in the booth is making a scheduled hourly broadcast to airmen.

teletype stations, for relaying messages to other points. Boston to Washington messages are quickly relayed at Newark and are received at Washington shortly after transmission at Boston.

The first report of soundings was put on the tape at approximately 6:30 AM. The radiotelemeter had been aloft nearly an hour and the data already received gave the forecasters in Washington and other centers advance information with which to begin work. The final message was dispatched at 7:12 AM and the information was in the forecaster's hands well ahead of the synoptic hour of 7:30 AM, E.S.T. when all data from all sections of the country are plotted for the daily forecasts.

Salvage

The question arises as to how many instruments are found and returned to the U. S. Weather Bureau and the damage done to them in landing and handling.

Below are a few examples:

Location	Number released	Percentage found
Fairbanks, Alaska	83	1%
Los Angeles, California	117	22%
Amarillo, Texas	8	50%
Dallas, Texas	77	83%
Waco, Texas	44	84%
Denver, Colorado	15	87%
Omaha, Nebraska	311	91%
Fargo, N. D.	64	91%
Huron, S. D.	26	92%
St. Louis, Mo.	123	92%
Nashville, Tenn.	15	81%
Atlanta, Ga.	30	43%
Boston, Mass.	80	4%

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These figures are a few months old, but they serve to indicate that the percentage of recovery is surprisingly high. Recovery of instruments sent up from Boston is very low due to the prevalence of prevailing winds from the west blowing the instruments to sea. Three of these instruments were found on Cape Cod, a narrow strip of land 65 miles east, southeast of Boston.

Sometimes the damage to the instrument is extensive, but usually it is trivial and the apparatus can be repaired and recalibrated at small expense. Information concerning the location where they are found is useful to the Weather Bureau.

DISCUSSION

Limitations and Trend

The present radiotelemeter has no means by which information concerning haze, visibility, snow levels, turbulence, etc. can be provided.

It is not yet able to determine accurately the height of clouds, except when the observer is thoroughly experienced in both instruments and meteorology. Improved hygrometers will help to remedy this deficiency. Blue Hills Observatory and other organizations are experimenting with the use of photo-electric cells for this purpose. It is generally believed that this is the proper method of attack on this problem which shows every indication of early solution.

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The present instrument has not yet been developed to the point where it can provide information concerning the direction and velocity of winds at different altitudes during periods of low ceilings. The method which has been the subject of extensive experimentation employed a radio sounding balloon emitting radio signals on which bearings were taken with radio direction finders from two points a few miles apart. The desired data were then calculated by triangulation. The errors were reduced to about 2°, but this was not accurate enough to be of any great value, the practical limits being less than ½ of 1° and the desirable precision of direction, 1/10 of 1°.

A research program of some magnitude looking to the solution of this problem has been in progress for several years at the California Institute of Technology. Able assistance and collaboration has been provided by Captain O. C. Maier, U. S. Army Signal Corps, at present attached to the Meteorological Section of the U. S. Army Air Corps.

The Institute has been working on a theory different from the one mentioned in the foregoing. Instead of the short wave previously used they are employing an ultra-short wave length of 1.67 meters with surprising success. A parabolic antenna is employed and the parabolic principle is used throughout. Only one receiving station is used instead of two as in the other plan. These experts, headed by research physicist Anthony Easton, are now tracking the radio sounding balloons experimentally with approximately the same

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degree of precision that is accomplished by the present theodolite system in clear weather. Work is going forward now in developing an automatic tracking device which is expected to be perfected in the near future.

The excellent work of the California Institute of Technology gives promise of an early solution of one of the most pressing needs of aviation.

U. S. Weather Bureau Program

Recognizing the value of aerological observations by radiotelemeters the U. S. Weather Bureau recently awarded contracts for the furnishing of instruments to stations at Nashville, Sault Ste. Marie, Oakland, Oklahoma City, Omaha, and Fargo for daily observations. This program began with the new fiscal year on July 1, 1938, and replaced airplanes for upper air soundings at those stations.

Contractors have the responsibility of furnishing the radiotelemeters and ground equipment on a lease basis, and installing the latter. Specifications called for close tolerances, but were broad enough so that any type or design of instrument would be acceptable if it met with performance requirements.

This is the first step taken by the U. S. Weather Bureau in establishing radiotelemeter aerological observation stations on anything but a trial or experimental basis. Only the lack of funds prevents the Bureau from having several times this many. In addition to the foregoing radiotelemeter stations, the Bureau is

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maintaining airplane stations at Salt Lake City, Spokane, Cheyenne, El Paso, Chicago, and Billings.

In cooperation with the U. S. Weather Bureau, the U. S. Army is making daily radiotelemeter observations at Patterson Field, Fairfield, Ohio, and at Barksdale Field, Shreveport, Louisiana.

The U. S. Navy is also cooperating by continuing the daily radiotelemeter observations at Anacostia Naval Air Station and approximately twelve daily airplane observations at scattered points throughout the Western Hemisphere.

CONCLUSIONS

For several years authorities have recognized the value of air - mass analysis as an important aid to accurate forecasting. It is well known that the assistance obtained from it, and the experience gained from the study of weather maps have proved an important adjunct to this work.

Forecasters are depending more and more on aerological data for analysis. Now, with the use of radiotelemeters this information can be available to them every day despite weather conditions. With the more complete and regular information now available from this source, it is certain that the work being conducted in air-mass analysis will become increasingly effective and forecasting further improved.

The step being taken by the U. S. Weather Bureau, described in the preceding chapter, denotes progress. The development and installation of this new but proven method of upper air soundings is well justified. The six aerological stations established by the Bureau in July will be very helpful, but more are needed.

Eventually, the Bureau hopes to have a network of 40 or 50 aerological stations distributed throughout the country. With such a system, the data will be assembled, charted, and analyzed at central points. When this enlarged program is put into effect, weather forecasting should be more dependable.

Greater coverage of reports will make possible greater precision in studying and analyzing trends, followed by improved forecasts.

The radiotelemeter, following the airplane, dominates a field almost untouched a few years ago in daily synoptic meteorology. It is contributing to safety in aviation by providing information which enables forecasters to predict weather accurately. This is one of the great needs of aviation.

Improvement in the instruments will continue to come. An enlarged program is quite certain to follow, resulting in an ever improving weather forecast service which promises to solve some of the problems which still confront students of weather.

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