W. B. 740.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

INSTRUCTIONS FOR AEROLOGICAL OBSERVERS.

BY

W. R. GREGG, in charge Aerological Division,

ASSISTED BY

MESSRS. V. E. JAKL, W. S. CLOUD, L. T. SAMUELS, AND R. C. LANE.

Prepared under direction of
C. F. MARVIN, Chief U. S. Weather Bureau.

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INTRODUCTION.

The value of free-air data is now universally recognized. Until a comparatively recent date these data were used very largely in studies whose purpose was to add to our knowledge of the characteristics of the free air in relation to latitude, topography, and different conditions of weather at the earth's surface. At some places monthly, seasonal, annual, and, to a less extent, diurnal values have been fairly well determined to considerable altitudes, and some important conclusions as to the changes in free-air conditions accompanying marked changes in those at the surface have likewise been reached. In general, however, it can truthfully be said that aerological investigations are still in what may be called the "pioneer" stage. Immense expansion of the work is necessary before our knowledge of free-air conditions is at all comparable to that of surface conditions. And even the latter is as yet far from complete, for most parts of the earth.

During the past few years the practical application of free-air data has come very decidedly to the front. For this the World War and the rapid development of aviation are largely responsible. Average values, though constituting important information, are no longer sufficient. It is now necessary to know the *current* conditions. Densities are required in ballistics, and wind direction and force in both ballistics and aviation. Moreover, free-air and surface conditions are so closely related that a study of the two, observed simultaneously and over widely distributed areas, can not fail to increase the accuracy of forecasts, not only of conditions in the higher strata, but of surface weather as well. It becomes therefore increasingly important that this work be developed as rapidly and as thoroughly as possible.

Aerological investigations are conducted for the most part by means of kites, pilot balloons, and sounding balloons. In the past small captive balloons have been used in calm weather, but because of difficulty of securing good ventilation and because, moreover, low altitudes only could be reached, this method has been largely discontinued. Manned balloons and kite balloons have also been used, but these are too expensive for ordinary purposes. Undoubtedly the airplane offers a means of exploring the air in a meteorological sense, and will in the future be adapted to this use. Before this is done, however, it will be necessary to work out certain details of equipment, instrumental exposure, etc.

Kites enable us to observe atmospheric pressure, temperature, humidity, wind, and electric potential at various altitudes up to 5 or 6 kilometers, but the average height reached is a little less than 3 kilometers. Kites can not be flown in very light or very strong winds, nor are they successfully used during stormy weather; nevertheless, the percentage of days on which kites are flown is high, being about 93 for 5 years' work at Drexel, Nebr. Pilot balloons give us wind conditions only; they can be used in weather unfavorable for kites, i. e., in gales or light winds, but, on the other hand, can not be observed in clouds or during other conditions of poor visibility. By means of sounding balloons we obtain valuable data, including pressure, temperature, humidity, and wind, at much greater heights than can be reached by kites. These data, however, are not immediately available, as several days are necessary as a rule for the recovery and return of the balloons. In this respect kites and pilot balloons are decidedly superior, since the records can be used at once for the information of the forecasters and others. It is evident that all three methods have limitations, to which due consideration must always be given in discussing the results.

In order to obtain reliable data it is necessary for the observers, computers, and others to become familiar with a mass of details as to construction, care, and use of apparatus; difficulties to be overcome in getting the best possible records; and reduction and interpretation of the results. Aerological investigations have been conducted by the Weather Bureau more or less regularly for nearly 25 years. From the experience thus gained much has been learned, but up to the present time this knowledge has for the most part been transmitted orally, although instructions covering certain features of the work have been furnished from time to time in typewritten or printed form. The purpose of this pamphlet is to bring together all necessary information in sufficient detail to enable those wholly unacquainted with the work to become efficient aerological observers and computers. These instructions are confined entirely to work with kites and pilot balloons, since sounding balloons can not be used for some time to come, owing to lack of funds, and, besides, several changes in methods and equipment are contemplated.

These instructions are in part original and in part have been prepared from the following sources:

"Kite Experiments at the Weather Bureau," by C. F. Marvin, W. B. 110, 1896.

"Instructions for Aerial Observers," by C. F. Marvin. Circular K, Weather Bureau, 1898.

"The Methods and Apparatus Used in Obtaining Upper Air Observations at Mount Weather, Va.," by Wm. R. Blair. *Bulletin of the Mount Weather Observatory*, vol. 1, pp. 12–19, 1908.

"The Construction of a Weather Bureau Kite," by A. J. Henry. *Bulletin of the Mount Weather Observatory*, vol. 2, pp. 227–236, 1910.

"The New Kite Reel," by Wm. R. Blair. *Bulletin of the Mount Weather Observatory*, vol. 1, pp. 237–238, 1908.

"Improved Kite Hygrometer and Its Records," by W. R. Gregg. *Monthly Weather Review*, vol. 45, pp. 153–155, 1917.

"The Use of a Flag Pole in Calibrating Kite Anemometers and Also for Observing at Close Range the Behavior of Kites in the Air," by B. J. Sherry. *Monthly Weather Review*, vol. 44, p. 327, 1916.

"Notes on Kite Flying," by V. E. Jakl. *Monthly Weather Review Supplement* No. 13 (Aerology No. 8), pp. 7–12, 1918.

"Instructions for Operation of Aerological Stations, 2d Order," issued in typewritten form by Meteorological Service, United States Signal Corps, 1918.

"Instructions to Observers in Field Kite Work," issued in typewritten form by Aerological Division, Weather Bureau.

In the preparation of these Instructions special mention is due Mr. V. E. Jakl, who has contributed sections 5, 8, and 9 of Part I; Messrs. W. S. Cloud and L. T. Samuels, sections 6, 7, and 10 of Part I; and Mr. R. C. Lane, who has written the major portion of Part II. Numerous helpful suggestions offered from time to time by various members of the field and Central Office force of the Aerological Division; by Mr. S. P. Fergusson, of the Instrument Division; and by Maj. Wm. R. Blair and Capt. B. J. Sherry, of the Meteorological Section, Signal Corps, have been incorporated in the Instructions. Acknowledgment is also due Mr. Roy N. Covert for furnishing specifications, with drawings (figs. 7 and 8), for installation of kite reel to insure protection against lightning (in Part I, section 3); and to Mr. Wm. C. Haines, who furnished instructions, with drawings (figs. 39, 40, 41, and 42), for adjustments of the theodolite (in Part II, section 2).—*W. R. Gregg.*

PART I. THE USE OF KITES.

1. SELECTION AND ESTABLISHMENT OF A KITE STATION.

Sites for kite stations must be chosen with considerable care. Experience has shown that the best location is one in level country rather than on a mountain top, the latter being undesirable because of its influence on the meteorological elements and the resulting erroneous relations indicated between the surface and free-air conditions. The country surrounding a kite station should be as free as possible from forested tracts, lakes, marshes, rivers, etc.; also, from towns, steam and electric railways, and high-tension power lines. Inasmuch as free-air winds in this country blow for the most part from some westerly direction, it is essential that there should be as few as possible of the undesirable features above mentioned on the east side of the station. Fairly good roads are necessary in order that kites that have broken away may be readily recovered. In many respects kite flying can be carried on most effectively if the station is completely isolated, so far as centers of population are concerned, but, on the other hand, difficulties of transportation, of procuring power and lights, and of providing good living conditions for the men render such a location inadvisable. As a compromise the Weather Bureau therefore selects sites with open country to the east, but with a small town (1,000 to 2,000 people) approximately 1 kilometer to the west. The plot used as a kite field is usually square and contains 40 acres of land, as nearly level as possible, cleared of trees, stumps, etc., and surrounded by a sufficiently strong fence to keep out live stock. In case there are telegraph, telephone, or high-tension lines within a distance of 2 or 3 kilometers to the north, east, or south, an extra "guard" wire is installed about 1 foot above the service wires. Power and lights are furnished from the town plant to the station by means of underground circuits. All buildings, except the reel house, and all surface instrumental equipment are located in such part of the western side of the field as is most readily accessible from the town. The instrument shelter, wind tower, etc., are installed in accordance with instructions issued by the Instrument Division. Figure 1 shows the customary arrangement of buildings and instrumental equipment, as well as the location of the kite field with respect to the adjacent town.

The geographic coordinates of the stations are determined in the same way as for all other Weather Bureau stations. Latitude and longitude can be found for many places in bulletins of the Geological Survey, Lippincott's Gazetteer, and other publications. The data from these sources are used, after verification as to their accuracy by reference to a recent issue of Rand McNally & Co.'s Atlas. When there are no published data, the latitude and longitude, as shown by the station's location in this atlas, are used. Altitude is determined by running a line of levels from the nearest "bench mark." The height of the barometer cistern is taken as the official station altitude above sea level. The methods of determining true meridian are fully described in Part II, section 2. As soon as the cardinal points are established, white posts are placed around the outer portion of the kite field, exactly north, northeast, east, etc., of the reel house, in order that wind direction, both at the surface and in the free air, may be accurately determined.

The main building is of frame construction, one and one-half stories high, and is used for office quarters, carpenter shop, and kite storage. It is 26 feet wide by 48 long and approximately 24½ feet from the ground to the peak of the roof. The dimensions of the office and computing room are 25 by 14 feet; of the carpenter shop, 25 by 12 feet; and of the kite storage room, 25 by 20 feet—all inside measure. An attic provides additional room for the storage of kites, extra kite sticks, and miscellaneous supplies and equipment. Full specifications and sketches are on file at the Central Office of the Weather Bureau. Figure 2 gives a front view of one of these buildings.

2. KITE REEL HOUSE.

It is necessary to have a small building of special design and construction in order to obtain the best results in kite flying. This building consists essentially of two parts—a turntable, by means of which the doorway may be presented to any desired direction, and a superstructure sufficiently large to accommodate the kite reel and accessory apparatus. The whole is mounted on a circular concrete wall 20 inches thick and 30 inches deep, inclosing a space 10 feet 8 inches in diameter. This inner space is excavated to a depth of 2 feet below the top of the wall, thus providing ample room for adjusting the electric wiring from time to time as it becomes twisted due to the turning of the house, and for inspecting the "ground" connections, turntable, etc. The turntable consists of five curved pieces of heavy iron rail, on which turn the wheels that carry the weight of the building, the turning being readily accomplished by means of an endless cable leading from the trucks to a suitable hand apparatus mounted inside the house. The wooden building itself is about 15 feet in diameter at the floor, tapering to 14 feet at the eaves. The floor is about 2 feet 9 inches above the ground; the eaves, 12 feet, and the peak of the roof, 15 feet. At the front of the building is a doorway about 8 feet in width and extending from the floor to the eaves. This large doorway is provided because, in addition to the reel and the theodolite which occupy a part of this space, it is necessary for the observers to pass in and out occasionally in order to launch or land kites, make observations of clouds, etc. A small window at the rear of the house gives additional light and ventilation, and a trapdoor provides easy access to the space inclosed by the foundation wall. At northern stations it has been found advantageous to have about one-third to one-half of the reel house divided off by a wooden partition, this small room being heated by an oil stove during cold weather to lessen the discomfort of the observers on duty.

sun's rays. Additional protection is provided in this case by a sloping roof attached to the reel house and projecting about a foot beyond the limits of the instrument shelter. Generally speaking, this extra precaution is unnecessary, since there is usually a good breeze blowing, and therefore plenty of ventilation, while a kite flight is in progress.

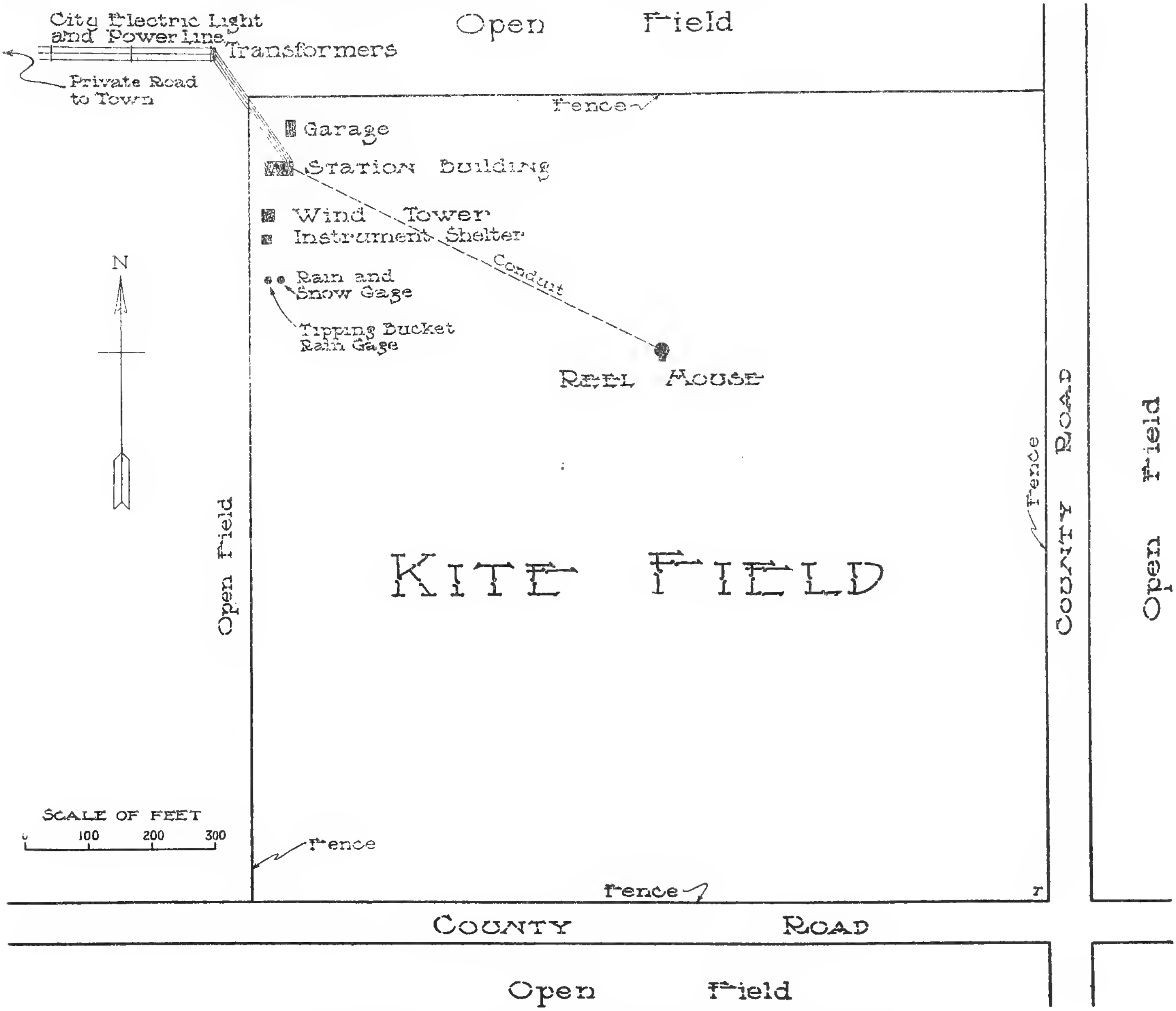


FIG. 1.—Plot showing the position of buildings and kite field at Ellendale Aerological Station.

A wind vane is attached to the top of a vertical shaft extending through the peak of the roof, and at the lower end of this shaft another arrow is fastened with the same orientation, thus making possible the determination of surface wind direction from inside the reel house. On the left side of the building, as one faces the doorway from the inside, a standard Weather Bureau instrument shelter is installed. This shelter, as is well known, has a double roof to prevent heating of the inside air by the

Complete specifications and drawings for the construction of reel houses are on file at the Central Office of the Weather Bureau. A general view of one of these reel houses is shown in figure 3.

3. KITE REEL AND MOTOR.

The kite reel, now in general use at Weather Bureau aerological stations, was originally designed by Prof. C. F. Marvin and later modified by Dr. Wm. R. Blair.

FIG. 2.—Front view of office and kite storage building at Broken Arrow Aerological Station.

FIG. 3.—Close view of kite-reel house at Ellendale Aerological Station.

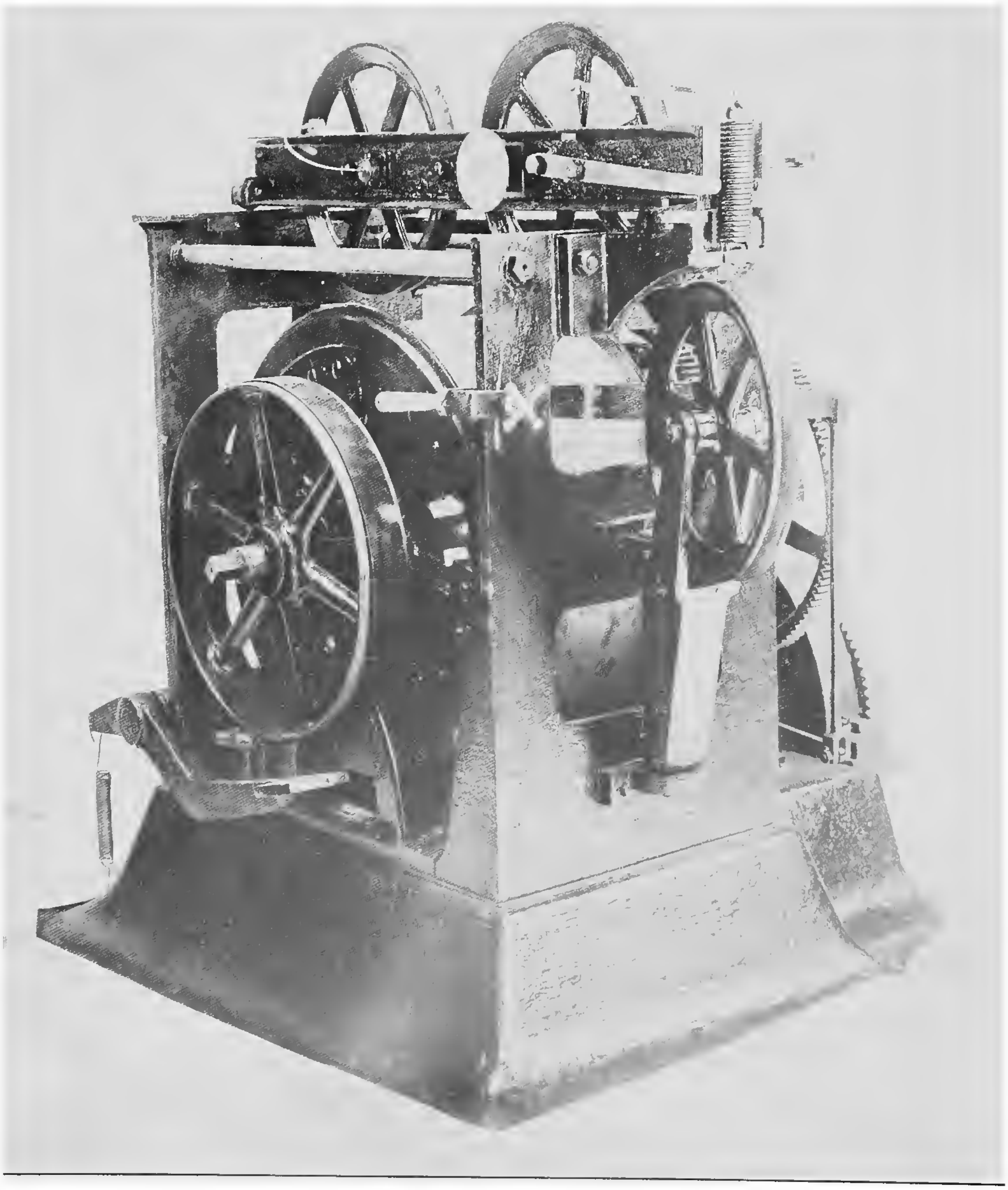


Fig. 4.—Right front view of kite reel.

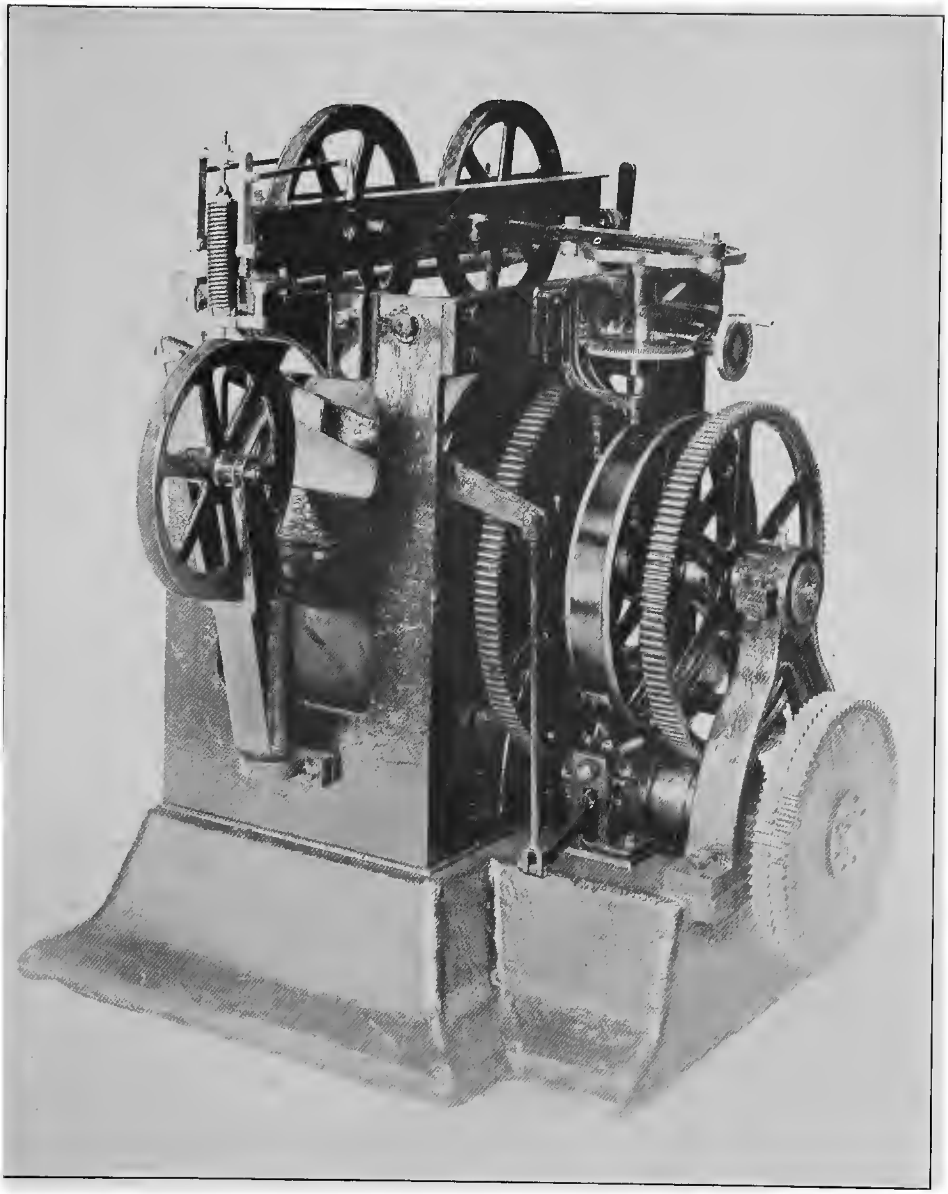


FIG. 5.—Left front view of kite reel.

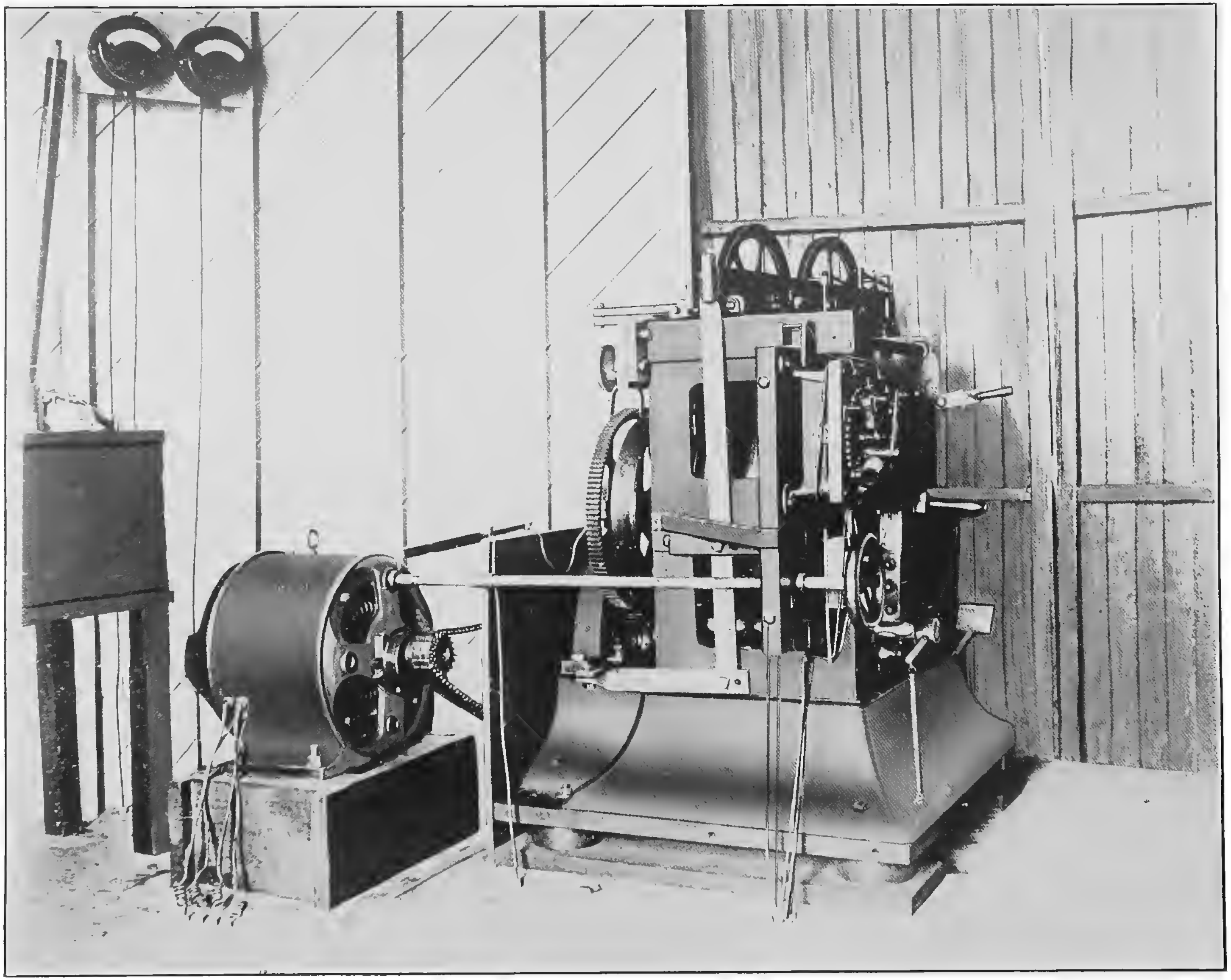


Fig. 6.—View of rear of kite reel; also of variable-speed motor.

Except for the drum, it is made largely of cast iron and its weight is such as to render it stable under any pull that may be exerted by the kites. Two views are shown in figures 4 and 5. The most prominent features are the solid base and substantial frame, the drum and the three small wheels which guide the wire from the drum to the kites. One of these wheels, at the front, is so mounted that it can accommodate itself to the direction which the wire assumes under the influence of the wind's action on the kites. The other two wheels, at the top, are mounted on a distributor carriage which travels back and forth under the action of a cam, shown in the upper right-hand part of figure 5. Other details in this figure are the hand brake and wheel and the operating gears. In figure 4 may be seen the foot brake and wheel (auxiliary to the hand brake), a Veeder counter, and a dynamometer for indicating amount of wire out and pull exerted by the kites, respectively. The drum, which is the result of numerous trials with different types, consists of three pieces—the barrel and two spiders. The former is made of cast semi-steel and the latter of cast iron. The spiders merely center the barrel on the shaft and rotate it, but carry none of the accumulated strain to which the drum is subjected by the piling up of the successive strands of wire. On the same shaft with the drum are mounted the two brake wheels and two driven gears, already referred to. The latter, shown in figure 5, are of different diameter, the larger being for slower speeds. The gears engaging these are always in mesh, and power is applied to either of them by means of a double-throw friction clutch at the rear of the reel within easy reach of the operator.

Complete specifications and drawings for construction of kite reels are on file at the Central Office of the Weather Bureau.

The kite reel motor.—Power is furnished by an electric motor, so designed as to run at any speed between about 400 and 1,800 revolutions per minute, and for any pull up to that equivalent to about 5 horsepower. Such motors can be obtained for either direct or alternating current. Power is transmitted by means of chain and sprockets. One of these motors (for direct current, in this case) is shown in figure 6. Speed is regulated by means of the shaft leading from the motor to a position within easy reach of the operator. As already stated, the speed can be still further regulated by the use of one or the other of the two driven gears shown in figure 5.

Protection against lightning (contributed in part by Mr. R. N. Covert, Meteorologist).—Both in and out of the Weather Bureau service the flying of kites has been attended by danger from lightning to the persons engaged in the work, and with the continued growth of the Aerological Section of the service it becomes more and more necessary to use every precaution to avoid possible injuries. In addition, damage to property should be minimized.

It is well known that even the wet string used in flying common kites will occasionally permit a considerable discharge to earth during a thunderstorm. But when steel wire is employed to hold a box kite, the metal provides a better conducting path for the lightning. A direct discharge from clouds to earth will quickly melt or vaporize the wire, but the wire will have directed the discharge, the air along the path becoming a good conducting medium by reason of its becoming ionized. There is also occasionally a considerable inductive discharge.

From the foregoing, there evidently must be some reliable means for conducting dangerous discharges to earth as well as for completely insulating the reel when it is desired to measure the atmospheric electric potential. This has been accomplished according to the following plan.

The kite reel is insulated from the floor by being mounted on blocks of fiber, as indicated in figure 6, and the sprocket which is driven by the chain from the motor is composed for the most part of fiber. This insulation makes possible the measurement of elec-

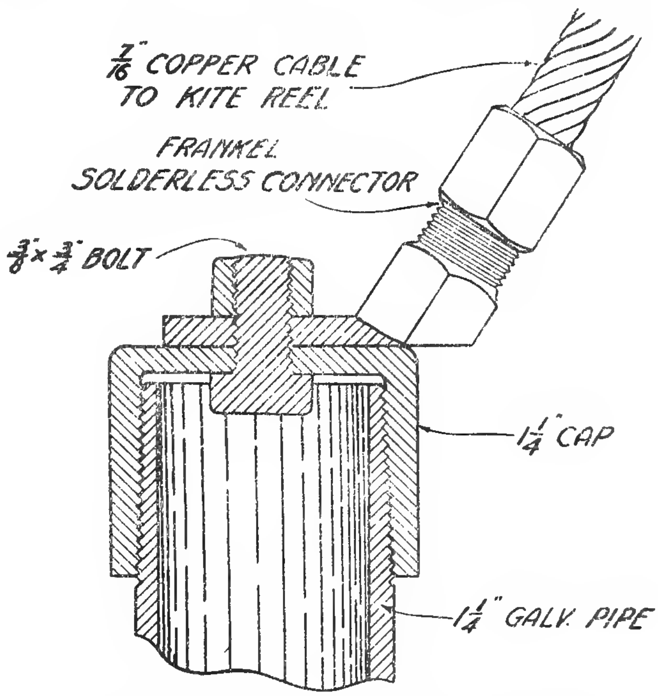


Fig. 7.—Method of attaching copper cable to main "ground" pipe.

tric current on the kite wire. Although such measurements have yielded little of scientific interest, they are useful, especially in summer, as indicators of possible trouble from approaching thunderstorms, of the existence of which, however, there is no other evidence. Under such conditions disruptive discharges of considerable intensity sometimes render advisable the shortening of a flight which otherwise might have been continued until too late for completion before the arrival of a thunderstorm. Accordingly, Weather Bureau stations are furnished with electrostatic voltmeters of the Braun type for this purpose. A long switch, which is opened during these measurements, at other times connects the reel with a $\frac{7}{16}$-inch stranded copper cable to a "ground" formed by driving a 10-foot length of $1\frac{1}{4}$-inch galvanized-iron pipe vertically into the earth and fitting the upper end to receive a connector, as shown in figure 7. The attachment at the reel is formed as directly as possible.

all sharp bends being avoided. As an added precaution, a copper cable is led from the reel to the trucks which carry the wheels, and the rail upon which the kite house turns is then grounded by making four connections through No. 6 copper wire to four 10-foot lengths of ¾-inch galvanized-iron pipes placed 90° apart just outside the periphery of the structure, as shown in figure 8.

The foregoing description and the following instructions should be supplemented by those given in Farmers' Bulletin No. 842, which contains general information regarding lightning protection.

Attention should, in particular, be given to the grounds to see that they are well made, and it should be known with certainty that the pipes are in contact with soil that is moist throughout the year. Furthermore, the iron-pipe grounds must be periodically inspected to learn to what extent corrosion is occurring, and the pipes replaced as often as needed. After the connections have been completed to the ground pipes, paint the upper ends of the pipes and the attached fittings with two coats of metallic paint.

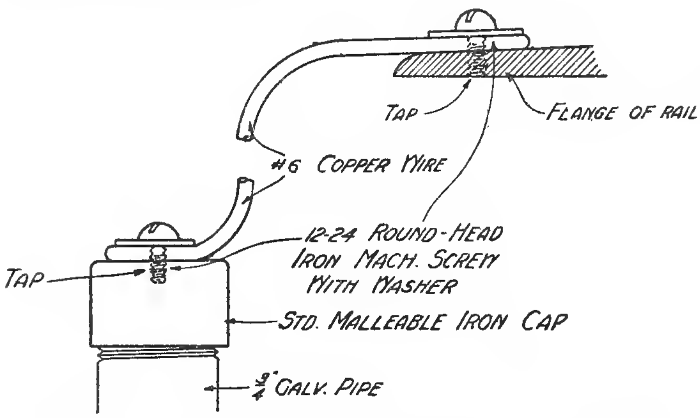


FIG. 8.—Method of attaching copper wire to "ground" pipes placed at stated intervals around the periphery of the reel house.

Following is a list of the material required for protecting one reel house:

12 feet $\frac{7}{16}$-inch copper cable.
2 $\frac{7}{16}$-inch solderless connectors.
1 ⅜ by ¾ inch galvanized machine bolt.
1 1¼-inch galvanized malleable-iron cap.
10 feet 1¼-inch galvanized standard pipe.
40 feet ¾-inch galvanized standard pipe.
4 ¾-inch malleable-iron caps.
8 ⅜-inch, 12–24, ronnd-head iron machine screws.
8 iron washers for same.
6 feet No. 6 copper wire.
1 switch for breaking "ground."

In addition to the precautionary measures above outlined, it has been found advisable for those engaged in the work to be provided with rubber gloves and boots during thunderstorms. Moreover, the utmost care should be taken in landing a secondary kite. The splice wire should be taken off at the reel house and the kite then landed at as great a distance from the wire as possible; otherwise the observer might readily form a short circuit for the lightning from the kite wire to the earth. During extreme conditions it is even advisable to clamp the brake securely and leave the reel house, with the kites still flying, until the passing of the storm.

4. KITE WIRE.

In meteorological kite flying, steel music wire, popularly known as "piano" wire, is generally used for the main line; it is far superior to any other material thus far tried for this purpose, because in it are combined the very desirable qualities of great and uniform strength in proportion to weight and bulk, and a smooth surface. This wire is manufactured in a large number of sizes varying between about 0.01 and 0.125 inch in diameter (Nos. 0 to 30, music-wire gage), and usually is sold in coils of various amounts and lengths, the smaller sizes, as a rule, being in longer pieces than the larger. For the main line, the longest pieces obtainable should be used in order to avoid the necessity of making numerous splices. Obviously, assuming adequate strength, the smaller the wire the better, for convenience in handling. The sizes between 0.028 and 0.044 inch in diameter are most frequently used in kite flying. The 0.028-inch size, used by the Weather Bureau during the early days of kite flying, is quite satisfactory for small kites and ascensions to moderate heights, although the tendency of small

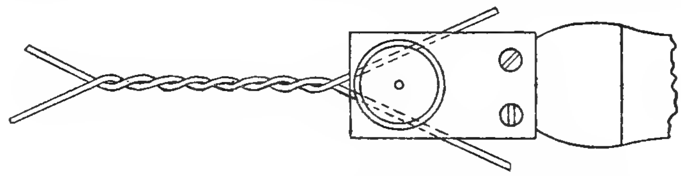


FIG. 9.—Method of splicing kite wire by means of "large twister."

wire to kink is a disadvantage. When high flights with a number of kites are desired, larger sizes of wire become necessary, and the usual procedure at aerological stations of the Weather Bureau is to make up the main line of the following sizes: 0.032 inch, 500 meters (approximately); 0.036 inch, 1,500 meters; 0.040 inch, 2,500 meters; 0.044 inch, 10,000 meters, or 14,500 meters in all. The proportions vary somewhat, according to the average wind conditions. In the South, for example, more of the smaller sizes can be used than in the North. The tensile strengths of the sizes indicated are, respectively, about 300, 330, 420, and 480 pounds, and the maximum working strains 200, 250, 300, and 350 pounds.

When wire is wound on the reel, the coil is placed on a spool; the end of the wire on the inside of the coil is attached to the drum or spliced to the outer end of the wire already on the drum, as may be necessary, and the entire coil is then wound on the drum, the reel being run by power or by hand, as preferred.

Splicing the wire requires considerable care. As the result of extended experience, it has been found that the best method is to twist the wires evenly about a common axis for a length of 5 or 6 feet, then turn the free ends closely around the main line for a length of about half an inch. These two processes are accomplished very

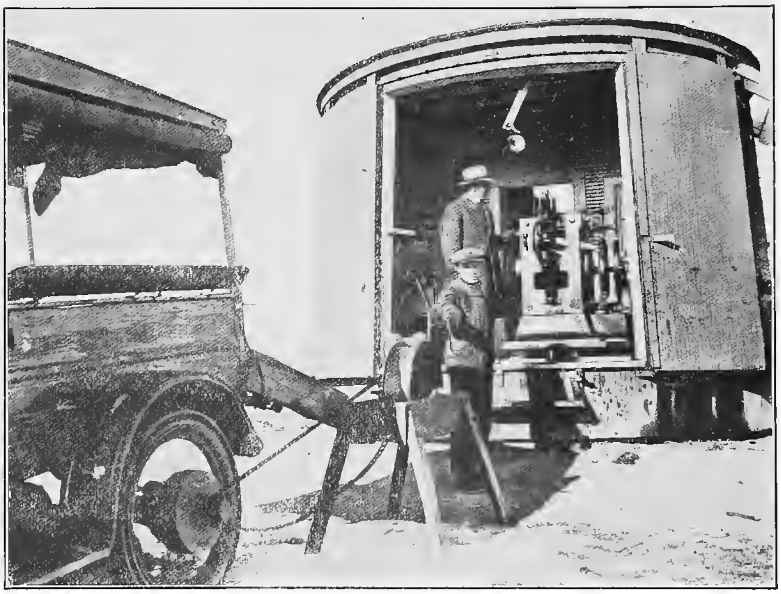


Fig. 11.—One method of reeling wire from the kite-reel drum to a smaller drum.

readily by means of simple tools, as shown in figures 9 and 10. The two wires to be spliced are held firmly by means of an ordinary machinist's hand vise, having brass jaws to prevent cutting the wire. This hand vise is not shown in the illustrations. The two wires are then placed in the shallow converging slots of the larger "twister," figure 9; held in position, but not clamped, by the spring and set screw above the part containing the slots; and finally twisted uniformly, each about a common axis. The free ends are then wound closely around the main wire by means of the smaller "twister," shown in figure 10, which scarcely needs explanation. Some difficulty is experienced in making an even splice of two wires of different sizes, and care must be exercised lest the smaller wire be the only one twisted. The process is aided if this smaller wire is held at a greater tension than the larger. It has not been found necessary or desirable to solder the splices, although that practice was followed during the earlier years of kite flying. The end of the wire to which the kite is to be

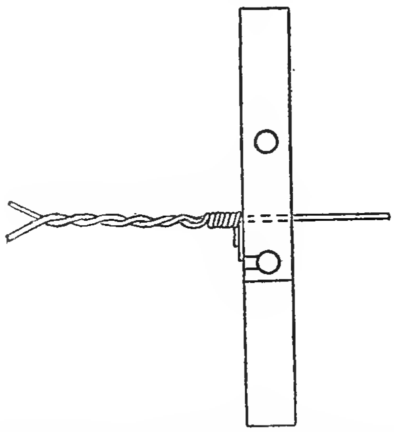


FIG. 10.—Method of turning end of loose wire around main wire by means of "small twister."

fastened is passed through a swivel and secured to the main line by splicing in the same manner as for ordinary splices, except that a length of about 1½ feet is sufficient.

While the wire is being wound on the drum, machine oil should be poured over it from time to time, in order to prevent it from rusting. This should also be done occasionally after the wire has been used during rainy or snowy weather. Vigilance in this respect is well repaid in reducing the number of breakaways due to defective wire. Moreover, it is well to examine the splices from time to time and to renew them, if the main wire at the ends of the splices shows signs of wear. Such renewal can be effected during kite flights, but a preferable method is to wind the wire from the reel on a small drum, make the splice or splices, and then rewind on the reel. Figure 11 shows one way of doing this. In winding the wire on the small drum, power is furnished, through chain and sprockets, by an automobile truck. As soon as all splices have been examined and, if necessary, renewed, the wire is rewound on the drum of the kite reel, power in this case being furnished by the motor in the usual way. During this process it is well to wipe off the old, dirty oil with a piece of waste, then pour new oil on the wire as it is being wound on the drum.

5. KITES AND KITE MAKING.

In practical kite flying, as exemplified at the aerological stations of the Weather Bureau, the object is to attain as great a height as possible, without incurring serious risk to the kites or line. Obviously, the larger the size and number of kites used, the stronger—and consequently heavier—must the kite line be. Considerations of the effects of wind pressure and ease of handling restrict the diameter of steel wire that it is practicable to use for line to certain narrow limits of tensile strength. Limitations in the dimensions, etc., of the line must, therefore, be met by efficiency in kite performance.

Of the qualities that an efficient kite should possess lightness, stability, and strength are the most important; but lightness must to some extent be sacrificed to realize the ideal practical kite. Of the many types and patterns of kites that have been suggested or tried the Hargrave cellular kite or some modification of it (in the work of the Weather Bureau, the Marvin-Hargrave) remains the standard. In addition to its good flying qualities, it is perhaps better adapted to the tandem method of flying than is any other type of kite.

The tandem method of flying and the design of kites and accessories best adapted to it were naturally developed from experience and the knowledge of the atmosphere obtained during early efforts to attain high altitudes by means of kites. Apart from practical reasons, the frequent stratified condition of the atmosphere as regards wind velocity and humidity imposes a limit upon the size of kites that should be used. It is not often that the wind is so uniform or increases so uniformly with altitude that a high flight can be safely made with one kite large enough to lift the necessary length of line. By distributing the kites along the line, suitably to the prevailing wind and weather conditions, the maximum lifting power of a given surface can be realized, without at any time exposing the whole of this surface to sudden changes in pressure of the wind.

Abrupt changes in wind and weather with time or altitude usually affect the lifting surface along only a portion of the line, the total increase of tension of the line from such causes depending largely on the area of lifting surface affected, and the methods for preventing excessive pull embodied in the construction of the kites. In the Marvin-Hargrave kite, excessive pull is prevented by its method of bridling, described in detail in a later paragraph. This feature of its construction is flexible, permitting a relatively greater margin of safety with increase in size of the kite.

The ideal conditions under which a high flight could be successfully made with one kite can not be foreseen with enough certainty to warrant the necessary equipment of suitable line or large kites, even if such equipment were safe or practicable. There is, in addition, the fact that the tension indicated at the lower end of a line from which a single kite is flying is only one factor of the maximum tension on the line. Including the effects of wind pressure on the line, the maximum tension occurs where the kite is attached, and is equal to the tension indicated at the reel plus the weight of the vertical projection of the line. Under actual conditions, the tension to which the line is subject is a complex of the action of gravity, the pressure of the wind on the line, and the pull of the kite, and departs more from the indications at the reel, the higher and farther away the kite is flying.[1] When the weight of the line is suspended from a number of kites at considerable intervals of distance, the difference between the maximum tension on the line and that indicated at the reel is practically negligible.

Under the adopted method of tandem flying, the range or variety in size of kites that it is advisable to build is established by the experience of the kite flier, the mechanical skill of the kite builder, and a knowledge of the tensile strength of the different sections of the line employed. It is unnecessary to build a kite much smaller than one which, under the most severe conditions, will exert a pull nearly equaling the tensile strength of the smallest diameter of line used. In the other extreme, the size of a kite should not go beyond that defined by caution in flying and limit in permissible fragility. One or two intermediate sizes in addition give a complement of kites that serves all purposes of every-day flying, and admits of easy standardization for manufacture.

The *Marvin-Hargrave kites* now used are essentially of the same type and construction as those devised by Prof. Marvin,[2] and used at 17 stations during the Weather Bureau kite campaign of 1898. The only important modifications that have been introduced since that date are in the dimensions and in the adoption of the elastic bridle, experience having shown that a smaller and stronger size of kite is required for high winds, while for light winds a greater spread of sustaining or lifting surface is necessary.

Three sizes of kites are most frequently used. They are illustrated in figure 12. They may be classed as high-wind kites, moderate-wind or standard kites, and light-wind kites. A fourth size, slightly larger than the standard but smaller than the light-wind kites, is sometimes used. The details of construction for the different sizes are precisely the same, the only differences being in the dimensions and proportions. As will be understood from the description and detail drawings which follow, this form of construction has certain advantages and disadvantages. One of the chief disadvantages is its frailty. Collision with the ground or other object almost invariably causes a bad smash of the kite; likewise, when the sails become water-logged the shrinkage of the cloth combined with the pressure of the wind is frequently powerful enough to crush the framework of the kite. On the other hand, broken sticks are easily and quickly replaced and the kite itself is conveniently collapsed for shipment. This is a very important point, since occasionally the kites have to be returned from the surrounding country.

As is well known, the kite consists of two cells joined together by longitudinal strips or sticks of straight-grained spruce. The front cell has a middle plane, and in this respect it differs from the original Hargrave pattern. The details which follow refer to what is known as the "standard kite." This size, modeled after the pattern used in 1898, has been found to be the most suitable for a wide range of wind velocity and weather conditions. When properly built it will fly well in winds of from 12 to 30 miles an hour (5 to 13 meters per second) near the ground, and 70 miles an hour (31 meters per second) when 2 or 3 miles high. Its extreme dimensions are as follows:

	Ft.	In.	cm.
Length or distance fore and aft	6	8½	204
Width or distance between the outside vertical surfaces	6	4½	194
Height or distance from top to bottom of cell	2	8½	83

The area of sustaining or lifting surface is 63.8 square feet (5.9 square meters), and of steering or neutral surface 21.7 square feet (2 square meters). The kite weighs about 9 pounds (4.1 kilos).

The *material required* in the construction of the *standard-size kite* includes:

(*a*) Forty-three sticks of the following dimensions:

1, ⅝ by ½ inch by 7 feet 6 inches. Center bridle stick; square edges.
1, ⅝ by ½ inch by 6 feet 10 inches. Back center; square edges.
4, ⅝ by $\frac{5}{16}$ inch by 6 feet 10 inches. Corners; square edges.
8, ⅝ by $\frac{5}{16}$ inch by 6 feet 6¼ inches. Horizontal front and back edges of kite; rounded edges.
12, ⅝ by $\frac{5}{16}$ inch by 2 feet 7½ inches. Horizontal sides; rounded edges.
8, ⅜ by $\frac{5}{16}$ inch by 2 feet 7½ inches. Horizontal intermediates, bracing horizontal front and back edges of kite; rounded edges.
6, ⅜ by $\frac{5}{16}$ inch by 3 feet 2 inches. Horizontal centers, bracing horizontal sides; rounded edges.
3, ⅝ inch by $\frac{5}{16}$ inch by 2 feet. Vertical center; rounded edges.

(*b*) The sticks are made of straight-grained spruce. All horizontal sticks should have their edges rounded, so that the end resistance of the kites to the wind will be as small as possible. Fourteen yards of Lonsdale cambric [3] 26 inches wide are used for the sails; some coarse waxed linen thread for lashing angles to sticks; 192 feet of No. 11 piano wire, diameter 0.024 inch, for guys.

(*c*) Forty-eight metal angles of the pattern shown in detail in figure 18 form the principal joints, 1 to 24,

[1] Monograph, "The Mechanics and Equilibrium of Kites," by Prof. C. F. Marvin, particularly pp. 64 to 70. (See Monthly Weather Review, April, 1897.) This monograph was submitted in competition for, and was awarded, the Chanute prize offered in 1896 by the Boston Aeronautical Society "for the best monograph on the kite, giving a full theory of its mechanics and stability, with quantitative computations appended." It was written at a time when the mechanics of the cellular kite—the progenitor of the heavier-than-air machine—was being closely studied. The student of the equilibrium of kites is referred to this monograph in its entirety for a full mathematical treatment of the subject.

[2] Concerning the history of the meteorological kites now used in the United States, it may be of interest to note that in the early days of kite flying at Blue Hill Observatory, Massachusetts, H. Helm Clayton made many improvements on the Hargrave box kite of 1895. The most important modification was the use of longitudinal sticks connecting the two cells at their outer corners, thereby greatly increasing the strength and stability of this kite. Prof. Marvin added the excellent folding feature, which not only makes it easy to ship kites, but also allows ready reassemblage with unimpaired strength.

FIG. 12.—Different sizes of box kites used at aerological stations.

FIG. 20.—Position and method of attachment of meteorograph in a kite.

figure 16; 34 metal angles of another pattern, shown in figure 19, are used for all intermediate joints, excepting at *b′*. *d′*, *n*, *p*, *y*, and *w*, which are simply lashed with waxed thread. The isometric detail, figure 18, shows how these joints are fastened. These metal angles are made especially for the Weather Bureau.

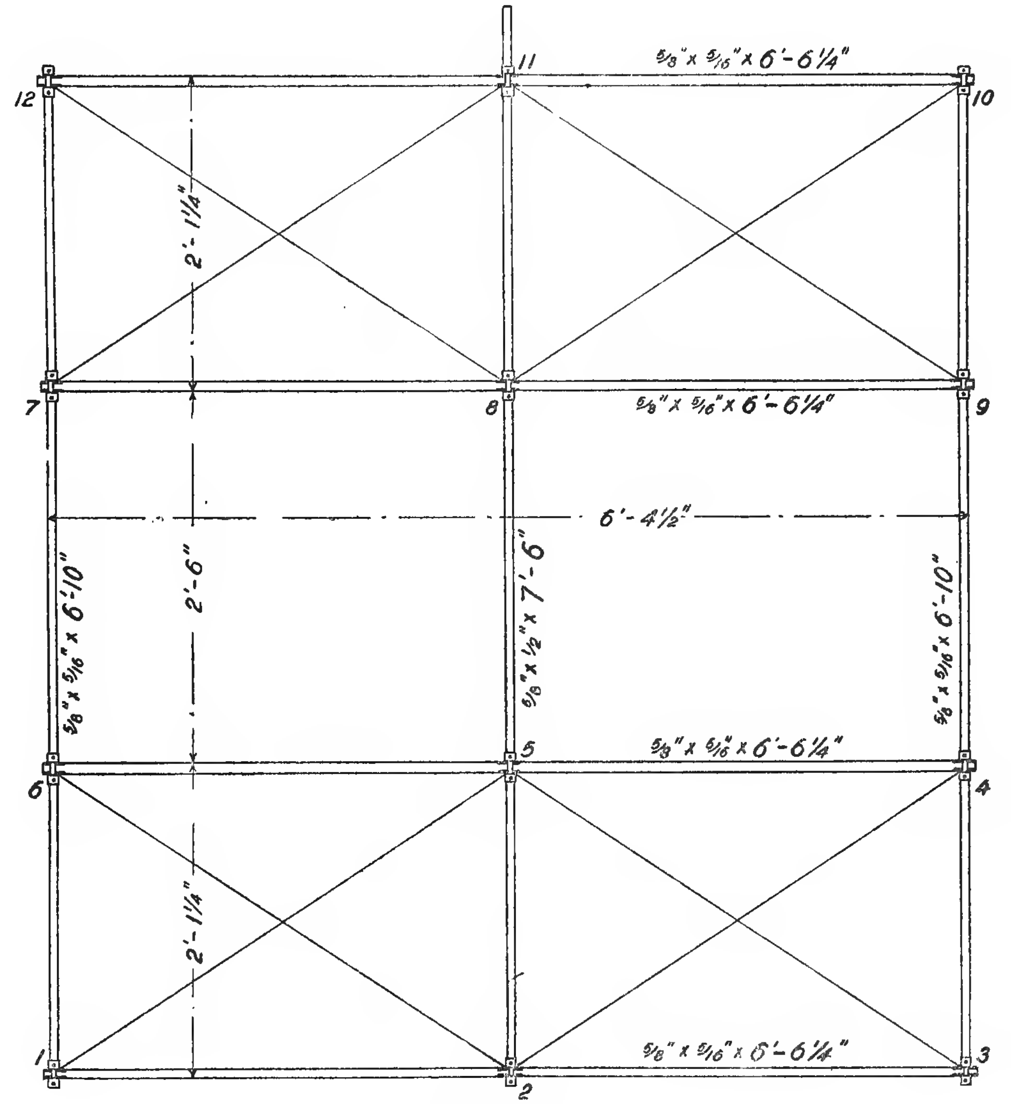


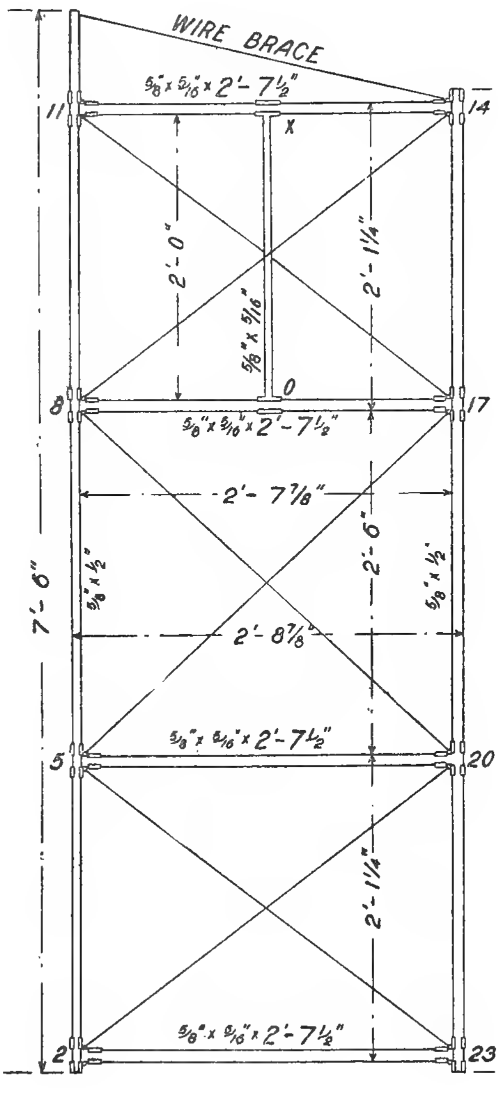
Fig. 13
front

Kite Sticks, Clamps Etc.

1	5/8"x 1/2"x 7'-6"	square edges		48 Metal clamps-Fig.
1	5/8"x 1/2"x 6'-10"	"	"	34 " " "
4	5/8"x 5/16"x 6'-10"	"	"	192 ft. 0.024" piano wire
8	5/8"x 5/16"x 6'-6 1/4"	rounded	"	14 yds. Lonsdale Cambric or mercerized silk 26" wide.
12	5/8"x 5/16"x 2'-7 1/2"	"	"	
8	3/8"x 5/16"x 2'-7 1/2"	"	"	
6	3/8"x 5/16"x 3'-2"	"	"	
3	5/8"x 5/16"x 2'	"	"	

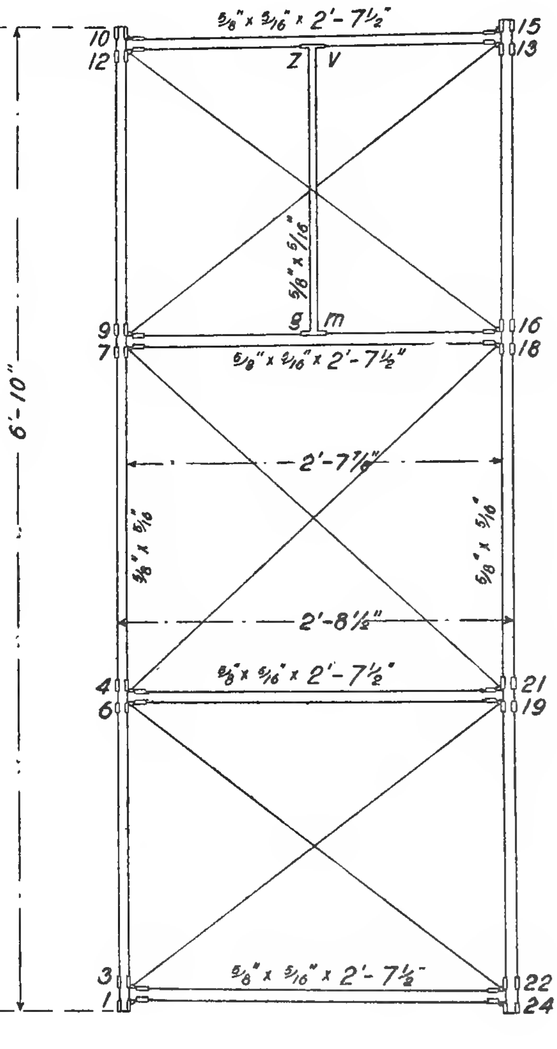
Figure 13 is an elevation of the front or bridle face of the kite—i. e., the lower surface when flying. The opposite face—i. e., the upper or rear surface of the kite—is the same except as to the size and length of the bridle stick. Figure 14 is a sectional elevation showing the central or bridle truss, and figure 15 is an elevation of one of the two side trusses. The fine diagonal lines in figures 13, 14, 15, and 16 show the system of wire bracing necessary to preserve the form and rigidity of the framework. This bracing is all done with very fine piano wire secured to the metal angles, as shown in figure 18, for the vertical cross bracing. In the horizontal and long vertical bracing the wire is looped over the small bolt head in the metal angles before the bolt is tightened up. All metal angles are lashed to the sticks with well waxed linen thread.

After the frame is put together and securely braced, care being taken that all angles are true and square, the kite is ready for the sails. These are made from white Lonsdale cambric,[3] 2 feet 2 inches wide and 18 feet 4 inches long, and are double hemmed one-half inch on each edge and each end. A strong cord should be passed through this hem to lessen the danger of tearing. The sails are stretched around the kite frame and lashed to the horizontal and vertical sticks with waxed thread



CENTER

Fig 14



ENDS

Fig. 15

A middle sail is placed in the center of the top section, extending from *MV* to *QZ* (see fig. 16). This sail should

[3] The rear cell and sometimes both cells are covered with a black fabric known to the trade as "mercerized" silk or French percaline, "batiste," etc. It has the property of shedding water to a much greater extent than cambric. For that reason kites covered with it are preferred during fog. Most kites are made with a white front cell and a black rear cell, the contrasting colors being very desirable for visibility.

be exactly 2 feet wide and 6 feet 4½ inches long after being hemmed, as described for the main sails, and should be lashed to the sticks in a similar manner.

this bridle is attached another stout cord in the form of a double loop about 18 inches long, having at its end a strong brass ring. This cord extends as shown and is

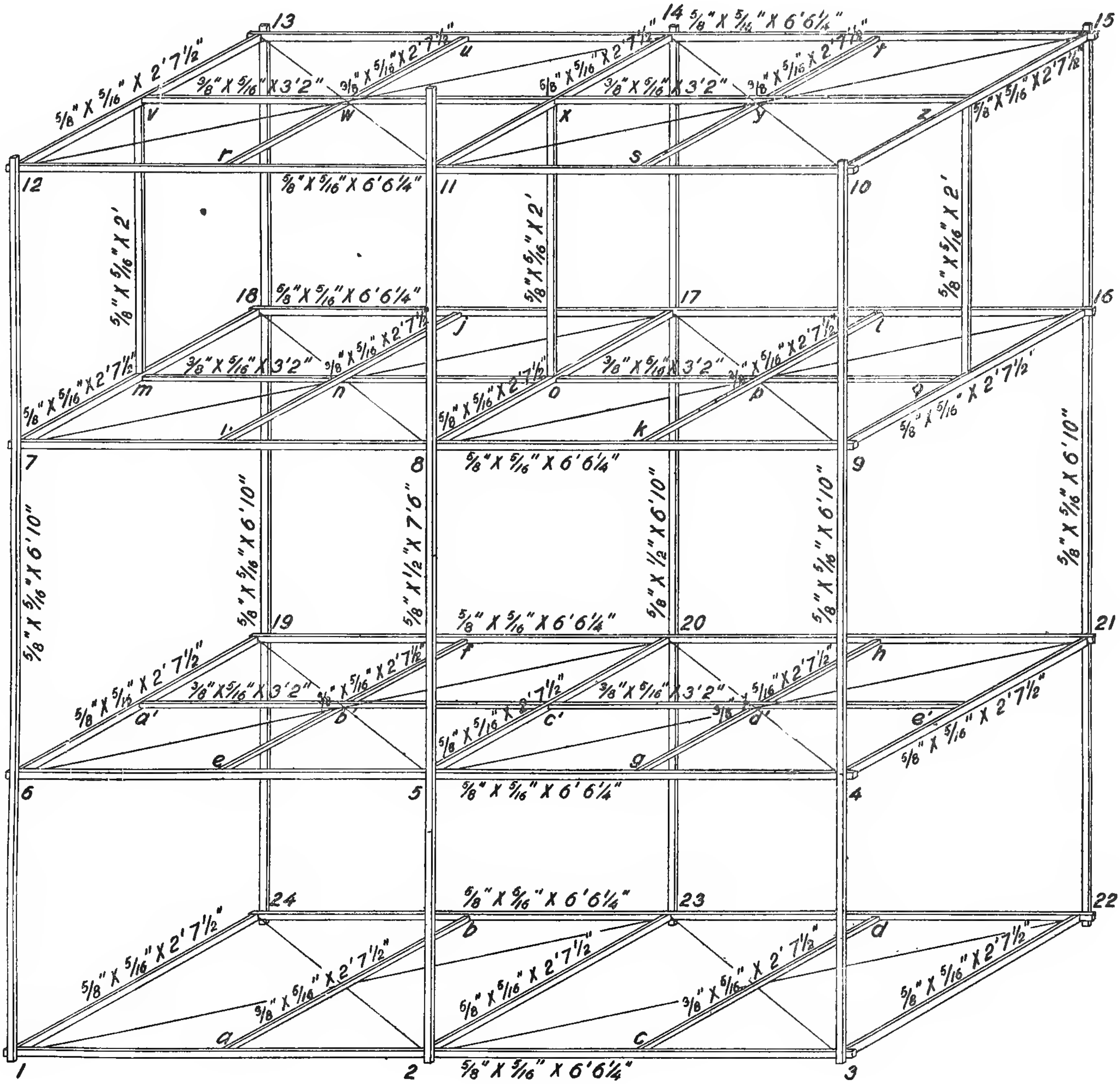


Fig. 16
Isometric view

The bridle and the method of attaching the kite to the line wire are shown in the isometric detail, figure 17. A stout cord about 18 inches long is fastened to the bridle stick at point 11, and to this is attached a cloth-bound elastic bridle, formed as shown. To the outer end of fastened to the extreme front end of the bridle stick. From this point a wire extends back and is fastened at point 14, as seen in figure 14. The elastic cord used in making bridles is manufactured especially for the Weather Bureau. It consists of thin strips of rubber about one-quarter of an inch wide tightly bound in a cloth cover, in the form of a small braided rope about five-eighths inch in diameter. On account of the elasticity of the rubber this arrangement protects the kite and wire from injury by sudden gusts or strong winds by allowing the kite to fly at a smaller angle of incidence, thus diminishing the pull.

The head kite, which carries the meteorograph, is fastened directly to the line by means of the brass ring in the outer end of its bridle. The secondary kites are flown by means of cords about 125 feet long. These cords are attached to the main line in the following manner: A piece of No. 9 soft iron wire about 6 feet long is bent so that a small open ring about an inch in diameter is formed near one end. About an inch of the wire at each end is then bent at right angles, thus: ┗━━━━o━┛. This piece of iron wire is wrapped tightly about the main line, and the cord holding the secondary kite is tied into the ring.

The method of attaching the meteorograph to the head kite is shown in figure 20.

In the *high-wind kite* the proportions and dimensions of the standard size are preserved, except that the width is made 11 inches less, thus reducing the width of the lifting surfaces and relatively increasing the area of neutral surface. It has a lifting surface of 54.6 square feet (5.1 square meters). This kite has been successfully flown in an 80 mile per hour (36 m. p. s.) wind at an altitude of 1 mile (1,600 meters) above the ground.

In the *light-wind kite* the change in proportions from the standard is the reverse of that of the high-wind kite—i. e., the width is increased in proportion to the length fore and aft. The dimensions are increased over all, giving this kite a lifting surface of 93 square feet (8.6 square meters) and a weight of 11½ pounds (5.2 kilos). It will fly in a slightly lighter wind than the standard, but its chief advantage is characteristic of all large kites—it will lift more line after it has ascended into a current stronger than necessary to lift itself. Its ability to fly in a lighter wind is due to the fact that it is lighter for the same lifting surface than the other kites. The frailty of this kite is partly compensated for by the fact that it is used only when surface winds are light to moderate, and the chances of the kite's striking the ground consequently small. It is not used when wind velocities aloft exceeding 30 miles per hour (13 m. p. s.) are expected, for, while it has been found to possess fairly good flying qualities in a 50 mile per hour (22 m. p. s.) wind at an altitude of 2 miles (3,200 meters) smaller kites can be more easily handled and more advantageously used in the stronger winds.

With a given pattern of kite, any increase in size, without a more than corresponding increase in weight, will be at the sacrifice of rigidity of the framework. In the three sizes of kites described and illustrated, and other sizes and shapes that have been experimented with in the past, there is only a small range in the minimum wind velocities in which they will rise from the ground. The

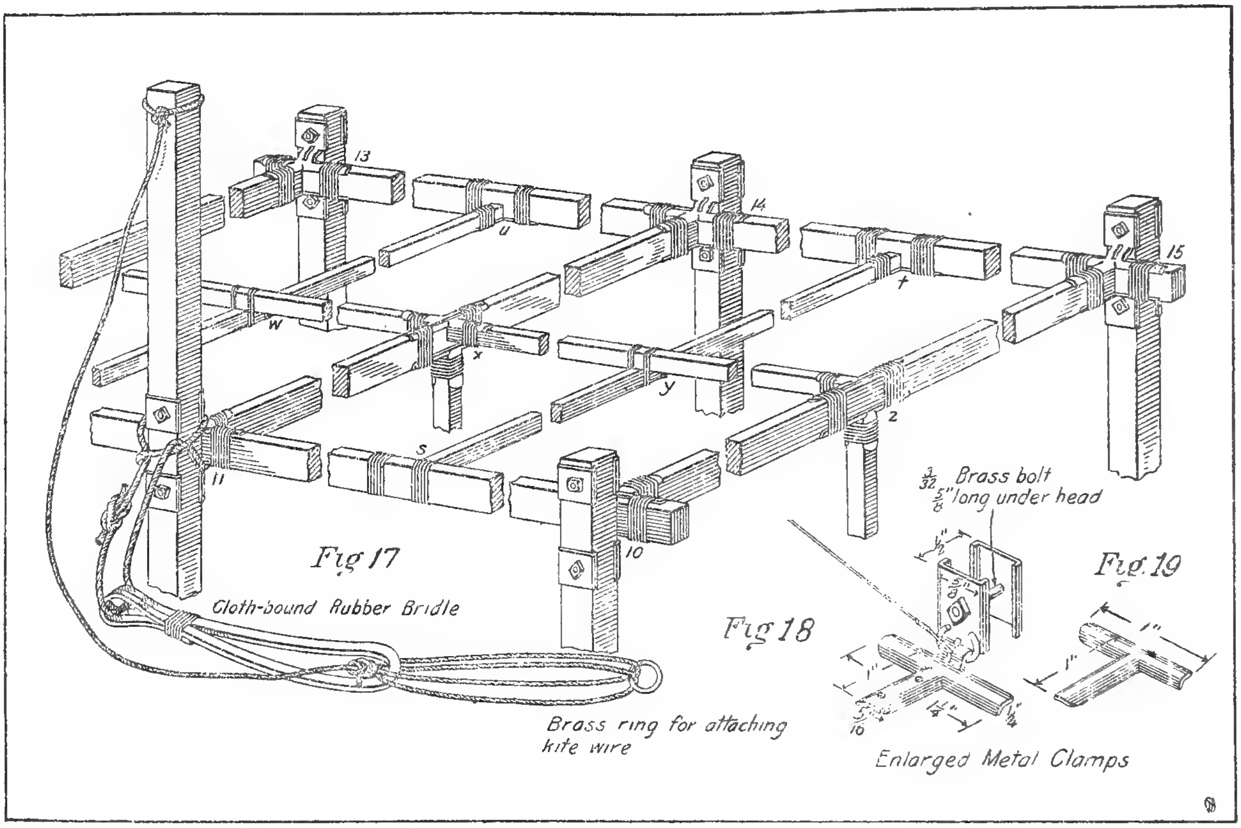


Fig 17

Fig 18

Fig. 19

excess of wind velocity above that necessary to fly the unburdened kite will be available to lift a weight roughly in proportion to its lifting surface.

The lifting capacity of a Hargrave kite is partly a function of its shape. For a given area of horizontal sail surface, the lifting capacity can be increased by making it wider relative to its length, since, in all kites the pressure of the wind is greatest near the front edge of the sails.[1] By increasing the length and depth relative to the width, the lifting capacity is lessened, but the stability of the kite improved. However, not much latitude is permitted the kite builder in either direction, as on the one hand a kite proportionally too wide will fly badly in any considerable wind, while a kite too long and deep will not have lifting power enough, in relation to the pull it is capable of, to justify its use.

A certain sturdiness of framework is necessary in all kites, not only to minimize breakage from inevitable collisions with the ground, but also to maintain good flying properties in strong wind. The wire ties in the Marvin-Hargrave kite serve to hold the framework symmetrical as a whole, and add little to the weight. A kite so braced will not collapse in any wind in which it is advisable to fly. An exception occurs when the sails become wet, but under such circumstances frailty is sometimes an advantage, by preventing a possible breakage of the line. However, unless the sticks are given an adequate thickness, distortion or deformation of the frame and sail surfaces, and consequent erratic action of the kite, will result during strong winds.

The stability of any kite is observed to increase with height above the ground, especially the first few hundred meters. For a considerable distance above the ground, the ability of a kite to withstand strong wind increases at a rate greater than can be accounted for by the diminishing density of the air. There seems little doubt that this can be explained entirely by turbulence, gustiness, eddies, and convectional currents, the effects of which on the kite are strongest near the ground.

6. METEOROGRAPH.

It is apparent that an instrument adapted to the purpose of exploring the atmosphere by means of kites must be accurate, light, durable, and compact. The meteorograph designed by Prof. Marvin is very satisfactory in all these respects, and is simply an ingenious combination of well-known devices used in recording pressure, temperature, relative humidity, and wind velocity. As shown in figures 21, 22, and 23, the essentials of this instrument are a light, rigid tube and framework, firmly united, which serve as supports for the several recording devices and provide satisfactory exposure for the sensitive elements. The anemometer, temperature element and hygrograph hairs are mounted inside this tube, and the pressure element is secured to the frame in which, also, is clamped the clock drum. The four pen arms are mounted on the outside of the tube and connected with the sensitive elements by means of a simple linkage, adjustable in order that the range of movement of the pens or their position on the record sheet (as explained in detail hereinafter) may be changed if necessary. With the exception of the clock movement, the bearings and links (which are of German silver) and the brass screws and nuts, the instrument is constructed of aluminum, and weighs but 2.5 pounds. A removable cover protects the mechanisms from injury when the instrument is in use. The screening tube is insulated from this cover by strips of bakelite.

During a flight the meteorograph is secured inside the kite in such a position that the wind passes freely through the tube containing the temperature element and hygrograph hairs. In this way a very satisfactory exposure is obtained; the ventilation is good, since the wind is always strong enough to support the kite, and insulation is further minimized or eliminated by the shading of the instrument by the kite. A brief description of each element and its characteristics will, perhaps, lead to a clearer understanding of the workings of the meteorograph. Reference should be made to figures 21, 22, and 23 for illustration of the parts described.

Pressure element.—Two nickel-plated, steel vacuum cells, such as are used in aneroid barographs, are prevented from collapsing by a strong steel spring. Any change in the air pressure causes an expansion or contraction of the cells and a consequent movement of the free end of the spring (the other end being rigid), and this causes the connecting arm to be raised or lowered the same amount. This vertical movement caused by the expansion or contraction of the cells is changed to a horizontal movement of the pen resting on the record sheet, and at the same time considerably magnified by a simple right-angle lever connection. Since the instrument is often carried to an altitude of 5 kilometers or more, and since this distance is recorded in a space of about 5 centimeters on the record sheet, it is very important that the pen record accurately. The usual difficulties met with in the aneroid cell are overcome as far as possible. The link is so simple and direct that there is little chance for lost motion or friction. These must be watched for, however. The combination of two cells gives twice the power of one to the spring and consequently the pen arm, and also makes the movement "stiffer;" that is, it takes a greater jar or vibration to move the pen from its proper position at any time, and any possible friction in the bearings or connections has a smaller effect on the movement of the pen arm. Since, then, a change in the pressure expands or contracts the cells, the movement of which is multiplied by the link and recorded by the pen, it is simply a matter of determining how much any certain change in pressure moves the pen on the sheet. The methods of determining this and similar values will be described in section 7.

All aneroid cells are affected by changes in temperature, an increase in temperature lessening the resistance of the spring and vice versa. To "compensate" for this a little air is allowed to remain in the cell and then after testing

[1] For footnote see page 12.

at the factory a bimetallic strip is introduced in the link to "compensate" the element with still greater refinement. The compensation, however, is never perfect; hence, it is necessary to determine just what effect any temperature change will have on the pressure element and make allowance for it.

The pressure pen is usually placed in the middle of the record sheet. Sometimes, however, it may be advisable to change this position, for example, if an unusually high flight is expected, and this is easily done by simply turning the adjusting screw on the pressure element. This screw should always press against the frame, as otherwise the element will be loose.

If we wish the pen to move farther than it does for any definite change in pressure, we can loosen the small set screw in the link and push this lever arm in toward the center; then the same motion of the element and its connecting arm will cause a larger angular motion of the adjusted arm and the pen. In this way the amount of motion of the pen arm compared to the actual change in the element, called the "scale value," can be made practically anything desired.

Temperature element.—The temperature element is made of "thermostatic" metal which consists of closely united strips of "invar" and bronze 25 mm. wide, bent into nearly a complete circle. A small steel spring inserted inside the element and attached to its ends increases its elasticity. The invar does not expand or contract with a rise or fall in temperature, but the bronze does, thereby causing the element to open or close; this motion is transmitted directly to the pen arm by means of a simple link. Since the coefficient of expansion of bronze is a linear function of the temperature, it is found that the movement of the pen arm is in direct ratio to the temperature change; in other words, the scale value for any one instrument is a constant. The exposure of the element being excellent, there is no appreciable sluggishness on account of lack of ventilation, and therefore the element adjusts itself quickly to any change in temperature.

The temperature pen is set near the top of the sheet, allowance being made for any increase in temperature with altitude. The position of the pen on the sheet may be changed by loosening the brass set screw and then turning the pinion situated just above this set screw and between two other small brass screws. One end of the temperature element is rigidly connected to a rack which is moved by this pinion. The other end of the element is connected to the lever arm and link. Moving the pen in this manner does not change the scale value, which is altered in exactly the same manner as is that of the pressure element.

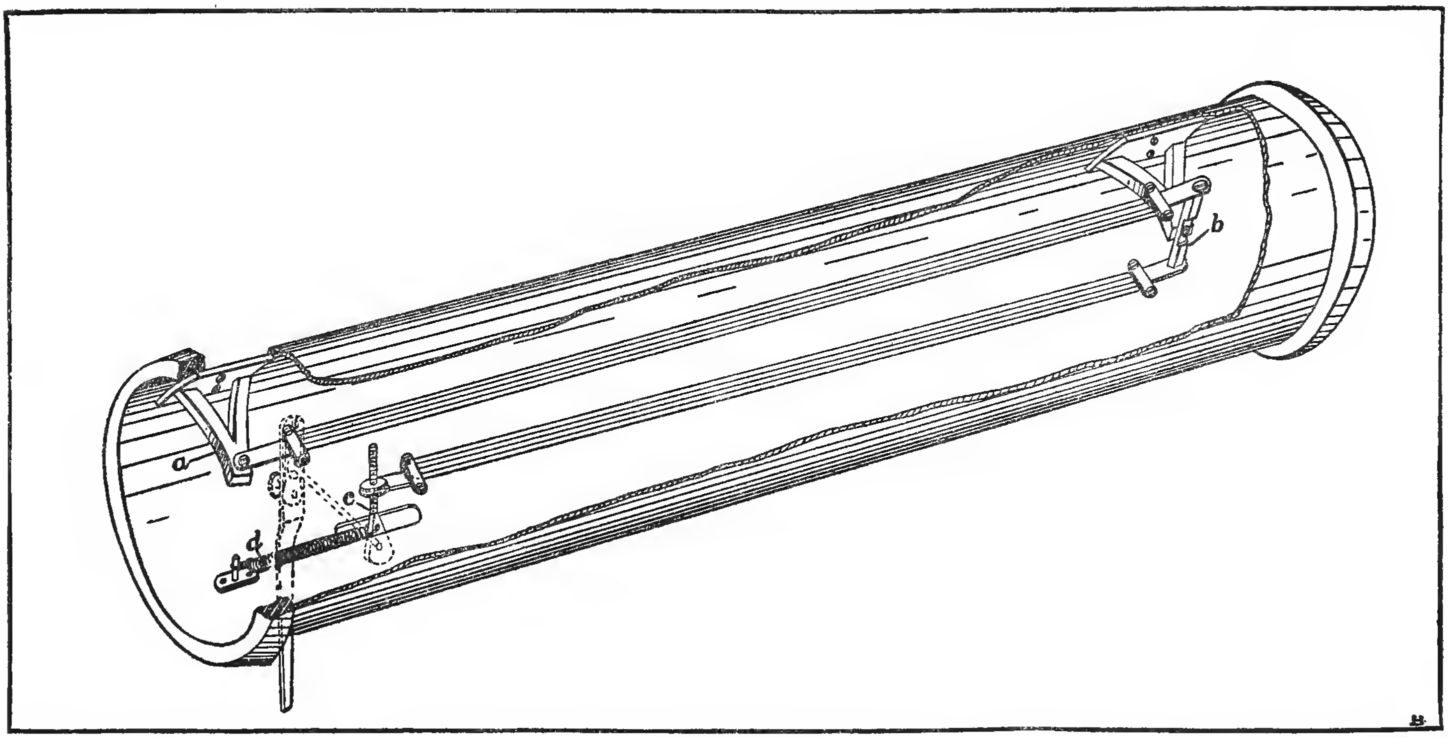


FIG. 24.—Horizontal screening tube in kite meteorograph, showing method of mounting hairs of hygrometer (*a*, fixed post; *b*, pivoted arm; *c*, pen arm; *d*, spring for holding hairs at constant tension).

In some of the newer meteorographs the link has been so constructed that the scale value may be changed in any of several ways. The principle of the mechanism, however, is the same in every case. Moving the connecting point toward the center of rotation causes that point to move through a greater angle with the same change of the element, and vice versa.

Humidity element.—Free-air relative humidities are usually obtained by means of the hair hygrometer. Human hair has the property of lengthening or contracting about 2 per cent, when subjected to extremes of moisture. The hairs are mounted longitudinally in the horizontal screening tube. (See fig. 24.) The individual

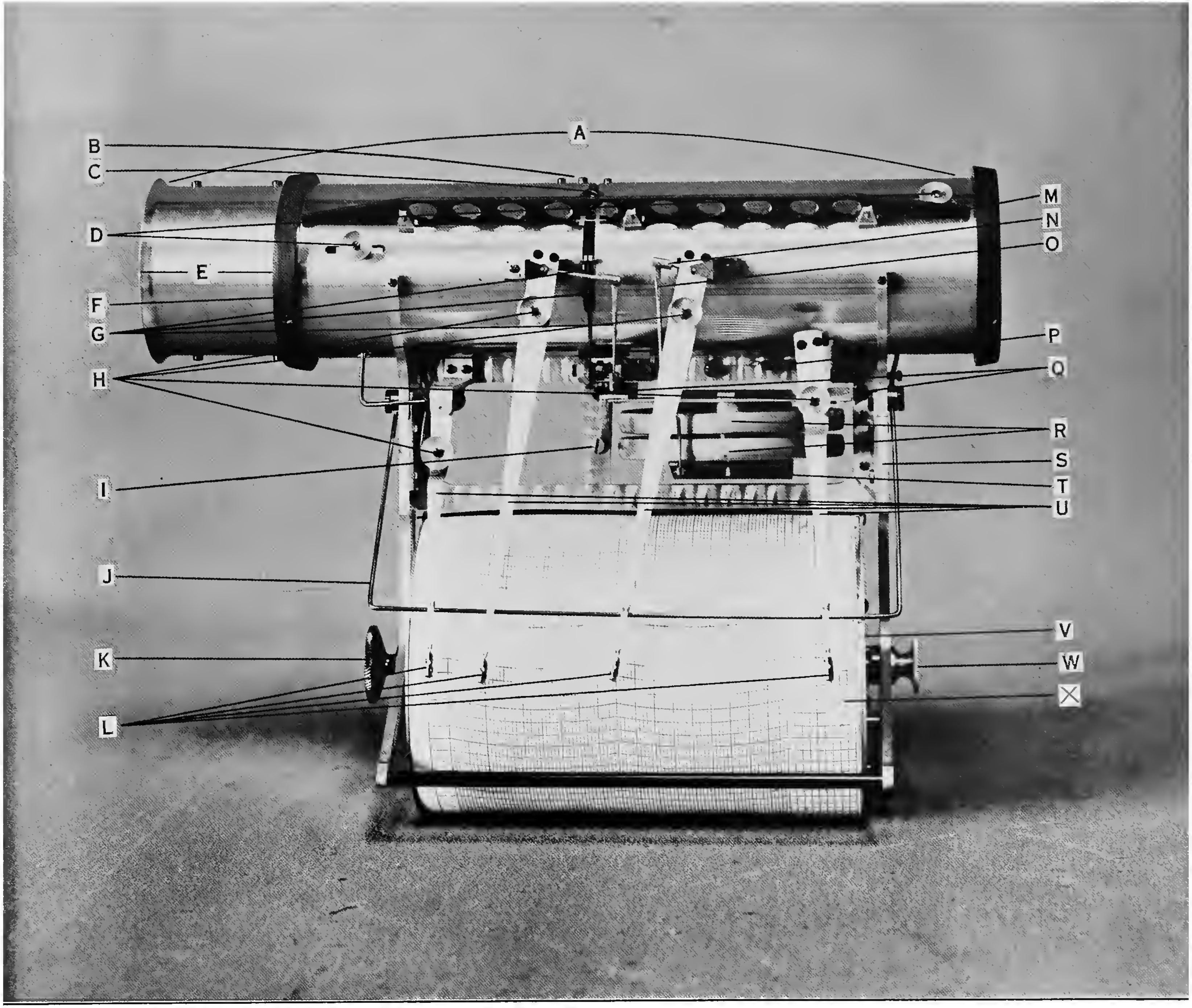


FIG. 21.—Front view of Marvin kite meteorograph (*A*, screening tube; *B*, pinion; *C*, set screw; *D*, adjusting screws (humidity); *E*, anemometer head; *F*, bakelite collar; *G*, connecting arms and lever; *H*, adjusting nuts on pen arms; *I*, adjusting screw (pressure); *J*, pen lifter; *K*, knurled nut; *L*, pens; *M*, bakelite strip; *N*, lever; *O*, connecting arm; *P*, spring on humidity element *Q*, pivots of pressure cell; *R*, aneroid cells; *S*, frame; *T*, steel spring; *U*, pen arms; *V*, clock cylinder; *W*, thumb screw; *X*, record sheet).

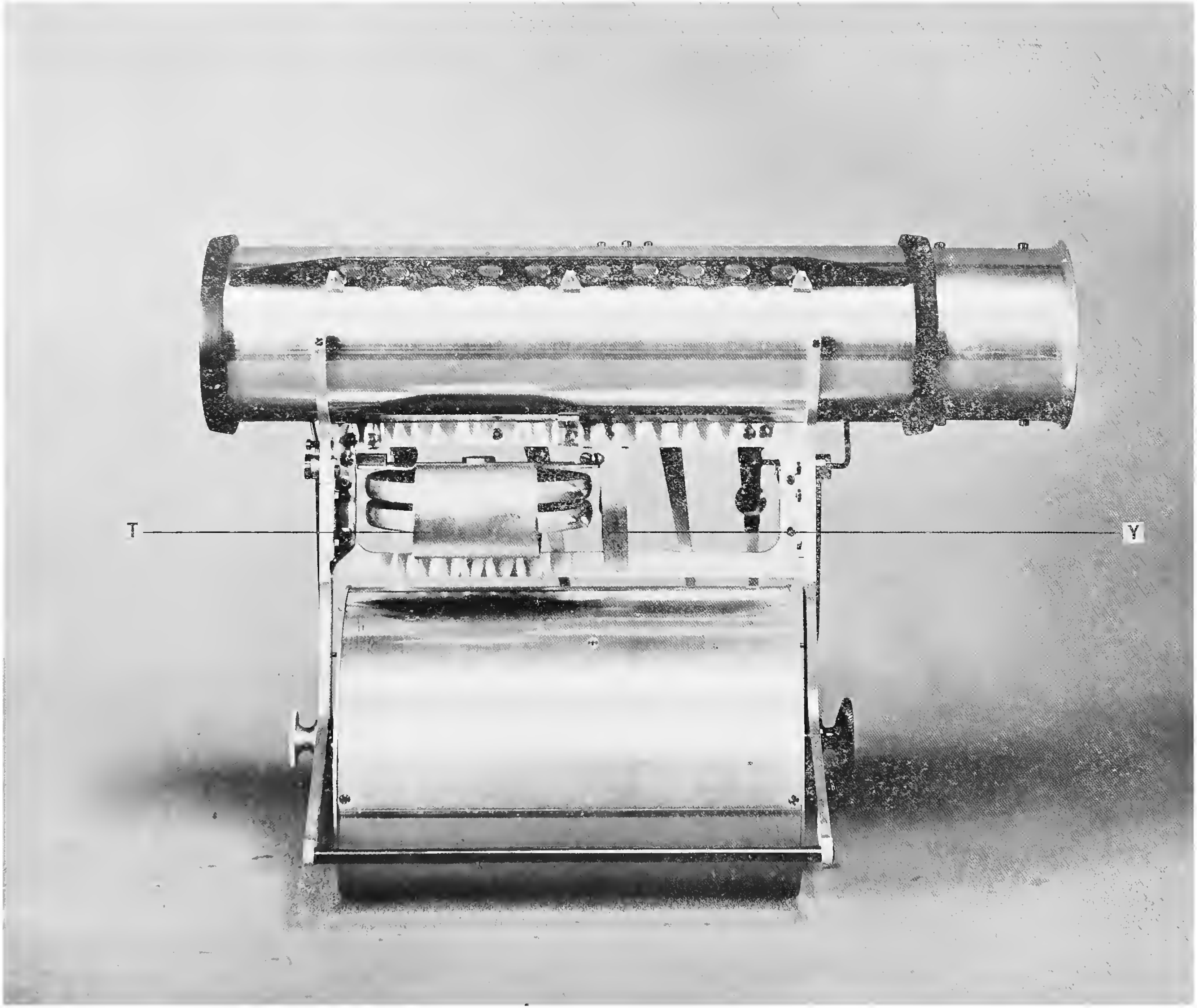


Fig. 22.—Rear view of Marvin kite meteorograph (*T*, steel spring; *Y*, tension spring).

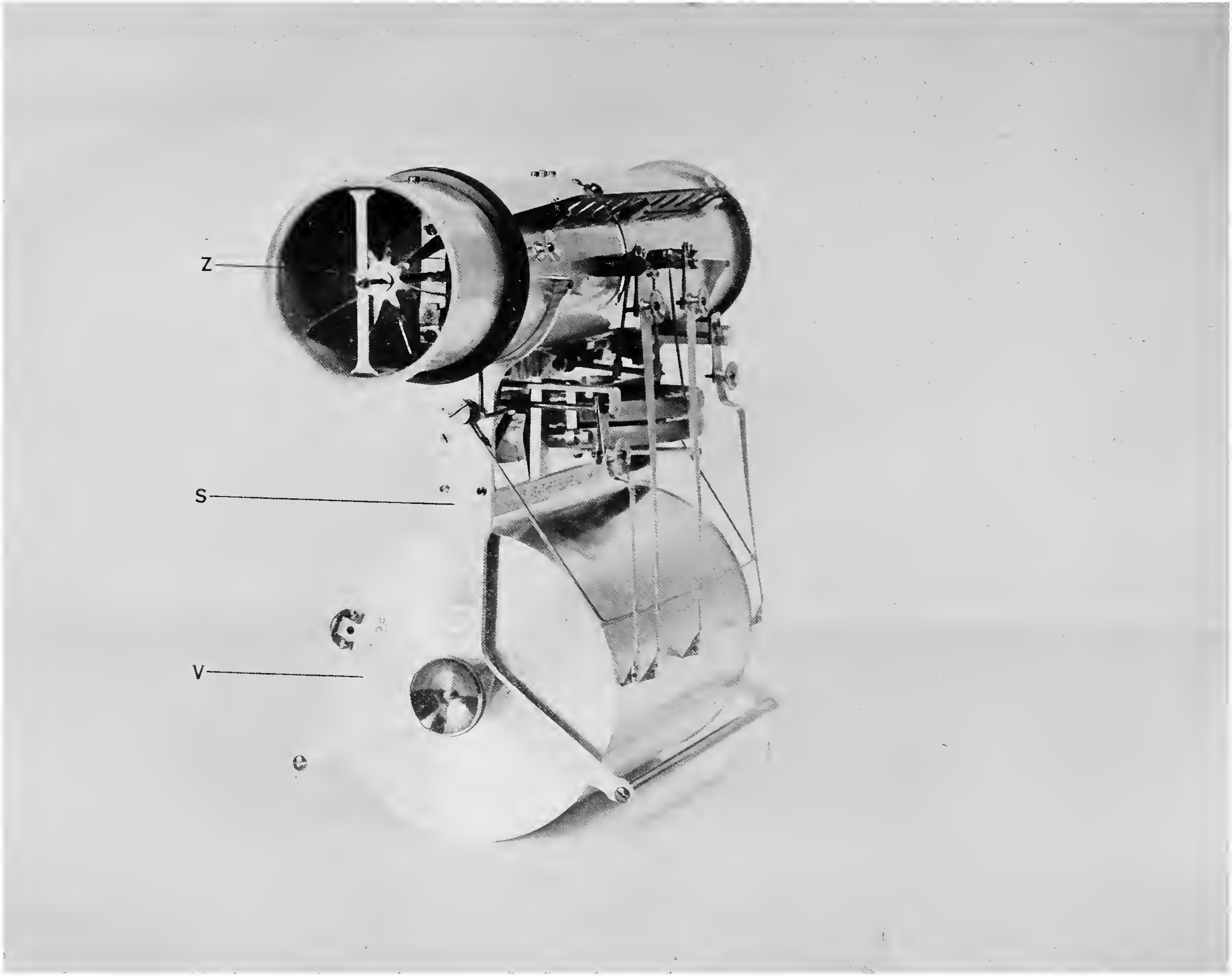


FIG. 23.—End view of Marvin kite meteorograph (S, frame; V, cylinder; Z, anemometer).

hairs are mounted separately instead of in a bundle. This method makes the element more quickly responsive to any change in humidity. The hairs are connected as directly as possible with the recording pen, thus reducing to a minimum the possibility of lost motion or friction in the bearings. Two sets of hairs are used—one running from an adjustable post at *a* to the pivoted arm at *b*, this arm also being connected with an adjustable post; the other from the lower end of the arm at *b* to the pen arm at *c*. A small spring at *d*, or outside the tube on new instruments, keeps the hairs at constant tension. This tension should simply be sufficient to take up any slack in the hairs and to overcome any possible friction in the movement of the pen arm. The doubling of the strands of hairs in this fashion is equivalent to extending the hairs for twice the distance of either strand alone and hence the movement of the pen arm is twice that of a single length. Before mounting, all of the hairs are subjected to the same conditions of temperature and humidity and the same tension and are fastened firmly with shellac. It has been found that an element in which the hairs are thus mounted responds very quickly to changes in humidity, whereas, when the hairs are arranged in a bundle they require a relatively long time to change from dry to wet conditions and especially from wet to dry.

Any change in the relative humidity, then, changes the length of the hairs, and this change is communicated directly to the pen arm. The change, however, is not linear with respect to the humidity change. Thus it is found that twice the change in humidity does not cause the pen to move twice the distance that a unit change would cause it to move as was found in the case of the temperature element. For this reason a special scale has to be made up for each humidity element showing the movement of the pen arm for any definite change in humidity.

The position of the humidity pen on the sheet may be easily changed. The two adjustable posts mentioned above are held in position by small thumbscrews on the outside of the screening tube and may be moved either way by loosening the thumbscrews. This either increases or decreases the distance between the posts, the slack or tension being adjusted by the small spring connected to the axle of the pen arm.

The post that is connected directly with the pen arm is threaded and the position of the small clamp nuts holding the hairs on this post may be changed by moving the clamp nuts up or down. In later instruments the adjustment is made by means of a set screw in a small cylindrical block which can be made to slide up or down the post. In either case a movement up or down causes a change in the scale value of the humidity element. Thus, when the device that holds the hairs is moved downward, the post moves through a greater angle than before for the same change in humidity. This greater angular motion of the pen arm causes the pen, of course, to move over a greater distance on the sheet. Thus by trial and adjustment the scale value can be made anything desired. The humidity pen should be placed in such a position that when the humidity is about 100 per cent the pen will be a little above the humidity space on the record sheet.

Wind element.—The velocity of the wind is recorded by a small anemometer fan placed in the forward end (that facing the wind) of the screening tube. In appearance it closely resembles a diminutive electric fan, except that the pitch of the blades is much greater. The wind passing through the screening tube causes the windmill to rotate; this rotation is transmitted through worm gearing to a cam against which bears a lever secured to the pivot of the recording pen; when the cam comes to the proper position the lever is suddenly pulled down and the pen makes a mark on the record sheet. It then returns slowly to its former position. The scale value of this element is changed only by changing the pitch of the blades on the fan. The entire anemometer fan and its immediate connections, called the "anemometer head," may be removed by unscrewing the three little brass screws in the collar running around the tube. This should be done only when absolutely necessary, as, for example, when it is desired to test the instrument in a small bell jar, for damage is easily done when replacing this head. The pen may be shifted forcibly when necessary to change its position on the sheet.

The record sheet used is the same for all instruments. The wide space at the top side of the sheet is for the wind record. The temperature pen should record between this space and the center of the sheet. The space for pressure runs from near this center line to the beginning of the space occupied by the humidity record. Here the lines are double spaced, for the record of humidity is not as accurate as are those of the pressure and temperature elements. Under extreme conditions it should be possible for the pens to record outside their ordinary limits. Thus at an altitude of about 7 kilometers the pressure pen could record on the humidity space and the temperature pen on the pressure space and there would probably be no interference.

The clock cylinder may be removed from the frame by loosening the thumbscrews on each end of the axis. Inside the cylinder is a specially made clock. The axis of the cylinder is one of the arbors of the clock and, when it is clamped in the frame at one end, the clock and cylinder rotate around it once in eight hours. The other end, the one with the large knurled thumbscrew, is used for winding the clock and rests lightly on the frame. The clock is wound by turning this large knurled nut, holding the cylinder at the same time. The paper on which the record is to be made is properly trimmed and placed on the cylinder, the latter being, of course, removed from the frame while winding the clock and attaching the paper. The record sheet is held in place by a brass strip which presses down upon the sheet and fastens in the side of the cylinder. The outer end of the sheet is always placed beneath the clip so as to give the greatest possible length of record before the pens have to pass over the clip.

A pen lifter is provided by which, when the instrument is in the case or otherwise, the pens may be raised from the sheet. The lifter should always be worked by the lever inside the screening tube.

The case or cover.—The instrument fits snugly into a light aluminum case in such a way that no part of the instrument except the inside of the screening tube and the anemometer head is exposed to the weather. Two bakelite strips insulate the tube from the case. A piece of mica in the case allows the action of the pens, whether they are inking properly, etc., to be seen while the instrument is still in the case. The case is fastened into the kite as explained in section 8.

7. CALIBRATION OF METEOROGRAPHS.

Before beginning any tests on an instrument it should be carefully examined to see that it is in good working condition. The cylinder should be removed from the frame and the clock wound. A record sheet should be trimmed along the line above the wind space and on the center line of the three close lines below the humidity space. The sheet is then placed on the cylinder so that the wind space is near the large knurled nut used to wind the clock. Where the ends of the sheet overlap the lines should be made to coincide and the paper should fit snugly against the front (wind) side of the cylinder. The brass strip is then put in place and the cylinder set in the frame in such a way that the pens are directly above the brass strip. The knurled nut at the right is tightened securely, but with the fingers only. The larger knurled nut is simply screwed up, not tightened.

For convenience in testing these instruments a stand is made of two parallel strips of wood with ridges provided for the lower part of the frame. This stand holds the instrument in the proper position and allows the cylinder to move freely.

The pens are filled with the special ink provided and the adjusting nuts on the pen arms screwed down until the pens press lightly against the paper. The pressure should be sufficient to hold the pen against the sheet when the instrument is tilted about 20° from the vertical. The pens should be made to ink properly. It is sometimes necessary to draw a thin slip of paper between the points of the pens in order to start the liquid flowing through them. With new pens it may be necessary to smooth the points a very little to prevent their catching in the paper. The pressure pen should then be run down to the center of the humidity space and back, this being done by turning the adjusting screw resting against the frame. If there is any mechanical obstruction to this motion it should be removed. If the difficulty can not be easily remedied the instrument should be returned to the instrument maker. No attempt should be made to repair the instrument. This applies to any adjustments, other than very simple ones, which may be found necessary. When repaired by other than an expert instrument maker the instrument suffers. While running the pen down and back it should be noticed whether it marks all the way or whether it rises from the sheet part of the way. (This may be due to a twisting of the frame and if serious the instrument should be returned for repairs.) The pen should then be forced two or three spaces to either side of its position of rest and allowed to return by itself. When the instrument is tapped lightly the pen should return to within at least two or three tenths of a space to its original position. If it does not do this there is something wrong. It may be lost motion or friction in the connecting link or perhaps the pressure of the pen against the sheet is too great. The latter may be tested by loosening the pen arm a bit and allowing the pen to rise slightly from the sheet. If it still fails to return the trouble is evidently elsewhere. The connections should be examined for tightness or looseness and altered, if necessary. The trouble may possibly be due to the fact that the adjusting screw is not resting tightly against the frame. If, after these and other trials that may suggest themselves, the pen does not return properly it is probably due to a weak or defective element which should be replaced by a new one.

The temperature element should then be tested in about the same way, making sure that the pen can go as far as the wind and pressure spaces. The pen is moved by loosening the brass set screw and turning the pinion above it as described previously. The set screw should be tightened again, of course. The humidity pen is tested similarly by moving either of the adjusting posts. If this pen does not return when slightly displaced and jarred it may be due to the tension of the little spring on the pen-arm axle being too small or too great. Too great a tension will tend to cause a lag in the element.

If the instrument is working properly to this point it is ready for the individual tests. These will be described separately and in detail; first, however, a brief description of the special apparatus necessary in testing each element will be given.

Pressure test.—For this test an ordinary bell jar large enough to hold the instrument, preferably without removing the anemometer head, an exhaust pump of the Geryk or other good type, a U-tube manometer, with attached thermometer, or other means of accurately measuring the pressure within the jar, together with the necessary connections, etc., are needed. Two pressure tests are necessary—a preliminary one for the purpose of adjusting the range of the pen, and an intensive one to determine scale values. The instrument is placed upon the wooden stand and the pressure pen lowered against the sheet. The time should be noted. (See Table 1 for entries referred to.) The instrument and stand are placed under the bell jar, and the pump is then started for the preliminary test. The pressure should be lowered gradually until the pen has run down to the top of the humidity space, and should then be about the minimum anticipated in any flight. If it is not, then the jar should be slowly refilled, the instrument removed, and the connecting link changed. In ordinary kite work the highest altitude often reached is about 5 kilometers, at which height the pressure is about 400 mm. Therefore the pen should be at the bottom of the pressure space at about this pressure. In a record flight the pen could go still lower, of course, since the humidity pen would doubtless be out of the way. Suppose, for example, that we run the pen down to the top of the humidity space and find the left arm of the manometer to read 260 and the right arm 275. The sum of these is 535 which, subtracted from the average pressure 760, gives 225 mm. as the pressure at that point. The pen has evidently moved over too small a distance for the indicated change; therefore the little connecting lever should be pushed in toward the axis of rotation so that the pen arm will move through a greater angle for the same change in pressure. Having adjusted the connecting lever until the desired range is reached, the intensive test follows. With the instrument still under the bell jar the clock is allowed to run until the pressure pen makes a straight or steady line. Then the air is pumped out until the pen has gone down about five spaces. The instrument is allowed to stay under this pressure until a straight line has been traced. The instrument should be jarred slightly a minute or so after the pump is stopped. When the steady line has been made, the pressure, as recorded by the arms of the manometer, and the temperature are read and entered and the pump started again. When the pen has gone down about five lines more the pump is again stopped for a similar period. These steps are repeated until the pen is about at the center of the humidity space. It is then allowed to return at about the same successive steps, the air being let into the jar by opening the stopcock or by some other convenient method. The times of the beginnings and endings of each of these stops may be noted in the proper column if desired. When the air in the jar is again at atmospheric pressure, the pen is given sufficient time to return to its original level. It should be jarred several times if necessary. If the pressure in the room has not changed during the test the pen should return to very approximately its original level in five minutes or so. A complete test usually occupies about one hour and a half or two hours. Since the instrument, when in the kite, is seldom or never subjected to changes as rapid as these, and since it is always under more or less vibration which tends to adjust the pens, it seems reasonable to assume that, if the element is working properly and the pen returns properly under these conditions, it is working all right and that it will work satisfactorily when in actual use. When this result is attained it is hardly necessary to simulate the actual conditions of flight by taking a longer time, etc., for the tests. If, however, the pen does not return to within at least several tenths of a space of its original level (providing the pressure has not changed) the element and its connections should again be examined and the element replaced if necessary.

In performing these tests it is always desirable to notice the general behavior of the elements. Thus the pen should move smoothly and should move every time the pump exhausts air, etc. If there is a leak in the connections or bell jar, as indicated by the manometer, this leak should be shown by the trace. A leak is rather an advantage if it is not too great, for a small leak indicated by the trace shows that the pen and element are working properly and smoothly and that the element is responsive to very small changes in pressure.

The above test is repeated at least once, since a single test is not sufficient to give accurate values for making up the necessary tables. The method of working up these tests to give the tables will be treated later on. Having obtained two or three pressure tests which are apparently satisfactory the temperature test is then made.

Temperature test.—For testing the temperature element there will be needed a warm and a cold room, box, or other receptacle in which the ventilation, produced by an electric fan or otherwise, is good. If a box is used it should have a glass window, so that a thermometer placed inside the box may be read from outside. In cold weather the instrument may be placed indoors and outdoors alternately. In warm weather it may be possible to secure a low enough temperature by placing the instrument in a tight box containing chopped ice mixed with salt. Other means of securing still lower temperatures are very convenient but not necessary. To secure the proper ventilation an electric fan is usually placed in the box or other compartment in such a way that the air current caused by it blows through the screening tube. An ordinary mercurial thermometer is suspended or placed in such a position that the bulb is exposed to the same current of air as the temperature element and can be read through the glass window.

In this test both the temperature and the pressure pens are allowed to record, for we wish to know the effect of temperature change on the pressure element as well as on the temperature element. The general method is the same as that followed in the pressure test. The instrument is set up before an electric fan and allowed to run for about five minutes or until straight lines are traced by the pens. The thermometer is then read and the instrument subjected to a temperature differing from the first by 25° to 30° C., if possible. It is placed in front of a fan in this compartment and allowed to run until a straight line is made at this new temperature. The temperature is then read again, this time through the window. After one or two such changes the number of lines which the pen has moved over should be compared with the temperature change as indicated by the thermometers. The recorded change in ordinate divided into the change in temperature gives the scale value, and if this is not approximately that desired the connecting link should be adjusted so as to give the desired value. In aerological work a factor between 0.9 and 1.0 is sought; that is, one space on the sheet should correspond to a temperature change between 0°.9 C and 1°.0 C. There are several reasons for this limitation of the scale value. It is evident that the farther the pen moves the easier it will be to read more accurately any definite temperature change. On the other hand, the distance that the pen can move is limited by the width of the record sheet; for, if it goes beyond its proper space, it is likely to interfere with the pressure trace and both records will be lost or useless. Hence, it is necessary to ascertain the extreme temperatures that are apt to be met with and then adjust the pen or connecting link in such a way that either extreme will be recorded, the lower usually being recorded about the middle of the sheet and the upper near the wind space. It has been found that within the limiting range stated little difficulty is ever met with on account of interference, but any smaller scale value with a greater movement of the pen arm would be liable to cause such trouble.

If the factor, as determined roughly from the first two or three changes, is approximately that desired the procedure is repeated at least half a dozen times. This will give about 12 changes in all which, when averaged, should give a good mean value. The number of values necessary to give a good mean depends mainly on the consistency of the values; and if this is good, 15 or 20 values seem to be sufficient. Two series of the above tests should therefore give a satisfactory scale value.

Humidity test.—Some kind of a humidity chest or box is necessary for this test. Any box which is nearly airtight and provided with a glass window and containing a ventilating fan will be found satisfactory. The temperature box, if such was used, may be made to serve this purpose also. The inside of this box should be lined or otherwise covered with blotting or absorbing paper which should be saturated with water. With the cover on tight and an electric fan going, the humidity inside will soon reach 90 per cent or higher. This gives a standard value of *high* humidity. A standard *low* humidity may often be reached in the open room. In winter when the temperature and humidity are low outside it is possible to get a very low humidity in a warm room. If such conditions obtain nothing further is needed. If not, then another box or a readjustment of the conditions in the same box is necessary. This time calcium chloride or sulphuric acid is placed in the box. The moisture present is soon absorbed by either of these and the humidity becomes very low. In addition to the box and electric fan some kind of a psychrometer is necessary. The ordinary psychrometer exposed to the electric fan will serve this purpose, but an Assmann ventilated psychrometer is more convenient.

The humidity pen is made to record, and the instrument is placed in front of the fan in either the wet or dry compartment until a straight line is made. The psychrometer is then read and the instrument changed to the opposite condition of humidity and the procedure repeated. A trial determination of the scale value is made as in the temperature test and the scale value changed if desired. If the hairs are lowered the pen will, of course, move farther for the same change in humidity. As has been stated, the scale value is a variable depending on the humidity. For this reason humidities ranging from about 10 per cent to nearly 100 per cent should be used to derive the proper changes in the scale value. By allowing the blotters to dry out partially the high humidity may be lowered and then by limiting the amount of the drying reagent the low humidity may be raised until all possible values are obtained. Wherever possible about fifty changes should be secured and these should be as evenly distributed as possible among the different possible percentages. The range of humidity for each test should not necessarily be large. A range of 20 per cent is sufficient to give a good test and is more desirable in some ways than a larger range.

It is often possible, especially in preliminary tests, to make the humidity and temperature tests at the same time. The instrument is placed in a room or box where the temperature is high and the humidity low. It is then changed to a box containing soaked blotters and cracked ice with salt. The temperature range secured in this way may be 20 or more degrees and the humidity range 30 per cent or more.

The temperature and humidity pens in these tests should be watched to see that they are responding properly; that is, they should respond immediately to any change in the temperature or humidity. The humidity pen, however, usually takes a few minutes, or more sometimes, to adjust itself. This does not happen very often in actual flight, for sudden changes are not the rule, and the vibration of the kite and instrument assists the pen in adjusting itself to any change. If the elements do not respond to the changes as quickly as desired they should be examined for friction, etc., or replaced if necessary.

Wind test.—In this test an anemometer, for recording the number of miles of wind passing a certain point, and an anemoscope or wind vane are necessary. Ordinarily the station anemometer and vane are used for this purpose.

The anemometer pen of the meteorograph is adjusted to touch the sheet and the time is noted. The meteorograph is then suspended from the anemoscope so that the ventilating tube carrying the anemometer always faces the wind. The time at which it is suspended should also be noted. The wind should be somewhere near the average met with in actual flights. At any rate it should not be an extremely light or high wind. The instrument is allowed to record for three or four hours or more and is then taken down, the time being noted. The number of miles of wind that have passed the instrument is taken from the record of the station anemometer. Two or more of these tests should be made.

In all the foregoing tests if the scale values as deduced later on do not agree fairly well, further tests should be made. A disagreement or lack of consistency may indicate a poor element or a poor test. At any rate tabular values for standard use should not be dependent on inconsistent tests.

Time test.—This test may be made separately or the times noted on the other tests may be used. If it is desired to make a special test on the clock, all that is necessary is to allow any pen to record for about three or four hours and raise it at a noted time. At least two such tests should be made.

Lengths of pen arms and centers of arcs.—For drawing the hour lines (see section 10) it is necessary to know the length of each pen arm and the point on the record sheet at which the pivot of the pen arm falls. To find these the length of each pen arm from the center of the pivoting point to the pen is measured. The inked pen is then run up and down the sheet making as large an arc as convenient. The record sheet is then removed and with the length of the pen arm as a radius and each end of the arc as a center small arcs are drawn. The point of intersection of these arcs is the center of the arc made by the pen arm. The position of each center is thus found and stated with reference to the number of lines that this center is below a certain point. Thus the temperature is measured from the top temperature line and the pressure from the middle line of the sheet, etc. All the instruments now made by the Weather Bureau instrument shop have standard lengths of pen arms and centers of arcs so that it is not necessary to make these measurements on the new instruments. These measurements are as follows: Lengths: Wind, 86 mm.; temperature, 130 mm.; pressure, 130 mm.; humidity, 99 mm. Center of arcs: Temperature, 25 lines below top temperature line; pressure, 20 lines below top pressure line; humidity, 5 lines below top humidity line; wind, center of wind space.

Reduction of the tests: Pressure.—Table 1 shows a pressure test that has been made in accordance with the method outlined above. If reference is made to this table the following procedure will be simple. The columns headed "Notes," "Time," "Att. ther.," "Manometer," "Left," and "Right" have already been filled in as described. The figures under the "Right" and "Left" columns are added and the total is entered under "Sum." Now, any change in the temperature of the mercury in the manometer will cause that mercury to expand or contract a certain amount, dependent on the height of the column and the coefficient of expansion of mercury. For this reason all readings are reduced to zero degrees centigrade. The glass also expands or contracts when heated or cooled, and so what we really wish to determine is the difference between these two expansions. The easiest way to do this is to make up a table or graph showing this result. The values generally used are given in the Smithsonian Meteorological Tables, 1918 edition, Table 47, but special graphs have been made up to facilitate these reductions. By reference to one of these graphs or to the original table the corrections indicated in Table 1, "Temp. cor." column, will be found to apply. The arguments are the "sum" and the "attached thermometer." Since the temperatures recorded are above zero, the mercury is occupying greater volume than it would at zero, and hence the corrections are subtracted. This gives the "corrected reading" in mm. In aerological work millibars are the units used, so mm. have to be converted to mb. by multiplying by 1.333224. This gives the corrected reading in mb. (For these corrected values, see Table 12, S. I. Metl. Tables, 1918 ed.)

TABLE 1.

[Washington, D. C., Dec. 24, 1919. Pressure tests Nos. 1 and 2. Meteorograph No. 25.]

Notes.	Time.	Att. ther.	Manometer.		Sum.	Temp. cor.	Corrected reading.		Ordinate.	Scale value.
			Left.	Right.			mm.	mb.		
Pens down....	9:04a	25.0	14.5	14.5	29.0	0.1	28.9	38.5	3.4	11.32
		25.0	26.0	26.5	52.5	.2	52.3	69.7	6.2	11.24
		25.0	37.0	38.5	75.5	.3	75.2	100.3	8.9	11.27
		25.0	49.5	51.5	101.0	.4	100.6	134.1	12.4	10.81
		25.0	65.0	68.0	133.0	.5	132.5	176.7	16.3	10.84
		25.0	83.0	87.5	170.5	.7	169.8	226.4	21.2	10.68
		25.0	109.0	115.5	224.5	.9	223.6	298.1	28.4	10.50
		25.0	131.5	139.5	271.0	1.1	269.9	359.8	35.4	10.16
		25.0	159.5	170.5	330.0	1.4	328.6	438.1	[illegible]	9.91
		24.5	188.5	201.5	390.0	1.6	388.4	517.8	[illegible] 53.6	9.64 9.66
		24.5	159.5	170.0	329.5	1.3	328.2	437.6	43.3	10.11
		24.5	121.0	128.5	249.5	1.0	248.5	331.3	31.8	10.42
		24.5	103.0	108.5	211.5	.9	210.6	280.8	26.8	10.48
		24.5	81.5	86.0	167.5	.7	166.8	222.4	21.4	10.39
		24.5	70.0	73.5	143.5	.6	142.9	190.5	18.3	10.41
		24.5	54.0	56.8	110.8	.4	110.4	147.2	14.1	10.44
		24.5	42.0	44.0	86.0	.4	85.6	114.1	10.9	10.47
		24.5	29.5	30.0	59.5	.2	59.3	79.1	7.4	10.69
		24.5	19.4	19.7	39.1	.2	38.9	51.9	4.8	10.81
		24.5	17.6	17.9	35.5	.1	35.4	47.2	4.1	11.51
		24.5	34.8	36.3	71.1	.3	70.8	94.4	8.3	11.37
		24.5	53.0	56.0	109.0	.4	108.6	144.8	13.0	11.14
		24.5	73.5	77.0	150.5	.6	149.9	199.8	18.4	10.86
		24.5	96.0	101.0	197.0	.8	196.2	261.6	24.7	10.59
		24.5	120.5	127.5	248.0	1.0	247.0	329.3	31.9	10.32
		24.5	147.0	157.0	304.0	1.2	302.8	403.7	40.0	10.10
		24.5	182.0	195.5	377.5	1.5	376.0	501.3	51.1 51.3	9.81 9.77
		24.5	144.0	154.0	298.0	1.2	296.8	395.7	39.2	10.09
		24.5	113.0	119.5	232.5	.9	231.6	308.8	29.9	10.33
		24.5	98.0	103.0	201.0	.8	200.2	266.9	26.1	10.23
		24.5	78.0	82.5	160.5	.6	159.9	213.2	20.5	10.40
		24.5	50.2	54.0	104.2	.4	103.8	138.4	12.9	10.73
		24.5	36.0	37.1	73.1	.3	72.8	97.1	9.2	10.55
		24.5	18.0	18.6	36.6	.1	36.5	48.7	4.6	10.59
Pens up.......	12:01p									

The next step is to determine the values of the ordinates. To do this we find the number of spaces and tenths of a space or division that the pressure pen moved from its initial position when each stop was made. Thus in figure 25 the starting line is 0.4 division above the line next below it. Then on the first stop, just before the pump was started or just at the time the pressure reading was made, the trace shows that the pen moved 3.4 divisions from the original point. The total number of whole divisions over which it has moved is 3. The lower point is exactly on the line, and hence its fractional ordinate is zero, and the addition of these values gives the ordinate stated. Each successive step is determined in the same way and entered as indicated in Table I under "ordinate." From the lowest point, coming back, all the points are computed in exactly the same way but from the last position of the pen. This is about 0.3 of a division above the line below it, and on refilling the bell jar all points are computed from this point. By the side of each step in figure 25 is placed a numeral which is the number of tenths of a space that the point at which the pressure reading was taken is below the line above it. This facilitates reading the trace and assists the computers in checking the work. The starting and ending points are computed from the line below rather than from the line above, and hence the numerals placed there signify so many tenths above the line below. The ordinate values having been filled in, each value is then divided into its corrected reading in mb., and this gives the scale values shown. This procedure is followed for all the pressure tests.

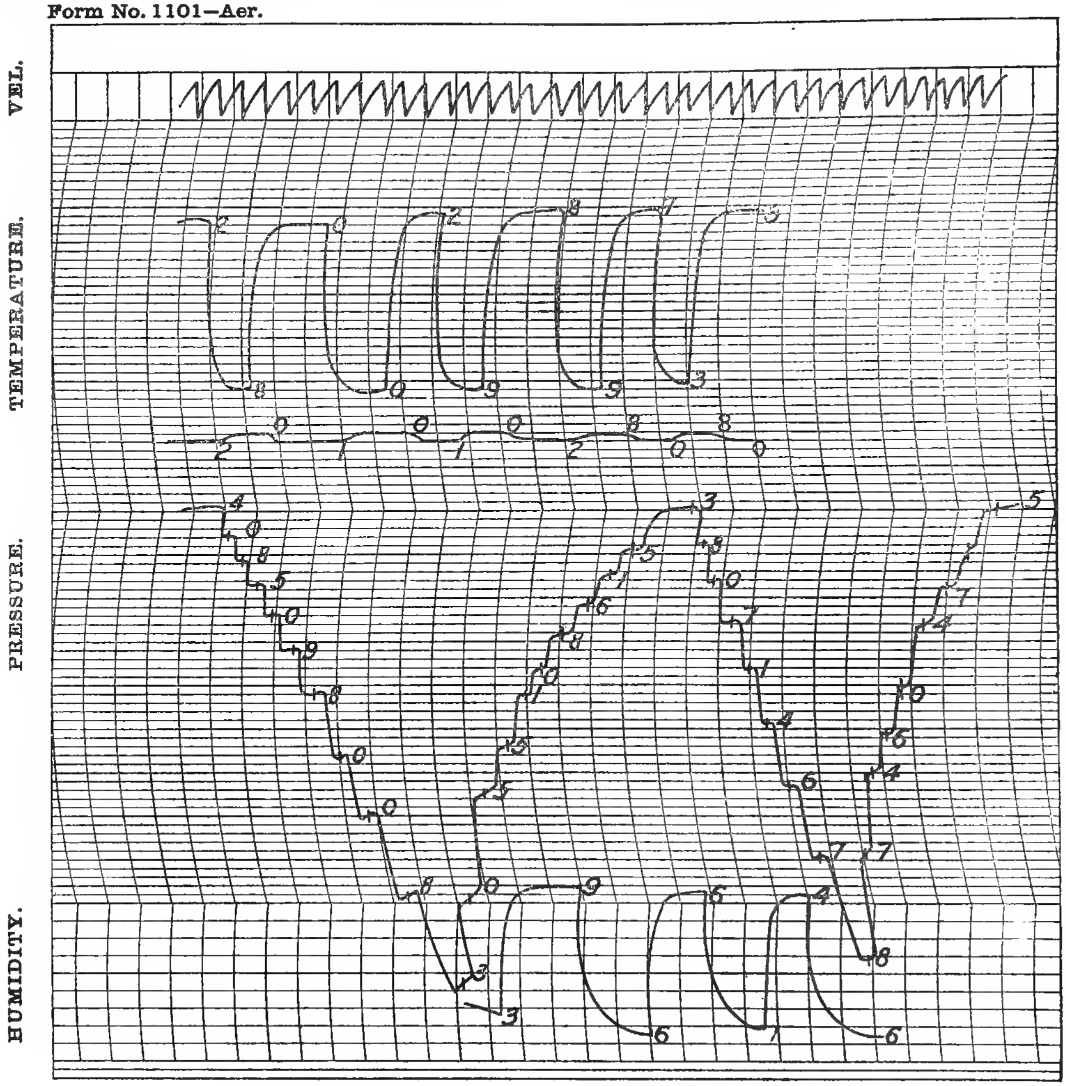


FIG. 25.—Calibration or test of the different elements in a kite meteorograph.

The scale values secured in the above manner now have to be plotted. Using coordinate paper and considering the scale values as abscissas and the divisions as ordinates, a graph is made similar to the one shown in figure 26. The scale values secured from other tests are plotted in the same way, either on the same or separate sheets, and straight lines drawn between successive points. The scale values at which each line passes through each fifth ordinate are set down and then the mean for each ordinate found. This method is shown in Table 6, which is self-explanatory. The mean values shown there are plotted in figure 26, as indicated by the large circles, and a mean curve drawn through them. In drawing the curves for the individual tests it seems best to make the lines straight between the successive points, but the final curve should be smooth.

Having determined the smooth curve showing the scale values of the element for various readings on the record sheet, the next step is to make up a table. The curve itself may be used for computing values, but a table is more convenient. To use the curve itself we take the ordinate reading and multiply it by the scale value for that ordinate as taken from the smooth curve. The table is made up in the same way, taking each ordinate and multiplying it by the scale value for that ordinate. A straight interpolation is made for the tenths of an ordinate. Thus, in the mean curve drawn above, the first ordinate gives the scale value of 11.19 which has been entered in Table 2. The second ordinate gives he value of 11.16, etc. Each of these is then multiplied

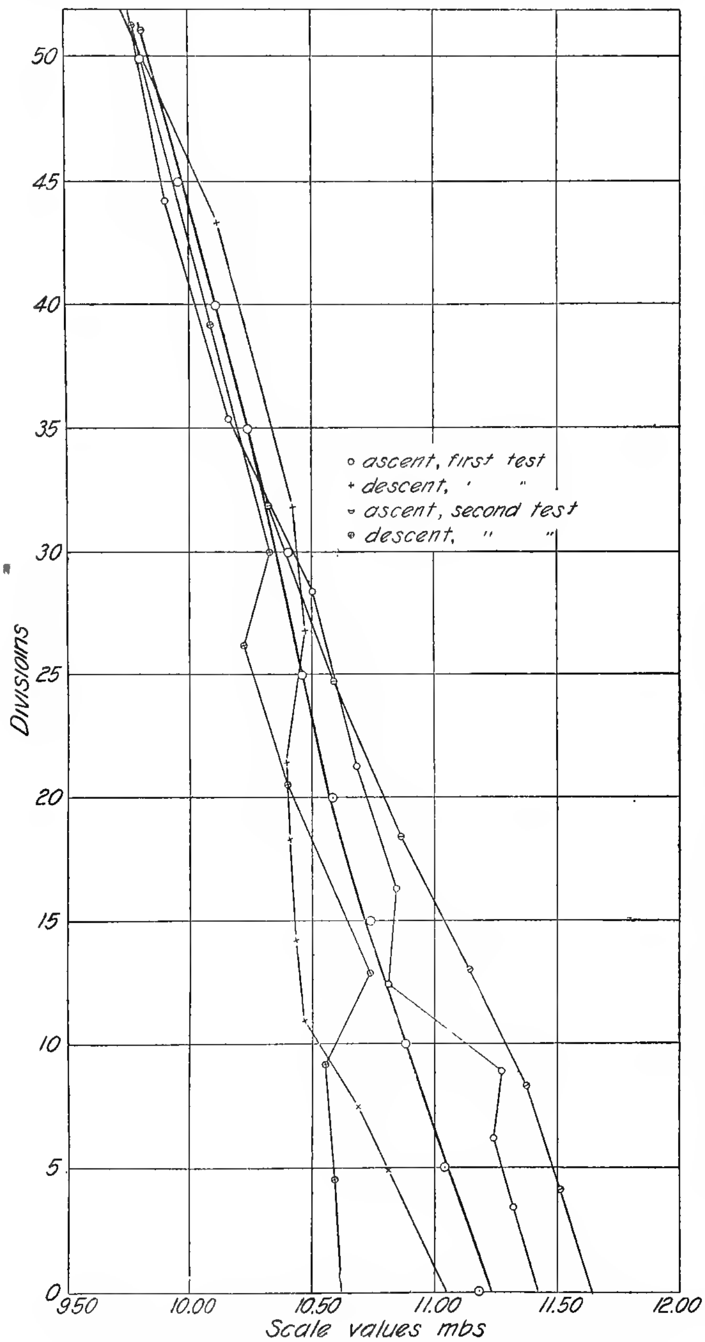


FIG. 26.—Pressure scale values for meteorograph, as determined from tests.

by its ordinate and the value set down as shown. This is done for all the whole ordinate values that it is expected will ever be used. These values for the whole ordinate values are then copied (to tenths only) in the first column of the table to be made up as shown in Table 3. As the points on the record sheets are read to tenths of a division, we have to make interpolations for these intermediate values. Very little error, or practically none, is introduced by assuming that the mean curve is a straight line between successive whole ordinate values. We therefore divide the differences (see Table 2) between any two whole ordinate values by 10 and add this figure successively to the scale value from the first to the second whole ordinate. Thus, in the example given, the difference in scale value between the fifth and sixth ordinate values is 10.87, which, divided by 10, gives 1.087. Starting with the value for the fifth ordinate, which is 55.25, and adding 1.087 successively to this value, we obtain the values shown in Table 3 for successive fractions of the fifth to sixth ordinate values. The difference between the sixth and seventh ordinate is then found and treated as in the preceding case. This is done for the whole table. Having read any ordinate on the record sheet, we simply have to refer to this table, and we have the change in millibars directly.

TABLE 2.—*Pressure differences (mb.) per sheet ordinates, from tests made Dec. 24, 1919, at Washington, D. C.*

[Meteorograph No. 25.]

Ordinate.	Scale value.	Ordinate × scale value.	Differences.
1	11.19	11.19	11.13
2	11.16	22.32	11.04
3	11.12	33.36	11.00
4	11.09	44.36	10.89
5	11.05	55.25	10.87
6	11.02	66.12	10.74
7	10.98	76.85	10.84
8	10.95	87.60	10.59
9	10.91	98.19	10.61
10	10.88	108.80	10.55
11	10.85	119.35	10.37
12	10.81	129.72	10.42
13	10.78	140.14	10.26
14	10.75	150.40	10.40
15	10.72	160.80	10.24
16	10.69	171.04	10.18
17	10.66	181.22	10.12
18	10.63	191.34	10.06
19	10.60	201.40	10.00
20	10.57	211.40	10.15
21	10.55	221.55	9.89
22	10.52	231.44	10.06
23	10.50	241.50	10.02
24	10.48	251.52	9.73
25	10.45	261.25	9.93
26	10.43	271.18	9.89
27	10.41	281.07	9.85
28	10.39	290.92	9.81
29	10.37	300.73	9.77
30	10.35	310.50	9.73
31	10.33	320.23	9.69
32	10.31	329.92	9.32
33	10.28	339.24	9.60
34	10.26	348.84	9.56
35	10.24	358.40	9.16
36	10.21	367.56	9.47
37	10.19	377.03	9.05
38	10.16	386.08	9.38
39	10.14	395.46	8.94
40	10.11	404.40	....

A table as just described is made for each instrument. If there is any indication that the scale values of the element have changed, as might happen in a fall or blow, etc., another series of tests is made and the mean curve is compared with the one formerly used; if the difference is appreciable a new table is made up. The instruments should be tested about once in every three months, even if no appreciable change in the elements is otherwise shown, for in that length of time it is possible that the scale values might change, because of a chemical or elastic change in the material of the element.

TABLE 3.—*Pressure differences (mb.) per sheet ordinates, from tests of Dec. 24, 1919, at Washington, D. C.*

[Meteorograph No. 25.]

Ordinate.	0	1	2	3	4	5	6	7	8	9
0	......	1.1	2.2	3.4	4.5	5.6	6.7	7.8	9.0	10.1
1	11.2	12.3	13.4	14.5	15.6	16.8	17.9	19.0	20.1	21.2
2	22.3	23.4	24.5	25.6	26.7	27.8	28.9	30.0	31.2	32.3
3	33.4	34.5	35.6	36.7	37.8	38.9	40.0	41.1	42.2	43.3
4	44.4	45.4	46.5	47.6	48.7	49.8	50.9	52.0	53.1	54.2
5	55.2	56.3	57.4	58.5	59.6	60.7	61.8	62.9	63.9	65.0
6	66.1	67.2	68.3	69.3	70.4	71.5	72.6	73.6	74.7	75.8
7	76.9	77.9	79.0	80.1	81.2	82.2	83.3	84.4	85.5	86.5
8	87.6	88.7	89.7	90.8	91.8	92.9	94.0	95.0	96.1	97.1
9	98.2	99.3	100.3	101.4	102.4	103.5	104.6	105.6	106.7	107.7
10	108.8	109.9	110.9	112.0	113.0	114.1	115.1	116.2	117.2	118.3
11	119.4	120.4	121.4	122.5	123.5	124.5	125.6	126.6	127.6	128.7
12	129.7	130.8	131.8	132.8	133.9	134.9	136.0	137.0	138.1	139.1
13	140.1	141.2	142.2	143.2	144.2	145.3	146.3	147.3	148.3	149.4
14	150.4	151.4	152.5	153.5	154.6	155.6	156.6	157.7	158.7	159.8
15	160.8	161.8	162.8	163.9	164.9	165.9	166.9	168.0	169.0	170.0
16	171.0	172.1	173.1	174.1	175.1	176.1	177.1	178.2	179.2	180.2
17	181.2	182.2	183.2	184.3	185.3	186.3	187.3	188.3	189.3	190.3
18	191.3	192.3	193.4	194.4	195.4	196.4	197.4	198.4	199.4	200.4
19	201.4	202.4	203.4	204.4	205.4	206.4	207.4	208.4	209.4	210.4
20	211.4	212.4	213.4	214.4	215.5	216.5	217.5	218.5	219.5	220.5
21	221.6	222.5	223.5	224.5	225.5	226.5	227.5	228.5	229.5	230.5
22	231.4	232.4	233.5	234.5	235.5	236.5	237.5	238.5	239.5	240.5
23	241.5	242.5	243.5	244.5	245.5	246.5	247.5	248.5	249.5	250.5
24	251.5	252.5	253.5	254.4	255.4	256.4	257.4	258.3	259.3	260.3
25	261.2	262.2	263.2	264.2	265.2	266.2	267.2	268.2	269.2	270.2
26	271.2	272.2	273.2	274.1	275.1	276.1	277.1	278.1	279.1	280.1
27	281.1	282.1	283.0	284.0	285.0	286.0	287.0	288.0	289.0	289.9
28	290.9	291.9	292.9	293.9	294.8	295.8	296.8	297.8	298.8	299.7
29	300.7	301.7	302.7	303.7	304.6	305.6	306.6	307.6	308.5	309.5
30	310.5	311.5	312.4	313.4	314.4	315.4	316.3	317.3	318.3	319.3
31	320.2	321.2	322.2	323.1	324.1	325.1	326.0	327.0	328.0	329.0
32	329.9	330.9	331.8	332.7	333.6	334.6	335.5	336.4	337.4	338.3
33	339.2	340.2	341.2	342.1	343.1	344.0	345.0	346.0	346.9	347.9
34	348.8	349.8	350.8	351.7	352.7	353.6	354.6	355.5	356.5	357.4
35	358.4	359.3	360.2	361.1	362.1	363.0	363.9	364.8	365.7	366.6
36	367.6	368.5	369.5	370.4	371.3	372.3	373.3	374.2	375.1	376.1
37	377.0	377.9	378.8	379.7	380.6	381.6	382.5	383.4	384.3	385.2
38	386.1	387.0	388.0	388.9	389.8	390.8	391.7	392.6	393.6	394.5
39	395.5	396.4	397.2	398.1	399.0	399.9	400.8	401.7	402.6	403.5

The date on which the test was made, the number of the instrument, the station, etc., are indicated on the tabular sheet in order to associate the table with the exact instrument and tests and to avoid any possible error in getting the wrong table, etc.

Temperature.—The reduction of the temperature test and the preparation of a table of values are comparatively easy matters. As indicated in the preliminary tests, the change in ordinate values of the pen is divided into the simultaneous change in temperature as shown by the mercurial thermometer. (Table 4.) This gives the scale value for that one change. The same is done for all the changes and then these are averaged. If there is any value which is seemingly too divergent from the others this should be checked carefully and judgment should be exercised in using such a value. If the number of individual tests on this element is small and the scale values found are not consistent further tests should be made. Having found a good scale value, any ordinate reading has only to be multiplied by this value to give the change in temperature for the ordinate change considered. This process may be followed each time a record is read, but it seems more convenient to make up a table with this factor, giving all the values that will ordinarily be used.

Temperature effect on pressure element.—The differences in temperature between successive steps in the temperature test are divided by the corresponding changes in the ordinate values (read to tenths as usual) of the pressure pen. These values are shown in Table 4. The individual values are then averaged and the result expressed as the number of degrees' change in temperature producing a change of 0.1 of a division in the pressure ordinate is used as the correction to be applied to the pressure ordinate values.

TABLE 4.

[Meteorograph No. 25. Tested Dec. 24, 1919, Washington, D. C.]

TEMPERATURE TEST.

Notes.	Temp.	Temp. diff.	Ord. diff.	Factor.	Temp. effect on pressure.	
					Pres. diff.	Factor.
Pens down 1:05 p	23.0					
	5.5	17.5	19.0	0.92	0.8	2.2
	22.8	17.3	18.8	.92	.9	1.9
	5.0	17.8	19.0	.94	.9	2.0
	24.1	19.1	20.2	.95	.9	2.1
	5.0	19.1	20.1	.95	.9	2.1
	24.2	19.2	20.7	.93	.8	2.4
	5.7	18.5	20.7	.89	.6	3.1
	24.2	18.5	20.6	.90	.8	2.3
	5.6	18.6	20.0	.93	.8	2.3
	23.8	18.2	19.6	.93	.8	2.3
				10)9.26		10)22.7
Pens up 3:10 p				.93		2.3

HUMIDITY TEST.

Notes.	Dry bulb.	Wet bulb.	Humidity.	Hum. diff.	Ord. diff.	Factor.
Pens down 3:20 p	27.2	14.2	21			
	22.6	21.2	89	68	7.2	.94
	26.0	12.8	18	71	8.5	.84
	22.0	20.8	90	72	8.2	.88
	26.2	12.8	17	73	7.7	.95
	21.8	20.2	87	70	7.5	.93
	26.8	13.2	18	69	8.0	.86
						6)5.40
Pens up 4:48 p						.90

TIME TESTS.

Test.	Pens down.	Pens up.	Time diff.	mm.	mm./hr.
Temperature	1:05	3:10	125	78.2	37.5
Humidity	3:20	4:48	88	55.2	37.6
Pressure	9:04	12:01	177	111.2	37.7
Wind	9:24	12:20	176	11.0	37.5
					37.6

WIND TEST.

Length of record, mm.	107.4
Time in hours	2.9
Number of marks	37
Number of miles	91.7

$$F=\frac{107.4\times 91.7\times .447}{2.9\times 37\times 64}=.64$$

Humidity.—The humidity scale value, as already stated, is a variable. It is greater at high than at low humidities. In reducing the tests the following procedure is used: The humidity ordinate values are divided into the actual humidity change as shown by the psychrometer. (Table 4.) These individual values are then classified. First, the average humidities during the individual tests are found simply by adding the two humidities and dividing by two. Then all the scale values for average humidities falling between successive intervals of 10 per cent are tabulated. (Table 5.) Thus, the scale values having an average humidity from zero to 10 per cent are placed in the first column, etc. The headings are inclusive. In addition to the values taken from the tests of the instrument, values computed from the beginnings and endings of flights are included. Thus, when the change in humidity from the beginning to the end of a flight is considerable, this change can be divided by the ordinate change and a scale value obtained. Altogether about 50 or more values should be obtained in one or both of these ways and then classified as outlined. If the values are not entirely consistent and there is some doubt as to the quality of the test the values that are widely divergent should be omitted. These average values then, as found for each successive 10 per cent, are plotted as shown in figure 27, using the scale values as ordinates and the average humidities as abscissas. A smooth line is then drawn through or near the points. Usually a straight line fits the points about as well as any other, but if it is evident that the points follow a curved line such a line should be made. So far, the method has been similar to that used in making the pressure table. In place of the table, however, two scales are constructed. First, some arbitrary scale the divisions of which represent the readings on the record sheet (see fig. 28) is adopted as a

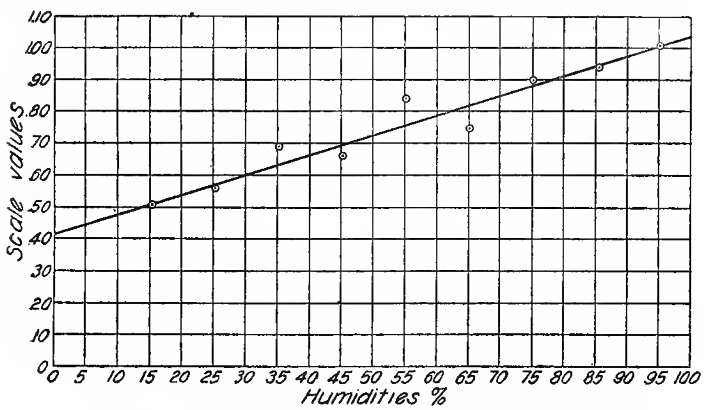


FIG. 27.—Curve showing humidity scale values for different humidities.

permanent scale. Another *special* scale (fig. 29) is then made up in such a way that, when placed alongside this first scale, the actual humidities corresponding to the ordinate values observed and indicated on the permanent scale will be shown. On this scale the value of 1 inch has been chosen arbitrarily to correspond to a change in humidity of 10 per cent. The scale is so graduated that one-tenth of an inch corresponds to a change in humidity of 1 per cent. The next step is to make the special scale for the instrument under consideration in such a way that the humidities shown on it when placed alongside the arbitrary scale will correspond with the tests. This is done in the following manner: From the smooth curve the values for each 5 per cent are read and entered in a table (Table 7) or on the same sheet. If a straight line has been drawn to represent the points it is evident that the differences between successive intervals of 5 per cent will be the same. Thus, in the illustration, the average scale value for 0 to 5 per cent is that shown at 2.5 per cent, or 0.429, and that for 95 per cent to 100 per cent is 1.018. Dividing the difference between these two figures by the difference in humidities we have $1.018-.429 \div 97.5-2.4=.0062$, which, multiplied by 5, gives the constant difference between successive intervals of 5 per cent. These values are entered in Table 7. Now 5 per cent on the permanent scale corresponds to one-half inch. It is evident that the distances on the special scales must be inversely as their scale values. Thus, if the scale value is small it will take more divisions on the permanent scale to cover that distance and consequently the distance between the humidities indicated on the special scale must be greater. Since 5 per cent corresponds to one-half inch and since we have chosen the scale values for each 5 per cent, we divide the scale values into the metric equivalent of one-half inch, which is 12.7 mm. This conversion is made since it is more convenient to use these units in making the special scale. The values thus found are the distances between the corresponding humidities on the special scale. These are then laid off on the special scale and the lines drawn as in figure 29. Thus, the distance from 100 per cent to 95 per cent is 12.5 mm. and from 95 to 90 is 12.9 mm., etc. In order to avoid an accumulative error in laying off these distances it is better to add the distances and lay off each successive distance from 100 per cent. These values for the successive intervals of 5 per cent are then evenly divided to give the intermediate percentages.

To use this scale, if the base line for the humidity record is 56 per cent, for example, the zero of the permanent scale is set on 56 per cent of the special scale.

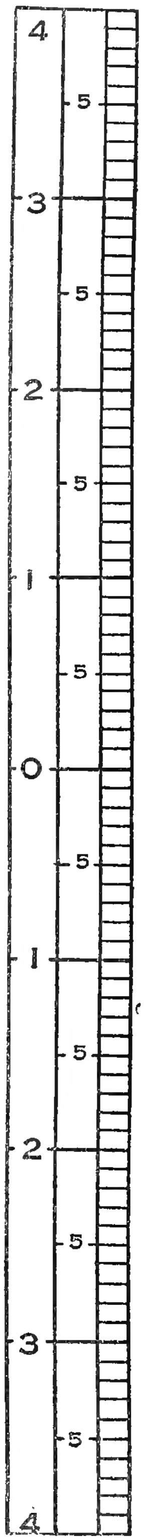


FIG. 28.—Arbitrary or measuring scale: Large divisions correspond to divisions on meteorograph sheet.

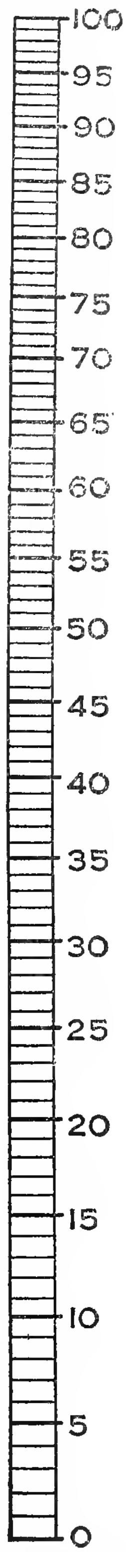


FIG. 29.—Percentage scale, used with scale in figure 28, for determining values of relative humidity for any ordinate on meteorograph sheet.

Then, if the ordinate is 3.4 divisions below this point, we look down on the permanent scale to 3.4 and opposite it is the humidity for that ordinate.

TABLE 5.—*Humidity tests classified.*

[Meteorograph No. 25. Tested Dec. 24, 1919, Washington, D. C.]

	Per cent.									
	0–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100
	....	0.60	0.62	0.74	0.85	0.94	0.87	0.85	1.12	1.11
	....	.42	.50	.64	.49	.84	.76	.92	1.10	.94
	....	....	.45	.59	.71	.88	.75	.88	1.04	.98
	....	....	.77	.79	.60	.95	.66	.95	.85	....
	....	....	.55	.63	.76	.93	.69	1.00	.60	....
	....	....	.45	.75	.56	.86	.70	.83	....	....
	....	....	....	.69	.72	.62	.82	.87	....	....
	....	....	....	....	.60	.74	....	....	....	....
Sums	....	1.02	3.34	4.83	5.29	6.76	5.25	6.30	4.71	3.03
Number	....	2	6	7	8	8	7	7	5	3
Mean	....	.51	.56	.69	.66	.84	.75	.90	.94	1.01

TABLE 6.—*Values of mean pressure curve.*

[Meteorograph No. 25. Tested Dec. 24, 1919, Washington, D. C.]

Ordinate.	Scale values.					
	No. 1 ascent.	No. 1 descent.	No. 2 ascent.	No. 2 descent.	Sums.	Means.
0	11.42	11.04	11.64	10.63	44.73	11.18
5	11.27	10.80	11.48	10.58	44.13	11.03
10	11.12	10.53	11.29	10.59	43.53	10.88
15	10.83	10.43	11.04	10.64	42 94	10.74
20	10.72	10.40	10.79	10.42	42.33	10.58
25	10.59	10.45	10.58	10.26	41.88	10.47
30	10.42	10.44	10.39	10.33	41.58	10.40
35	10.18	10.34	10.24	10.20	40.96	10.24
40	10.03	10.20	10.10	10.07	40.40	10.10
45	9.89	10.04	9.98	9.94	39.85	9.96
50	9.80	9.82	9.85	9.81	39.28	9.82

TABLE 7.—*Humidity scale values.*

Humidity.	Scale value.	12.7÷ scale value.	Accumulative sums.
2.5	0.429	29.6	375.4
7.5	.460	27.6	345.8
12.5	.491	25.9	318.2
17.5	.522	24.3	292.3
22.5	.553	23.0	268.0
27.5	.584	21.7	245.0
32.5	.615	20.7	223.3
37.5	.646	19.7	202.6
42.5	.677	18.8	182.9
47.5	.708	17.9	164.1
52.5	.739	17.2	146.2
57.5	.770	16.5	129.0
62.5	.801	15.9	112.5
67.5	.832	15.3	96.6
72.5	.863	14.7	81.3
77.5	.894	14.2	66.6
82.5	.925	13.7	52.4
87.5	.956	13.3	38.7
92.5	.987	12.9	25.4
97.5	1.018	12.5	12.5

Time rate.—To get the time rate the length of the record in mm. is divided by the time in hours; this gives the time rate in mm. an hour. (Table 4.) A scale is then made up for dividing time rate into minutes; for convenience it is usually made to cover a space of several hours. (See fig. 30.) The time rate will be found to vary somewhat, due to the influence of different temperatures on the clock, and due allowance must be made for this.

Wind.—In general the number of meters of wind necessary to make one mark of the velocity pen is found from the tests by dividing the number of meters of wind that have passed the instrument by the number of marks made by the pen in any test. The average of several tests is adopted as the true value. Then the time, in seconds, between any two marks, divided into this scale value gives the velocity in meters per second for the time included between the marks considered.

In the work of the Aerological Division a modification of the above method is followed. The ordinary wind velocity scale of the Weather Bureau is used in the customary way and the velocity so obtained is multiplied by a constant or scale value. This scale value not only converts the miles per hour into meters per second (since miles per hour are given by the scale and meters per second is the unit desired) by multiplying by 0.447 (the conversion factor converting m. p. h. into m. p. s.), but it also takes into account the different time rates of the instruments, i. e., the triple register and the meteorograph, and the number of miles of wind necessary to make one mark. The time rate of the triple register for which this standard scale is made is 64 mm. per hour; consequently, any other time rate will change the scale value proportionally. Thus, for the time rate found

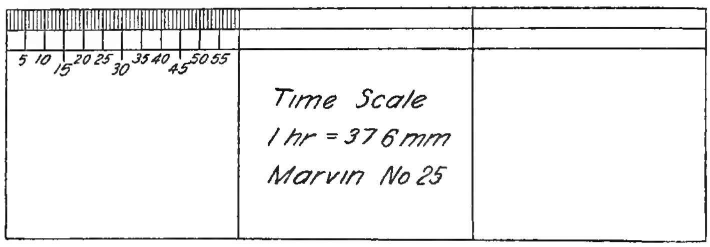


FIG. 30.—Time scale for use with kite meteorograph.

above (37.6), the fraction, $\frac{37.6}{64}$, must be included in the formula shown below. On the triple register one mark of the anemometer pen means 1 mile, but this is not the case with the meteorograph. The number of miles per mark is found by dividing the number of miles of wind that have passed the instrument by the number of marks recorded. Thus, in the wind test illustrated there are 37 marks for 91.7 miles, one mark representing 2.48 miles. The velocity indicated by the wind scale must then be multiplied by this value. Condensing the above factors into a simple equation we have the scale value equals

$$\frac{\text{length of record in mm.} \times \text{miles of wind} \times 0.447}{\text{time in hours} \times \text{number of marks} \times 64}, \text{ or}$$

$$\text{Scale value} = \frac{\text{length of record in mm.} \times \text{miles of wind} \times 0.4188}{\text{time in minutes} \times \text{number of marks.}}$$

Substituting the values found in the above test we have the result shown in Table 4. The velocity at any desired point is then found by first placing the Weather Bureau wind scale in such a position that two of the lines on that scale coincide with the marks on either side of the point selected; the indicated velocity on this scale is then multiplied by the scale value already determined from the formula above given.

8. MAKING THE FLIGHTS.

In order to make successful kite flights, it is important that the apparatus used in the work be maintained in first-class condition, and that all preparations be made before the flights are started. All the men engaged in the work should become familiar with the handling of the kites, kite wire, tying of various knots, and, in fact, every phase of the work. The men should become familiar with the different sizes of kites used and the weather conditions in which the various sizes fly best. The behavior of the various kites should be noted from time to time, for it frequently happens that there are considerable differences in the flying qualities of kites that appear to be similar in every other respect.

The kite that carries the meteorograph is known as the lead or the head kite; the other kites as secondary kites. It is best to use for lead kites only those that have been previously tried and found to be satisfactory. Of those used as secondary kites, the ones that fly best should be used nearest to the lead kite.

Ordinarily, three men are necessary to make a kite flight, but when conditions are favorable, and three men are not available, it has been found that two can do the work satisfactorily; this is especially true when flights are being made during the night. When three men are available, one man operates the reel, another keeps the meteorological record and all notes of the flight, and the third launches and lands the kites, keeps the reel house clean and in order, and assists in other work. If but two men are available, one man operates the reel, and the other keeps the meteorological record. The other work is divided between them as best suited to the occasion.

Carrying the kites.—When a kite is brought out of the storage room into the open, care should be taken to handle it properly. The man handling the kite should consider the wind velocity and direction. If the wind is light, the kite can usually be handled best by taking a position inside, between the cells, and grasping the bridle stick near the front cell with the right hand and one of the corner sticks with the left hand. If the wind is higher than 6 or 7 m. p. s., the kite can be handled best by taking a position in front of the kite as it lies flat on the ground and grasping the front end of the bridle stick with the right hand and the front end of the upper rib with the left hand. The rear or black cell of the kite is then free to swing around, and care should be taken that it is not damaged by a sudden puff of wind blowing this end of the kite against some obstruction. However, a kite held in this manner with its front end toward the wind can usually be handled without difficulty. A kite should always be held so that the wind will pass through it, and in no case should it be held by any other portion than at, or very near, the junctions of the sticks. When a kite in the open is not needed immediately, it should be placed flat on the ground, in such a manner that the wind can pass freely through it, and held down by weights placed within the cells.

Care of meteorograph.—The meteorological observer should examine the meteorograph and see that it is in working order before each flight. He should wind the clock, ink the pens, and see that the pens mark. (See Part I, sec. 7.) The pens should occasionally be thoroughly cleaned out, and always after a flight in clouds when the ink becomes watery through exposure to the damp air. The ink should flow a little more freely than is the case with surface recording instruments, since frequently at high altitudes the combined effect of strong wind and low humidity may dry the ink faster than it can flow to the points of the pens. The pens should rest lightly on the paper, but should still touch when the meteorograph is inclined at least 30° away from the vertical; otherwise portions of the record may be lost, especially if the kite flies to one side. The shorter pen arms, having less flexibility and describing arcs of smaller radii, should be given slightly more tension than the longer pen arms, in order to allow for the curved surface of the record sheet on the cylinder. Care should be taken that the movements of the pen arms are not obstructed, and that the anemometer is working properly.

The meteorograph sheet should be trimmed along the red line at the top and enough cut from its lower edge to allow it to fit in between the flanges of the clock cylinder. The sheet should be placed carefully on the cylinder with its top edge fitted snugly against the flange of the cylinder, and so that the lines meet exactly. In clamping the cylinder in its place the thumbscrew on the right side should be made quite tight; otherwise the cylinder is likely to fall out of place during the flight and the record be lost. The exact time of putting the pens down should be recorded as the first note of the flight. A complete observation of the surface meteorological conditions should be made at this time and recorded. This observation should include the temperature of the wet and dry bulb thermometers, the direction of the wind, and the amount, kind, and direction of clouds. If more than one kind of cloud is observed, the highest should be entered first. The meteorograph should be put into its case by grasping the framework between the clock cylinder and the ventilating tube with the left hand and lowering the meteorograph carefully into the case, the case being held in the right hand. The cover of the case should be put on and fastened by the two side catches. The meteorograph should then be put into the shelter. Before and after each flight, base-line values should be obtained, the instrument being allowed to record until the pressure, temperature, and humidity pens trace straight lines; for this, an interval of from 5 to 12 minutes is usually required, during which two or three readings of the psychrometer should be made. A reading of the station barometer should be made while the meteorograph is in the shelter both before and after each kite flight.

The meteorograph should be tied to the upper rib of the kite a little forward of the center, and it should be braced by four pieces of twine running from the junctions of the sticks at the four corners below. (See fig. 20.) Before releasing the kite the observer should see that the pens are recording and that the clock is running. All of the work done by the meteorological observer, in the way of preparing the meteorograph for the flight and recording the meteorological conditions prevailing at the time of the flight, should be checked by the man operating the reel. Both men should satisfy themselves that the meteorograph is working satisfactorily before the kite is released.

Launching the kites.—In taking the kite out for launching, care should be exercised that the wire is not allowed to become slack. The kite should be held by the bridle stick at the rear edge of the front cell with the right hand, and at the lower corner stick with the left hand, as in figure 31. The man holding the kite should walk out with it held up at an angle of about 45° with the horizon, keeping a good tension on the wire between himself and the reel all of the time. When the head kite is to be launched in a moderate wind, it should be taken about 60 meters to the leeward of the reel house and released, if possible, while the wind is fairly steady; in a light wind it should be taken out 100 meters or more and pulled up into the air by reeling in; if the wind is strong, the kite should be released while walking away from the reel and should be allowed to go out rapidly, in order to prevent its diving to the ground, or jerking so as to injure the record.

Readings called for on the data sheet should be made at the times of launching and landing of kites, when kites enter or leave clouds, and whenever there is a decided change in weather conditions. Wind directions should be given to 16 points. The exact times at which readings of the theodolite are made should be noted, as these are used in checking the altitudes determined from the meteorograph record. It is not so essential to get other readings precisely at the times noted, e. g., when a secondary kite is launched or landed, the time entered should be the time at which the angle is read, the exact time of the launching or landing being relatively unimportant. While reeling in the first one or two thousand meters of wire, several observations of angle of the head kite and the amount of wire out, with the usual other readings, except that of the voltmeter, should be made in order to have a record of surface conditions at the time the meteorograph is at its greatest altitude. When the head kite is within 1,000 meters of the reel, the speed of reeling in should be reduced in order that a good record of inversions and other conditions near the surface may be obtained.

Notes should be kept of changes in the kind, amount, direction, and altitude of the clouds. Whenever a kite, either the head or a secondary, enters or leaves a cloud layer, its angular altitude and distance out should be noted, as changes in altitude with time are most interesting and important. However, when the cloud layer does not appear to change much in altitude or structure, only occasional notes of the entry of secondary kites into the cloud base are necessary. Enter notes on all miscellaneous phenomena, such as times of beginning and ending of rain, snow, etc., solar and lunar halos, rainbows, thunderstorms and tornadoes. In making notes on the surface record, and in stamping and trimming meteorograph sheets, it is desirable that the work be done in a uniform manner; that is, when several people are doing this work, they should all do it in the same way.

When a secondary kite is to be launched, it is attached to the main wire by a piece of No. 32 blocking cord, about 30 meters long. The cord is secured to the main wire by a Dines clasp, which is a piece of No. 9, 10, or 11, galvanized-iron wire, this wire being about 1½ meters long with short right-angle bends at each end, and a loop in it about half a meter from one of the ends. This wire is wound around the main kite line, with the loop end up, and the blocking cord is tied in the loop. A supply of these wires and cords should be kept in the reel house. The kite should be taken out about 50 to 150 meters, depending on the strength of the wind. If the wind velocity is high, the kite should be let out rapidly after launching, at the same time watching for a chance to get it above the main line. The kites should be let out at such speed that they maintain fairly good angles, but if a kite catches on the main line, it should be let out as rapidly as possible; if it fails to release it should be reeled in, as many a flight is ruined by a kite caught on the wire. If a kite falls on the wire from above, the "reel" man should stop reeling out and, if necessary, reel in a short distance, in order to allow the wind to lift it.

Landing the kites.—When a secondary kite is landed, it can usually be brought close to the reel, but in a gusty wind it is best to stop 30 or 40 meters out in order that the wire may respond to the unsteadiness of the wind. The head kite should be landed about 40 to 80 meters out. While it is being run down, the reel man should have the handle on the axle of the reel drum, in order to let out or pull in quickly, according to sudden changes in the surface wind. The head kite should be handled as carefully as possible, as accidents to the head kite nearly always damage the record of the flight. It is generally advisable when landing a kite in a strong wind to pay out line to the kite at the same time the kite is being pulled down. On the other hand, when landing a kite in a very light wind, it is best to walk away from the kite as though to fly it, while pulling it down, as otherwise the mere act of pulling the kite down is liable to cause it to fly almost overhead, and then suddenly "volplane" down to the ground.

In the case of breakaways, or the kites coming down, or any other accidents, complete notes should be made at the time on the record sheet by the meteorological observer. If the kite breaks away he should note the time of the breakaway and make a complete meteoro-

FIG. 31.—Proper method of holding a kite preparatory to launching it.

logical observation at this time. He should watch the kite through the theodolite[4] as long as possible and record the angles of elevation and azimuth and the time at which the kite disappeared. The official in charge and every man on the station should be notified immediately of the accident, and every man on the station should exert all possible effort to protect all roads, in order to prevent persons and vehicles from running into the wire while it is lying on the ground, and every effort should be made to gather up the wire as soon as possible. At times of accidents it is important that everyone on the station act quickly and intelligently in an effort to gather up the wire in order that no damage be done by it.

Kite wire.—As safe kite flying is so largely dependent on the condition of the steel piano wire used, the utmost vigilance should be observed to prevent injury to it and detect any evidence of weakness throughout its length. When it is necessary to put new wire on the reel or to make splices in the wire, it is important that this be done with the utmost care. The wire should never be held by anything but a brass or copper jawed vise. The ordinary steel pliers have rough jaws that make indentations in the wire and weaken it considerably, and should not be used to grasp the wire. Too much emphasis can not be laid on the importance of always keeping the wire taut. After being repeatedly wound on and unwound from the reel drum and over pulleys, and particularly if the wire has been run under tension over wheels of too small diameter, or has rubbed against some solid object, such as the side of the reel house, a fence post, or tree, internal strains are developed that will cause the wire to coil as soon as it is slackened. If, on again tightening, a single coil becomes a kink, a breakaway beyond the kink is inevitable. The tendency to coil varies inversely as the diameter of the wire, and it is therefore advisable to feel out the smaller sizes of wire frequently when reeling in or out.

Opportunities for the wire to slacken sufficiently to coil are always present when flying in light winds, and when, under such conditions, it becomes necessary to reel in rapidly to assist in raising the kites the reel should always be slowed down gradually before coming to a stop, if conditions permit. Rapid reeling out in a light wind, especially when pronounced convection currents are present, will often cause coiling and probably kinking of the wire. With a wind barely strong enough to sustain the kites in the air and convection currents prevailing, a wave-like effect is often observed, the kites rising and falling in succession. Then, if wire is paid out rapidly to the rising kite, the wire between it and the falling kite immediately in advance will slacken and probably coil.

Another common source of damage to the wire is faulty wrapping of the heavy branch wire used to attach secondary kites. Under the direction of an experienced man a novice should learn how to attach this wire without leaving permanent sharp bends in the piano wire. Occasionally this branch wire should be shifted a few meters[5] from its usual position on the line. When, after landing a secondary kite, it is found that the cord is wrapped around the main line, care should be taken not to pull the cord too hard in the attempt to unwrap it, as this causes an injurious twisting strain on the wire. In an emergency it is better to cut the cord than to try to unwrap it hurriedly.

The wire should be kept clean and slightly oiled. Incrustations of ice or frost should be wiped off when reeling in, and the wire again wiped with a piece of oiled waste when reeling out in the next flight. This wiping of the wire should be frequent; it not only serves to prevent rusting, but also, prevents kinks from passing by unnoticed Few breakaways are caused by the pull exceeding the normal tensile strength of clean undamaged wire. Kinks, sharp bends, rust spots, or flaws in the splices cause the majority of accidents.

Observation and experience.—After having acquired training in the practical details of kite flying, as outlined in the foregoing paragraphs, the beginner should supplement this knowledge as soon as possible by close observation of weather conditions and kite flying, and as diligent study of upper-air records as his opportunities and capabilities permit.

It should be the aim of the kite flying force to obtain the highest possible flights consistent with safety under various weather conditions, to preserve the continuity of daily flights for as long periods as wind and weather permit, and to reduce breakaways and other accidents to a minimum. All the competency of the force derived from experience and study will be needed to bring about these desired results.

Because of ever-changing weather conditions with which the kite flier has to contend, it is evident that, except in a general way, no set of rules can take the place of experience that has been acquired by close observation. Much of what follows has a general application, and while many of the assumed situations relating to weather conditions and kite flying should be taken with the reservation that they apply more strictly to the Middle West, it is felt that a discussion of them will serve the useful purpose of guiding the interested beginner into the proper channels of observation and study. On the whole, the experiences met with in kite flying in different portions of the country are undoubtedly similar enough in many respects to justify some general rules or suggestions.

While a profound knowledge of meteorology is not necessary to practical kite flying, it must be admitted that the greatest justification for upper-air investigations will come from those stations where the interest of the men

[4] The theodolite used in kite work is of the same design and construction as that used for observing pilot balloons. It is described in detail in Part II, section 2.

[5] Ordinarily, the secondary kites are attached at more or less regular intervals from the head kite—e. g., 500, 1,200, 2,000 meters, etc. Thus, there is a possibility of weakening the kite wire by repeated wrappings of the "splice" or galvanized-iron wire at the same place.

is aroused in the results as well as in the performance of their work. To the interested observer, a day-to-day comparison of the upper-air records with the weather map offers an unlimited field for study. As ordinarily the aerological stations do not have available weather maps of current weather conditions, it is desirable that the observers make a study of local weather conditions, chiefly the record from the barograph, the observations of clouds, the kite records, and the weather maps that are received, and correlate these with the view of ultimately being able to anticipate to some extent upper-air conditions from local indications alone. For example, it is well to follow the progress of the barograph from day to day, and thus try to grasp the sequence of HIGHS and LOWS, and their approximate relation to the station. At many of the kite stations observations are made twice daily with pilot balloons. The one in the early morning is of great value in connection with kite flying, in that it gives an accurate measurement of wind conditions at various altitudes and thus assists materially in determining the number and sizes of kites to be used. Obviously such observations are limited by the height of the lowest cloud stratum, but even then they give valuable information as to the wind speed at any height below that level.

Accuracy of record and good judgment in observation are essential to a logical interpretation of the kite records. Opportunities for observations leading to important deductions in meteorology occur frequently in kite flying, apart from those that make a part of the routine record. Initiative and alertness in work and observation are therefore valuable assets in the field.

Discrimination should be used in those instances in kite flying that permit latitude of opinion. An example is the case of determining the direction of the wind aloft. This should be ascertained not only by observing the apparent direction of the head kite from the observer and the other kites, but also by the position of the kite in the theodolite (assuming that the head kite flies straight) and by whatever horizontal movement it may have. The observer should familiarize himself with the appearance of the kite in the theodolite at close range, in order that he may, when necessary, associate an angular appearance of the kite in the theodolite with direction of the wind in which it is flying. When the kites make a large "swing" during flights, a careful comparison of the apparent directions aloft recorded when reeling out with the apparent directions at corresponding altitudes when reeling in, will, to a large extent, eliminate the possibility of error. As it is often difficult to determine actual directions of the wind aloft at night and when the kites are obscured by clouds, experience should be directed toward observing the relation between the azimuth of the wire as it leaves the reel and the direction aloft.

When to reel in.—The observer should memorize the values of the sines of angles commonly recorded with the theodolite, thereby enabling him to compute approximate altitudes quickly when necessary, and to keep constantly in mind the relation between the altitude of the head kite and the amount of wire out. So long as the head kite maintains a fairly steep angular altitude, (say 30° or more) it may be assumed that the pull is at its maximum and that, barring a change in the weather conditions, reeling in will not throw the kites much higher nor materially increase the pull. Such a flight may be considered a normal one, and the number of kites to use and the distance to reel out will be clearly indicated by the dynamometer.

Ordinarily, the final reeling in should commence when the stationary pull shows indications of passing 200 pounds. Also, more kites should not be launched after the dynamometer reads between about 160 and 200 pounds, this also depending on the number of kites already flying. A little computation will generally settle this point. For example, when the pull of two kites is 150 pounds, another kite is likely to increase the pull to 225 pounds; while a pull of 175 pounds, with seven kites, will probably not be increased to more than 200 pounds by the addition of another kite. The same reasoning should be used when estimating the probable result of reeling in, or of an increase in wind. Given a certain pull, it is obvious that reeling in or an increase in wind will augment that pull in proportion to the number of kites used. The tensile strength of the different sizes of wire used should be kept in mind, and precautions taken to avoid, as far as possible, taxing any of the wire to much more than half its normal capacity.

Number of kites to use.—Judgment in the matter of number of kites to use should also be influenced by the possibility of the kites ascending into a decidedly stronger wind aloft with further reeling out. The winds normally increase with altitude, but occasionally this rise in velocity is much more rapid or abrupt than usual. Indications of an abnormal increase in velocity with altitude will usually be apparent to the careful observer by the action of the dynamometer, the movement of whatever clouds may be present, the results of the preceding pilot balloon observation, if such was made, and especially by the tendency of the head kite to maintain or even increase its angle when reeling out.

As long as the kites maintain a good angular altitude, there should ordinarily be but little difficulty in making an excellent flight without subjecting the wire to excessive pull. If, however, there is much wire out with many kites and the angle is low, success and safety will necessitate a rather tedious program of work. Under such circumstances, reeling in might raise all or most of the kites to such higher altitudes and stronger winds as to increase the pull to the danger point. It will then be advisable to sound the strength of the upper winds by occasionally reeling in a few hundred meters before putting on additional kites, meanwhile watching the head kite through the theodolite. If the trial reeling in is not successful in permanently raising the kites, a note should be made, mental or otherwise, of the depth of the light wind. Eventually the decision should be made whether to reel in all the kites and rearrange them with a view to greater lifting surface by using more or larger kites, or to continue the flight with the expectation of finally lifting them into sufficiently strong winds aloft.

After an altitude of between 2,500 and 3,000 meters has been sounded without indications of strong wind it is probable that no wind of dangerous strength will be encountered to an indefinite height. When an altitude of about 3,000 meters has been reached, with only a moderate pull and a good angle, experience has shown that still higher altitudes may generally be obtained by adding more kites and reeling out farther, without materially increasing the pull. This may be explained by the tendency of light wind to extend to high altitudes, and the fact that actual increase of velocity with elevation is to some extent offset by the diminishing air density.

The circumstance of kites flying at a low angle is often associated with a stratified condition of the air, manifested by a brisk shallow wind, on top of which the kites seem to float as though on a liquid surface, *apparently* in a calm and all flying at about the same altitude. This condition may be met with in winds from any direction; and except in easterly winds (for reasons explained later), requires the exercise of caution lest too many kites be launched and exposed to the danger of a rise into winds too strong for the wire. The danger is to some extent proportional to the proximity of the lower winds to a westerly direction, being at a minimum in easterly winds, and at a maximum in winds between northwest and southwest. When kites rise above such a calm stratum they will as a rule enter a wind from some westerly direction, and cause a pull at the reel that will be partially a resultant of the direction and amount of the pulls of the individual kites.

Kites floating above a shallow wind, other than easterly, can generally be reeled up into higher winds aloft after four or five kites have been launched on a few thousand meters of wire. With easterly winds, however, the change in direction is often so abrupt, and of such angular magnitude in comparatively short intervals of altitude, that repeated reeling in will be useless. In such a case the final ascent of the leading kites into stronger upper winds can often be accomplished by exercising patience. When, after a few attempts, it becomes apparent that reeling in is futile, it will be necessary simply to await the automatic rising of the kites incident to the development of wind that sometimes attends or follows a pronounced change in direction with altitude. With easterly winds near the ground and westerly winds aloft, it has been observed that the kites will more often show a tendency to shift to the right than to the left as they rise above the lower strata. This shifting is generally slow and will not result in raising the kites until the upper portion of the wire is approximately in line with the drift of the upper winds. The total change in azimuth from the surface wind to the direction of the highest kite may be as much as 200°.

A stratification of the air, causing the kites to apparently "float," is quite common, and is due most often to abrupt, though not necessarily large, changes in wind direction with altitude. Sometimes a stratum of comparatively calm air intervenes between two winds having nearly the same direction, in which case it is probable that the stratification is related to abrupt changes in temperature and humidity.

Veering of winds with altitude averages greater than backing, both in frequency and angle, and is characteristic of approaching LOWS and retreating HIGHS. Backing of winds, associated with retreating LOWS and approaching HIGHS, is usually more gradual, and in the case of retreating LOWS, is sometimes preceded by veering in the lower levels. The amount of shifting in wind direction with altitude has an important bearing on the number and size of kites that can safely or advantageously be used. The accuracy with which this disposition of the winds can be foreseen will depend largely on the ease with which observations of cloud direction and velocity are made.

Easterly winds as a rule should occasion no anxiety to the observer from the standpoint of excessive pull, unless complicated by heavy rapidly moving clouds. This assurance of generally safe conditions in easterly winds may not, however, apply to other than interior sections of the country. In the Middle West it has been found that deep east winds are nearly always light to some unknown limit, and that when strong easterly winds occur, they either diminish with altitude or are rather uniformly strong with altitude. In the latter case, the number of kites to use is easily apparent. The condition of light easterly winds surmounted by strong easterly winds is probably rare. While in the case of kites swinging from lower easterly winds to upper westerlies a strong current from the latter direction may be encountered, it is likely that the pull will not be excessive, owing to the more or less opposing pull of the kites.

Weather types—A few flights will convince the observer to what extent success in kite flying is measured by ability to anticipate conditions in altitude and changes with time. Considerations of pressure rank first in making deductions of probable upper-air conditions and should be judged somewhat as follows: The state of the barometer, whether rising, falling, or stationary, and whether above or below normal; the duration and magnitude of the rise or fall; and the probable geographic distribution of the pressure.

Changes in the surface wind are inclined to be synchronous with changes in pressure and the velocities themselves proportional to the pressure gradient. This relation between the surface pressure and wind is not so simple when applied to velocities aloft. It will often be found that surface winds alone fail as an index to the probable velocities aloft and that they should be considered in connection with the previous few hours' pressure record. It will often be necessary to wait until the first kite has ascended a few hundred meters before coming to a final decision as to what conditions to expect.

A pronounced condition that has been repeatedly found in the Middle West, and that probably occurs in some modified form over the greater portion of the country, is that which accompanies a period of rising pressure when the pressure is already high. During the period of rising pressure strong winds, often increasing with altitude, will usually be found, while the least indication of flattening out of the barograph trace seems to be followed by diminishing winds—near the ground first, and progressively later at higher altitudes. The height to which the strong winds extend varies according to the structure of the HIGH and the intensity of the preceding LOW. While, without the aid of current weather maps, it will not ordinarily be possible to estimate the intensity of the pressure gradients surrounding the station, a knowledge of these facts, together with whatever telegraphic information is available, will be helpful. If a flight has been started while the pressure is rising steadily, and the pull soon reaches the limit of safety, it will sometimes be found advantageous to apply the brake and wait, an hour or more if necessary, until the expected stable pressure, with its attendant abatement of winds, makes further reeling out possible. The higher the pressure the more likelihood there is that it will soon reach its crest. Periods of rising pressure are often accompanied by stormy weather, more especially while the pressure remains low. The barograph and wind-register record should then be watched, as well as the weather, in order that the most opportune time for starting a flight may not pass by. Under these conditions the pressure will sometimes stop rising simultaneously with, or soon after, the ending of precipitation and the wind become too light to launch a kite.

After the pressure becomes high and stationary, the winds will be light to moderate to a considerable altitude, their average strength depending on a number of factors, chiefly the area and magnitude of the HIGH and the position of its crest, and the intensity and distance of the surrounding LOWS. The surface wind may then be too light to launch a kite until the pressure has begun to fall. Occasionally, though, a temporary interruption of the stationary pressure may strengthen the surface wind sufficiently to start a flight—a circumstance the observer should be on the alert to take advantage of.

If a flight has been started after a more or less continuous fall in pressure has set in, increasing winds may be expected during the progress of the flight. The velocity to which the winds will rise in any given time will depend not only on the rate of fall in pressure, but also, in a sense, will vary inversely as the pressure. In other words, it will generally be found that the greater the magnitude of the retreating HIGH the longer (in terms of hours) will the maximum intensity of the on-coming LOW be delayed. On the other hand, a slowly moving HIGH, even though it be comparatively flat, appears effectively to delay the advance circulation of a following LOW. Shallow winds, above which it is difficult to raise the kites unless much lifting surface is used, are common in the rear of HIGHS.

If the pressure is low and stationary, the surface winds may be light, and under such circumstances one should resist the temptation to use large and many kites until the preceding fall in pressure has been ascertained. If the fall has been very slow and no very low level reached, this, together with the light surface winds, may be construed as indicating comparatively light winds to a fairly good height. If the pressure is quite low and the preceding fall has been rapid, a more or less sudden rise in velocity may be looked for at some not very great altitude; or may accompany a sudden shift in direction.

If a flight is made during a period of rapidly falling pressure, and the pressure is below normal, the winds will very likely be strong practically from the ground up; in this case, if a flight is possible, it will naturally be limited to few kites. Ordinarily, strong winds do not preclude the possibility of a flight unless they attain gale force near the ground. Where the strength of the wind limits the number of kites to three or less, flights to nearly 3,000 meters above the ground may be obtained by rapid reeling out and without risk of materially increasing the pull on the reel-in since, as explained elsewhere, the Marvin-Hargrave kite is self-adjusting to strong winds. In such a case care should be taken not to reel out more wire than the kites can hold above the ground, bearing in mind that the wire will drop to a lower angular altitude as soon as reeling in commences.

When the barometer is low and rising, the winds are likely to be more uniform in direction and velocity with altitude, and less given to abrupt changes, than when the pressure is low and falling. Much the same precautions should be observed in either phase of low pressure, although in the case of rising pressure there is smaller probability of the pull increasing after the highest possible altitude has been attained, the supposition being that the winds have already reached their maximum. On the whole, it may be said that falling pressure presents more difficulties than rising pressure. Low pressure, owing to the complexities of cyclonic circulation, has more elements of danger than high pressure.

While the different conditions of pressure met with from day to day are, of course, infinite in number, their relation to the probable velocities may be summed up as depending on the barometric tendency, and the position of the centers of high and low pressure areas. The latter qualifying circumstance is the most difficult to make deductions from, in the absence of current weather maps, and all available sources of information should therefore be studied carefully to determine the probable direction from the station of a near-by center of low pressure.

When the direction of movement of a LOW coincides with the direction of the gradient winds, there is evidence that winds at the various altitudes average strongest, other things being equal, and that when such a condition is impending the rise in velocities will be most rapid. The trend of the isobars can be estimated closely from the surface winds, the barograph trace, and the aspect of the first kite launched after it is a few hundred meters high.

In estimating the probable direction of the centers of high and low pressure from the station at the beginning of a flight, in the absence of other information, the observer should supplement his knowledge of the general laws of surface circulation with observations of the wind direction a few hundred meters above the ground. Unless surface winds are quite strong and have blown from a certain direction for some time they do not give conclusive evidence of the direction of the pressure gradient, owing to the susceptibility of light winds to local topography and diurnal change in temperature. Judgment will therefore have to be deferred until the behavior of the first kite launched has been observed.

With a little practice, conclusions concerning the pressure distribution can be arrived at that will be accurate enough for the purpose of kite flying. This refers more particularly to the cold season, when pressure conditions and changes are sharply defined. With approaching warm weather the whole problem of analyzing pressure conditions becomes increasingly difficult; and unless some telegraphic information is available, one will often be at a loss to know what to expect. This has its compensation, however, in the comparative freedom from unsafe conditions, except such as are of a local nature, in summer weather.

The trend of the isobars can be approximated by considering the direction of the wind at that moderate altitude above the ground where surface friction is surmounted and to which the kites gradually veer. In LOWS and in the rear of HIGHS, gradient winds will usually be found at only a few hundred meters above the ground. While their direction with reference to the isobars varies somewhat with the rate of movement of the LOW or HIGH and their depth varies considerably in different quadrants, it will be of aid to know when these gradient winds have been reached, considering that their direction is approximately parallel to the surface isobars, with low pressure to the left. Above these gradient directions the winds in a LOW will ordinarily veer or possibly back to the higher levels, depending on whether the LOW is approaching or receding. In the front of a HIGH the winds will often back from the ground up, no veering being apparent at any level.

Clouds.—Low-lying dense clouds add to the perplexities of kite flying. They are likely to be a menace in any wind direction and during any season of the year, more especially, however, with low pressure prevailing. Stratus clouds are characteristic as trouble breeders, and any indication of strato-cumulus blending into stratus should be reason for caution; and conversely, stratus breaking into strato-cumulus should be considered encouraging. It is desirable, of course, to obtain a record of upper-air conditions in any cloud condition, but judgment should be used in deciding on the number of kites to expose when conditions seem threatening. In warm weather dense stratus are not necessarily dangerous unless they are moving rapidly and rain is falling or seems imminent. The combined effect of rain and strong wind often completely crushes one or two kites. It will sometimes tax the initiative of the flying force, when caught in such conditions, to limit the danger to one or two kites and avoid excessive pull on the wire. If a flight is started during the prevalence of such conditions, reeling out and the launching of kites should proceed cautiously until the absence of any strong wind in the cloud layer is assured.

During periods of more or less continuous rain, the most opportune time for making a flight without risk of the kites collapsing appears to be about midday, when evaporation from the clouds often causes a lull in the rain.

Dense fog usually occurs with light surface wind. It has been the experience of the writer, in the middle West, when flying in dense fogs, that if the wire and dynamometer show that the kites have entered a stronger wind of different direction a few hundred meters above the ground, it can be taken for granted that the fog sheet has been surmounted, and need give no further concern. In other conditions of fog, the kites will fly at a low angular altitude, become water-logged and heavier, and eventually fall to the ground, unless reeled in soon after the flight has been started. A useful precaution to observe when the kites are flying at a low angle in a fog is to take frequent readings of atmospheric voltage, in order to watch for the possibility of the wire touching the ground.

In the cold season of northern latitudes an additional difficulty connected with flying in heavy clouds lies in the accumulation of ice or frost on the kites and wire in amounts that may be sufficient to cause them to fall in spite of rapid reeling in. This danger is present only when the surface temperature is in the neighborhood of freezing or somewhat below. When any of the lower types of clouds prevail with this state of temperature, a certain amount of ice will almost always form on the wire, but excessive deposits on wire and kites will occur only when the sky is overcast or nearly so, and the circumstances favor a prolonged exposure of the clouds. The deposit is caused by minute globules of the subcooled water, sometimes having a temperature as low as $-10°$ C., freezing on contact with the solid surfaces—a process that is facilitated by wind. There is but little danger of more than a light coating of ice on the wire when snow is falling freely, but moist snow with wind may cause an excessive pull in the same manner as rain with wind.

If, after rising above a strong surface wind, the kites float on top of or in the clouds, this fact will be indicated by the dynamometer. With freezing temperature, unless the kites can be thrown up higher by reeling in, accumulation of ice will proceed over a long approximately horizontal line of kites and wire and gradually cause them to settle down. A common condition attending a period of rising pressure in winter is a strong cold under-running northerly wind, near the summit of which dense clouds form. Often the wind above the under-running cold current is too light to lift the kites free of the influence of the clouds, with the result that the heavily laden kites will fall into the strong lower wind and cause excessive pull. If the dynamometer indicates that the kites are flying at a good angle, a condition of great cloud depth may be present, the possible consequence of which will be indicated only by a lowering in the angle of the wire and a lessening of whatever atmospheric electric potential might previously have been recorded. A normal potential will dwindle almost to zero as the wire becomes increasingly bulky with ice or frost and lower in angle. Dynamometer readings can be relied upon only to indicate the approximate angle of the kites before they and the wire have had time to become heavily coated, after which the pull is inclined to be deceptive, owing to their increased weight enabling the kites to present a more nearly normal surface to the wind.

When in the judgment of the observer the conditions seem to be favorable for the formation of ice or frost-work on the wire, it is a good plan to reel out as rapidly as is consistent with a good ascensional rate of the kites, thereby penetrating the cloud layer with minimum exposure thereto. A good rule to observe in any threatening cloud condition is to begin the final reeling in when the pull is well on the safe side of 200 pounds in order to leave a margin of safety for any possible increase in pull later on.

The fact that deposits of rime (frostwork) on the wire, which have been observed as large as half an inch in diameter,[6] are most pronounced when snow is not actually falling, seems to indicate the lack of some final stage necessary for precipitation, when all the other essentials for condensation are present. An interesting circumstance bearing on this point is the evidence, in numerous records of kite flights, that the beginning of precipitation is often preceded or attended by a sudden increase in the electric charge on the wire.

Diurnal series.—A knowledge of pressure distribution over the country is of considerable help when attempting to make 24 to 36 hour series of flights, as the series are often ended or interrupted by the wind becoming too light or too strong, or the weather becoming stormy. There are a number of conditions that have been observed at Drexel, Nebr., to be favorable for the steady winds and fair weather desirable for an unbroken series of flights of fairly uniform altitudes. These conditions are perhaps typical of considerable of the interior portion of the country.

[6] Mo. Wea. Rev. Supplement No. 10 (Aerology No. 5), p. 5.

An area of high pressure receding to the east generally causes a prolonged, somewhat vigorous drainage of air from a southerly direction in the lower levels, and more or less steady, lighter winds from a westerly direction in the higher levels. If the pressure is quite high and the surface wind is strong enough to begin a series while still in the crest of the HIGH, or as soon as the pressure begins to fall, the probabilities are for favorable flying weather for 24 to 36 hours or more.

An area of low pressure, centered north of the station and moving eastward, is often attended by generally fair weather and continuous moderate southerly winds in the lower levels. At higher levels, the winds will probably be strong and veer from southwesterly to westerly or northwesterly, as the LOW drifts eastward.

In the winter excellent series of flights are possible when a pronounced high-pressure area is approaching from the west or northwest. In this condition, however, a series may have to be started while the weather is still cloudy, in order to obtain at least 24 hours continuous record, since the crest of the HIGH, with its attendant light surface winds, often comes not long after the weather clears.

Thunderstorms.—Since a thunderstorm is largely a local phenomenon, no general rules can be laid down for detecting its approach. No precaution seems ordinarily of avail other than listening attentively for thunder on days when conditions seem to favor thunderstorm development, and frequently breaking the electrostatic ground for evidence of "flash" discharges. By "flash" discharge is meant a momentary increase in the potential that causes intermittent sparks at the ground gap and are synchronous with discharges of lightning in the vicinity. As such irregular discharges may be an accompaniment of storms passing the station as well as of one approaching it, and are, moreover, often observed when the sky is mostly clear, they are not, in the majority of cases, necessarily a warning of unsafe conditions. Flashes of lightning on the horizon should be considered in connection with the observed drift of such clouds as are visible. The probable course of the outlying storm may thus be determined.

A possible indication of thunderstorm development may be inferred from the strong vertical currents of great depth that are frequently evident in warm weather during kite flights. If these are associated with high surface humidity and increasing Cu. or St. Cu. clouds, conditions are probably ripe for thunderstorm formation. In general, when the sky is overcast during the warm season, an erratic action of the electrostatic voltmeter, or thunder, should be considered a warning.

Flights have on a number of occasions been caught in thunderstorms, and, while the records during such storms are extremely valuable, the danger of personal injury and damage to equipment is too great to justify other than unavoidable flights under such conditions. The danger to the person in thunderstorms lies chiefly in the landing of secondary kites. The person removing the branch wire by means of which a secondary kite is attached to the main line should be provided with rubber gloves and boots, and under no circumstances should he stand on the ground. The person landing the kite should also be provided with rubber gloves and boots, but when the cord to which the secondary kite is attached is wet, and the danger seems very great, no attempt should be made to land the kite other than to cut the cord and allow the kite to go adrift. It is of course hardly necessary to add that the reel should be grounded as thoroughly as it is possible to do so.

Local conditions.—The continuity of daily flights will depend a great deal on the vigilance and energy of the station force, as on many days when comparative calm prevails a brief interval of breeze will be sufficient to carry the kites into steady sustaining winds aloft.

Although surface velocities are higher in daytime than at night, this fact, particularly in warm weather, has often the opposite significance in kite flying. This is undoubtedly explained by the fact that convectional currents, even though they may cause a slight acceleration of surface movement, have a damping influence on the normal increase of wind velocity with altitude, and, moreover, constitute a mechanical hindrance to successful launching of kites. Strong convectional currents tend to cause continual confusion of kites, cords, and wire. This sometimes becomes so aggravated as to necessitate reeling in to prevent the kites from falling to the ground. Flights, therefore, should be started early enough on summer mornings to assure a height of a thousand meters or more before convectional currents are well under way.

Sometimes on clear, quiet days, during which a flight has been impossible, the kites will readily go up about sunset, or when nocturnal cooling sets in. It completes the often-observed paradox, just mentioned, of flying conditions and surface wind, as in such instances the station anemometer is very likely to record lower velocities than at any time during the day. A plausible explanation is that the sudden cessation of convection currents permits the normal tendency for horizontal air movement to come into play and that the intense radiation at that hour confines the stagnant air to those very lowest levels immediately above the ground. At Drexel this condition has been frequently observed and taken advantage of, although it has been found to be decidedly peculiar to south winds.[7]

The foregoing paragraph illustrates one of the many causes that operate to mask the possibility of a flight from indications of the station anemometer. Notwithstanding that it requires a velocity of at least 5 m.p.s. to sustain a kite and several hundred meters of wire, velocities as low as 1.5 m.p.s. need be no discouragement to those attempting a flight.

[7] See Mo. Wea. Rev., Supplement No. 8 (Aerology No. 4), p. 7, and Mo. Wea. Rev., June, 1919, 47: 373.

Breakaways.—Experience in kite flying will be valuable in the measure that it develops not only prescience of danger, but confidence in action when doubtful conditions obtain. Overcautiousness may spoil or curtail many a flight that would otherwise have been safe and high. On the whole, it may be said that dangerous conditions for kite flying, apart from those that are clearly evident from surface conditions, are exceptional. Therefore, whenever weather conditions on the ground permit, a flight can generally be started with all assurance of safe return of the kites.

Breakaways may be divided into two classes—(*a*) accidental and (*b*) those caused by overloading the wire. The former may be largely prevented by attention to the condition of the wire, while the latter may be subdivided into a number of causes as follows:

1. Kites floating on top of a shallow wind, or flying at a low angle, and finally rising into strong wind aloft.
2. Reeling out too rapidly to permit the dynamometer to show increase in velocity aloft.
3. Wind increasing rapidly soon after beginning to reel in.
4. Too long exposure of kites to damp, fast-moving clouds.
5. In rarer cases, kites caught in a thunderstorm or sudden squall.

To these may be added the occasional risk of kites falling on account of accumulations of ice, and the unsteady effects of light winds or convection currents.

The prevention of trouble from all these causes will, to a large extent, be under the control of the field force. Cause 3 will call for the greatest caution on the part of the observer in charge of the flight. Winds increasing during the progress of a flight generally accompany falling pressure. The rise in wind velocity attending the approach of a low-pressure center has often been observed to begin at some moderate altitude, and subsequently become more general. Close attention to the dynamometer while launching secondary kites will give early evidence of increasing wind force aloft.

9. REDUCING RECORDS FOR TELEGRAPHIC MESSAGE.

For the purpose of forecasting it is desirable that the daily observations made by kite flights at the different stations be as nearly simultaneous as possible and that the reports of observations be received at the forecast centers without delay. At all the aerological stations, therefore, kite flights are made whenever possible during the morning hours, that time of day being preferable for taking observations to be used in forecasting and most suitable for favorable flying conditions. As soon as possible after the completion of each daily flight a quick computation of the record is made and the value of the various elements at suitable elevations is enciphered and telegraphed to the designated forecasting centers. At present these centers are Washington and Chicago.

The data telegraphed are altitude, pressure, temperature, wind direction and velocity, and humidity, both at the surface and aloft. Altitudes are reported in meters above sea level, pressures in millibars, temperatures in centigrade, wind velocity in meters per second, wind direction to eight points of the compass, and relative humidities in percentages.

The pressure, temperature, wind velocity, and humidity are readily computed from the records by means of the known factors of the instrument used. Wind direction is recorded by eye observation during the flight. In computing altitude only the factors of pressure and average temperature of the air column are used, the latter being approximated by simply taking the mean of the temperature aloft and at the surface. Form No. 1103–Aer. is used for the computations. This is very similar to Form No. 1102–Aer. (Table 9, section 10), the only difference being that Form No. 1103–Aer. has extra spaces for the entry of code words.

The observations are telegraphed only when heights equaling or exceeding 500 meters above the ground are attained, since ordinarily conditions below that level can be assumed from surface observations and the weather map. As most kite observations extend to about 3,000 meters or higher above the ground the elevations for which the values of the elements are computed and telegraphed are generally those of 1,000, 2,000, and 3,000 or more meters above the surface. The data for these levels usually convey in the abstract a complete survey of the atmosphere from the ground to the highest altitude sounded since ordinarily the changes in the values of temperature, wind force and direction, and humidity from one level to the next are uniform enough to admit of close approximation for any intervening elevation by interpolation. Very often, however, particularly in winter, marked inversions in temperature and other abrupt deviations from the normal altitude change in the elements are observed. When such abnormalities occur and cover a sufficient range in altitude to distinguish them from diurnal, local, or other temporary effects, the levels for which data are to be reported by telegraph are chosen with a view to indicating these conditions clearly to the forecast centers.

To give brevity to the messages, to make them easier to send and less liable to error, etc., a code is used. Briefly this code consists of a list of common words and names, selected for their sequence of key consonants and vowels in order to give any desired numerical or other value to one or more syllables. The key letters consist of nine consonants and the five vowels, representing multiples of 10 up to 90, and the even digits from 0 to 8, respectively. Eight of these consonants have an alternate meaning for the cardinal points of the compass. As the key letters are few in number the code words are readily translatable at sight; and as the position of the word in the message determines the element to which it refers, making possible a repetition of the same word in a message, a comparatively small list of code words with a few arbitrary words serves to encipher any desired weather message.

The code adopted for reporting free-air conditions is an adaptation of the Weather Bureau Code, 1916 edition, regularly used in transmitting surface observations. The following key and examples show how this adaptation is accomplished:

First word.—Time of observation, from pages 95–97 of Weather Bureau Code Book, 1916 edition. Example: Each—8:40 a. m.

Second word.—Altitude to nearest 10 meters, from pages 54–59, "T" words. Examples: Taggings—1,470 meters; Titus—3,910 meters.

Third and fourth words.—Actual pressure aloft and at the surface in millibars. Third word gives hundreds of millibars aloft; first syllable of fourth word gives the two following figures in pressure aloft; second syllable, ditto at surface, from pages 26–35. Examples: Six sacred—pressure aloft, 682 millibars; at surface, 974 millibars. (NOTE.—At most stations the surface pressure is between 900 and 999 millibars; for all such the one word is sufficient. If, however, this pressure is 800+ or 1,000+ the words "surface eight" or "surface ten," as the case may be, should follow the words expressing pressure.)

Fifth and sixth words.—Temperatures, °C, aloft and at surface, from pages 54–59; "S" words, above zero; "T" words, below zero. Examples: Tardiness—Subdues—Temperature aloft, $-12°.7$ C.; at surface, $+2°.1$ C.

Seventh and eighth words.—Wind direction and velocity, meters per second, aloft and at surface, from pages 26–35. First letter of each word gives direction; second letter gives first figure in velocity when latter is above 9.9 meters per second. (a, e, i, o equal, respectively, 10+, 20+, 30+, 40+); first two letters of second syllable give the last two figures in the velocity to tenths of a meter per second. Example: Nemuel—Guarantee—aloft, SW.—25.0, meters per second; surface, SE.—7.2 meters per second.

Ninth word.—Relative humidity aloft and at surface, pages 26–35. Example: Fumosity—aloft, 30 per cent; at surface, 58 per cent.

The following excerpt from a telegraphic message, referring to one upper air level, illustrates the code and its translation:

Example of message: Full—Tinselly—Six Doremus—Tutoring—Subastral—Resale—Surname—Nonology.

Translation: Time of observation, 11 a. m. Altitude, 3,840 meters. Pressure aloft, 628 millibars; at surface, 974 millibars. Temperature aloft, $-9°.8$ C. Temperature at surface, 1°.2 C. Wind aloft, west, 28.2 m. p. s. Wind at surface, northwest, 6.2 m. p. s. Humidity aloft, 68 per cent; at surface, 68 per cent.

10. FINAL REDUCTION OF RECORDS.

As indicated in the preceding section, the kite records are partially reduced for telegraphic purposes at the stations. This includes the computation of base-line values and of the meteorological elements at a few selected altitudes. The records themselves are then forwarded to Washington for final reduction. This final reduction is made in such detail as to furnish what may be described as a complete history of the flight; i. e., "levels" or points on the traces which show changes in the gradients (or rates of change with altitude) of the different elements are computed. This computation, although not difficult, is comparatively laborious because of the fact that altitudes are not directly observed, but must be determined by means of the hypsometric equation, into which enter several variable factors. A detailed account of all the steps necessary in this reduction of kite records is given in the following pages.

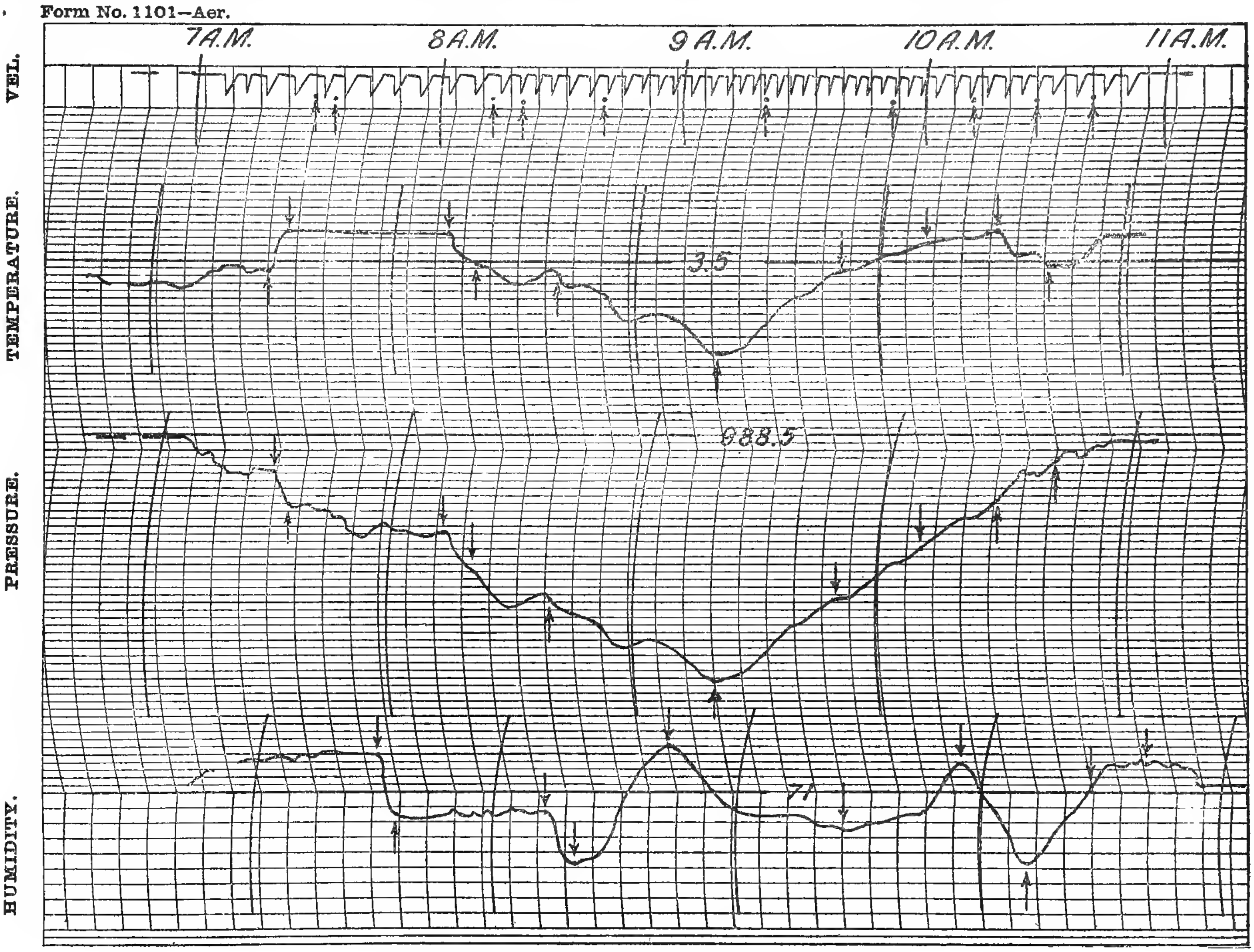


Fig. 32.—Typical meteorograph record of a kite flight.

Hour lines.—Because the regulation of the clocks of the various instruments can not be kept identical "hour lines" must be drawn on each record. This is accomplished by drawing arcs, as described in section 7 and as indicated in figure 32. The positions of these hour lines are determined with the aid of a special time scale. (See fig. 30.) The length of the record, in millimeters, is divided by the time in hours, and from this a scale for several hours is made. This is divided into minutes so that, knowing the time at which the pens were placed on the record sheet, for example, 6:43 a. m. (fig. 32), the time scale is so placed that the beginning of the trace is opposite the proper time on that scale (43 minutes in this case). The positions of the hour lines are then noted and an arc drawn for each one. In doing this care should be taken that the proper lengths of pen arms and centers of arcs, as previously determined, are used.

Base lines.—Before values can be computed from either the temperature, pressure, or humidity traces it is necessary to establish "base lines." This is done by drawing a light pencil line along one of the horizontal printed lines on the record sheet, choosing that line which is nearest the ends of the trace under consideration. The value of the temperature base line is obtained by taking the number of divisions, to tenths—the beginning of the trace is above or below the base line—and multiplying this number by the proper scale value or "factor."

This result is applied to the surface temperature recorded at the corresponding time. The operation is repeated at the end of the trace, and the mean of these two values is used as the temperature of the base line.

The humidity base line is established in a similar manner with a slight difference in the method of converting the ordinates to per cent. Instead of multiplying by a constant scale value, as was done for the temperature, scales are used, the construction of which is described in section 7.

The pressure base line is determined by noting the number of divisions, to tenths—the beginning of the trace is above or below the base line—taking the corresponding number of millibars from a table constructed for the instrument in use; and applying this result to the surface pressure in millibars recorded at the time for which the readings were taken. To obtain the value at the end of the trace similar steps are taken with the addition of a correction to compensate for the change in surface temperature that usually occurs between the beginning and the end of the flight. This is a correction for instrumental error due to incomplete compensation of the aneroid for temperature and acts in the same direction for nearly all instruments, i. e., a *rise* in temperature causes the pressure element to register too *low*, while a fall in temperature acts in the opposite direction. The amount of change in degrees centigrade necessary for a correction of 0.1 division in pressure is predetermined by tests. From this it is obvious that when the pressure trace is below the base line and the temperature has *fallen* sufficiently for a correction of 0.2 of a division this amount will be added to the pressure ordinate, since the latter is 0.2 of a division too high. The mean of the values found for the beginning and end of the trace determines the value of the base line.

Form No. 1108–Aer. is used in computing base-line values. (See Table 8.) In the typical record (fig. 32) the value of the temperature ordinate at 6:54 a. m. is 3.1 divisions below the base line. This is multiplied by the scale value for the instrument, 0.93, and found to be 2°.9 C. To this is added the surface temperature recorded at this time, obtaining 3°.4 C. At the time pens were last lifted, 11:06 a. m., the ordinate value is 3.4 divisions above the base line. Multiplying this by the scale value gives 3°.2 C., and subtracting from the recorded surface temperature gives 3°.6 C. The mean of 3°.4 C. and 3°.6 C. is the desired base-line value.

On the pressure trace the ordinate at 6:54 a. m. is 0.3 of a division below the base line. From the tabular values this is found to be equivalent to 3.4 millibars. Adding 3.4 to the surface pressure for 6:54 a. m. gives 988.2. At 11:06 a. m. the ordinate value is 0.9 of a division below the base-line. The surface temperature has risen during the interval, 6:54 to 11:06 a. m. from 0°.5 C. to 6°.8 C. or 6°.3 C.; this temperature change requires a correction of 0.3 of a division to be subtracted from the pressure ordinate making the corrected pressure ordinate 0.6, which is equivalent to 6.7 millibars. Since this has a negative sign with respect to the base line, it is added to 982.1, surface pressure at 11:06 a. m., and the result is 988.8. The mean of 988.2 and 988.8 is the desired base-line value.

TABLE 8.

[Form No. 1108–Aer.]

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

BASE-LINE VALUES.

Station, ...

Date, ...

Meteorograph No. .... Flight No. ....

Time, a. m.	Temperature.		Corrected values:
6:54	Ordinate	−3.1	
	Temperature	0.5	
	Ord. value	2.9	3.4
11:06	Ordinate	3.4	
	Temperature	6.8	
	Ord. value	3.2	3.6
			3.5
	Pressure.		
6:54	Ordinate	−0.3	
	Pressure	984.8	
	Ord. value	3.4	988.2
11:06	Ordinate	−0.9	
	Temp. cor	0.3	
	Cor. ord	−0.6	
	Pressure	982.1	
	Ord. value	6.7	988.8
			988.5
	Humidity.		
6:54	Ordinate	2.0	
	Humidity	87	
	Scale value		69
11:06	Ordinate	0.5	
	Humidity	77	
	Scale value		73
			71

The ordinate value on the humidity trace at 6:54 a. m. is 2.0 divisions above the base line. With a surface relative humidity of 87 per cent at this time, the humidity scale gives a value of 69 per cent. The end of the trace shows an ordinate value of 0.5 division above the base line. Applying this to the humidity scale, using a surface relative humidity of 77 per cent, gives 73 per cent. The mean of 69 per cent and 73 per cent is the desired base-line value. The agreement of the base-line values obtained at the beginning and end of the traces should be carefully observed, and when these values are found to vary considerably for several successive flights, the instrument should be retested.

Placing and computing levels.—The levels are indicated by arrows placed at synchronous points on all four traces according to the following rules:

1. In general, arrows are desired near the beginning and end of the flight, not more that three or four divisions below the pressure base line; this being usually on the first and last "stop."[8] (But note suggestion 3 in this connection.)

[8] By "stop" is meant a 5-minute interval during which the kites are allowed to remain at some definite height; i. e., the wire is neither reeled out nor reeled in.

2. Between these arrows should be placed (on, preferably at the end of, "stops" when possible) at intervals of 5 to 8 divisions (or, under exceptionally favorable conditions, at even greater intervals when the scale value is less than 1.4 mb. for 0.1 division).

3. Arrows should always be placed, irrespective of "stops," at the immediate beginning and ending of temperature inversions and isothermal conditions, also at the lowest point in the pressure trace and highest and lowest points in the temperature trace.

4. Abnormal changes in the humidity record should be indicated by arrows. Since the humidity element has been found in some cases to lag somewhat, the arrow should be placed at the point believed to be in agreement with the temperature and pressure curves. Individual judgment must be exercised in such cases. (See arrow at 9:19 a. m., fig. 32.)

5. Wherever a decided rate of change in the temperature trace, with respect to the pressure curve, occurs indicating a change in the temperature gradient, arrows should be placed to show the beginning and ending of this change.

6. In general, a straight interpolation between two arrows should show the true conditions, and arrows should be placed so as to bring out this fact.

7. In entering the time of the arrow in ink on the data sheet, it is desirable to make the time agree with that of the surface reading when a difference of a minute or less is found, so that a comparison of the altitude obtained from the angle may be made.

A computation sheet, Form No. 1102–Aer., Table 9, is used for each level, and the time of the arrow is entered in the proper place on this sheet. Many of these necessary entries will be readily understood by inspection.

TABLE 9.

[Form No. 1102-Aer.]

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

KITE-RECORD COMPUTATION SHEET.

Station.............. Date.............. Time..........m.

Summary.	Altitude, S. L. m.	Pressure. mb.	Temperature. °C.	Rel. hum. %	Vap. pres. mb.	Wind dir.	Wind vel. m. p. s.
Aloft..........	....	....	....	....	....	....	....
Surface..........	....	....	....	....	....	....	....

Pressure. mb.		Temperature. °C.	
Ordinate			
Temp. correction..........	Base		Base ....
Corrected ordinate	× factor =	Ordinate	× factor =

Relative humidity. %		Wind velocity. m. p. s.	
	Base	Scale reading	× factor = ...
Ordinate	× factor =		Correction for reeling

Altitude from pressure. m.	T. & H. correction.	Ascent.	Descent.
Z_a			
Z_s	T_a		
$Z_a - Z_s$	T_b	....	....
T & H	$\frac{T_a+T_b}{2}$	=	=
Z_1	Sum for	=	=
L & G	$\frac{T_a+T_b}{2}\times$	=	=
Z	Cor. $\frac{\times}{2}$	=	$\frac{\times}{2}$ =
Station	Sums	....	....
Sea level	Means		
Altitude from angle.	Cor. H_a		
Wire out, *m.*	Cor. H_s..........	....	....
Angle °; sin.,..........	Corrected mean temperature..........	....	....
Station..........	Mean of ascent and descent..........		

The pressure, temperature, relative humidity, and wind direction at the surface are taken from the data sheet, Table 10. When necessary, interpolations are made between the adjacent times occurring on this sheet. The surface wind velocity is taken from Form No. 1017–Met'l. (W. B. triple register record) for the required time and converted to meters per second. The base line values of pressure, temperature, and relative humidity are entered in their proper places. The ordinates of these elements, read to tenths, are entered with their proper signs with respect to the base line. The temperature ordinate is multiplied by the proper factor and the result applied to the base-line value. This gives the value in degrees C. of the point on the temperature trace and is entered as the temperature aloft in its proper place on the sheet.

The relative humidity aloft is determined by applying the ordinate to the base-line value, using for this purpose the proper humidity scale, as described in section 7.

The temperature correction for pressure is obtained by taking the difference in temperature aloft at the time of the level and the initial surface temperature at the time taken for obtaining this same correction in computing the pressure base line. With this correction applied, the pressure ordinate is converted into millibars from the proper table and the result applied to the base-line value. The value thus obtained is entered as the pressure aloft.

The wind direction aloft is taken from the data sheet, proper interpolation being made when a "level" occurs between two observations.

The vapor pressure is determined by the use of tables giving the aqueous vapor pressure in millibars for various temperatures. The proper value, as found in this table, is multiplied by the relative humidity already determined, and the result is the vapor pressure for the level in question. (See Table 17.)

TABLE 10.

[Form No. 1107-Aer.]

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

RECORD OF KITE FLIGHT.

Station.. Meteorograph, ...

Observer at reel, ...; at record, ... Date, ...

Miscellaneous data.	Time.	Wire out.	Angle.	Thermometers.		Relative humidity.	Wind direction.		Voltmeter.		Weather notes.
				Dry.	Wet.		Surface.	Aloft.	Scale.	Volts.	
	a. m.	Meters.	°	°	°	%					
Pens down	6:43			0.6	−0.2	86	ese.				4 St. Cu. ssw.
Pens lifted	6:50			0.5	−0.2	87	ese.				
Pens down	6:54			0.5	−0.2	87	ese.				
No. 45 launched	7:06			0.5	−0.2	87	ese.				
No. 44 launched	7:11	300	58	0.6	−0.2	86	ese.	se.		0	
Stop	7:16	790	39	0.8	0.0	86	ese.	s.		565	
No. 43 launched	7:21	700	52	0.6	0.0	89	ese.	s.		565	
Stop	7:29	1,400	20	0.6	0.0	89	ese.	s.		950	
No. 41 launched	7:34	"	38	0.6	0.0	89	ese.	sse.		1,500	
Stop	7:47	2,400	35	0.8	0.1	87	ese.	sse.		2,200	
No. 42 launched	7:52	"	31	1.0	0.3	88	ese.	sse.		2,000	
Stop	8:12	4,000	18	1.6	0.8	86	ese.	sse.		3,400	
Reading	8:21	"	26	1.6	0.8	86	se.	s.		5,400	
No. 32 launched	8:27	"	33	1.8	1.0	86	se.	ssw.		5,600	No. 43 entered St. Cu. base at 8:30, ∠ 32°, 4,200 m. out.
Reading	8:38	5,000		1.8	1.0	86	se.	ssw.		6,000	
	8:40										
Stop	8:50	6,000		2.2	1.2	83	se.	ssw.		6,909	
Reel out	8:55	"		2.4	1.4	83	se.	ssw.		7,400	
Stop	9:06	6,800		2.8	1.8	84	se.	ssw.		7,000	7 St. Cu. ssw.
Reel in	9:11	"		2.8	1.8	84	se.	ssw.		7,500	
Reading	9:19	6,000		3.0	2.0	84	se.	sw.			
Reading	9:26	5,000		3.6	2.4	82	se.	sw.			
No. 32 landed	9:35	4,000		4.2	3.0	82	se.	sw.		5,200	
Stop	9:47	3,200		4.0	2.8	82	se.	ssw.		4,000	
Reel in	9:50	"	42	3.8	2.7	83	se.	ssw.		4,300	No. 45 out of St. Cu. base at 9:50, ∠ 37°, 3,200 m. out.
No. 42 landed	10:00	2,400	53	4.4	3.0	79	se.	ssw.		2,500	
Reel in	10:05	"	41	4.6	3.2	80	se.	s.		2,500	
	10:11										
No. 41 landed	10:18	1,400	51	5.4	3.7	77	se.	s.		1,200	
Reel in	10:23	"	43	5.8	4.2	79	se.	s.		1,200	
	10:29										
No. 43 landed	10:32	700	51	5.8	4.2	79	sse.	s.		565	
Reel in	10:37	"	33	6.0	4.4	79	sse.	s.		490	
	10:40										
No. 44 landed	10:42	300	51	5.8	4.2	79	se.	se.		0	
Reel in	10:47	"	43	6.6	4.8	77	se.	se.		0	
No. 45 landed	10:53			6.6	4.9	79	se.				9 St. Cu. ssw.
Inst. in shelter	10:55			6.6	4.9	78	se.				
Pens up	11:06			6.8	5.0	77	se.				

BAROMETRIC PRESSURE.

Time	6:00 a.	7:00 a.	8:00 a.	9:00 a.	10:00 a.	11:00 a.
In	29.08	29.08	29.06	29.04	29.02	29.00
mb	984.8	984.8	984.1	983.4	982.7	982.1

The wind velocity aloft is obtained by measuring the length of one complete mark, i. e., one complete cycle of the recording pen, as operated by the cam, occurring at the indicated time, with a wind-velocity scale used by the Weather Bureau in determining velocities as recorded on Form No. 1017. The value thus obtained is multiplied by a factor determined from tests of the instrument. To this result a reeling correction is applied and consists in determining the rate in meters per second at which reeling has taken place. This correction is added for reeling out and subtracted for reeling in. Printed tables having minutes of time and meters of wire as arguments give the amount of this correction. (See Table 16.)

Hypsometric equation.—After the data mentioned above have been computed there remains to be determined the altitude of these levels. The determination of this is based upon the hypsometric formula:

$$Z = K\,(1+a\Theta)\left(\frac{1}{1-0.378\frac{e}{b}}\right)\left(1+\frac{g-g_L}{g}\right)\left(1+\frac{h-h_o}{R}\right)\log\frac{p}{p_o}$$

in which h = height of the upper station.

h_o = height of the lower station.

$Z = h - h_o$.

p = atmospheric pressure at the upper station.

p_o = atmospheric pressure at the lower station.

R = mean radius of the earth.

Θ = mean temperature of the air column between the altitudes h and h_o.

e = mean pressure of aqueous vapor in the air column.

b = mean barometric pressure of the air column.

K = barometric constant (18,400).

a = coefficient of the expansion of air.

g = standard value of gravity (980.665 dynes).

g_L = local value of gravity.

A detailed explanation of the derivation of the constants and the several variables used in this formula will be found in the Smithsonian Meteorological Tables, 1918 edition, pages xxx to lii.

The lower half of the computation sheet, Table 9, pertains to a direct application of this formula.

Z_a and Z_s are obtained individually from a printed table (Table 13) the values in which are based on the expression, 18,400 log $\frac{1013.3}{B}$, where B is the barometric pressure. Z_s is then subtracted from Z_a and the value thus obtained is the approximate altitude of the level above the surface. To this value there must be applied corrections for temperature, humidity, latitude, and gravity.

The table for the determination of altitudes from pressure is based upon a mean temperature of the air column of 0° C. Whenever the mean temperature has another value, a correction is applied by multiplying the approximate altitude by a factor $a = 0.00367\ \Theta$, in which 0.00367 is the coefficient of the expansion of air and Θ the mean air temperature. This correction is added when the mean temperature is above 0° C. and subtracted when it is below 0° C. For values of a corresponding to different values of Θ, see Table 14.

For the lowest computed altitude of a flight the mean air temperature is simply half the sum of the temperatures aloft and at the surface. This method is not used for higher levels; it would be correct, if the temperature gradient were uniform at all altitudes, but this is rarely the case, and it is therefore necessary to take into consideration these variations in the gradient. In order to do this the mean temperatures for successive levels are weighted according to the altitude intervals between them, these differences being considered only to the nearest hundred meters. For example, if the first level is at a height h, the mean air temperature is $\frac{t_s+t_a}{2}$. In the case of the next higher level at a height h', the mean temperature is

$$\frac{h\left(\frac{t_s+t_a}{2}\right)+(h'-h)\left(\frac{t_a-t_a'}{2}\right)}{h'}$$

In computing kite records it is necessary also to take into consideration the changes that occur in the temperature at the surface and for some distance above the surface during the flight. If all the observations were made at one time there would be no such correction, but in kite flights this is never the case. The correction then is essentially one of time. The height to which the increase or decrease of temperature extends depends largely upon the diathermance of the lower strata, and therefore upon the extent of convectional activity. To determine this limiting height it is necessary to plot the temperatures as observed at various altitudes during the ascent and descent. These lines will meet at some point and that point is accepted as the height to which the surface warming or cooling extends.

In figure 33, suppose that at 8 a. m. t_s is the surface temperature, t_a that at some height h; at 9 a. m., $t_{s'}$ is the surface temperature, $t_{a'}$ that at some height h'; at 10 a. m., $t_{s''}$ is the surface temperature, $t_{a''}$ that at some height h''. The mean air temperature for the level at 8 a. m. is $\frac{t_s + t_a}{2}$. Now, if we applied no surface-temperature correction the mean air temperature for the higher level at 9 a. m. would be

$$\frac{h\left(\frac{t_s+t_a}{2}\right)+(h'-h)\left(\frac{t_a-t_{a'}}{2}\right)}{h'}.$$

This would give an entirely erroneous value, for during the interval 8 a. m. to 9 a. m. the surface temperature has changed to $t_{s'}$ and that at the intermediate height h, to some value x. The correct mean air temperature would be

$$\frac{h\left(\frac{t_{s'}+x}{2}\right)(h'-h)\left(\frac{x+t_{a'}}{2}\right)}{h'},$$

but we do not know this value x. We can only assume that the change in temperature at the height h and at all other altitudes from the surface to the the point of intersection of the lines (in this case at the height h') is a proportional one. We then obtain the mean air temperature by correcting for this *time* change in temperature and the corrected value is

$$\frac{h\left(\frac{t_s+t_a}{2}\right)+(h'-h)\left(\frac{t_a+t_{a'}}{2}\right)\pm h'\left(\frac{t_s-t_{s'}}{2}\right)}{h'}.$$

For any level below the point of intersection of the lines, the altitude to which the surface temperature correction is applied is the altitude of the level itself. For altitudes greater than the point of intersection of the lines this limiting height is the one used.

The values of θ (mean temperature of air column) between levels are computed, beginning at the surface

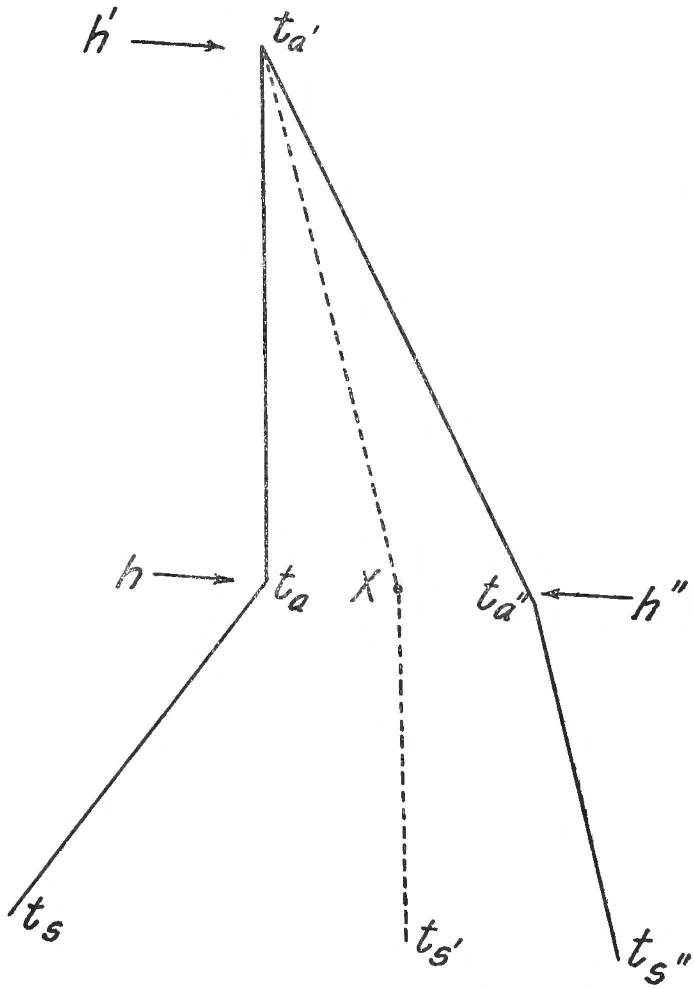


FIG. 33.—Diagram showing method of determining the mean temperature of the air column.

and continuing upward to the highest level; then again working upward, through the descent, from the surface to the highest. The value of θ, for the highest level, is considered as the mean of the two values thus obtained for this level.

The correction for humidity is determined from the following arrangement of expressions taken from the hypsometric formula, $\frac{1}{2}\left(\frac{0.378\frac{e}{b}}{0.00367}\right)$ and gives the result in terms of temperature. This value is included in that used to obtain the final temperature-correction factor, this latter being multiplied by $Z_a - Z_s$ and the result then added to $Z_a - Z_s$ when the temperature is above 0°C., and subtracted when it is below 0°C. (See Table 15.)

The correction for latitude and gravity is determined from the following terms taken from the hypsometric formula,

$$\left(1+\frac{g+g_L}{g}\right)\left(1+\frac{h+h_0}{R}\right).$$

This correction with respect to latitude is predetermined for each station and therefore will vary only as regards the value of Z_1. The amount of correction applied is readily obtained from a table and is additive. This special table is made up for each station and is based upon Tables 62 and 63, 1918 edition, Smithsonian Institution Meteorological Tables. To the value of Z add the station elevation above sea level.

The altitude of the kite carrying the instrument is also obtained trigonometrically whenever the level occurs at a time when a theodolite reading is made. This is determined by the expression $h=l$ (sin ϕ), where h is the vertical height, l, the length of wire out in meters and ϕ, the angular altitude of the kite. It has been found that on the average a deduction of about 2 per cent must be made from the altitude obtained in this way to allow for the sag in wire, number of kites out, etc. This altitude is used principally as a check on the former.

The altitudes of observed values of electric potential are computed trigonometrically whenever possible, but in those flights made at night or when the kites are obscured by clouds it is necessary to employ another method. The pressure ordinate at the time at which the potential reading was made is corrected for temperature, and with this corrected ordinate those two levels are taken which occur immediately before and after the time of the potential reading. Using the corrected pressure ordinates of these levels, the altitude of the potential reading is directly interpolated, since the altitude varies inversely as the pressure or, rather, approximately so, for the comparatively short intervals between two levels. Form No. 1104–Aer., Table 11, is used for computing the electric potential data.

Tabulation.—The data are now ready for tabulation and Form No. 1105–Aer., Table 12, is used for this purpose. The first entry is taken from the data sheet and gives the values observed at the time at which the instrument kite is launched, the altitude of the station above sea level being entered as the first altitude. Between the computed levels spaces are left for interpolated levels at altitudes above sea level 250 meters apart, except that the intervals are increased to 500 meters for altitudes greater than 1,500 meters above sea level. The last entry is taken from the data sheet at the time the head kite is landed. In the first and last entries the data for both the surface and aloft are identical. For the computed levels, the surface data are entered to the left of the double line and the data aloft to the right.

TABLE 11.

[Form No. 1104–Aer.]

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

ALTITUDES AT TIMES OF ELECTRIC POTENTIAL READINGS.

Station, ... Date, ...

Time (a. m.)	7:11	7:21	7:34	7:52	8:27	8:38	8:55
P. ordinate						21.0	27.5
T. correction						.1	.1
Cor. P. ordinate						20.9	27.6
T. ordinate			Same as 7:34 level.			−1.2	−7.0
T. ordinate × factor						−1.1	−6.5
T. of base line						3.5	3.5
Temperature						2.4	−3.0
Initial T.						0.5	0.5
T. change						1.9	−2.5
Altitude, S. L.	645	938	1,191	1,607	2,536	2,417	3,041
Electric potential	0	565	1,500	2,000	5,600	6,000	7,400

Time (a. m.)	9:11	9:35	9:50	10:05	10:23	10:37	10.47
P. ordinate	28.5	27.0					
T. correction	.2	.1					
Cor. P. ordinate	28.7	27.1					
T. ordinate	−8.5	−7.0	Same as 9:50 level.				
T. ordinate × factor	−7.9	−6.5					
T. of base line	3.5	3.5					
Temperature	−4.4	−3.0					
Initial T.	0.5	0.5					
T. change	−3.9	−2.5					
Altitude, S. L.	3,272	3,086	2,458	1,940	1,331	770	598
Electric potential	7,500	5,200	4,300	2,500	1,200	490	0

TABLE 12.

[Form No. 1105–Aer.]

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

FREE-AIR DATA FROM KITE FLIGHTS.

Station, ... Meteorograph, ... Date, ...

Surface.						At different heights above sea.										
				Wind.						Humidity.		Wind.		Potential.		
Time.	Pressure.	Temperature.	Relative humidity.	Direction.	Velocity.	Altitude.	Pressure.	Temperature.	$\frac{\Delta t}{100 \text{ m.}}$	Relative.	Vapor pressure.	Direction.	Velocity.	Gravity.	Electric.	Remarks.
a. m.	*mb.*	° *C.*	%		*m. p. s.*	*m.*	*mb.*	° *C.*		%	*mb.*		*m. p. s.*	10^6 *ergs.*	*Volts.*	
7:06	984.7	0.5	87	ese.	5.4	396	984.7	0.5	....	87	5.51	ese.	5.4	....	....	4/10 St. Cu. ssw.; changing to 7/10 St. Cu. ssw. by 9:05 a. m. and to 9/10 St. Cu. ssw. by end of flight.
						500	973.0	1.0	....	89	5.84	se.	6.6	....	....	
						750	943.0	2.1	....	92	6.53	s.	9.4	....	0	
7:29	984.5	0.6	89	ese.	4.5	799	936.5	2.3	−0.45	93	6.71	s.	9.9	....	....	
						1,000	914.2	4.8	....	75	6.45	sse.	11.8	....	560	
7:34	984.4	0.6	89	ese.	4.9	1,191	892.4	7.2	−1.25	58	5.89	sse.	13.6	....	....	
						1,250	886.0	7.1	....	58	5.85	sse.	13.3	....	1,500	
						1,500	860.0	6.9	....	59	5.87	sse.	12.0	....	....	Altitude of St. Cu. base about 2,250 m. at 8:30 and 2,300 m. at 9:50 a. m.
8:12	984.0	1.6	86	ese.	5.8	1,567	852.5	6.8	0.11	59	5.83	sse.	11.7	....	2,000	
						2,000	808.9	3.8	....	39	3.13	s.	16.2	....	....	
8:21	983.9	1.6	86	se.	6.3	2,070	801.2	3.3	0.70	36	2.79	s.	16.9	....	....	
8:40	983.6	1.9	86	se.	6.3	2,487	761.0	1.6	0.41	100	6.86	ssw.	19.0	....	6,000	
						2,500	760.1	1.5	....	99	6.74	ssw.	19.0	....	....	
						3,000	714.0	−2.3	....	80	4.03	ssw.	18.7	....	7,400	
						3,500	670.1	−6.1	....	60	2.19	sw.	18.3	....	7,500	
9:19	983.2	3.0	84	se.	5.4	3,723	651.1	−7.8	0.78	51	1.61	sw.	18.2	....	....	
						3,500	670.1	−6.0	....	58	2.13	sw.	18.3	....	....	
						3,000	713.2	−2.1	....	72	3.69	ssw.	18.6	....	5,200	
						2,500	759.2	1.9	....	87	6.09	ssw.	18.9	....	....	
9:50	982.8	3.8	83	se.	6.3	2,458	763.0	2.2	0.49	88	6.30	ssw.	18.9	....	4,300	
						2,000	807.4	4.4	....	53	4.43	s.	17.6	....	2,500	
10:11	982.6	5.0	79	se.	5.8	1,778	829.8	5.5	0.24	36	3.25	s.	16.9	....	....	
						1,500	859.1	6.2	....	52	4.93	s.	16.3	....	1,200	
						1,250	885.2	6.8	....	67	6.62	s.	15.9	....	....	
10:29	982.4	5.8	79	sse.	5.4	1,121	898.8	7.1	−0.93	75	7.57	s.	15.6	....	....	
						1,000	913.3	6.0	....	78	7.29	s.	13.9	....	....	
						750	942.0	3.6	....	85	6.72	sse.	10.2	....	490	
10:40	982.3	5.9	79	se.	4.9	671	949.6	2.9	1.34	87	6.54	sse.	9.1	....	....	
						500	971.0	5.2	....	82	7.25	se.	6.8	....	0	
10:53	982.2	6.6	79	se.	5.4	396	982.2	6.6	....	79	7.69	se.	5.4	....	....	

Linear interpolations are made for the intermediate values of temperature, relative humidity, wind direction, and velocity. The atmospheric pressures for these levels are determined by plotting the pressures for the calculated levels, using the altitudes as ordinates and the pressures as abscissæ. This is necessary because in this instance the interpolation is not a linear one but approaches a logarithmic curve. This, however, is dependent upon the temperature at the various levels.

The column headed $\frac{\Delta t}{100}$ is the change in temperature per 100 meters, or the temperature gradient. The gradient values are obtained by dividing the difference in temperature between two adjacent levels by the number of hundred meters difference in their elevation, and the results are given to two decimal places. The gradient is positive when the temperature decreases with altitude, and negative when the the temperature increases with altitude.

The vapor pressures are obtained from the corresponding temperature and relative humidity as in the case of the computed levels. (See Table 17.)

The values of electric potential are entered to the nearest 10 opposite the altitudes nearest which they occur.

Under "Remarks" are recorded all meteorological phenomena observed during the flight, including cloud changes, halos, thunderstorms, beginning and ending of precipitation, etc. Whenever kites are observed to enter or leave the cloud base, a reading of the theodolite is made and the altitude above sea level computed; the result is expressed to the nearest even 50 meters below the computed value. This result is entered under "Remarks" with a brief statement, together with a record of the kind and direction of the clouds.

11. REDUCTION TABLES.

Tables 13 to 18, inclusive, are regularly used in the reduction of every free-air record obtained by means of kites. Tables 13, 14, and 15 are exactly the same as Tables 57, 58, and 61 of the 1918 edition, Smithsonian Meteorological Tables, and a description of their use may be found in the introduction of that work.

The values in Table 16 were obtained by dividing the number of meters indicated at the tops of the columns by the number of seconds in the minutes listed in the extreme left-hand column.

Table 17 corresponds to Tables 71 and 72 in the Smithsonian Meteorological Tables, 1918 edition, except that vapor pressures are expressed in millibars instead of millimeters.

Table 18 gives values of relative humidity, or percentage of saturation, for air temperatures from −39° C. to + 44° C. (side argument) and for depressions of the wet-bulb thermometer at 0.1° C. intervals (top argument). Thus, only a single interpolation is necessary. The values have been computed for a barometric pressure of 990 mb., this being approximately the average pressure at the kite stations now maintained by the Weather Bureau. When the air is very dry, errors of 1 or 2 per cent in the relative humidity are possible with pressures markedly differing from the mean here adopted, but such instances are infrequent, and even then the errors are no greater than those of observation. Hence, it is deemed unnecessary to use two or three different sets of tables, the one, computed for an average pressure, being sufficiently accurate for all practical purposes.

TABLE 13.—*Determination of heights by the barometer.*

$\left(\text{Values of } 18400 \log \frac{1013.3}{B}\right)$

Pressure (mb.)	0	1	2	3	4	5	6	7	8	9	P. P.		
	METERS.												
500	5645	5629	5613	5597	5581	5565	5549	5533	5518	5502	....	16	15
510	5486	5471	5455	5439	5424	5408	5393	5377	5362	5346	0.1	2	2
520	5331	5316	5300	5285	5270	5255	5239	5224	5209	5194	.2	3	3
530	5179	5164	5149	5134	5119	5104	5089	5074	5059	5044	.3	5	4
540	5030	5015	5000	4985	4971	4956	4941	4927	4912	4898	.4	6	6
550	4883	4868	4854	4839	4825	4811	4796	4782	4768	4753	.5	8	8
560	4739	4725	4710	4696	4682	4668	4654	4640	4626	4612	.6	10	9
570	4598	4583	4569	4556	4542	4528	4514	4500	4486	4472	.7	11	10
580	4459	4445	4431	4417	4404	4390	4376	4363	4349	4335	.8	13	12
590	4322	4308	4295	4281	4268	4254	4241	4228	4214	4201	.9	14	14
600	4188	4174	4161	4148	4134	4121	4108	4095	4082	4069	....	14	13
610	4056	4042	4029	4016	4003	3990	3977	3964	3951	3939	0.1	1	1
620	3926	3913	3900	3887	3874	3861	3849	3836	3823	3810	.2	3	3
630	3798	3785	3772	3760	3747	3735	3722	3709	3697	3684	.3	4	4
640	3672	3659	3647	3635	3622	3610	3597	3585	3573	3560	.4	6	5
650	3548	3536	3523	3511	3499	3487	3475	3462	3450	3438	.5	7	6
660	3426	3414	3402	3390	3378	3366	3354	3342	3330	3318	.6	8	8
670	3306	3294	3282	3270	3258	3246	3235	3223	3211	3199	.7	10	9
680	3187	3176	3164	3152	3141	3129	3117	3106	3094	3082	.8	11	10
690	3071	3059	3048	3036	3025	3013	3002	2990	2979	2967	.9	13	12
700	2956	2944	2933	2922	2910	2899	2888	2876	2865	2854	....	12	11
710	2842	2831	2820	2809	2798	2786	2775	2764	2753	2742	0.1	1	1
720	2731	2720	2708	2697	2686	2675	2664	2653	2642	2631	.2	2	2
730	2621	2609	2599	2588	2577	2566	2555	2544	2533	2523	.3	4	3
740	2512	2501	2490	2479	2469	2458	2447	2437	2426	2415	.4	5	4
750	2405	2394	2383	2373	2362	2351	2341	2330	2320	2309	.5	6	6
760	2299	2288	2278	2267	2257	2246	2236	2225	2215	2205	.6	7	7
770	2194	2184	2173	2163	2153	2142	2132	2122	2112	2101	.7	8	8
780	2091	2081	2071	2060	2050	2040	2030	2020	2009	1999	.8	10	9
790	1989	1979	1969	1959	1949	1939	1929	1919	1909	1899	.9	11	10
800	1889	1879	1869	1859	1849	1839	1829	1819	1809	1799	....	9	8
810	1789	1780	1770	1760	1750	1740	1731	1721	1711	1701	0.1	1	1
820	1692	1682	1672	1662	1653	1643	1633	1623	1614	1604	.2		2
830	1595	1585	1575	1566	1556	1547	1537	1527	1518	1508	.3	3	2
840	1499	1489	1480	1470	1461	1451	1442	1433	1423	1414	.4	4	3
850	1404	1395	1386	1376	1367	1357	1348	1339	1329	1320	.5	4	4
860	1311	1302	1292	1283	1274	1264	1255	1246	1237	1228	.6	5	5
870	1218	1209	1200	1191	1182	1173	1164	1154	1145	1136	.7	6	6
880	1127	1118	1109	1100	1091	1082	1073	1064	1055	1046	.8	7	6
890	1037	1028	1019	1010	1001	992	983	974	965	956	.9	8	7
900	948	939	930	921	912	903	894	886	877	868	....	7	....
910	859	850	842	833	824	815	807	798	789	781	0.1	1	
920	772	763	755	746	737	729	720	711	703	694	.2	1	
930	686	677	668	660	651	643	634	626	617	608	.3	2	
940	600	592	583	575	566	558	549	541	532	524	.4	3	
950	516	507	499	490	482	474	465	457	448	440	.5	4	
960	432	424	415	407	399	390	382	374	365	357	.6	4	
970	349	341	332	324	316	308	300	292	283	275	.7	5	
980	267	259	251	243	234	226	218	210	202	194	.8	6	
990	186	178	170	162	154	146	138	130	122	114	.9	6	
1000	106	98	90	82	74	66	58	50	42	34			
1010	26	18	10	2	−6	−13	−21	−29	−37	−45			
1020	−53	−61	−68	−76	−84	−92	−100	−107	−115	−123			
1030	−131	−138	−146	−154	−162	−169	−177	−185	−192	−200			
1040	−208	−215	−223	−231	−238	−246	−254	−261	−269	−277			

TABLE 14.—*Temperature correction factor.* (*a.*)

(Multiply values of $Z_a - Z_o$ by *a;* add correction when mean temperature is above 0° C; subtract when below 0° C.)

Mean Temp. θ.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
°C.	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
0	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.003
1	.004	.004	.004	.005	.005	.006	.006	.006	.007	.007
2	.007	.008	.008	.008	.009	.009	.010	.010	.010	.011
3	.011	.011	.012	.012	.012	.013	.013	.014	.014	.014
4	.015	.015	.015	.016	.016	.017	.017	.017	.018	.018
5	.018	.019	.019	.019	.020	.020	.021	.021	.021	.022
6	.022	.022	.023	.023	.023	.024	.024	.025	.025	.025
7	.026	.026	.026	.027	.027	.028	.028	.028	.029	.029
8	.029	.030	.030	.030	.031	.031	.032	.032	.032	.033
9	.033	.033	.034	.034	.034	.035	.035	.036	.036	.036
10	.037	.037	.037	.038	.038	.039	.039	.039	.040	.040
11	.040	.041	.041	.041	.042	.042	.043	.043	.043	.044
12	.044	.044	.045	.045	.046	.046	.046	.047	.047	.047
13	.048	.048	.048	.049	.049	.050	.050	.050	.051	.051
14	.051	.052	.052	.052	.053	.053	.054	.054	.054	.055
15	.055	.055	.056	.056	.057	.057	.057	.058	.058	.058
16	.059	.059	.059	.060	.060	.061	.061	.061	.062	.062
17	.062	.063	.063	.063	.064	.064	.065	.065	.065	.066
18	.066	.066	.067	.067	.068	.068	.068	.069	.069	.069
19	.070	.070	.070	.071	.071	.072	.072	.072	.073	.073
20	.073	.074	.074	.075	.075	.075	.076	.076	.076	.077
21	.077	.077	.078	.078	.079	.079	.079	.080	.080	.080
22	.081	.081	.081	.082	.082	.083	.083	.083	.084	.084
23	.084	.085	.085	.086	.086	.086	.087	.087	.087	.088
24	.088	.088	.089	.089	.090	.090	.090	.091	.091	.091
25	.092	.092	.092	.093	.093	.094	.094	.094	.095	.095
26	.095	.096	.096	.097	.097	.097	.098	.098	.098	.099
27	.099	.099	.100	.100	.101	.101	.101	.102	.102	.102
28	.103	.103	.103	.104	.104	.105	.105	.105	.106	.106
29	.106	.107	.107	.108	.108	.108	.109	.109	.109	.110
30	.110	.110	.111	.111	.112	.112	.112	.113	.113	.113
31	.114	.114	.115	.115	.115	.116	.116	.116	.117	.117
32	.117	.118	.118	.119	.119	.119	.120	.120	.120	.121
33	.121	.121	.122	.122	.123	.123	.123	.124	.124	.124
34	.125	.125	.126	.126	.126	.127	.127	.127	.128	.128
35	.128	.129	.129	.130	.130	.130	.131	.131	.131	.132
36	.132	.132	.133	.133	.134	.134	.134	.135	.135	.135
37	.136	.136	.137	.137	.137	.138	.138	.138	.139	.139
38	.139	.140	.140	.141	.141	.141	.142	.142	.142	.143
39	.143	.143	.144	.144	.145	.145	.145	.146	.146	.146

TABLE 15.—*Humidity correction—Add to mean temperature.*

Air pressure (mb.)	VAPOR PRESSURE (MB.)													
	0.5	1	2	3	4	5	6	7	8	9	10	20	30	40
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
1040	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	1.0	1.5	2.0
1020	.0	.1	.1	.2	.2	.3	.3	.4	.4	.5	.5	1.0	1.5	2.0
1000	.0	.1	.1	.2	.2	.3	.3	.4	.4	.5	.5	1.0	1.5	2.1
980	.0	.1	.1	.2	.2	.3	.3	.4	.4	.5	.5	1.1	1.6	2.1
960	.0	.1	.1	.2	.2	.3	.3	.4	.4	.5	.5	1.1	1.6	2.1
940	.0	.1	.1	.2	.2	.3	.3	.4	.4	.5	.5	1.1	1.6	2.2
920	.0	.1	.1	.2	.2	.3	.3	.4	.4	.5	.6	1.1	1.7	2.2
900	.0	.1	.1	.2	.2	.3	.3	.4	.5	.5	.6	1.1	1.7	2.3
880	.0	.1	.1	.2	.2	.3	.4	.4	.5	.5	.6	1.2	1.8	2.3
860	.0	.1	.1	.2	.2	.3	.4	.4	.5	.5	.6	1.2	1.8	2.4
840	.0	.1	.1	.2	.2	.3	.4	.4	.5	.6	.6	1.2	1.8	
820	.0	.1	.1	.2	.3	.3	.4	.4	.5	.6	.6	1.3	1.9	
800	.0	.1	.1	.2	.3	.3	.4	.5	.5	.6	.6	1.3	1.9	
780	.0	.1	.1	.2	.3	.3	.4	.5	.5	.6	.7	1.3	2.0	
760	.0	.1	.1	.2	.3	.3	.4	.5	.5	.6	.7	1.4		
740	.0	.1	.1	.2	.3	.3	.4	.5	.6	.6	.7	1.4		
720	.0	.1	.1	.2	.3	.4	.4	.5	.6	.6	.7	1.4		
700	.0	.1	.1	.2	.3	.4	.4	.5	.6	.7	.7	1.5		
680	.0	.1	.2	.2	.3	.4	.5	.5	.6	.7	.8			
660	.0	.1	.2	.2	.3	.4	.5	.5	.6	.7	.8			
640	.0	.1	.2	.2	.3	.4	.5	.6	.6	.7	.8			
620	.0	.1	.2	.2	.3	.4	.5	.6	.7	.7				
600	.0	.1	.2	.3	.3	.4	.5	.6	.7	.8				
580	.0	.1	.2	.3	.4	.4	.5	.6	.7	.8				
560	.0	.1	.2	.3	.4	.5	.6	.6	.7					
540	.0	.1	.2	.3	.4	.5	.6	.7	.8					
520	.0	.1	.2	.3	.4	.5	.6	.7	.8					
500	.1	.1	.2	.3	.4	.5	.0	.7						
480	.1	.1	.2	.3	.4	.5	.6	.8						
460	.1	.1	.2	.3	.4	.6	.7	.8						
440	.1	.1	.2	.4	.5	.6	.7							
420	.1	.1	.2	.4	.5	.6	.7							
400	.1	.1	.3	.4	.5	.6	.8							
380	.1	.1	.3	.4	.5	.7								
360	.1	.1	.3	.4	.6	.7								
340	.1	.2	.3	.5	.6	.8								
320	.1	.2	.3	.5	.6									
300	.1	.2	.3	.5	.7									
280	.1	.2	.4	.6	.7									
260	.1	.2	.4	.6										
240	.1	.2	.4	.6										
220	.1	.2	.5	.7										
200	.1	.3	.5											
180	.1	.3	.6											
160	.2	.3	.6											
140	.2	.4												
120	.2	.4												
100	.3	.5												
80	.3													
60	.4													
40	.6													
20	1.3													
10	2.6													

TABLE 16.—*Correction for wind velocity.*

REELING OUT +. [In meters per second.] REELING IN −

	TIME AND DISTANCE BETWEEN OBSERVATIONS.															
Minutes.	m. 500	m. 600	m. 700	m. 800	m. 900	m. 1,000	m. 1,100	m. 1,200	m. 1,300	m. 1,400	m. 1,500	m. 1,600	m. 1,700	m. 1,800	m. 1,900	m. 2,000
3	2.8	3.3	......	......	......	......	......	......	......	......	......	......	......	......	......	......
4	2.1	2.5	2.9	3.3	......	......	......	......	......	......	......	......	......	......	......	......
5	1.7	2.0	2.3	2.7	3.0	3.3	......	......	......	......	......	......	......	......	......	......
6	1.4	1.7	2.0	2.2	2.5	2.8	3.0	3.3	......	......	......	......	......	......	......	......
7	1.2	1.4	1.7	1.9	2.2	2.4	2.6	2.8	3.1	3.3	......	......	......	......	......	......
8	1.0	1.2	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	......	......	......	......
9	0.9	1.1	1.3	1.5	1.7	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.3	......	......
10	0.8	1.0	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.3	2.5	2.7	2.8	3.0	3.2	3.3
11	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1	2.3	2.4	2.6	2.7	2.9	3.0
12	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1	2.2	2.4	2.5	2.6	2.8
13	0.6	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.6
14	0.6	0.7	0.8	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.2	2.3	2.4
15	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.1	2.2
16	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1
17	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
18	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.8
19	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
20	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7
21	......	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.4	1.5	1.6
22	......	......	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.4	1.5
23	......	......	......	0.6	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.5
24	......	......	......	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4
25	......	......	......	0.5	0.6	0.7	0.7	0.8	0.0	0.9	1.0	1.1	1.1	1.2	1.3	1.3
26	......	......	......	......	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.2	1.2	1.3
27	......	......	......	......	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1.0	1.0	1.1	1.2	1.2
28	......	......	......	......	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.0	1.0	1.1	1.2
29	......	......	......	......	......	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.0	1.0	1.1	1.2
30	......	......	......	......	......	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.0	1.1
31	......	......	......	......	......	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1
32	......	......	......	......	......	......	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0
33	......	......	......	......	......	......	0.6	0.6	0.6	0.7	0.8	0.8	0.8	0.9	1.0	1.0
34	......	......	......	......	......	......	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0
35	......	......	......	......	......	......	......	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.9	1.0
36	......	......	......	......	......	......	......	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9
37	......	......	......	......	......	......	......	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.9
38	......	......	......	......	......	......	......	......	0.6	0.6	0.6	0.7	0.8	0.8	0.8	0.9
39	......	......	......	......	......	......	......	......	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8
40	......	......	......	......	......	......	......	......	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8

TABLE 17.—*Pressure of aqueous vapor.*

Temp. °C.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	MILLIBARS.									
−34	0.25	0.25	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23
−33	.28	.28	.27	.27	.27	.26	.26	.26	.26	.25
−32	.31	.31	.30	.30	.30	.30	.29	.29	.28	.28
−31	.34	.34	.34	.34	.33	.33	.32	.32	.32	.31
−30	.38	.38	.38	.37	.37	.36	.36	.36	.35	.35
−29	.43	.42	.42	.41	.41	.40	.40	.40	.39	.39
−28	.47	.47	.46	.46	.45	.45	.44	.44	.44	.43
−27	.52	.52	.51	.51	.50	.50	.49	.49	.48	.48
−26	.58	.57	.57	.56	.56	.55	.54	.54	.53	.53
−25	.64	.63	.63	.62	.62	.61	.60	.60	.59	.58
−24	.71	.70	.69	.69	.68	.67	.67	.66	.65	.65
−23	.78	.77	.77	.76	.75	.74	.74	.73	.72	.71
−22	.86	.85	.84	.84	.83	.82	.81	.80	.80	.79
−21	.95	.94	.93	.92	.91	.90	.89	.89	.88	.87
−20	1.04	1.03	1.02	1.01	1.00	1.00	.99	.98	.97	.96
−19	1.15	1.14	1.13	1.12	1.11	1.10	1.09	1.07	1.06	1.05
−18	1.26	1.25	1.24	1.23	1.22	1.20	1.19	1.18	1.17	1.16
−17	1.39	1.37	1.36	1.35	1.34	1.32	1.31	1.30	1.29	1.27
−16	1.52	1.51	1.49	1.48	1.47	1.45	1.44	1.43	1.41	1.40
−15	1.67	1.65	1.64	1.62	1.61	1.59	1.58	1.57	1.55	1.54
−14	1.83	1.81	1.80	1.78	1.76	1.75	1.73	1.72	1.70	1.69
−13	2.00	1.99	1.97	1.95	1.93	1.92	1.90	1.88	1.86	1.85
−12	2.19	2.17	2.15	2.13	2.12	2.10	2.08	2.06	2.04	2.02
−11	2.40	2.38	2.35	2.33	2.31	2.29	2.27	2.25	2.23	2.21
−10	2.62	2.60	2.57	2.55	2.53	2.51	2.48	2.46	2.44	2.42
− 9	2.86	2.83	2.81	2.78	2.76	2.74	2.71	2.69	2.67	2.64
− 8	3.12	3.09	3.07	3.04	3.01	2.99	2.96	2.93	2.91	2.88
− 7	3.40	3.37	3.34	3.31	3.29	3.26	3.23	3.20	3.17	3.15
− 6	3.70	3.67	3.64	3.61	3.58	3.55	3.52	3.49	3.46	3.43
− 5	4.03	4.00	3.97	3.93	3.90	3.87	3.83	3.80	3.77	3.74
− 4	4.39	4.35	4.31	4.28	4.24	4.21	4.17	4.14	4.10	4.07
− 3	4.77	4.73	4.69	4.65	4.61	4.58	4.54	4.50	4.46	4.42
− 2	5.18	5.14	5.10	5.06	5.01	4.97	4.93	4.89	4.85	4.81
− 1	5.63	5.58	5.53	5.49	5.44	5.40	5.36	5.31	5.27	5.23
− 0	6.11	6.06	6.01	5.96	5.91	5.86	5.81	5.77	5.72	5.67
0	6.11	6.15	6.20	6.24	6.29	6.33	6.38	6.42	6.47	6.52
1	6.56	6.61	6.66	6.71	6.76	6.81	6.86	6.90	6.95	7.00
2	7.05	7.10	7.16	7.21	7.26	7.31	7.36	7.42	7.47	7.52
3	7.58	7.63	7.68	7.74	7.79	7.85	7.90	7.96	8.02	8.07
4	8.13	8.19	8.25	8.30	8.36	8.42	8.48	8.54	8.60	8.66
5	8.72	8.78	8.84	8.91	8.97	9.03	9.09	9.16	9.22	9.28
6	9.35	9.41	9.48	9.54	9.61	9.68	9.74	9.81	9.88	9.95
7	10.02	10.09	10.16	10.22	10.30	10.37	10.44	10.51	10.58	10.65
8	10.73	10.80	10.87	10.95	11.02	11.10	11.17	11.25	11.32	11.40
9	11.48	11.56	11.64	11.71	11.79	11.87	11.95	12.03	12.12	12.20
10	12.28	12.36	12.44	12.53	12.61	12.70	12.78	12.87	12.95	13.04
11	13.13	13.21	13.30	13.39	13.48	13.57	13.66	13.75	13.84	13.93
12	14.03	14.12	14.21	14.31	14.40	14.50	14.59	14.69	14.78	14.88
13	14.98	15.08	15.18	15.28	15.38	15.48	15.58	15.68	15.78	15.89
14	15.99	16.09	16.20	16.30	16.41	16.51	16.62	16.73	16.84	16.95
15	17.06	17.17	17.28	17.39	17.50	17.61	17.73	17.84	17.96	18.07
16	18.19	18.30	18.42	18.54	18.66	18.78	18.90	19.02	19.14	19.26
17	19.38	19.51	19.63	19.76	19.88	20.01	20.13	20.26	20.39	20.52
18	20.65	20.78	20.91	21.04	21.17	21.31	21.44	21.58	21.71	21.85
19	21.98	22.12	22.26	22.40	22.54	22.68	22.82	22.96	23.11	23.25
20	23.40	23.54	23.69	23.83	23.98	24.13	24.28	24.43	24.58	24.73
21	24.88	25.04	25.19	25.35	25.50	25.66	25.82	25.98	26.14	26.30
22	26.46	26.62	26.78	26.94	27.11	27.27	27.44	27.61	27.78	27.94
23	28.11	28.28	28.46	28.63	28.80	28.98	29.15	29.33	29.51	29.68
24	29.86	30.04	30.22	30.40	30.59	30.77	30.96	31.14	31.33	31.51
25	31.70	31.89	32.08	32.28	32.47	32.66	32.86	33.05	33.25	33.45
26	33.64	33.84	34.04	34.25	34.45	34.65	34.86	35.06	35.27	35.48
27	35.69	35.90	36.11	36.32	36.53	36.75	36.96	37.18	37.40	37.62
28	37.84	38.06	38.28	38.50	38.73	38.95	39.18	39.41	39.64	39.87
29	40.10	40.33	40.56	40.80	41.04	41.27	41.51	41.75	41.99	42.23
30	42.48	42.72	42.97	43.21	43.46	43.71	43.96	44.21	44.47	44.72
31	44.98	45.23	45.49	45.75	46.01	46.27	46.54	46.80	47.07	47.33
32	47.60	47.87	48.14	48.42	48.69	48.97	49.24	49.52	49.80	50.08
33	50.36	50.65	50.93	51.22	51.50	51.79	52.08	52.37	52.67	52.96
34	53.26	53.56	53.85	54.15	54.46	54.76	55.06	55.37	55.68	55.99
35	56.30	56.61	56.92	57.24	57.56	57.87	58.19	58.51	58.84	59.16
36	59.49	59.81	60.14	60.47	60.81	61.14	61.47	61.81	62.15	62.49
37	62.83	63.17	63.52	63.86	64.21	64.56	64.91	65.27	65.62	65.98
38	66.34	66.69	67.06	67.42	67.78	68.15	68.52	68.89	69.26	69.63
39	70.01	70.38	70.76	71.14	71.53	71.91	72.30	72.68	73.07	73.46
40	73.86	74.25	74.65	75.04	75.44	75.85	76.25	76.66	77.06	77.47
41	77.88	78.30	78.71	79.13	79.55	79.97	80.39	80.81	81.24	81.67
42	82.10	82.53	82.97	83.40	83.84	84.28	84.72	85.17	85.61	86.06
43	86.51	86.96	87.42	87.87	88.33	88.79	89.26	89.72	90.19	90.66
44	91.33	91.60	92.07	92.55	93.03	93.51	93.99	94.48	94.97	95.46

TABLE 18.—*Relative humidity, per cent—centigrade temperatures.*

[Pressure=990 mb.]

Air temperature (t).	Depression of wet-bulb thermometer (t—t').																													
	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
0	98	96	94	93	91	89	87	85	83	81	80	78	76	74	73	71	69	67	66	64	62	60	59	57	55	53	52	50	48	46
1	98	97	95	93	92	90	88	86	85	83	81	80	78	76	75	73	71	70	68	66	64	63	61	59	58	56	54	53	51	49
2	98	97	95	93	92	90	89	87	85	84	82	81	79	78	76	74	73	71	70	68	67	65	63	62	60	59	57	55	54	52
3	98	97	95	94	92	91	89	88	86	84	83	82	80	78	77	76	74	72	71	70	68	67	65	64	62	61	59	58	56	55
4	99	97	96	94	93	91	90	88	87	85	84	82	81	79	78	77	75	74	72	71	69	68	67	65	64	62	61	60	58	57
5	99	97	96	94	93	91	90	88	87	86	84	83	82	80	79	77	76	75	73	72	71	69	68	67	65	64	62	60	60	58
6	99	97	96	94	93	92	90	89	88	86	85	84	82	81	80	78	77	76	74	73	72	70	69	68	67	65	64	63	61	60
7	99	97	96	95	93	92	91	89	88	87	86	84	83	82	80	79	78	77	75	74	73	72	70	69	68	67	65	64	63	62
8	99	97	96	95	94	92	91	90	88	87	86	85	84	82	81	80	79	77	76	75	74	73	71	70	69	68	67	65	64	63
9	99	98	96	95	94	93	91	90	89	88	87	85	84	83	82	81	79	78	77	76	76	74	72	71	70	69	68	67	66	64
10	99	98	96	95	94	93	91	90	89	88	87	86	84	83	82	81	80	79	78	77	76	74	73	72	71	70	69	68	67	66
11	99	98	97	95	94	93	92	91	90	89	87	86	85	84	83	82	81	80	79	78	76	75	74	73	72	71	70	69	68	67
12	99	98	97	96	94	93	92	91	90	89	88	87	86	85	84	82	81	80	79	78	77	76	75	74	73	72	71	70	69	68
13	99	98	97	96	95	93	92	91	90	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75	74	73	72	71	70	69
14	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	79	79	78	77	76	75	74	73	72	71	70
15	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75	74	74	73	72	71
16	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84	83	82	82	81	80	79	78	77	76	75	74	73	72	71
17	99	98	97	96	95	94	93	92	91	90	89	89	88	87	86	85	84	83	82	81	80	79	78	78	76	75	74	73	72	72
18	99	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	83	82	81	80	79	78	77	76	76	75	74	73
19	99	98	97	97	95	95	94	93	92	91	90	89	88	87	87	86	85	84	83	82	81	80	80	79	78	77	76	75	75	74
20	99	98	97	96	96	95	94	93	92	91	90	89	89	88	87	86	85	84	83	83	82	81	80	79	78	78	77	76	75	74
21	99	98	97	97	96	95	94	93	92	91	90	90	89	88	87	86	84	85	84	83	82	81	81	80	79	78	77	77	76	75
22	99	98	97	97	96	95	94	93	92	92	91	90	89	88	87	87	86	85	84	83	83	82	81	80	80	79	78	77	76	76
23	99	98	97	97	96	95	94	93	93	92	91	90	89	89	88	87	86	85	85	83	83	82	81	81	80	79	78	78	77	76
24	99	98	98	97	96	95	94	94	93	92	91	90	90	89	88	87	87	86	85	84	83	83	82	81	80	80	79	78	77	77
25	99	98	98	97	96	95	94	94	93	92	91	91	90	89	88	88	87	86	85	84	84	83	82	82	81	80	79	79	78	77
26	99	98	98	97	96	95	95	94	93	92	91	91	90	89	88	88	87	86	86	85	84	83	83	82	81	80	80	79	78	78
27	99	99	98	97	96	95	95	94	93	92	92	91	90	89	89	88	87	87	86	85	84	84	83	82	82	81	80	79	79	78
28	99	99	98	97	96	96	95	94	93	93	92	91	90	90	89	88	88	87	86	85	85	84	83	83	82	81	81	80	79	78
29	99	99	98	97	96	96	95	94	93	93	92	91	90	90	89	88	88	87	86	86	85	84	84	83	82	82	81	80	80	79
30	99	99	98	97	96	96	95	94	94	93	92	91	91	90	89	89	88	87	87	86	85	86	84	83	83	82	81	81	80	79
31	99	99	98	97	96	96	95	94	94	93	92	92	91	90	90	89	88	87	87	86	86	85	84	84	83	82	82	81	80	80
32	99	99	98	97	96	96	95	94	94	93	92	92	91	90	90	89	88	88	87	86	86	85	84	84	83	83	82	81	81	80
33	99	99	98	97	97	96	95	94	94	93	92	92	91	90	90	89	89	88	87	87	86	85	85	84	83	83	82	82	81	80
34	99	99	98	97	97	96	95	95	94	93	93	92	91	91	90	89	89	88	87	87	86	86	85	84	84	83	82	82	81	81
35	99	99	98	97	97	96	95	95	94	94	93	92	91	91	90	90	89	88	88	87	86	86	85	85	84	83	83	82	82	81
36	99	99	98	97	97	96	95	95	94	94	93	92	92	91	90	90	89	88	88	87	87	86	85	85	84	84	83	82	82	81
37	99	99	98	97	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	87	87	86	86	85	84	84	83	82	82	82
38	99	99	98	97	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	88	87	86	86	85	84	84	84	83	82	82
39	99	99	98	98	97	96	96	95	94	94	93	93	92	91	91	90	90	89	88	88	87	87	86	86	85	84	84	83	83	82
40	99	99	98	98	97	96	96	95	94	94	93	93	92	91	91	90	90	89	89	88	87	87	86	86	85	85	84	84	83	82
41	99	99	98	98	97	96	96	95	95	94	93	93	92	92	91	91	90	89	89	88	88	87	87	86	85	85	84	84	83	83
42	99	99	98	98	97	96	96	95	95	94	93	93	92	92	91	91	90	89	89	88	88	87	87	86	86	85	84	84	83	83
43	99	99	98	98	97	96	96	95	95	94	94	93	92	92	91	91	90	90	89	88	88	87	87	86	86	85	85	84	84	83
44	99	99	98	98	97	97	96	95	95	94	94	93	93	92	91	91	90	90	89	89	88	88	87	86	86	85	85	84	84	83

Air temperature (t).	Depression of wet-bulb thermometer (t—t').																													
	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0
0	45	43	41	40	38	36	34	33	31	29	28	26	24	23	21	20	18	16	15	13	11	10	8	7	5					
1	48	46	45	43	41	40	38	36	35	33	32	30	28	27	25	24	22	21	19	17	16	14	13	11	10	8	7	5		
2	51	49	48	46	44	43	41	40	38	37	35	34	32	31	29	28	26	25	23	22	20	19	17	16	14	13	11	10	8	7
3	53	52	50	49	47	46	44	43	41	40	39	37	36	34	33	31	30	28	27	26	24	23	21	20	19	17	16	14	13	12
4	55	54	53	51	50	48	47	46	44	43	42	40	39	37	36	35	33	32	31	29	28	26	25	24	22	21	20	18	17	16
5	57	56	54	53	52	51	49	48	47	45	44	43	42	40	39	38	37	35	34	33	31	30	29	28	26	25	24	22	21	20
6	59	58	56	55	54	53	51	50	49	48	46	45	44	43	41	40	39	38	37	35	34	33	32	31	29	28	27	26	25	24
7	60	59	58	57	56	54	53	52	51	50	48	47	46	45	44	43	41	40	39	38	37	36	34	33	32	31	30	29	28	26
8	62	61	59	58	57	56	55	54	52	51	50	49	48	47	46	45	44	42	41	40	39	38	37	36	35	34	32	31	30	29
9	63	62	61	60	59	58	56	55	54	53	52	51	50	49	48	47	46	45	43	42	41	40	39	38	37	36	35	34	33	32
10	65	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	47	46	45	44	43	42	41	40	39	38	37	36	35	34
11	66	65	64	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36
12	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	40	39
13	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	51	50	49	48	47	46	45	44	43	42	42	41
14	69	68	67	66	65	64	63	62	61	60	59	58	58	57	56	55	54	53	52	51	50	50	49	48	47	46	45	44	43	42
15	70	69	68	67	66	65	64	63	62	61	61	60	59	58	57	56	55	54	54	53	52	51	50	49	48	48	47	46	45	44
16	71	70	69	68	67	66	65	64	63	63	62	61	60	59	58	58	57	56	55	54	53	52	52	51	50	49	48	47	47	46
17	71	70	70	69	68	67	66	65	64	64	63	62	61	60	60	59	58	57	56	55	55	54	53	52	51	51	50	49	48	47
18	72	71	70	70	69	68	67	66	65	65	64	63	62	61	61	60	59	58	57	57	56	55	54	53	53	52	51	50	49	49
19	73	72	71	70	70	69	68	67	66	65	65	64	63	62	62	61	60	59	58	58	57	56	55	55	54	53	52	52	51	50
20	74	73	72	71	70	70	69	68	67	66	66	65	64	63	63	62	61	60	59	59	58	57	56	56	55	54	54	53	52	51
21	74	73	73	72	71	70	70	69	68	67	66	66	65	64	64	63	62	61	61	60	59	58	58	57	56	55	55	54	53	53
22	75	74	73	73	72	71	70	70	69	68	67	66	66	65	64	64	63	62	61	61	60	59	59	58	57	56	56	55	54	54
23	75	75	74	73	72	72	71	70	70	69	68	67	66	66	65	64	64	63	62	62	61	60	60	59	58	58	57	56	55	55
24	76	75	74	74	73	72	72	71	70	69	69	68	67	67	66	65	65	64	63	62	62	61	60	60	59	58	58	57	56	56
25	76	76	75	74	74	73	72	72	71	70	69	69	68	67	67	66	65	65	64	63	63	62	61	61	60	59	59	58	57	57
26	77	76	76	75	74	74	73	72	71	71	70	69	69	68	67	67	66	65	65	64	63	63	62	62	61	60	60	59	58	58
27	77	77	76	75	75	74	73	73	72	71	71	70	69	69	68	67	67	66	65	65	64	64	63	62	62	61	60	60	59	58
28	78	77	77	76	75	75	74	73	73	72	71	71	70	69	69	68	67	67	66	65	65	64	64	63	62	62	61	61	60	59
29	78	78	77	76	76	75	74	74	73	72	72	71	71	70	69	69	68	67	67	66	66	65	64	64	63	62	62	61	61	60
30	79	78	77	77	76	75	75	74	74	73	72	72	71	70	70	69	69	68	67	67	66	66	65	64	64	63	63	62	61	61
31	79	78	78	77	77	76	75	74	74	73	73	72	72	71	70	70	69	69	68	67	67	66	66	65	64	64	63	63	62	61
32	79	79	78	78	77	76	76	75	75	74	73	73	72	72	71	70	70	69	68	68	67	67	66	66	65	64	64	63	63	62
33	80	79	78	78	77	77	76	76	75	74	74	73	73	72	71	71	70	70	69	68	68	67	67	66	66	65	65	64	63	63
34	80	79	79	78	78	77	76	76	75	75	74	74	73	72	72	71	71	70	70	69	68	68	67	67	66	66	65	65	64	68
35	80	80	79	79	78	77	77	76	76	75	75	74	73	73	72	72	71	71	70	69	69	68	68	67	67	66	66	65	65	64
36	81	80	79	79	78	78	77	77	76	75	75	74	74	73	73	72	72	71	70	70	69	69	68	68	67	66	66	65	65	64
37	81	80	80	79	79	78	78	77	76	76	75	75	74	74	73	73	72	72	71	70	70	69	69	68	68	67	67	66	66	65
38	81	81	80	80	79	78	78	77	77	76	76	75	75	74	74	73	72	72	71	71	70	70	69	69	68	68	67	67	66	66
39	82	81	80	80	79	79	78	77	77	77	76	76	75	74	74	73	73	72	72	71	71	70	70	69	69	68	68	67	67	66
40	82	81	81	80	80	79	79	78	77	77	76	76	75	75	74	74	73	73	72	72	71	71	70	70	69	69	68	68	67	67
41	82	82	81	80	80	79	79	78	78	77	77	76	76	75	75	74	74	73	73	72	72	71	71	70	70	69	69	68	68	67
42	82	82	81	81	80	80	79	79	78	78	77	77	76	75	75	74	74	73	73	72	72	71	71	70	70	69	69	68	68	67
43	82	82	81	81	80	80	79	79	78	78	77	77	76	76	75	75	74	74	73	73	72	72	71	71	70	70	69	69	68	68
44	83	82	82	81	81	80	80	79	79	78	78	77	77	76	76	75	75	74	74	73	73	72	72	71	71	70	70	69	69	68

TABLE 18.—*Relative humidity, per cent—centigrade temperatures*—Continued.

Depression of wet-bulb thermometer (*t*—*t*′).

Air temperature (*t*).	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5
2	6														
3	10	9	8	6	5										
4	14	13	12	11	9	8	7	5							
5	18	17	16	15	13	12	11	10	8	7	6	5			
6	22	21	20	19	17	16	15	14	13	11	10	9	8	6	5
7	25	24	23	22	21	20	19	18	17	15	14	13	12	11	10
8	28	27	26	25	24	23	22	21	20	19	18	17	16	16	14
9	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17
10	33	32	31	30	29	28	27	26	25	24	23	22	22	21	20
11	35	35	34	33	32	31	30	29	28	27	26	25	24	23	22
12	38	37	36	35	34	33	32	31	30	29	29	28	27	26	25
13	40	39	38	37	36	35	34	34	33	32	31	30	29	28	28
14	42	41	40	39	38	37	36	36	35	34	33	32	31	31	30
15	43	43	42	41	40	39	38	38	37	36	35	34	33	32	32
16	45	44	43	43	42	41	40	39	39	38	37	36	35	35	34
17	47	46	45	44	43	43	42	41	40	40	39	38	37	37	36
18	48	47	46	46	45	44	43	43	42	41	40	40	39	38	38
19	49	49	48	47	46	46	46	44	44	43	42	41	40	40	39
20	51	50	49	48	48	47	46	46	45	44	44	43	42	41	41
21	52	51	50	50	49	48	48	47	46	46	45	44	44	43	42
22	53	52	52	51	50	50	49	48	48	47	46	46	45	44	44
23	54	53	53	52	52	51	50	50	49	48	48	47	46	46	45
24	55	54	54	53	53	52	51	51	50	49	49	48	47	47	46
25	56	55	55	54	54	53	52	52	51	50	50	49	49	48	47
26	57	56	56	55	54	54	53	53	52	51	51	50	50	49	49
27	58	57	67	56	56	55	54	54	53	52	52	51	51	50	50
28	59	58	58	57	56	56	55	55	54	53	53	52	52	51	51
29	60	59	58	58	57	57	56	65	55	54	54	53	53	52	52
30	60	60	59	59	58	57	57	56	56	55	55	54	53	53	52
31	61	60	60	59	59	58	58	57	57	56	65	55	54	54	53
32	62	61	61	60	60	59	58	58	57	57	56	56	55	55	54
33	62	62	61	61	60	60	59	59	58	57	67	56	56	55	55
34	63	62	62	61	61	60	60	69	59	58	58	57	57	56	56
35	64	63	63	62	61	61	60	60	59	59	58	58	57	57	56
36	64	63	63	62	62	61	61	60	60	59	59	58	58	57	57
37	65	64	64	63	63	62	62	61	61	60	60	59	59	58	58
38	65	65	64	64	63	63	62	62	61	61	60	60	59	59	58
39	66	65	65	64	64	63	63	62	62	61	61	60	60	59	59
40	66	66	65	65	64	64	63	63	62	52	61	61	60	60	59
41	67	66	66	65	65	64	64	63	63	62	62	61	61	60	60
42	67	67	66	66	65	65	64	64	63	63	62	62	61	61	61
43	67	67	66	66	66	65	65	64	64	63	63	62	62	61	61
44	68	67	67	66	66	66	65	65	64	64	63	63	62	62	62

Air temperature (*t*).	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
7	9	8	7	5											
8	12	11	10	9	8	7	6	5							
9	16	16	14	13	12	11	10	9	8	7	6	5			
10	19	18	17	16	15	14	13	12	11	10	9	8	7	7	6
11	22	21	20	19	18	17	16	15	14	13	13	12	11	10	9
12	24	23	22	22	21	20	19	18	17	16	16	15	14	13	12
13	27	26	25	24	23	22	22	21	20	19	18	17	17	16	15
14	29	28	27	27	26	25	24	23	22	22	21	20	19	18	18
15	31	30	29	28	27	27	26	25	24	24	23	22	22	21	20
16	33	32	32	31	30	29	29	28	27	26	26	25	24	23	23
17	35	34	34	33	32	31	31	30	29	28	28	27	26	26	25
18	37	36	35	35	34	33	33	32	31	30	30	29	28	28	27
19	39	38	37	36	36	35	34	34	33	32	32	31	30	30	29
20	40	39	39	38	37	37	36	35	35	34	33	33	32	31	31
21	42	41	40	40	39	38	38	37	36	36	35	34	34	33	32
22	43	42	42	41	40	40	39	39	38	37	37	36	35	35	34
23	44	44	43	42	42	41	41	40	39	39	38	38	37	26	36
24	46	45	44	44	43	43	42	41	41	40	40	39	38	38	37
25	47	46	46	45	44	44	43	43	42	41	41	40	40	39	39
26	48	47	47	46	46	45	44	44	43	43	42	42	41	40	40
27	49	48	48	47	47	46	46	45	44	44	43	43	42	42	41
28	50	49	49	48	48	47	47	46	46	45	44	44	43	43	42
29	51	50	50	49	49	48	48	47	47	46	46	45	44	44	43
30	52	51	51	50	50	49	49	48	48	47	47	46	45	45	44
31	53	52	52	51	51	50	50	49	49	48	48	47	47	46	45
32	54	53	52	52	51	51	50	50	49	49	48	48	47	47	46
33	54	54	53	53	52	52	51	51	50	50	49	49	48	48	47
34	55	65	54	54	53	53	52	52	51	51	50	50	49	49	48
35	56	55	54	54	54	53	53	52	52	51	51	50	50	49	49
36	56	56	55	55	54	54	53	53	53	52	52	51	51	50	50
37	57	67	56	56	55	55	54	54	53	53	52	52	51	51	51
38	58	57	57	56	56	55	55	55	54	54	53	53	52	52	51
39	58	58	57	57	57	56	56	55	55	54	54	53	53	52	52
40	59	59	58	58	57	57	56	56	55	54	54	54	54	53	53
41	60	59	59	58	58	57	57	56	56	56	55	55	54	54	53
42	60	60	59	59	58	58	57	57	57	56	56	55	54	54	54
43	61	60	60	59	59	58	58	58	57	57	56	56	55	55	55
44	61	61	60	60	59	59	58	58	58	57	57	56	56	56	55

Depression of wet-bulb thermometer (*t*—*t*′).

Air temperature (*t*).	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5
10	5														
11	8	7	6	6	5										
12	11	10	10	9	8	7	6	5	5						
13	14	13	13	12	11	10	9	9	8	7	6	6	5		
14	17	16	15	15	14	13	12	11	11	10	9	8	8	7	6
15	20	19	18	17	16	16	15	14	13	13	12	11	11	10	9
16	22	21	20	20	19	18	17	17	16	15	15	14	13	13	12
17	24	23	23	22	21	21	20	19	18	18	17	16	16	15	14
18	26	26	25	24	23	23	22	21	21	20	19	19	18	17	17
19	28	28	27	26	26	25	24	24	23	22	22	21	20	20	19
20	30	29	29	28	28	27	26	26	25	24	24	23	22	22	21
21	32	31	31	30	29	29	28	28	27	26	26	25	24	24	23
22	34	33	32	32	31	30	30	29	29	28	28	27	26	26	25
23	35	34	34	23	33	32	32	31	30	30	29	29	28	27	27
24	37	36	35	35	34	34	33	33	32	31	31	30	30	29	29
25	38	37	37	36	36	35	35	34	33	33	32	32	31	31	30
25	39	39	38	38	37	37	36	35	35	34	34	33	33	32	32
27	41	40	39	39	38	38	37	37	36	36	35	35	34	34	33
28	42	41	41	40	40	39	39	38	38	37	36	36	35	35	34
29	43	42	42	41	41	40	40	39	39	38	38	37	37	36	36
30	44	43	43	42	42	41	41	40	40	39	39	38	38	37	37
31	45	44	44	43	43	42	42	41	41	40	40	40	39	39	38
32	46	45	45	44	44	43	43	42	42	41	41	41	40	40	39
33	47	46	46	46	45	44	44	43	43	42	42	42	41	41	40
34	48	47	47	46	46	45	45	44	44	43	43	43	42	42	41
35	49	48	48	47	47	46	46	45	45	44	44	44	43	43	42
36	49	49	48	48	48	47	47	46	46	45	45	44	44	44	43
37	50	50	49	49	48	48	47	47	47	46	46	45	45	44	44
38	51	50	50	50	49	49	48	48	47	47	46	46	16	45	45
39	52	51	51	50	50	49	49	48	48	48	47	47	46	46	46
40	52	52	51	51	51	50	50	49	49	48	48	48	47	47	46
41	53	52	52	52	51	51	50	60	50	49	49	48	48	47	47
42	53	53	53	52	52	51	51	51	50	50	49	49	48	48	48
43	54	54	53	53	52	52	52	51	51	50	60	50	49	49	48
44	55	54	54	53	53	53	52	52	51	61	61	60	60	49	49

Air temperature (*t*).	10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	12.0
14	6	5													
15	8	8	7	6	6	5									
16	11	10	10	9	8	8	7	6	6	5					
17	14	13	12	12	11	10	10	9	8	8	7	6	6	5	
18	16	15	15	14	14	13	12	12	11	10	10	9	8	8	7
19	18	18	17	17	16	15	15	14	13	13	12	12	11	10	10
20	21	20	19	19	18	18	17	16	16	15	15	14	13	13	12
21	23	22	22	21	20	20	19	19	18	17	17	16	16	15	14
22	25	24	23	23	22	22	21	20	20	19	19	18	18	17	17
23	26	26	25	25	24	24	23	22	22	21	21	20	20	19	19
24	28	27	27	26	26	25	25	24	24	23	23	22	21	21	20
25	30	29	29	28	28	27	26	26	25	25	24	24	23	23	22
25	31	31	30	30	29	28	28	27	27	26	26	25	25	24	24
27	33	32	32	31	31	30	30	29	29	28	28	27	27	26	26
28	34	33	33	32	32	31	31	30	30	29	29	28	28	27	27
29	35	35	34	34	33	33	32	32	31	31	30	30	29	29	28
30	36	36	35	35	35	34	34	33	33	32	32	31	31	30	30
31	38	37	37	36	36	35	35	34	34	33	33	32	32	32	31
32	39	38	38	37	37	36	36	36	35	35	34	34	33	33	32
33	40	39	39	38	38	37	37	36	36	36	35	35	34	34	33
34	41	40	40	39	39	39	38	38	37	37	36	36	35	35	35
35	42	41	41	40	40	40	39	39	38	38	37	37	37	36	36
36	43	42	42	41	41	40	40	40	39	39	38	38	38	37	37
37	44	43	43	42	42	41	41	41	40	40	39	39	38	38	38
38	44	44	44	43	43	42	42	41	41	41	40	40	39	39	39
39	45	45	44	44	43	43	43	42	42	42	41	41	40	40	39
40	46	46	45	45	44	44	44	43	43	42	42	42	41	40	40
41	47	46	46	45	45	45	44	44	43	43	43	42	42	41	41
42	47	47	46	46	46	45	45	45	44	44	43	43	43	42	42
43	48	48	47	47	46	46	46	45	45	44	44	44	43	43	43
44	49	48	48	47	47	47	46	46	46	45	45	44	44	44	43

TABLE 18.—*Relative humidity, per cent—centigrade temperatures*—Continued.

Air temperature (*t*).	Depression of wet-bulb thermometer (*t*—*t*′).																												
	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0
18	7	6	5	5																										
19	9	9	8	7	7	6	6	5																						
20	12	11	10	10	9	9	8	7	7	6	6	5	5																	
21	14	13	13	12	12	11	10	10	9	9	8	8	7	7	6	5	5													
22	16	15	15	14	14	13	13	12	12	11	10	10	9	9	8	8	7	7	6	6	5	5								
23	18	17	17	16	16	15	15	14	14	13	13	12	12	11	11	10	10	9	9	8	8	7	7	6	6	5	5			
24	20	19	19	18	18	17	17	16	16	15	16	14	14	13	13	12	12	11	11	10	10	9	9	8	8	7	7	6	6	5
25	22	21	21	20	20	19	19	18	18	17	17	16	16	15	15	14	14	13	13	12	12	11	11	10	10	9	9	9	8	8
26	23	23	22	22	21	21	20	20	19	19	19	18	18	17	17	16	16	15	15	14	14	13	13	12	12	11	11	11	10	10
27	25	25	24	24	23	23	22	22	21	21	20	20	19	19	18	18	17	17	17	16	16	15	15	14	14	13	13	12	12	12
28	27	26	26	25	25	24	24	23	23	22	22	21	21	20	20	20	19	19	18	18	17	17	16	16	16	15	15	14	14	13
29	28	28	27	27	26	26	25	25	24	24	23	23	22	22	22	21	21	20	20	19	19	19	18	18	17	17	16	16	16	15
30	29	29	28	28	28	27	27	26	26	25	25	24	24	24	23	23	22	22	21	21	21	20	20	19	19	18	18	18	17	17
31	31	30	30	29	29	28	28	28	27	27	26	26	25	25	25	24	24	23	23	22	22	22	21	21	20	20	20	19	19	18
32	32	31	31	31	30	30	29	29	28	28	28	27	27	26	26	25	25	25	24	24	23	23	23	22	22	21	21	21	20	20
33	33	32	32	32	31	31	30	30	30	29	29	28	28	28	27	27	26	26	26	25	25	24	24	24	23	23	22	22	22	21
34	34	34	33	33	32	32	32	31	31	30	30	30	29	29	28	28	28	27	27	26	26	26	25	25	24	24	24	23	23	23
35	35	35	34	34	34	33	33	32	32	32	31	31	30	30	30	29	29	28	28	28	27	27	26	26	26	25	25	25	24	24
36	36	36	35	35	35	34	34	33	33	33	32	32	31	31	31	30	30	29	29	29	28	28	28	27	27	26	26	26	25	25
37	37	37	36	36	36	35	35	34	34	34	33	33	33	32	32	31	31	31	30	30	30	29	29	28	28	28	27	27	27	26
38	38	38	37	37	37	36	36	35	35	35	34	34	33	33	33	32	32	32	31	31	31	30	30	29	29	29	28	28	28	27
39	39	39	38	38	38	37	37	36	36	36	35	35	34	34	34	33	33	33	32	32	32	31	31	30	30	30	29	29	29	28
40	40	40	39	39	38	38	38	37	37	36	36	36	35	35	35	34	34	34	33	33	32	32	32	31	31	31	30	30	30	29
41	41	40	40	40	39	39	39	38	38	37	37	37	36	36	36	35	35	35	34	34	33	33	33	32	32	32	31	31	31	30
42	42	41	41	40	40	40	39	39	39	38	38	37	37	37	36	36	36	35	35	35	34	34	34	33	33	33	32	32	32	31
43	42	42	42	41	41	40	40	40	39	39	39	38	38	38	37	37	37	36	36	35	35	35	34	34	34	33	33	33	32	32
44	43	43	42	42	42	41	41	40	40	40	39	39	39	38	38	38	37	37	37	36	36	36	35	35	35	34	34	34	33	33

Air temperature (*t*).	Depression of wet-bulb thermometer (*t*—*t*′).																												
	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5	16.6	16.7	16.8	16.9	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0
24	5																													
25	7	7	6	6	5	5																								
26	9	9	8	8	7	7	7	6	6	6	5																			
27	11	11	10	10	9	9	9	8	8	7	7	6	6	6	5	5														
28	13	13	12	12	11	11	10	10	10	9	9	8	8	8	7	7	6	6	6	5	5									
29	15	14	14	13	13	13	12	12	11	11	11	10	10	9	9	9	8	8	7	7	7	6	6	5	5	5				
30	16	16	16	15	15	14	14	14	13	13	12	12	12	11	11	10	10	10	9	9	9	8	8	7	7	7	6	6	5	5
31	18	18	17	17	16	16	16	15	15	14	14	14	13	13	12	12	12	11	11	11	10	10	9	9	9	8	8	8	7	7
32	19	19	19	18	18	17	17	17	16	16	15	15	15	14	14	14	13	13	13	12	12	11	11	11	10	10	10	9	9	9
33	21	20	20	20	19	19	19	18	18	17	17	17	16	16	16	15	15	15	14	14	13	13	13	12	12	12	11	11	11	10
34	22	22	21	21	21	20	20	20	19	19	18	18	18	17	17	17	16	16	16	15	15	14	14	14	13	13	13	12	12	12
35	23	23	23	22	22	22	21	21	21	20	20	19	19	19	18	18	18	17	17	17	16	16	16	15	15	15	14	14	14	13
36	25	24	24	23	23	23	22	22	22	21	21	21	20	20	20	19	19	19	18	18	18	17	17	17	16	16	16	15	15	15
37	26	25	25	25	24	24	24	23	23	23	22	22	22	21	21	21	20	20	20	19	19	19	18	18	18	17	17	17	16	16
38	27	27	26	26	26	25	25	24	24	24	23	23	23	22	22	22	21	21	21	20	20	20	19	19	19	18	18	18	18	17
39	28	28	27	27	27	26	26	26	25	25	25	24	24	24	23	23	23	22	22	22	21	21	21	20	20	20	19	19	19	18
40	29	29	28	28	28	27	27	27	26	26	26	25	25	25	24	24	24	23	23	23	22	22	22	21	21	21	20	20	20	20
41	30	30	29	29	29	28	28	28	27	27	27	26	26	26	25	25	25	24	24	24	23	23	23	23	22	22	22	21	21	21
42	31	31	30	30	30	29	29	29	28	28	28	27	27	27	26	26	26	25	25	25	24	24	24	24	23	23	23	22	22	22
43	32	31	31	31	30	30	30	29	29	29	28	28	28	28	27	27	27	26	26	26	25	25	25	24	24	24	24	23	23	23
44	33	32	32	32	31	31	31	30	30	30	29	29	29	28	28	28	28	27	27	27	26	26	26	25	25	25	24	24	24	24

Air temperature (*t*).	Depression of wet bulb thermometer (*t*—*t*′).																												
	18.1	18.2	18.3	18.4	18.5	18.6	18.7	18.8	18.9	19.0	19.1	19.2	19.3	19.4	19.5	19.6	19.7	19.8	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8	20.9	21.0
30	5																													
31	7	6	6	5	5	5																								
32	8	8	8	7	7	7	6	6	6	5	5	5																		
33	10	10	9	9	9	8	8	7	7	7	6	6	6	5	5	5														
34	11	11	11	10	10	10	9	9	9	8	8	8	7	7	7	6	6	6	6	5	5	5								
35	13	13	12	12	12	11	11	11	10	10	10	9	9	9	8	8	8	7	7	7	6	6	6	6	5	5	5			
36	14	14	14	13	13	13	12	12	12	11	11	11	10	10	10	10	9	9	9	8	8	8	7	7	7	6	6	6	6	5
37	16	15	15	15	14	14	14	13	13	13	12	12	12	12	11	11	11	10	10	10	9	9	9	9	8	8	8	7	7	7
38	17	17	16	16	16	15	15	15	14	14	14	14	13	13	13	12	12	12	11	11	11	11	10	10	10	9	9	9	9	8
39	18	18	17	17	17	17	16	16	16	15	15	15	14	14	14	14	13	13	13	12	12	12	12	11	11	11	10	10	10	10
40	19	19	19	18	18	18	17	17	17	16	16	16	16	15	15	15	14	14	14	14	13	13	13	12	12	12	12	11	11	11
41	20	20	20	19	19	19	18	18	18	17	17	17	17	16	16	16	16	15	15	15	15	14	14	14	13	13	13	13	12	12
42	21	21	21	21	20	20	20	19	19	19	19	18	18	18	17	17	17	17	16	16	16	15	15	15	15	14	14	14	14	13
43	22	22	22	22	21	21	21	20	20	20	20	19	19	19	18	18	18	18	17	17	17	16	16	16	16	15	15	15	15	14
44	23	23	23	22	22	22	22	21	21	21	21	20	20	20	19	19	19	19	18	18	18	18	17	17	17	17	16	16	16	16

TABLE 18.—*Relative humidity, per cent—centigrade temperatures*—Continued.

Air temperature (t).	Depression of wet-bulb thermometer ($t-t'$).																												
	21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8	21.9	22.0	22.1	22.2	22.3	22.4	22.5	22.6	22.7	22.8	22.9	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7	23.8	23.9	24.0
36	5	5																												
37	7	6	6	6	5	5	5	5																						
38	8	8	8	7	7	7	6	6	6	5	5	5	5																	
39	9	9	9	8	8	8	8	7	7	7	7	6	6	6	6	5	5	5												
40	11	10	10	10	10	9	9	9	8	8	8	8	7	7	7	7	6	6	6	6	5	5	5	5						
41	12	12	11	11	11	10	10	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6	6	6	6	5	5	5	5	
42	13	13	13	12	12	12	11	11	11	11	10	10	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6	6	6	6
43	14	14	14	13	13	13	13	12	12	12	11	11	11	11	11	10	10	10	10	9	9	9	9	8	8	8	8	7	7	7
44	15	15	15	15	14	14	14	13	13	13	13	12	12	12	12	11	11	11	11	10	10	10	10	10	9	9	9	9	8	8

Air temperature (t).	Depression of wet-bulb thermometer ($t-t'$).															
	24.1	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.9	25.0	25.1	25.2	25.3	25.4	25.5	25.6
42	5	5	5	5	5											
43	7	7	6	6	6	6	5	5	5	5						
44	8	8	7	7	7	7	7	6	6	6	6	5	5	5	5	5

Air temperature (t).	Depression of wet-bulb thermometer ($t-t'$).																												
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
−39	56	11																												
−38	60	21																												
−37	64	28																												
−36	68	36																												
−35	71	42	13																											
−34	74	48	22																											
−33	77	53	30	6																										
−32	79	57	36	15																										
−31	81	62	42	23																										
−30	83	65	48	30	13																									
−29	84	68	53	37	21	5																								
−28	86	71	57	43	28	14																								
−27	87	74	61	48	35	22	9																							
−26	88	76	64	52	40	29	17	5																						
−25	89	78	67	57	46	35	24	13																						
−24	90	80	70	60	50	40	31	21	11																					
−23	91	82	73	64	55	46	37	28	18	9																				
−22	92	83	75	67	58	50	42	34	25	17	9																			
−21	92	85	77	69	62	54	47	39	31	24	16	9																		
−20	93	86	79	72	65	58	51	44	37	30	23	16	9																	
−19	94	87	81	74	68	61	55	48	42	35	29	23	16	10																
−18	94	88	82	76	70	64	58	52	46	40	34	29	23	17	11	5														
−17	94	89	83	78	72	67	61	56	50	45	40	34	29	23	18	12	7													
−16	95	90	85	80	75	69	64	59	54	49	44	39	34	29	24	19	14	9												
−15	95	91	86	81	76	72	67	62	58	53	48	44	39	34	30	25	21	16	11	7										
−14	96	91	87	82	78	74	69	65	61	56	52	48	43	39	35	30	26	22	18	13	9	5								
−13	96	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	20	16	12	8							
−12	96	92	89	85	81	77	73	70	66	62	58	55	51	47	44	40	36	32	29	25	21	18	14	11	7					
−11	96	93	89	86	82	79	75	72	68	65	61	58	54	51	47	44	40	37	34	30	27	23	20	17	13	10	6			
−10	97	93	90	87	84	80	77	74	70	67	64	61	57	54	51	48	44	41	38	35	32	28	25	22	19	16	13	9	6	
−9	97	94	91	88	84	81	78	75	72	69	66	63	60	57	54	51	48	45	42	39	36	33	30	27	24	21	18	15	12	9
−8	97	94	91	88	85	83	80	77	74	71	68	65	62	60	57	54	51	48	45	43	40	37	34	32	29	26	23	20	18	15
−7	97	95	92	89	86	84	81	78	75	73	70	67	65	62	59	57	54	52	49	46	44	41	38	36	33	31	28	25	22	20
−6	97	95	92	90	87	85	82	79	77	74	72	69	67	64	62	59	57	54	52	49	47	45	42	40	37	35	32	30	27	25
−5	98	95	93	90	88	86	83	81	78	76	74	71	69	66	64	62	59	57	55	52	50	48	45	43	41	39	36	34	32	29
−4	98	95	93	91	89	86	84	82	79	77	75	73	71	68	66	64	62	59	57	55	53	51	49	46	44	42	40	38	36	33
−3	98	96	93	91	89	87	85	82	80	78	76	74	72	70	68	66	64	62	59	57	55	53	51	49	47	45	43	41	39	37
−2	98	96	94	92	90	88	86	84	81	79	77	75	73	71	70	68	66	64	62	60	58	56	54	52	50	48	46	44	42	40
−1	98	96	94	92	90	88	86	84	83	81	79	77	75	73	71	69	68	66	64	62	60	58	56	54	53	51	49	47	45	43
0	98	96	94	93	91	89	87	85	83	81	80	78	76	74	73	71	69	67	66	64	62	60	59	57	55	53	52	50	48	46

Air temperature (t).	Depression of wet-bulb thermometer ($t-t'$).																								
	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5
−9	6																								
−8	12	10	7																						
−7	18	15	13	10	8	5																			
−6	23	20	18	15	13	11	8	6																	
−5	27	25	23	20	18	16	14	11	9	7	5														
−4	31	29	27	25	23	21	19	17	14	12	10	8	6												
−3	35	33	31	29	27	25	23	21	19	17	15	13	11	10	8	6									
−2	39	37	35	33	31	29	27	25	23	22	20	18	16	14	12	11	9	7	5						
−1	42	40	38	36	34	33	31	29	27	26	24	22	20	19	17	15	14	12	10	8	7	5			
0	45	43	41	40	38	36	34	33	31	29	28	26	24	23	21	20	18	16	15	13	11	10	8	7	5

PART II. THE USE OF PILOT BALLOONS.

1. SELECTION OF STATIONS AND OBSERVATION POINTS.

Observations with pilot balloons are made for the purpose of determining wind direction and velocity at various altitudes; also the height, direction, and velocity of clouds whenever the balloons enter their bases. The apparatus and methods used are described in detail in the following sections. Briefly, the observations are made by following with a theodolite the flight of small rubber balloons filled with hydrogen. The angles of azimuth and elevation are observed and recorded, and these data, together with the balloon's altitude at successive intervals of time, make possible the construction of a horizontal projection of the path followed and the determination from this projection of wind direction and velocity at various levels.

Generally speaking, the selection of a suitable site for this work is simpler than is that for observations by means of kites, and it is therefore practicable to make pilot-balloon observations at all kite stations, a description of the principal requisites of which has already been given. In addition, they can be and are made at many other places not suitable for kite work, even in populous cities, provided these are comparatively free from factory smoke, etc.

Pilot-balloon stations are of two kinds, viz, "single-theodolite" and "double-theodolite" stations. Similarly, methods of observation are known as "single-theodolite" and "double-theodolite" methods.

By the first method the theodolite is set over a fixed point and oriented with zero of the azimuth circle on either a north or a south point. The balloon is assumed to rise at a constant rate of speed. Computation involving the ascensional rate, elevation angle, and azimuth angle determines the position of the balloon. By the double-theodolite method, two theodolites are homologously oriented (that is, with zeros of the azimuth circles in the same direction), one at either end of a definite base line. Computation involving the length and bearing of the base line and the observed azimuth and elevation angles determines the horizontal position of the balloon and its height above the surface.

Since the two methods have so much in common, and since the majority of the stations now in operation are, and probably most of those of the future will be of the single-theodolite type, these instructions will treat chiefly of the single-theodolite method. However, departures from this method applicable to the double-theodolite method will be fully considered herein.

The selection of an observation point for single-theodolite work will be determined by the following:

(*a*) Geographical location.
(*b*) Low horizon.
(*c*) Angular altitude of obstructions.
(*d*) Convenience to office.

In addition to the above, double-theodolite work will also depend upon—

(*e*) Base line, length, and bearing.
(*f*) Unobstructed view along base line.
(*g*) Common level of primary and secondary points.

The shape of the earth's surface and the obstructions on it influence the surface winds and the winds aloft in the lower levels. When the surface is abnormal or the obstructions are pronounced, the local influences will be met with through 1,000 or 1,500 meters in elevation. Therefore, if these modifying influences are so marked as to cause divergence from the normal wind conditions, the data obtained will be abnormal and local rather than normal and of the general wind circulation near the surface. And, since we are more interested in the conditions of the general circulation than of the local influences, a choice of station must be made which will give as nearly as possible wind data little affected by local influences.

An ideal observation point would be in the open, level country or on the crest of a slight rise. The ground should be firm and the position well removed from buildings and tall trees that might interfere with the line of sight upon the balloon. The maximum angular altitude of obstructions such as buildings and trees should never exceed 6 degrees above the sensible horizon. Smokestacks and chimneys in close proximity to the station give much annoyance and should be avoided, if possible, since even slight amounts of smoke therefrom are sufficient to obscure the balloons.

The observation point should be as convenient to the administration office as satisfactory location will permit. In single-theodolite work this may well be on the roof of the office building or on one near by. In double-theodolite work either primary or secondary point, and sometimes both, will necessarily be a little distance from the administration office.

The observation point for single-theodolite work may be any convenient point from which, as far as possible, an unobstructed view may be obtained. Since most of the administration offices are located in or near cities or large towns, satisfactory ground conditions with convenient location will seldom be found. The next in order will be a position on a flat-roofed, well-exposed building. In the selection of such a site due consideration must be given to superstructures such as towers, penthouses, cupolas, etc. Where it becomes impracticable to observe from the top of the superstructure itself, a position to one side of the structure, and sometimes one also on the opposite side, will answer. Many instances will arise in which the range of vision is affected only by the central structure. When this is not too high, the difficulty may be overcome by erecting upon the main roof a platform from which to observe, but, in general, two points of observation, one on either side, are preferred to one on top, inasmuch as by the latter method stability and rigidity are likely to be diminished. In selecting the observation points on a roof having a central structure it is well to consider the prevailing wind direction for the station. The observation point should be selected on the leeward side and as far removed from the central structure as extent of roof will permit.

The geographical location of a double-theodolite station is not materially different from that of a single-theodolite station. Low horizon and angular altitude of obstructions have a similar application in either case. A double-theodolite station is provided with two theodolites, one at either end of a suitable base line. The station at which the balloons are prepared and released may be known as the "primary station," "home station," or "station A." The second may be known as the "secondary station," "field station," or "station B, C, etc." The system of base lines should be carefully laid out and should radiate from the primary station.

The major base line should be about 2,000 meters or more in length and nearly at right angles to the direction of prevailing wind for the station. Minor base lines should be laid out as nearly as possible in a direction that will afford the best possible results when the surface wind direction is other than the prevailing direction. Two base lines are sometimes sufficient, though three or more will afford a wider choice in selecting the base line at the time of observation to give the best results for the current wind conditions, for in double-theodolite work a base line as nearly as possible at right angles to the wind direction aloft is invariably used. Computation is simpler and the results more accurate. A base line nearly parallel to the movement aloft is to be avoided.

The view along the base line from either station must be entirely free from obstruction. Each station must be in plain sight of the other in order to facilitate signaling the release of balloon at the primary station and the disappearance of the balloon at either station.

The angular elevation of obstructions at the secondary station, in the direction of the primary station, along either side of the base line must be low enough to prevent interference of line of sight upon the balloon as it moves away from the primary station in strong winds. Under ordinary conditions there will be little difficulty, but when strong surface winds prevail, especially if blowing across the base line, the change in azimuth angle will greatly exceed the change of elevation angle at the secondary station. Therefore the elevation angle at the secondary station for the first few minutes will be low.

Both stations should have about the same elevation; otherwise, computations from the two stations will show a difference in elevation of balloon equal to the difference in elevation of the two stations. Therefore, an altitude correction equivalent to the difference in level of the two stations must be applied to the elevation of the balloon as computed from the data at the secondary station. This correction will be added when the secondary station is higher than the primary station and deducted when it is lower.

The observation points, whether for single- or double-theodolite work, must be marked permanently. If the point selected is on the bare earth, an iron pipe about 3 feet long may be driven into the ground until quite rigid. A wooden peg is then set in the upper end of this pipe and a small nail or tack in the end of the peg marks the exact point of observation. If the position is on a graveled roof, the point may be marked by setting a small bolt or screw in cement over the point desired. Whenever it becomes necessary to use a platform for observation, a nail may be driven into the planking. Any method whereby the point is permanently marked is acceptable.

Whenever it is necessary to do observational work from a platform, the latter will be so constructed that no vibration will be transmitted from it to the theodolite. This is accomplished by building a second platform or support for the theodolite, in such a way that there is a space and no immediate connection between the two. Figure 34 shows a section of such a platform and theodolite stand. Three posts in the form of an equilateral triangle, about 36 inches from center to center, are substantially arranged and rigidly braced. When secured about the observation point, caps for the theodolite foot blocks are placed over the posts in a common horizontal plane. The observation platform is then constructed with the upper surface of flooring flush with the top of the theodolite foot block but not in any way connected with the theodolite stand. A space of at least half an inch should be left between the two. The observation point will be the common center of this equilateral triangular inclosure. As a common center, and along the major axis of the theodolite foot blocks, lay off equal distances from the observation point, and start holes with brace and bit half an inch in diameter to receive the tips of the theodolite legs. Let the holes on each foot block be about 1 inch apart. The size and shape of the platform may be arranged to suit the needs of the station force, but the general scheme above outlined should be followed and the construction made as rigid as possible. Any plan wherein the observation platform is well insulated from the theodolite stand and rigidly constructed will answer. Note that in figure 38 observation platform (*o*) and theodolite stand (*t*) are entirely separated. The only vibration transmitted to the theodolite is the vibration of the roof of the building.

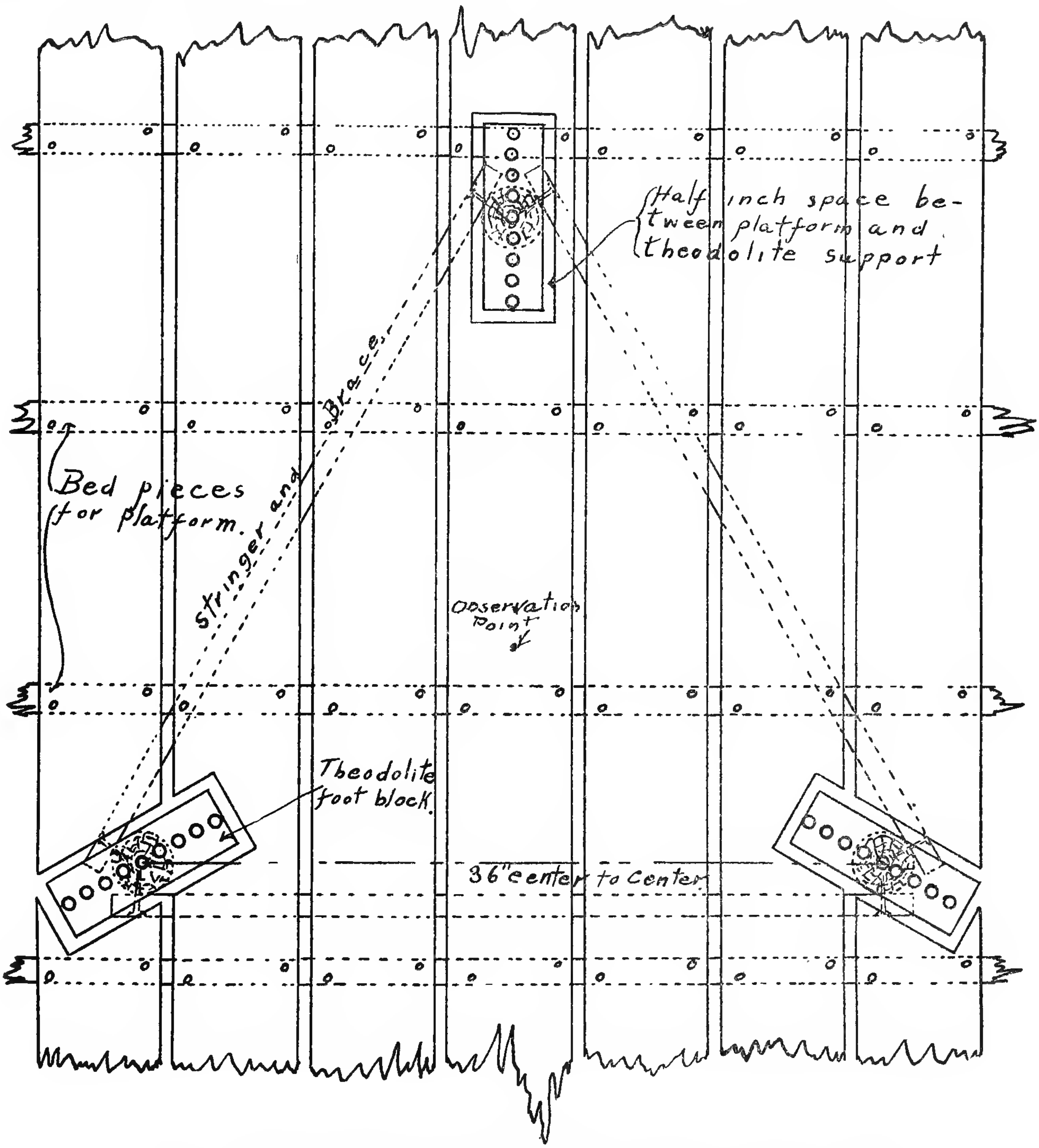


Fig. 34.—Section of observation platform and theodolite stand, showing the insulation of the one from the other.

2. THEODOLITE.

The theodolite, figure 35, is a specially designed and constructed instrument similar in many respects to the transit yet possessing distinctive features which make it far superior for balloon work. A small telescope is mounted over a horizontal circle in such manner that it turns on a horizontal axis through the center of the horizontal circle and revolves about the vertical axis passing through the horizontal axis.

The telescope is bent through an angle of 90 degrees. The eyepiece is produced through the angle of the bend to act as the horizontal axis of the telescope, while the object end turns freely in the vertical plane about this axis. In a cubical chamber about the right-angle bend of the telescope a 45-degree triangular prism, acting as a mirror, is rigidly fixed in such a position that the shorter sides of the prism are perpendicular to the central line along the two tubes. The function of this prism is to turn the line of sight with the bend of the telescope and give a clear, well-defined image. The eyepiece is further provided with cross hairs stretched over a reticle for centering the objective and a rack and pinion for focusing the telescope. The objective end terminates in a cylindrical sleeve, which acts as a sunshade to protect the object lens. The mass of both eyepiece and object end of telescope are compensated by counterweights, thus providing a free, even movement of little resistance.

The telescope is supported over the center of the horizontal plate by a yoke standard. A vertical circle for elevation and a horizontal circle for direction are provided for determining the relative movement of the telescope. Both vertical and horizontal circles are graduated in whole degrees. More accurate readings may be made by using verniers. Essentially, the vernier,

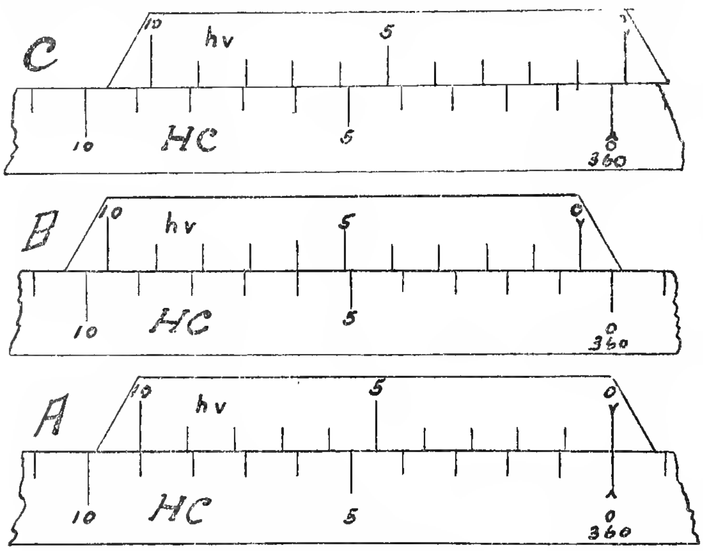


FIG. 36.—Theodolite vernier.

figure 36, *hv*, consists of a small graduated scale the unit divisions of which are just a certain amount smaller than the divisions of the scale upon which it is applied. This is accomplished on the circles of the theodolite by taking a space equal to 9 degrees, laying it off on the vernier, and dividing it into 10 equal parts. In figure 36, drawing *A*, let *HC* be the horizontal circle divided into degrees, and *hv* the horizontal vernier. Note that while the zero of both *HC* and *hv* are coincident, the tenth division of *hv* is coincident with only the ninth division on *HC*. Thus, each division of *hv* is one-tenth degree less than each division on *HC*. When two such scales are placed together, some particular line of the one will always be coincident or nearly coincident, with one of the divisions on the other. The position of the coinciding divisions, or the nearly coinciding divisions, determines the vernier reading. For example, when the third, fourth, or sixth division of *hv* is coincident with some division on *HC*, the fractional parts of degree will be 0.3, 0.4, or 0.6, respectively. On drawing *B* of figure 36, the vernier reading is 0.6 of a degree, and on drawing *C*, it will be noticed that no one division of *hv* is coincident with any other of the scale *HC* but that the seventh and eighth of *hv* are both between two of the divisions of *HC*, which shows that the vernier reading is more than 0.7 and less than 0.8 of a degree. The second place of the vernier reading must be gained by estimating the fractional part of one of the vernier divisions, which is represented by the space between 6 on *HC*, and 7 on *hv*. In drawing *C* of figure 36, this space is about half of one-tenth, or 0.05 of 1 degree. Thus we see the vernier reading in this particular case is 0.75 of a degree, which, added to the index reading of the scale, determines the degrees and hundredths. The practical application of these verniers is shown by the sectional view of the theodolite in figure 37. The accompanying table gives the reading of each vernier in figures 36 and 37.

	VV	*HV*	*hv*
Figure 36 A			0.00
Figure 36 B			.60
Figure 36 C			359.75
Figure 37	85.71	00.00	315.00

The levels are arranged on the horizontal plate, one parallel to the horizontal axis called the plate level, *PL*, figure 35, while the other, perpendicular to the first, is known as the standard level, *SL*, figure 35.

The instrument thus far assembled revolves about a vertical axis, whose bearing is a sleeve and spindle, at the center of a graduated horizontal circle known as the base plate. An extension of the vertical axis, or the sleeve and spindle, passes through the shifting center and terminates in a spring and knurled nut to form the shifting center tension. The base plate is capable of revolution about this center but is ordinarily held in a rigid position by plate clamp screw, *P*, figure 35. The shifting center, *S*, assembled with and encircled by a heavy ring or handle, *H*, is supported above the tripod head, *T*, by means of three leveling screws, *LS*. Each leveling screw is provided with a tension or clamp screw, *L*. Pendent from the vertical axis and center of instrument *VA* is a small chain and hook, *p*, for the attachment of the plumb bob and line.

Assembling the theodolite.—Assuming that the crates have been removed and that no damage has been done either in shipping or unpacking, the tripod will be opened up and planted firmly upon the floor with legs well spread and securely set to prevent slipping. Loosen the milled tension nut of the shifting center, figure 35, and run well down to the knurled head of spindle. Then remove the round wooden cap. Loosen the shifting-center nut or clamp ring, *CR*, figure 35, and adjust the shifting center *S*, so that the seats of the leveling screws, *LS*, are symmetrically arranged over their respective plates of the tripod head *T*. After tightening the clamp ring to retain the shifting center in that position, the tripod is in readiness for the instrument itself.

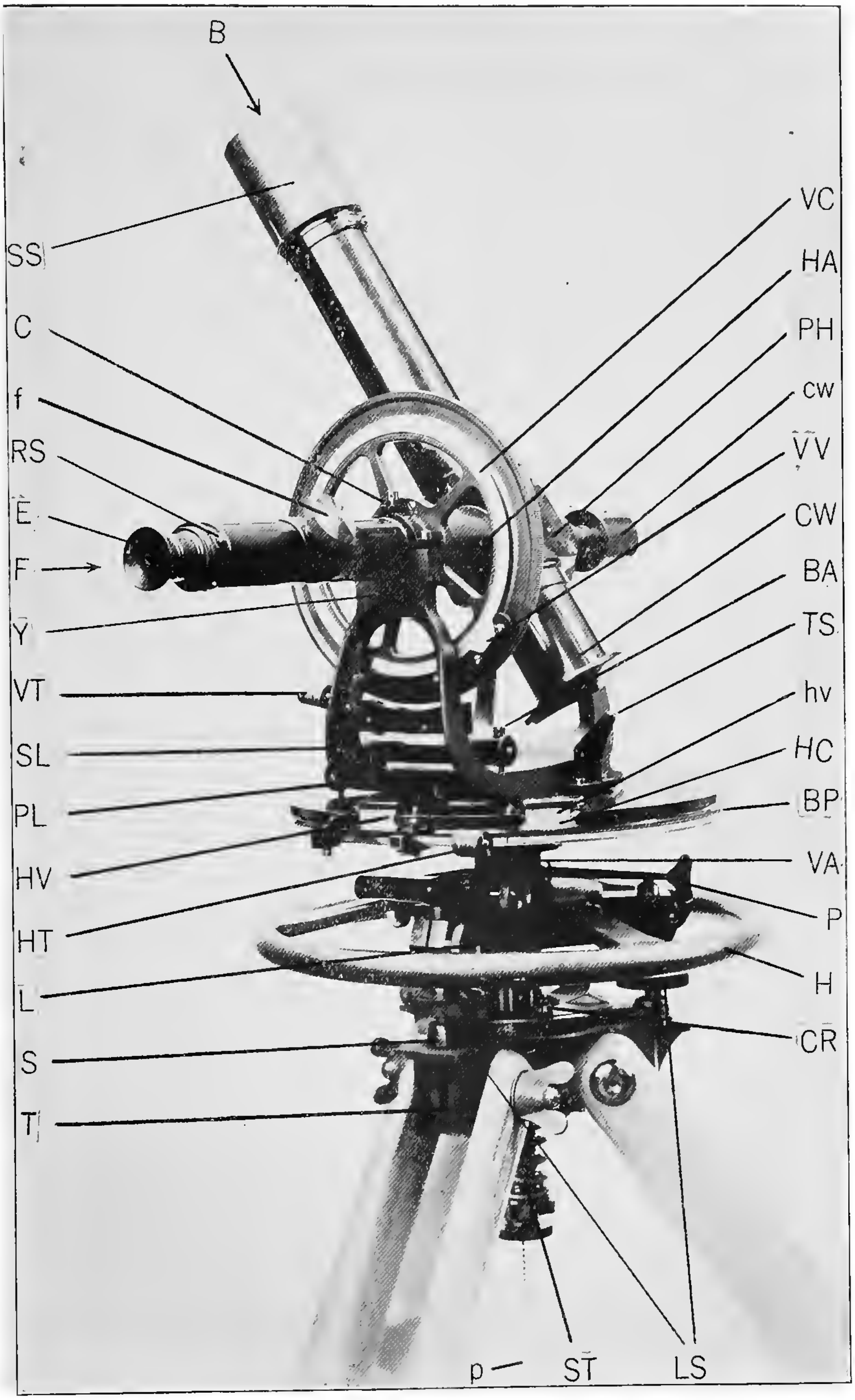


Fig. 35.—Theodolite used in kite and balloon work (*B*, back of instrument; *BA*, bubble adjustment screw; *BP*, base plate; *C*, cap or cover block; *CR*, clamp ring; *CW*, back counterweight; *cw*, front counterweight; *E*, eyepiece; *f*, focusing screw; *F*, front of instrument; *H*, handle or ring; *HA*, horizontal axis; *HC*, horizontal circle; *hv*, horizontal limb and 45° vernier; *HV*, horizontal limb and right vernier; *HT*, horizontal tangent screw; *L*, leveling clamp screw; *LS*, leveling screws; *p*, plumb bob hook; *P*, plate clamp screw; *PL*, plate level or bubble; *PH*, prism housing; *RS*, reticle screws; *S*, shifting center; *SL*, standard level or bubble; *SS*, sun shade; *ST*, shifting center tension; *T*, tripod head; *TS*, telescope stop; *VA*, vertical axis; *VC*, vertical circle; *VV*, vertical limb and vernier; *VT*, vertical tangent screw; *Y*, yoke standard).

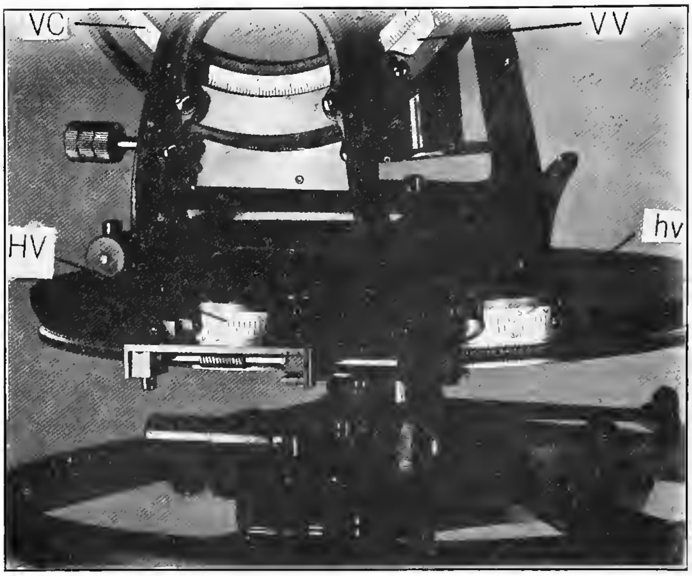


FIG. 37.—Section of theodolite showing arrangement of verniers with horizontal and vertical circles (*HV*, horizontal limb and right vernier; *hv*, horizontal limb and 45° vernier; *VC*, vertical circle. *VV*, vertical limb and vernier).

In most cases it will be found that the telescope has been removed from its bearings and packed in a separate rack in the case above the carriage. When so packed, the procedure will be as follows: The door of the theodolite case must be wide open to allow the removal of the lower shelf supporting the assembled yoke standard, base plate, and shifting center. These parts, so assembled, when removed from the case are placed upon a table or bench. With a firm grip on one edge of the shelf or rack tilt the whole upon one edge to allow access to the underside where a brass thumb nut retains the assembly to the rack. Unscrew this thumb nut but *do not* remove instrument from rack. When returned to the initial position as it was placed on the table or bench, remove the string tied about the horizontal tangent screw and right telescope stop, *HT* and *TS*, figure 35, and disengage tangent screw from horizontal circle, *HC*, by pulling the head of the screw away from the circle. Turn the yoke standard and base plate upon its axis, *VA*, until both elevation and azimuth tangent screws, *VT* and *HT*, are on the extreme right; then throw in the azimuth tangent screw, *HT*, to retain the base plate in that position. The two telescope bearings of the yoke standard will now be equidistant from the observer as he stands before the instrument.

With a small thin-bladed screw driver, remove the screws in each end of the cap or cover block, *C*, over the telescope bearing of each yoke standard, *Y*. Remove each cover block carefully, with both screws in their relative positions in the block, and lay to one side in such a manner that there will be no confusion as to the exact position from which it was removed; that is, observe that the screws are not changed about in the immediate cover block and that the cover blocks do not become exchanged for one another, or reversed end for end. In short, when they are replaced see that they are in no other position than that from which they were removed. The carriage is now ready for the telescope.

The telescope is removed from the shipping case in the same manner as is the carriage itself. It is placed upon the table by the side of the carriage and with the object end of the telescope toward the observer. To set upon the standard, grasp the telescope at both ends of the main tube and, holding in this position, move to the carriage and carefully set in its bearings, which, if the preceding instructions have been carried out, will be properly set to receive. *Caution:* Do not let moisture or oil from the hands come in contact with the brass bearings of either telescope or yoke standard; likewise the silvered vertical circle and vernier. Note that the graduations on the vertical circle are coincident with the vernier on the right standard. Making sure that the telescope is firmly set in its bearings, replace the caps or cover plates in the same position as that from which they were removed. Turn in the screws firmly but do not force them. Under no consideration should the leatherized bushing screw at the middle of the cover plates or the Y-block screw on the underside of the left bearing be touched at this time. These materially affect the adjustment of the instrument and should not be disturbed.

Replace the brass cap on the object end of the telescope with the aluminum cylinder, or sun shade, found in the back right-hand corner of the shipping case. The function of this shade is to protect the object lens, and the instrument should never be used without it. Direct rays of the sun or strong light will cause the cement between the sections of the object lens to run to one side, causing a "fern leaf" which interferes with the visibility through the lens. The cap on the axis of the telescope, just above the right horizontal tangent screw, is now removed. The eyepiece is taken from its rack in the back left-hand corner of the shipping case, freed from its protecting cap on the lower end, where it is screwed to the axis of the telescope in place of the cap which was just removed therefrom. This eyepiece is provided with a special pivoted attachment containing a disc of colored glass (dark green) for use when the the balloon is near the sun.

The assembled instrument is now lifted from the supporting rack by the ring or handle and carefully placed upon the tripod, making sure that the chain and hook, *p*, figure 35, drop straight through the hollow spindle of shifting center *ST*, and that the three leveling screws, *LS*, are properly seated in the grooves in the respective arms of the shifting center plate. Insuring that the tension nut is run down well to the knurled end of the spindle, the shifting center tension, *ST*, is now raised until the threaded socket engages the threaded end of the vertical axis, *VA*, and turned on securely. The tension nut is then run up on the spindle to compress the spring and hold the instrument firmly on the tripod. However, the nut must not be run up too far, so that there is no room left between the turns of the spring for equalizing the adjustment of the leveling screws. The theodolite is now completely assembled, and after adjustment and checking will be ready for observation work.

Care of the theodolite.—The theodolite, being a delicate and costly instrument, should be given particular care and attention. It should never be left standing without the assurance (1) that the instrument is securely fastened upon the tripod, accomplished by the complete union of the vertical axis of instrument with the spindle of the shifting center tension; (2) that the tripod is well opened—that is, the free ends of the legs not too close together; and (3) that the legs are firmly planted to prevent slipping—a slight pressure of the foot upon the projecting plate of the tip of the tripod leg will accomplish the last.

When left standing, the instrument should be protected from all dust and foreign matter by covering with a light cloth and frequently wiping off the exposed parts. Should it become necessary to remove dust or moisture from the object lens, only a clean, dry chamois should be used on the exterior side of the lens. The lens is not to be removed from the tube for this purpose. The joints and seams of the telescope are so closely fitted that it is practically impossible for dust to get on the inside of the tube. Therefore, there will be no reason for taking the instrument apart for cleaning purposes. The lens at the eyepiece will rarely need this attention, and in such event is easily accessible by removing the aperture disk *only* on the extreme end of the eyepiece or front of the telescope. Attempts at further removal and cleaning of this lens are most certain to result in the destruction or disarrangement of the cross hairs on the reticle.

Special attention should be given to the tangent screws of both vertical and horizontal circles. A little light clock oil in limited amounts and applied properly will eliminate much friction and reduce the wear on the base plate. Close examination of the instrument from time to time will reveal small parts and screws which have become loosened. These should be attended to immediately, so far as possible without the interference of proper adjustment; that is, if the parts which have become loosened materially affect the adjustment of the instrument it will be necessary to readjust and check the instrument after such parts have been tightened.

The instrument is not to be taken apart more than is necessary for packing and shipment. Further taking apart for the purpose of cleaning or repairs should be done only by one experienced with the construction of the instrument, or by a competent person, and upon the receipt of authoritative instructions from the Central Office.

Care should be taken that the hands do not come in contact with silvered surfaces of the circles or the verniers, for the moisture and oil thereby deposited tend to oxidize the surfaces, making the graduations indistinct and difficult to read. If these parts do become tarnished they may be brightened to some extent with a soft rubber pencil eraser.

Packing the theodolite—Whenever it becomes necessary to ship the theodolite, a great deal of care must be given to the packing and preparation for shipment. The packing case in which the instrument is received should be preserved for this purpose. The style of case ordinarily used necessitates the separation of telescope from the assembled standard and base plate. This is accomplished by reversing the instructions given in section 2, under "Assembling the theodolite." In addition, the horizontal tangent screw *HT*, figure 35, is to be thrown in mesh with the base plate *BP* and secured there by wrapping and tying a short length of string about the horizontal tangent screw *HT* and telescope stop *TS*. See that the vertical tangent screw *VT* is disengaged and that the base-plate clamp screw *P* is loosened. Place the assembled standard and base plate, which has been secured to auxiliary shelf for that purpose, in the bottom part of the case so that the right horizontal vernier *HV* is about midway and toward the front of the case. Now prepare 4 rolls of excelsior about 6 inches long and 2 inches in diameter for packing the assembled standard. These rolls are to be placed one on either side of each telescope standard, in such a way that the ends of each roll will be against the side wall of the shipping case and the right or left edge of the telescope standard. When the last of these excelsior rolls is in position the telescope standard will be held rigidly from moving about on the rack. In placing the excelsior roll against the left hand edge of the forward yoke standard *be sure that it does not* press too hard against the vertical tangent screw *VT*, figure 35. The telescope, with sunshade and eyepiece tube removed, is then laid in its supporting rack and placed in the upper part of the shipping case, with a piece of folded paper inserted between the telescope tube and the stay-blocks on underside of top of packing case. After closing and securely locking the door, fasten the key to case by means of a screw through the head. Each theodolite should be packed in its own case—that is the case bearing the same serial number. For shipment from station to station the shipping case containing the theodolite must be substantially crated.

Carrying the theodolite.—The best method for carrying the theodolite is shown in figure 38. This position is obtained from the standing theodolite as follows: The observer, with the instrument close to his left, grasps it firmly on opposite sides of the ring or handle, then, placing his right foot in front of the nearest leg of tripod to prevent slipping, pushes the instrument forward to rest entirely upon that one leg and closes the others in by its side. Resuming the handhold upon the ring and turning a little to the right, followed by a step forward, will allow the observer to place the left hip in front of the closed tripod, and a second step forward with the lowering of the instrument head turning over the hip as a pivot will obtain the illustrated position. The advantage of carrying the instrument in this manner, rather than over the shoulder, is that the particular part of the instrument needing the most attention is right before the observer where he can watch it while passing through doorways, up and down stairs, or close to walls and buildings. When the theodolite is carried over the shoulder, the mass of the instrument itself exerts a strain upon the vertical axis, *VA*, figure 35, but when carried in the above-described position the strain is overcome, since the mass of the instrument is supported by the ring or handle designed for that purpose. It also affords more ease and comfort to the observer if the instrument is to be carried any distance.

Adjustments of the theodolite.—Before the new theodolite is used it must be thoroughly adjusted and checked. This will be done at the Central Office before the instrument is assigned to any station. However, due to rough handling in shipment, it becomes necessary to recheck and sometimes to readjust the theodolite at the field station. An instrument in daily use should be checked occasionally—at least once every four months. If the initial adjustment is carried out carefully and accurately, these periodic corrections will be slight if at all noticeable, yet they should not be neglected.

When the theodolite adjustment has been completed, the entire series of tests should be gone over as a means

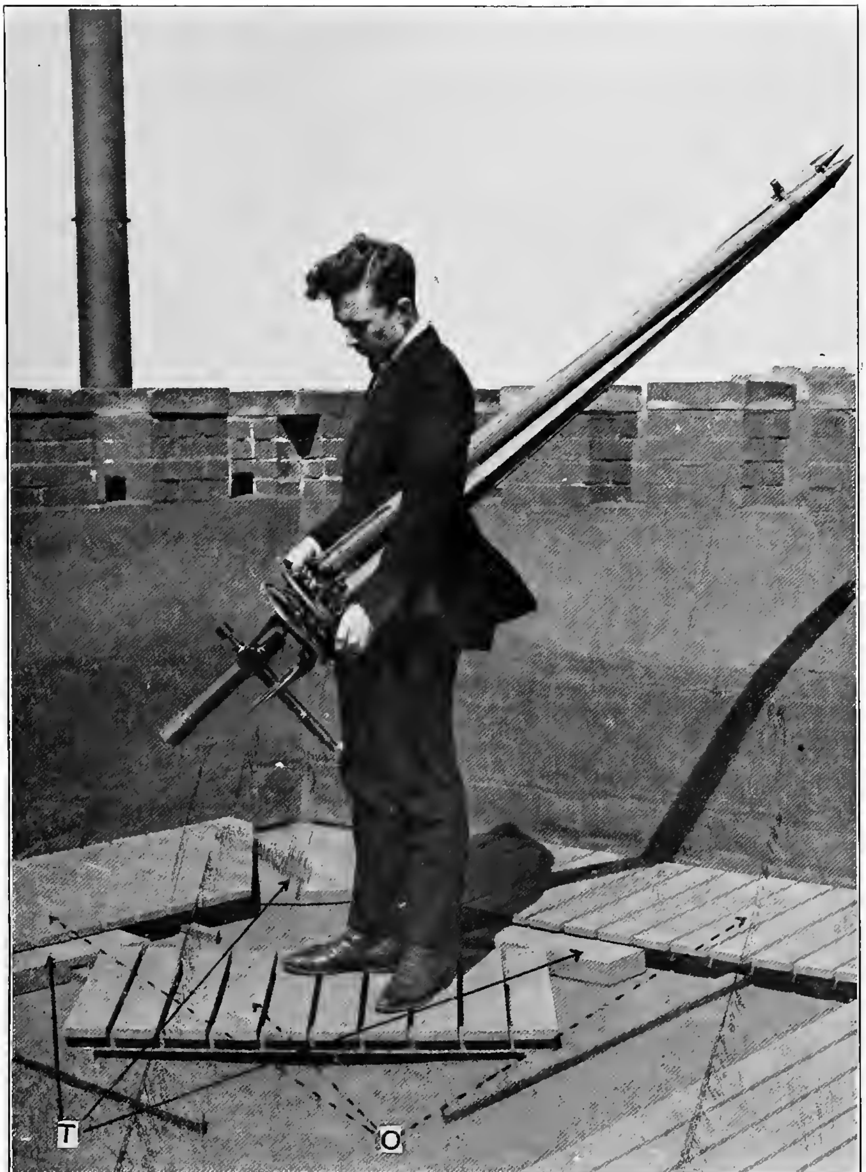


FIG. 38.—Proper method of carrying theodolite, and insulation of theodolite stand (*T*) from observation platform (*O*).

of checking. It will often be found necessary to make slight corrections which exemplify the need of much attention during the initial adjustment. Before making any one of the adjustments, note that the instrument is properly seated at leveling screws and that the horizontal base plate is level. Check for levels before each of adjustments 2, 3, and 4 is attempted.

The instructions for the adjustment and checking of instruments follow and are to be closely adhered to. They were prepared by Mr. William C. Haines, Observer,

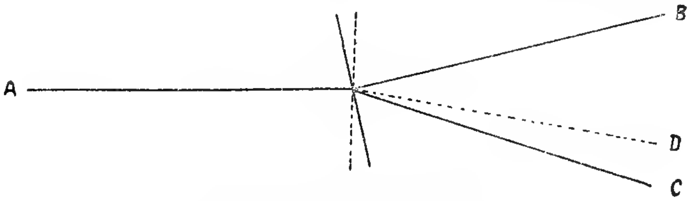


FIG. 39.—Collimation adjustment.

as the result of extended experience with these instruments.

The adjustments of the theodolite are such as to cause (1) the instrument to revolve in a horizontal plane about a vertical axis, (2) the line of collimation to generate a vertical plane through the instrument axis when the telescope is revolved on its horizontal axis, and (3) the vernier on the vertical circle to give true readings of the angle of elevation of the line of collimation. These results may be brought about by the following adjustments:

1. The plate-level adjustment: To make the axis of each plate level lie in a plane perpendicular to the vertical axis, bring one of the level tubes in line with two of the leveling screws. Level with leveling screws, revolve the instrument 180° in azimuth, correct one-half the movement of the bubble on the leveling screws and the other half by raising or lowering the adjustable end of the level tube. Now level up again and revolve 180°, and the bubbles should remain in the center. If not, adjust for one-half the amount as before, and so continue until the bubbles remain in the center for all positions.

2. The collimation adjustment: To make the line of sight perpendicular to the horizontal axis of the telescope. When this is done the line of sight will generate a plane when the telescope is revolved on its horizontal axis. Set up the theodolite on level ground where a view can be had in opposite directions. (If the ground is not level a small error may be introduced into this test due to the horizontal axis.) With the telescope pointing to the left, set the line of sight on a definite point *A*, figure 39, a few hundred feet away. Revolve the telescope about its horizontal axis and set another point *B* in the opposite direction. Now rotate the instrument in azimuth until the line of sight comes upon the first point *A*. Revolve the telescope about its horizontal axis again and fix a third point *C* on the line of sight beside the second point *B*. From the last point set, measure off one-fourth the distance between these two points to a point *D* and bring the line of sight to this position by moving the reticle laterally. This movement is reversed in the theodolite, as it is an inverted instrument. This adjustment should be repeated as a check.

It is often found that the line of sight can not be brought to position without moving the reticle too far from the center of the tube. In this case adjustment must be made on the 45° glass prism which is placed in the cube at the axis of the telescope for the purpose of deflecting the line of sight at right angles. Unless the reflecting surface of the prism makes an angle of 45° with the incident beam of light, the deflection is no longer at right angles, but may be either greater or less than 90°, depending upon the relative position of the prism.

Before attempting to adjust the prism, first determine whether the angle of deflection is greater or less than 90°. This may readily be done from the above test. If point *C*, the last point set, falls to the left of point *B* (the observer facing the points), the angle of deflection is apparently less than 90°. If it falls to the right of point *B*, the angle of deflection is apparently greater than 90°. The reverse of the above is actually true, however, because of the fact that the theodolite inverts the objects. In the first case the angle of deflection is in reality greater

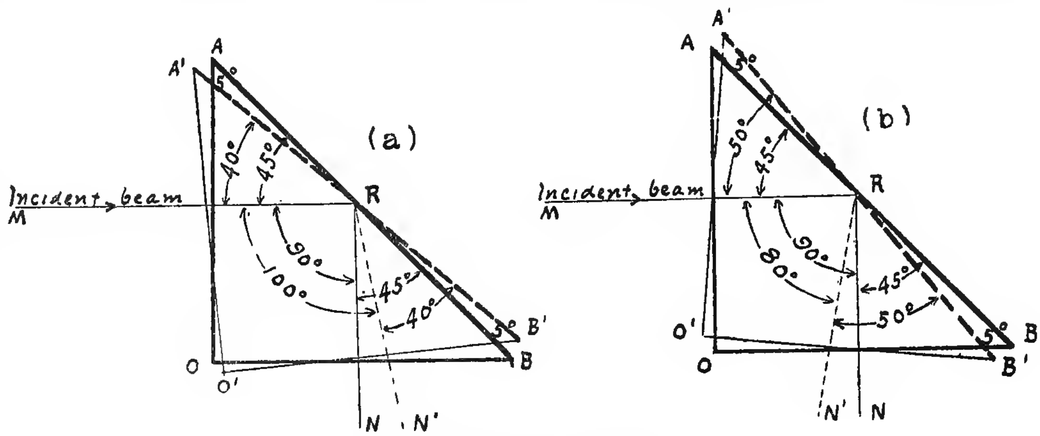


FIG. 40.—Effect of prism on line of sight.

than 90°, and the prism must be moved so as to increase the angle made by its reflecting surface to that of the incident beam of light. In the second case the angle of deflection is in reality less than 90°, and the reflecting surface must be moved so that it will make a smaller angle with the incident beam. In figure 40 (neglecting the effects of refraction of light in the glass) (*a*) shows position of prism with reference to incident beam of light to cause deflection greater than 90° and (*b*) position to cause deflection less than 90°.

To make this adjustment, the prism must be removed from the telescope. This is accomplished by removing the small brass screws from the plate covering the cube at the axis of the telescope. The prism is attached to this plate and is removed with it. Two set screws hold the prism in position on the plate. Its reflecting surface may be moved with reference to the line of sight by loosening one set screw and tightening the other. Care should be taken not to overadjust the prism, for a glance at figure 40 will show that any movement in the reflecting surface to the incident beam of light will be doubled in the reflected rays. In this instance, the assumed movement of 5 degrees in the reflecting surface produces 10 degrees difference in the angle of deflection. In so far as the deflection of the line of sight is concerned, the 45-degree prism produces the same effect as a plane mirror placed in the position of the reflecting surface of the prism. Any refraction that is produced at the entrant face of the prism is nullified by corresponding refraction on emergence of the ray of light.

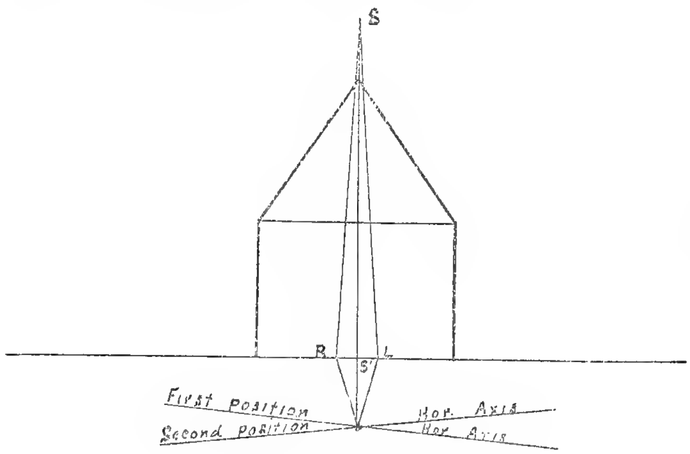


FIG. 41.—Horizontal axis adjustment.

3. The standard adjustment: To make the horizontal axis of the telescope perpendicular to the vertical axis of the instrument, carefully level the theodolite and sight on some high point, as a steeple S, figure 41, lower the telescope and set a point R below S on about the same level as the instrument. Revolve the telescope about its horizontal axis and turn the instrument upon its vertical axis and again sight at S. Lower the telescope as before and set a point L opposite R. A point S' midway between R and L must be in the same vertical plane with S. Now raise or lower the adjustable end of the horizontal axis by means of the capstan-headed screws at the one end of the axis. The high end of the axis is always on the same side as the last point set. If this end of the axis is not adjustable, the other end can be raised instead. The test should be repeated until the line of sight coincides with $S\,S'$. Care should be taken to leave the cap screws tight enough to insure that the axis rests on its bearing but not tight enough to cause friction in turning the axis.

4. The vernier adjustment: To make the vernier read zero when the line of sight is horizontal. This adjustment is usually made by one of the peg methods. The following is perhaps the simplest:

The instrument is set up midway between two pegs N and S, figure 42. With the vernier set on zero the rod is held and read on these two points. Care should be taken that the vernier setting is not disturbed while making this test. Even if out of adjustment the difference between the rod readings gives the true difference in level between N and S. The instrument is next set up near the higher peg so that looking through the telescope with the eye at the object end a point can be set in the exact center of the small field of view and the reading taken. The rod is next held on the distant peg and read in the usual way. If the true difference in level between the pegs be added to the near peg reading it will give what the distant rod reading should be if the instrument is in adjustment. The difference between this amount and the actual distant rod reading represents the error in adjustment. To correct the error, set line of sight on correct reading on distant rod, then shift the

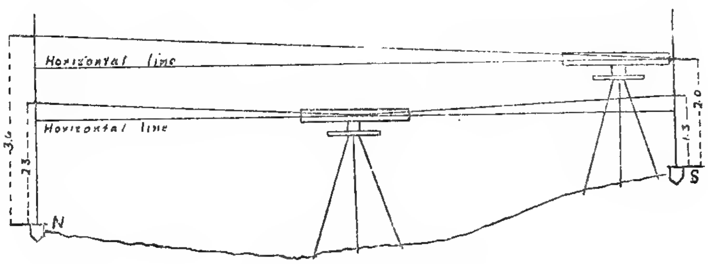


FIG. 42.—Peg adjustment.

vernier and carefully adjust it to read zero in this new position.

Setting up theodolite for observation.—Place the theodolite over the observation point so that the base plate of the instrument is nearly level and centered over the exact point selected. To do this, see that the tripod is well opened, with legs firmly and symmetrically implanted about, and equidistant from, the exact point. It is well to arrange the theodolite, when setting up for observation, with plate clamp screw, P, figure 35, on the opposite side of vertical axis, VA, from the orientation point which is being sighted upon. The significance of this will be understood later.

To level the theodolite, turn the telescope upon the horizontal axis HA, figure 35, until it is about perpendicular to the base plate (the vertical circle set at or near 90 degrees, see reading of VV, figure 37). Disengage the horizontal tangent screw HT, figure 35, and turn the instrument about its vertical axis until one of the levels, preferably the standard level SL, is parallel with the line joining any two of the leveling screws, LS. As a guide for this setting bring the right horizontal vernier, HV, over one of the three spokes of the ring or handle, and use the leveling screws on each side. See that the shifting center tension spring is sufficiently loosened to allow ample adjustment of leveling screws, then bring the bubble between the marks of the standard level by turning the two leveling screws in opposite directions; that is, both in or both out as the occasion demands. While in this position, adjust plate level, *PL*, by raising or lowering with third leveling screw. Attach plumb bob to hook and chain, *p*, pendent from the vertical axis, and adjust until the bob just swings freely over the point. When the bob comes to rest, if not centered over the point of observation, loosen the thumb plate, *CR*, clamping the triangular shifting center, *S*, and shift theodolite head to the position in which the point of the plumb bob, when at rest, is pendent directly over the observation point, then lock by means of the thumb plate. If necessary, relevel the instrument by the above method, noting that each bubble is equally spaced between the marks on the appropriate tube. Now turn the instrument about its vertical axis successively through 90, 180, and 270 degrees, and observe that the bubbles are still in the central positions. If they are not, then return the telescope to the initial position and readjust until this is accomplished.

The theodolite now being leveled, turn the instrument about its vertical axis until either the right horizontal vernier, *HV*, figure 35, or the 45-degree horizontal vernier, *hv*, figure 35, is set on the azimuth bearing of the reference point, then lock by throwing in the horizontal tangent screw, *HT*. Set the vertical circle of the telescope at or near zero, loosen plate clamp screw and turn the locked telescope and base plate about the vertical axis until the telescope is sighted upon reference point of orientation, accomplished by means of the ball and *V* sights along the main tube of the telescope. Be sure that the azimuth setting on base plate for the particular reference point has not been disturbed, then lock base plate to the horizontal axis by tightening the plate clamp screw *P*.

Upon sighting through telescope, if it is found that intersection of cross hairs is not coincident with reference point, raise or lower by means of the vertical tangent screw, *VT*, and shift horizontally by means of the slow-motion or base-plate adjustment screw. This final horizontal adjustment must not be made with the horizontal tangent screw, since this would disturb the orientation setting of the particular reference point.

Adjustment of the eyepiece, by turning the aperture disk either in or out, to obtain the maximum sharpness of cross hairs, and focusing the telescope by use of the rack and pinion, will complete the orientation and setting of the theodolite for observation work.

Orientation of the theodolite is the process of placing the telescope in the vertical plane of a particular meridian and is accomplished by the method which immediately precedes. However, before orientation can be accomplished, the exact position of a north-south line must be determined, and this line must also be determined for each point of observation, with the exception of secondary stations at the far end of a base line. The line for this observation point may be derived from the azimuth bearing of base line from the primary station. Three distinct methods are here given for the determination of the north-south line.

Determination of north-south line.—The first method is by the culmination of Delta Cassiopeia and Mizar; the second, by determining the hour angle and azimuth bearing of Polaris by observations on that star; and, third, the azimuth bearing between some terrestrial object and any definite celestial object.

The culmination method is much the simplest of the three, requiring neither computation nor tables; it is necessary to know only the approximate time of culmination. However, during certain periods it will be inconvenient to determine the north-south line by the culmination method, due to clouds obscuring one or both constellations, or culmination occurring at a time when the sky is so well lighted that the stars can not be seen. Such conditions lead to the second and third methods, which are adapted for any time at which Polaris or other celestial object selected for the observation may be seen. Both of the latter methods involve simple computation and the use of the American Ephemeris and Nautical Almanac.

Much care and attention should be given to adjustment and leveling of the instrument, determination of angles, and the disposition of decimals in computation. All angles should be read to the nearest hundredth of a degree.

Whichever method is used, the theodolite must be in perfect adjustment and the actual point of observation selected and permanently marked. The observer's watch will be compared with the standard of time in local use, and corrections made as become necessary. The theodolite will be placed centrally over the point to be determined and the greatest care given to leveling.

In either the first or second method, it will be necessary to provide a means of illuminating the cross hairs. Any method whereby a beam of light can be reflected or thrown into the object end of telescope giving sufficient illumination to set forth the intersection of cross hairs and not flood the field with light to the extent that the image of the star is lost will answer the purpose.

First method.—Delta Cassiopeia is the lower left hand star in the constellation Cassiopeia, figure 43, when this constellation is in the position of the letter W. During culmination this star crosses the north-south line 10 minutes in advance of Polaris and at the same time as Mizar, or the middle star in the handle of Ursa Major. These two stars mentioned are on opposite sides and nearly equidistant from Polaris. Culmination of these two stars occurs twice in 24 hours, and is followed within 10 minutes by Polaris crossing the same meridian. These facts, with the aid of an instrument, afford a simple means of determining the north-south line.

Having determined the approximate time of culmination of Delta Cassiopeia and Mizar, the theodolite is set over the exact point for which the meridian is to be determined, plumbed, and leveled very carefully. It is well to do this while it is yet light. Be sure that the base plate is firmly locked and that both vertical and horizontal tangent screws can be turned freely without resistance. Sight the telescope upon some prominent point, as the tip of church spire, peak of gable roof, sharp corner of building, etc., and note the azimuth reading of this point on either the right or the 45-degree horizontal vernier. Take particular care that all subsequent azimuth readings during this observation are made from the same horizontal vernier. A little time before culmination occurs, say half to three-quarters of an hour, a little practice should be gained by sighting upon the upper of the two stars and rapidly shifting the sight to the lower one. By the time culmination occurs, if the practice of raising and depressing telescope has been carried out, the observer will have gained considerable proficiency in the act, and the final movement at time of culmination will be performed with little or no difficulty.

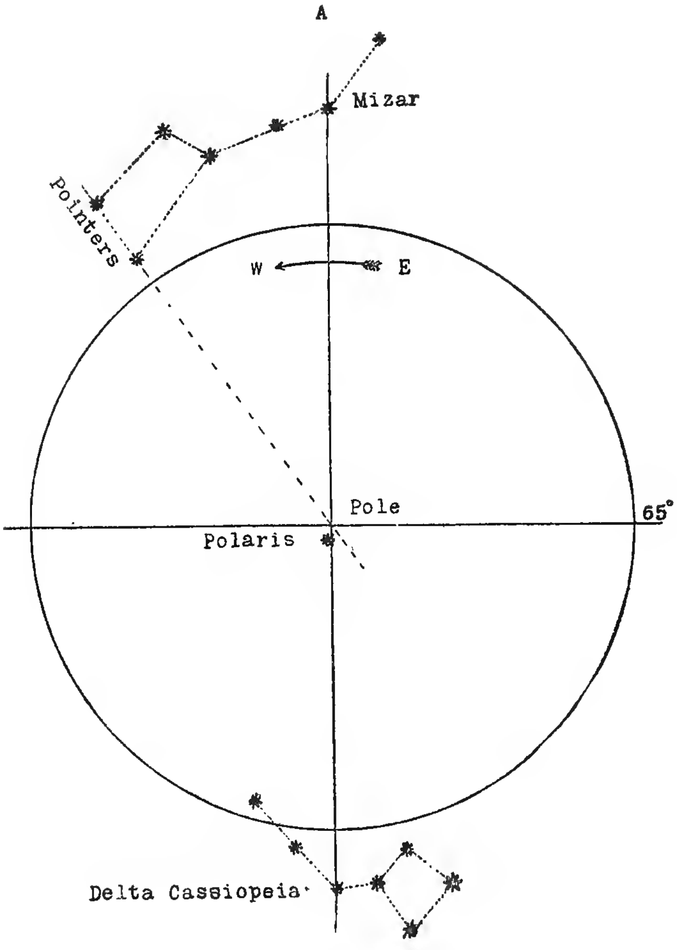


Fig. 43.—Constellations of Ursa Major and Cassiopeia.

Have the cross hairs illuminated as mentioned above and the telescope properly focussed. Engage both vertical and horizontal tangent screws and bring the intersection of the cross hairs centrally over the star in question. Quickly note the readings on the respective verniers and rapidly depress the telescope to elevation of the lower star by turning the vertical tangent screw, but do not disturb the horizontal tangent screw during the depression. The lower of the two stars will appear to the left of the vertical cross hair, but it will gradually approach the vertical hair as the time of culmination is approached. Raise the telescope to the upper of the two stars again, reset, read the angles from the same two verniers, and immediately depress the telescope as before. Repeat the foregoing operation until it is observed that the lower of the two stars also falls upon the vertical cross hair when the telescope is depressed. When this is obtained, raise the telescope to the altitude position of Polaris, *but do not disturb the azimuth setting*, or the result of the observation will be of no avail. As a check, note that Polaris culminates just 10 minutes after the culmination of Delta Cassiopeia and Mizar. Note and record the azimuth setting, then depress the telescope to sight upon some conveniently accessible object where a distinct point coincident with the intersection of cross hairs will be placed. This point so placed will be true north.

Example 1: Suppose the theodolite is first sighted upon the cross of a church spire to the right of north, and the azimuth bearing, read from the right horizontal vernier, is 126.15 degrees. Let 98.4 degrees be the reading from the same vernier when Delta Cassiopeia and Mizar are in culmination. The difference between these two readings will give the angle at observation point between true north and the reference point, or the bearing of reference point from north: $126°.15 - 98°.4 = 27°.75$; thus, when theodolite is set up with zero of base plate on north, the azimuth bearing of cross on church spire will be 27.75 degrees. But, if the theodolite is set up with zero of base plate on south then the azimuth bearing of the church spire will be 180.0 degrees more, or 207°.75.

Second method.—Polaris, in its apparent counterclockwise revolution about the pole, takes 23 hours 56.1 minutes of our regular 24-hour day, thus culminating or crossing the meridian twice in 24 hours, and nearly 4 minutes earlier each day. From this we see that the position of Polaris east or west of the meridian for any specified time will vary from day to day. Knowing the correct local mean time and the time of upper culmination, the hour angle of Polaris (or the angle at the pole between the north-south line and the hour circle passing through Polaris), may be found. From the hour angle of Polaris, with the aid of the American Ephemeris and Nautical Almanac, the true azimuth of Polaris may be easily computed. The observations are made on Polaris at any convenient time after it becomes visible.

The theodolite is carefully set and leveled over the exact point of observation as in the preceding method, the cross hairs are likewise illuminated, and the watch compared with the correct local mean time. After the base plate is locked, the telescope is sighted upon some well-defined point as a reference mark, and the azimuth reading carefully noted and recorded. The telescope is then trained upon Polaris, and at the instant that the intersection of cross hairs is brought centrally over Polaris, the exact watch time to seconds is first noted, followed by the reading on the same azimuth vernier from which the azimuth reading of the reference point was made. All angles will be read to the nearest hundredth of a degree. A series of three or more observations, 10 to 15 minutes apart, should be taken as a check on the first and the computation as a whole. The final result of each computation should be no more than 0.02 or 0.03 of a degree from the mean result.

Example 2: On July 2, 1919, in lat. 42° 27′ N., long. 76° 29′ W., or 5 h. 06 m. earlier than Greenwich, a series of three observations was made at 8 h. 42 m. 00 s., 8 h. 55 m. 00 s., and 9 h. 10 m. 00 s., seventy-fifth meridian time. The base-plate reading of the right azimuth vernier, when sighted upon a definite point on the left of north, was 189.64 degrees. The azimuth readings from the same vernier when sighted upon Polaris during the observations were 237°.80, 237°.89, and 237°.98, respectively.

Date, July 2, 1919. Position, lat. 42° 27′ N., long. 76° 29′ W.—5 h. 06 m. earlier than Greenwich.

	H.	m.	s.	H.	m.	s.	H.	m.	s.
Time of observation (St. 75th).	8	42	00	8	55	00	9	10	00
Earlier than seventy-fifth meridian		06	00		06	00		06	00
Local mean time	8	36	00	8	49	00	9	04	00
Reduction to sidereal time (A. E. and N. A., Table III)		+01	25		+01	25		+01	25
Sidereal time mean noon Greenwich, or right ascencension of mean sun this date (A. E. and N. A., for Greenwich mean noon)	6	37	54	6	37	54	6	37	54
Correction for long., 5 h. 06 m. 00 s., (A. E. and N. A., Table III)		+00	50		+00	50		+00	50
Local sidereal time	15	16	09	15	29	09	15	44	09
Apparent right ascension of Polaris this date (A. E. and N. A., apparent place of stars)	1	31	34	1	31	34	1	31	34
Hour angle of Polaris before upper culmination	10	15	25	10	02	25	9	47	25
	H.	m.		H.	m.		H.	m.	
Same in decimals of minutes	10	15.42		10	02.42		9	47.42	
Azimuth of Polaris at this hour angle and latitude (A. E. and N. A., Table IV)		39.58			44.23			50.29	
Same reduced to degrees		.66			.74			.84	
Observed azimuth of Polaris		237°.80			237°.89			237°.98	
True north on base plate		237°.14			237°.15			237°.14	

Accepting 237°.14 as the direction of true north when the theodolite is set with 189°.64 on the reference point, the bearing or horizontal angle between the reference point and true north will be the difference between 237°.14 and 189°.64 or 47°.50. Now, then, with the zero of base-plate setting on north, the azimuth bearing of the reference point is 360° minus 47°.50, or 212°.50.

Third method.—The method of determining the north-south meridian by observation on the sun necessitates the use of a ray filter or smoked glass placed over the eyepiece during the observation. In the absence of both, the observer may wear smoked glasses or if these are not at hand, an image of the sun may be cast on a piece of white paper held at a distance from the eyepiece. By adjusting the focus the shadow of cross hairs will be seen on the paper and thus facilitate proper centering over the sun. Do not leave the object lens of the telescope exposed to the direct rays of the sun for any length of time. Such continued exposure is likely to render the lens unfit for use, as already explained.

The preparation and setting of theodolite for this method is essentially the same as for the other two methods mentioned above, namely, properly place, level, and check the theodolite, lock base-plate, establish reference point, and note the actual time of observation. By the following method of computation, the north-south line may be determined from observations upon any known celestial body, it being only necessary to substitute the other definitely known body for the sun. However, the sun affords the most convenient object for the determination. The factors resolve themselves into a spherical triangle, which may be computed by the following formulæ:

Let $S = \frac{1}{2}$(polar distance + co-latitude), p + co-lat.;
Let $D = \frac{1}{2}$ (polar distance − co-latitude), p − co-lat.
Let $\frac{1}{2}t = \frac{1}{2}$ hour angle;
Let Z = true azimuth;
Then $\tan X = \sin D \operatorname{cosec} S \cot \frac{1}{2}t$
$\tan Y = \cos D \sec S \cot \frac{1}{2}t$
and[1] $Z = X + Y$, or $X - Y$.

Example 3: On June 19, 1920, in latitude 38° 54′ 12″ N., longitude 77° 03′ 03″ W., or 5 h. 08 m. 12 s. earlier than Greenwich, observations were made on the sun at 1 h. 36 m. 44 s., seventy-fifth meridian time.

The baseplate reading of the right azimuth vernier when sighted upon reference point to the left of sun was		142°. 28	
Observed azimuth reading of sun, same vernier		239°. 78	
Azimuth difference of points		97°. 50	
	H.	m.	s.
Time of observation, seventy-fifth meridian	1	36	44
Earlier than seventy-fifth meridian time		08	12
Local mean time of observation	1	28	32
Equation of time (apparent − mean, A. E. and N. A.)		−01	04
Local apparent time	1	27	28
Hour angle of sun (t)	1	27	28
$\frac{1}{2}t$		43	44
The same converted to degrees[2]	10°	56′	00″

[1] If S is less than 90 degrees, and (a) polar distance greater than co-lat., use sum of X and Y; (b) polar distance less than co-lat., use difference of X and Y.

If S is greater than 90 degrees, always use difference of X and Y, which, subtracted from 180 degrees, results in the true azimuth.

[2] Since 15° = one hour in time, the hour angle may be converted to degrees by using 15 as a factor, and reducing the whole to the simplest form in degrees, minutes, and seconds.

	H. m. s.
co-lat. (90°−latitude of station)	51° 06′ 00″
Polar distance of sun (90°−declination)	66° 34′ 00″
p+co-lat	117° 40′ 00″
S, or $\frac{1}{2}(p+\text{co-lat.})$	58° 50′ 00″
p−co-lat	15° 28′ 00″
D, or $\frac{1}{2}(p-\text{co-lat.})$	7° 44′ 00″

$\frac{1}{2}t=10° 56' 00''$ log cot $\frac{1}{2}t=0.71405$ log cot $\frac{1}{2}t=0.71405$

$S=58° 50' 00''$ log cosec $S=0.06770$ log sec $S=0.28607$

$D=7° 44' 00''$ log sin $D=9.12892$ log cos $D=9.99603$

log tan $X=9.91067$ log tan $Y=0.99615$

$X=39° 08' 55''$ $Y=84° 14' 20''$

$X+Y=123° 23' 15''$, or 123°.39

True bearing of sun from north through west	123°.39
Azimuth difference	97°.50
Bearing of reference point from north through west	220°.89

True bearing of reference point from north, 360°−220°.89, or 139.11 degrees.

Whenever it is possible all computations should be made before the theodolite is disturbed or moved from its setting. When the true north-south line has been determined, the true bearing of reference point from observation point with at least two others at different distances should be determined. These points with their bearings from north or south will constitute the orientation points of the station. A plan of these points will be constructed to some convenient scale on a card 4 inches by 6 inches and mailed to Central Office for file, along with a brief description of the arrangement of equipment. At double-theodolite stations, a second card will show the length, bearing, and arrangement of base lines.

Orientation of theodolite.—In single theodolite work, zero of the base plate will be set on north, for when the data are plotted upon the regular single-theodolite plotting board, the wind directions are more easily determined than otherwise. Further explanation will be given in later sections.

For double-theodolite work, the setting of zero on the base plate may vary with the different methods used in plotting the data obtained. In any event both instruments should be homologously oriented, that is, the zeros of the base plates of both instruments on the same geographic point. Three methods of double-theodolite orientation are accepted. Namely, base-line orientation, north orientation, and south orientation. In all methods of plotting, base-line orientation is preferred, wherein the theodolite at primary station is set with zero of base plate on the base line, or secondary station, and the theodolite at the secondary station is set with 180° on base line or primary station. In north orientation and south orientation, both theodolites are set with the zero of base plate on north and south respectively. These latter methods are well adapted for the graphical method of two-theodolite plotting, but involve azimuth corrections equal to the base-line bearing with north-south line, when the slide-rule method is used. The same exception holds for logarithms. Therefore when the flight is to be computed by slide rule or logs and then plotted, orientation by the base line method should be adopted.

3. BALLOONS.

The balloons in use for pilot balloon work are made from the best grades of raw gum rubber to be obtained. They are manufactured by the "dip" process, and are therefore without seams and nearly spherical in shape. An extension of the longer axis about 2 inches in length and 1½ inches in diameter, terminating in a rolled edge, forms the neck or appendix through which inflation is accomplished. Balloons of two sizes are used, the first, 6 inches in diameter when uninflated, for single-theodolite work, and the second, 9 inches in diameter uninflated, for special double-theodolite work. Both sizes of balloons may be procured either uncolored or colored.

Color.—The uncolored balloons are those of natural gum, appearing to be a light tan or pale gray, while the colored may be either vermillion, maroon, blue, or purple. The color of balloons when inflated is much less intense, and frequently of different color, than when uninflated. As a whole, the appearance of balloons when at full inflation may be classed as transparent, translucent, or opaque. Balloons colored with a pigment in the body of the rubber are likely to be opaque when inflated, and those colored by a stain will be opaque only when colored with a *dense* stain, and even then are more likely to belong to the translucent class. The uncolored balloon becomes transparent under ordinary conditions of inflation.

If the sky were of one color continuously, it would be necessary to have but one color of balloon for all times. That color would be one which would present a strong contrast with the color of the sky. Since the sky coloring may be either blue, white, or gray, the balloons most easily seen with the aid of the theodolite will necessarily be those which present the strongest contrast to these sky colors. In general, the strongest contrast of colors is that of black and white. Next in order come the association, or juxtaposition, (1) of two primary colors, (2) of one primary and one complementary secondary, and (3) of a light tint of one primary and a dark shade of the same or another primary, the strength of contrast decreasing in the order given. If we let the primary colors be red, blue, and yellow, the secondaries pairs of primaries combined in equal volumes, and a complementary secondary to a primary be a secondary composed of two other primaries, then the above scheme of contrasts used by the United States Coast and Geodetic Survey is represented by the following table:

For color contrasts, juxtapose.

(1) Primary with other primary.	(2) Primary with complementary secondary.	(3) Light tint of primary with dark shade of same or other primary.
Red with— Blue or yellow.	Red with— Blue and yellow or green.	Light red with— Dark red, dark blue, or dark yellow.
Blue with— Red or yellow.	Blue with— Red and yellow or orange.	Light blue with— Dark blue, dark yellow, or dark red.
Yellow with— Red or blue.	Yellow with— Red and blue or violet.	Light yellow with— Dark yellow, dark red, or dark blue.

From the above we see that the strongest contrast formed against a blue sky would be obtained by using a red or a yellow balloon, and a strong contrast, though less marked, would be obtained by the use of an orange-colored balloon. When the sky is a light blue or fading into white and finally becoming gray, a strong contrast is obtained by the use of dark shades of blue, yellow, or red. The same relative principles would hold if the sky coloring were red or yellow instead of blue. Since these colors but rarely exist at the times of balloon observation, and even then in but the lightest of tints, we may confine our interest to the method of contrasts by (3). The application is similar to and essentially the same as for light blue.

Cloudiness, haze, or mist is nearly always associated with the sky colors. Tints of red, blue, and yellow, in the majority of cases, fade into the whites or gradually deepen into the grays so common during cloudiness. But these conditions of sky coloring, we learn from the above table, are most strongly contrasted by the use of dark red, blue, or yellow. Experience has shown that dark-red balloons, or even light red, if the coloring has rendered the balloons opaque, are best adapted for all round use whether the sky be blue, white, or gray. When the sky is cloudless and well tinted with blue, remarkable results may be gained by the use of an uncolored or gray balloon. But this is nothing more than a reversal of contrast by (3) method. However, the successful use of the uncolored balloon is measured by the degree of clearness, the absence of haze and mist, and the predominance of bright sunlight throughout the flight, for the uncolored balloon against a white or gray background readily blends and becomes invisible. In bright sunlight, the uncolored balloon possesses the main properties of a mirror, for the light upon it from the sun is reflected to the observer so long as the balloon does not come directly between the observer and the sun. If the latter condition obtains, the light then passes through the balloon, rendering it invisible.

On days of few and very light clouds a balloon of translucent coloring may be used with equal success; but on days with appreciable cloudiness or haze a balloon of opaque coloring must be used to obtain the best results. In general—

Uncolored balloons will be used upon clear days, or when there is an assurance that the sun will shine on the balloon throughout the flight, and

Colored balloons will be used upon days when clouds, haze, or mist cause the sky to present a white or grayish appearance.

Occasions will arise when the supply of colored balloons will become exhausted, and a satisfactory run can not be made without one. One of the uncolored type may then be satisfactorily colored by the following method:

The materials needed are some raw linseed oil and a small quantity of printer's ink. It is well to have two or three colors such as red, blue or black, and yellow. Add sufficient linseed oil to each can of ink to make a thick syrup or paste. There will be little difficulty in this since the ink is so readily soluble in the oil. To color the balloon successfully and conveniently, and without damage to the clothing, requires a little special manipulation, which is accomplished as follows: Place the thumbs of each hand within the neck of the balloon and allow the fingers to extend down the outside. Slightly distend the neck and bend the extended fingers in toward the palm of the hand at the same time pushing the walls of the balloon up to the region of the neck. Then by exerting a double kneading movement, by rolling the back of the hands over each other, the walls of the balloon will be passed through the small passage of the neck, exposing the greater portion of the interior surface of the balloon. However, the balloon is not to be turned inside out completely, but the apex is left protruding from the underside, sufficiently to allow a finger hold for turning the balloon back to the initial position. The balloon thus prepared will appear with the greater portion of the interior surface exposed above and outside the neck, and forming a depression at the point where it passes through the appendix of the balloon to the remaining portion of the unturned balloon on the underside of the hand. Now, in this depression, place a small quantity of the ink and oil mixture to the amount of about 2 or 3 grams. After the ink has been so placed, turn the balloon to the initial position by pulling on the lower protruding portion. This will close the surplus walls of the balloon over the ink mixture, thus preventing it from coming in contact with the neck or exterior surface of the balloon. When completely turned, proceed with the kneading until the color is evenly distributed. The kneading is quite desirable in itself and provides for maximum inflation of balloon, as will be explained later.

Patching leaky balloons.—Occasionally balloons, when received from the manufacturers, will be found to have small "pinholes." In some cases such holes may develop during inflation due to small "air bubbles" or other defects. These defective balloons should not be discarded, but can and should be patched and made ready for use by the following method:

Procure a piece of very fine emery paper, an ounce or two of benzine, a small tube of Goodyear rubber cement, and a piece of a previously burst balloon. Turn the defective balloon inside out and lay it upon a flat surface, with the portion to be patched uppermost. Slightly roughen the rubber around the pinhole, also the piece of "patch" rubber, with the emery paper, wash each with a little benzine, and then apply to each a thin layer of the cement. The cement should be allowed to dry for about five minutes, when another layer should be applied. Place the patch on the prepared surface of the balloon, press it firmly down and then lay a small weight upon it, in order to insure even and complete coherence. The balloon should remain thus for 12 to 24 hours, after which it is turned back so that the patch is on the inside. The balloon is now ready for use, but should not be inflated to give a rate of ascent greater than 180 m/m (preferably 160). During inflation the patch should be closely watched; if it curls up at the edges appreciably, the balloon should be laid aside and the patch later recemented.

The size of the patch to be used will vary somewhat with the size of the hole, but in general a diameter of 1½ to 2 inches is recommended.

Experience has shown that it is well to inspect each lot of balloons as soon as received and to patch all defective ones at one time.

Size.—At present the balloons in use for pilot balloon work are 6 and 9 inches in diameter uninflated. In practically all single-theodolite observations 6-inch balloons will be used, while the 9-inch will be reserved for double theodolite work. The 9-inch are sometimes used in single-theodolite work when it is observed that an extremely high wind velocity obtains either aloft or at the surface. But a 6-inch balloon filled to a high ascensional rate is recommended in preference to a 9-inch for single-theodolite work. In double-theodolite work either 6-inch or 9-inch balloons may be used, depending upon the sky conditions at the time of observation. On hazy days or when low clouds predominate, or when the velocities at the surface and lower levels are low, 6-inch balloons should be used, thus leaving the 9-inch for days when there is an assurance of a fairly long flight.

Weighing.—The weight of the empty balloon varies widely for both the 6-inch and the 9-inch sizes. The weight of the 6-inch will range from 15 grams to 50 grams, with a mean weight of about 25 grams, while the 9-inch will range from 30 grams to 75 grams, with a mean weight around 52 grams. In determining the weight of a balloon, a balance like that shown in figure 44 is used, and the accuracy is carried to the nearest whole gram. Before weighing the balloon, it is noted that the beam of the balance is in true equilibrium when both pans are free from load and the rider is in position at the zero point on the scale. The balloon is then folded two or three times along the major axis to form a long narrow strip, which is then firmly rolled into a ball, commencing at the apex of balloon, that all air may be expelled through the neck in the process of rolling. If the balloon is prepared in this manner, the weight obtained will for the most part be the actual weight of the empty envelope. If a filling apparatus such as that shown in figure 44 is used, the procedure will vary but little. Equilibrium will be established as with the free balance, the balloon likewise rolled and expelled of air, will be placed over the nozzle and weighed to the nearest whole gram.

Inflation.—Inflation may be classed as "indefinite" and "definite." By indefinite inflation the balloon is filled to a convenient size, and the resulting ascensional rate interpolated from Table 26 (section 8), or computed from the formula. First, the balloon is selected as to size and color, then it is vigorously worked and kneaded in the hands until it becomes warm and flexible. Stretching and kneading it well before attaching it to the nozzle eliminate much bursting during inflation. A mild kneading is not sufficient; it should be pulled and stretched until there is a sensibility of heat when pulled over the hands. The balloon is then carefully folded, rolled, and weighed on a free balance as described above. With the balloon still rolled tightly, it is placed in the palm of the hand with about 1½ or 2 inches of the neck free and protruding from between the fingers and thumb. It is then brought near the nozzle of the filler pipe where it is held until the gas has been turned on at the hydrogen tank. A quick spurt of the gas will drive the air from the tube and this operation is quickly followed by the placing of the balloon over the nozzle. Thus the system is practically free of air and gas. The balloon is then securely wrapped and tied to the nozzle with tape and the gas is allowed to enter the balloon, slowly at first, until the rubber begins to stretch in all directions when the flow may be increased and carried to full inflation. Full inflation should not be accomplished in less than 40 to 50 seconds. Much of the bursting during inflation is due to too rapid filling. The size to which inflation can be carried will depend upon the convenience of the station, that is, the size of passages and openings through which the inflated balloon must be transported to the free air. Balloons should always be inflated inside a building or in a place well sheltered from drafts and currents. The presence of these disturbances, though small in themselves, materially affects the ascensional rate of the balloon. It is necessary that this rate of ascent be measured in still air, free from such gusts. Since the filling will be done inside, the width or size of the opening through which the balloon must be passed to the free air will generally limit the diameters of the inflated balloon. An opening 29 inches wide, the average width of a common door, is equivalent to about 74 cm. and the balloon to be passed through this opening should not be inflated much beyond this diameter, for compression of the balloon to allow passage, and contact with the sharp edges and corners of casings will often result in the puncture of an inflated balloon.

Much care must be given to the handling of the inflated balloon until it is released, for the tightly stretched rubber becomes quite delicate and is easily punctured by contact with relatively blunt corners or rough surfaces. For this reason it is best to set the movable arm of the calipers at the width of the smallest opening through which a successful passage must be made, and then fill the balloon to that diameter. Thus, for an opening of 74 cm. in width, the calipers should be set for not more than 75 cm., and as the inflated balloon approaches this diameter, place the calipers in a horizontal position about the balloon so that one arm of the calipers is in contact with the surface of the balloon. As the increasing size of the balloon reaches the setting of the calipers, shut off the gas by closing the valve on the hydrogen tank.

Sealing.—The balloon is now ready to be sealed and this is accomplished in the following manner: Prepare two No. 16 rubber bands for the tie, by placing them together over the fingers. The two bands are then given a half twist and doubled over to make a 4-stranded ring or loop. With a finger of each hand in this 4-stranded loop, the bands are slightly stretched and the fingers meanwhile twirled a few times so that the strands of the loop may be made even in tension, or the stress on the various strands equalized. The bands will now undergo considerable stress before any one of the strands will break. When this is completed the tie so prepared is slipped half way over the thumb and fingers of one hand, leaving the other entirely free. To apply the tie to the balloon, firmly grasp the neck of the balloon with the free hand about the nozzle and untie the tape. Place the other hand on the under side of the balloon with palm upward and fingers extended to form a shallow cup, and while the inflated balloon is held on the nozzle, it is raised or stretched vertically at the neck, and turned about until the neck is twisted upon itself. Care should be exercised that long or sharp finger nails do not puncture the balloon. By lessening the grip upon the nozzle, the balloon is allowed to slip therefrom and the neck is twisted further to insure a close hard roll or stem. With the free hand the band prepared for sealing is removed from about the fingers and slipped over the twisted portion of the neck where it is tightly wrapped by a series of alternating half twists and loopings accompanied by a firm tension on the bands to insure a tight joint. The balloon is now inflated and, if the foregoing directions have been closely followed, is properly sealed. The next procedure is to measure the free lift or the mass in whole grams which the inflated balloon will just lift from a horizontal plane.

The free lift of a balloon is measured by attaching it to the left-hand pan of the free balance and placing weights thereon sufficient to bring the beam system of balance into equilibrium. In the event that the balloon can not be attached to the scale pan, it may be attached to a 200-gram, or any other known weight greater than the free lift, by means of a rubber band looped at each end as a slip noose. One end of the band is drawn over the neck of the balloon and the other is drawn over the knob of the weight. A weight of 200 grams will ordinarily be greater than the free lift of the balloons inflated to a maximum diameter of 74 cm. When the free lift is greater than 200 grams, the balloon may be attached to a larger weight. The weight with the balloon attached is then placed on the left-hand pan of the free balance which it will depress to the stop. Smaller weights are then applied to the right-hand pan of the balance until equilibrium of the beam system is reestablished. The difference between this weight and that to which the balloon is attached will give the free lift of the balloon. As an example, suppose the weight attached is a 200-gram weight, and the weight applied to the opposite side of the free balance amounts to 19 grams, then the free lift (l) is equal to 200 grams − 19 grams or 181 grams.

With the weight of the balloon (w), and the amount of the free lift (l), as factors, the ascensional rate of the inflated balloon is computed from the formula:

$$V=72\left(\frac{l}{L^{\frac{2}{3}}}\right)^{\frac{5}{8}}, \text{ or} \qquad (1)$$

$$V=72\left(\frac{l^3}{L^2}\right)^{.208} \qquad (2)$$

wherein V = ascensional rate, or vertical velocity of balloon,

l = the free lift, representing the actual lifting force in grams, of the inflated balloon,

L = the total lift, or the free lift plus the weight of the balloon expelled of air.

Formula (1) may be further simplified to the following working form, without alteration of the resulting values:

$$V=72\ (\log l-\frac{2}{3}\log L)^{.625} \qquad (3)$$

Example: Let the weight (w) be 29 grams, and the free lift (l) be 181 grams, then the total lift (L), will be $w+l$, or 210 grams (29 grams + 181 grams = 210 grams). Substituting these values in formula (3) and solving, we have:

$$\log l=2.25768$$
$$-\log L=2.32222\times\tfrac{2}{3}=1.54815$$
$$0.70953\times .625=\log 0.44346=$$
$$\text{antilog } 2.7762\times 72=199.89$$

Thus the ascensional rate for the balloon inflated under these conditions is 200 meters per minute. This operation is greatly simplified by referring to table 26 (section 8), in which the ascensional rate may be found at the intersection of weight column and free-lift line. Reference to table 27 (section 8), "Altitude time-tables for various rates of ascent," for the ascensional rates found will give the height of the balloon for the end of any particular minute during which the balloon may be in the air. In this table it will be observed that the values for the first five minutes do not increase regularly by multiples of the ascensional rates given in the headings of the columns, but that they are in each case slightly larger than the values indicated by those rates. These increased values have been obtained by applying certain additive corrections, viz., 20 per cent for the first minute, 10 per cent for each of the second and third minutes, and 5 per cent for each of the fourth and fifth minutes. For a discussion of the necessity of applying these corrections, see paper by Capt. B. J. Sherry on "The Rate of Ascent of Pilot Balloons," MONTHLY WEATHER REVIEW, December, 1920, pp. 692–694. In case any ascensional rate is used other than those given in table 27, it will be necessary to apply the additive corrections at the time of observation. The computed altitude of the balloon at the end of the first minute will then be 120 per cent of the ascensional rate; at the end of the second minute it will be this value plus 110 per cent of the ascensional rate; and so on. To eliminate this inconvenience it is urged that the "definite inflation" method be employed whenever possible.

Measuring.—Two diameters of the balloon are then measured: The vertical diameter or that along the major axis from the neck to the apex; and the horizontal diameter, or that in a plane perpendicular to the vertical diameter. In making these measurements of balloon diameters, with the balloon calipers, it has been found best to lay the calipers alongside the balloon with the graduated bar about parallel with the diameter to be measured, and the arms well opened and extending to one side disengaging the balloon. Upon the bar as an axis, turn the calipers to engage the balloon at the greatest width and move the sliding arm until the opening between the two arms just contains the balloon. The reading on the main bar at inside edge of the movable arm will be the desired diameter in centimeters. Manipulation of the calipers after this fashion will eliminate much of the bursting during inflation. The balloon is now ready for release.

By "definite inflation," the ascensional rate to be used is decided upon, and the balloon inflated to meet those requirements. Inflation of this nature can be accomplished only with the aid of some filling apparatus, which should be sufficiently sensitive to register the weight of the balloon and the free lift to the nearest whole gram. Figure 44 shows a simple arrangement of such apparatus and works very well when carefully assembled. The balance regularly supplied for balloon work is fitted up as follows: A wooden nozzle, N, figure 44, about 2 inches long by 2 inches in diameter, is turned from a piece of compact wood. The circular surface is corrugated in rings about one-fourth inch apart, which will assist in retaining the neck of the balloon and generally eliminate the need for tying. Through the center of the cylindrical block is bored a hole sufficiently large to receive the end of an elbow or right-angle bend of piping. This completed nozzle is securely fastened to the right-hand side of the balance, centrally over the pan, and with the free end of the elbow extending in a horizontal direction and perpendicular to the line of the beam system. A piece of lead tubing, T, about 20 to 24 inches in length, is passed through the round hole in the base of the balance and thence between the scale bar and fulcrum support until about 6 inches of tubing extend above this point. Note that there is sufficient space between the lead tubing and scale bar to allow the passage of rider on the scale bar. This will necessitate the bending and slight flattening of the tubing at that point. When the lead tubing is all placed, the set screw in the base of balance is turned in to hold the tubing in place, and the remainder of the tubing extending below the base is bent at right angles to pass out at the back of the balance.

A short length of rubber tubing is here attached to connect the lead tubing with a three-way stopcock, C. The remainder of hydrogen line, L, is identical with that supplied for indefinite inflation. About 2 inches of the lead tubing extending above the balance is bent through a right-angle bend toward the front of the balance or in the same general direction as that of the free end of nozzle elbow, N, and the two ends connected with a rubber U-tube, U, of very light flexible material. Tare, or counterweight, W, is then added to the left-hand pan of the balance to bring the beam system into equilibrium, and the apparatus is then complete.

The procedure for definite inflation is as follows: Decide upon the rate of ascent to be used, 160, 180, or 200, etc., meters per minute, Table 28 (sec. 8); see that filling apparatus is in equilibrium; select color and size of balloon, knead, fold, roll, and weigh as above stated. While still firmly rolled, stretch the neck of the balloon over the filler nozzle in a manner similar to that described under indefinite inflation, and turn on the gas slowly. In some instances it will be necessary to tie the balloon on the nozzle, in which case the string is placed on the nozzle side of the balance and the whole system adjusted for equilibrium before the balloon is weighed. While the balloon is being filled, determine the amount of free lift to be given to it by referring to Table 28, under the column head of selected ascensional rate and opposite to the weight of the balloon.

As an example, suppose the ascensional rate selected is 200 m/m, and the weight of the balloon is 34 grams. Then in Table 28, under 200 and opposite 34, it is found that the necessary free lift to which this particular balloon must be inflated is 188.0 grams. Had the ending of free lift been in tenths of grams, it would have been reduced to nearest whole grams. Weights equivalent to that mass are placed on the pan of balance under the balloon. This end of the beam system will then be depressed to the stop. When sufficient gas has been admitted to raise the beam system to the point of equilibrium the valve at the tank is closed. The final adjustment is made by means of the three-way stopcock. Generally the balloon is filled to a point just beyond equilibrium and the surplus of gas allowed to escape through the three-way cock. When the balance is brought to equilibrium under these conditions this particular balloon is properly inflated to give an ascensional rate of 200 m/m. It is now sealed and measured as in indefinite inflation.

If the foregoing instructions have been closely followed, everything is in readiness for an actual observation.

Caution.—Never allow the presence of lighted cigars, pipes, cigarettes, lamps, or lanterns in or near the buildings during the process of inflation. Hydrogen gas when mixed with the air in correct proportions forms a very powerful explosive. Even glowing coals and cinders are sufficient to ignite the gas.

4. MAKING AN OBSERVATION.

Regularly, at all stations unless otherwise specified, observations will be taken at 8 a. m. and 4 p. m., seventy-

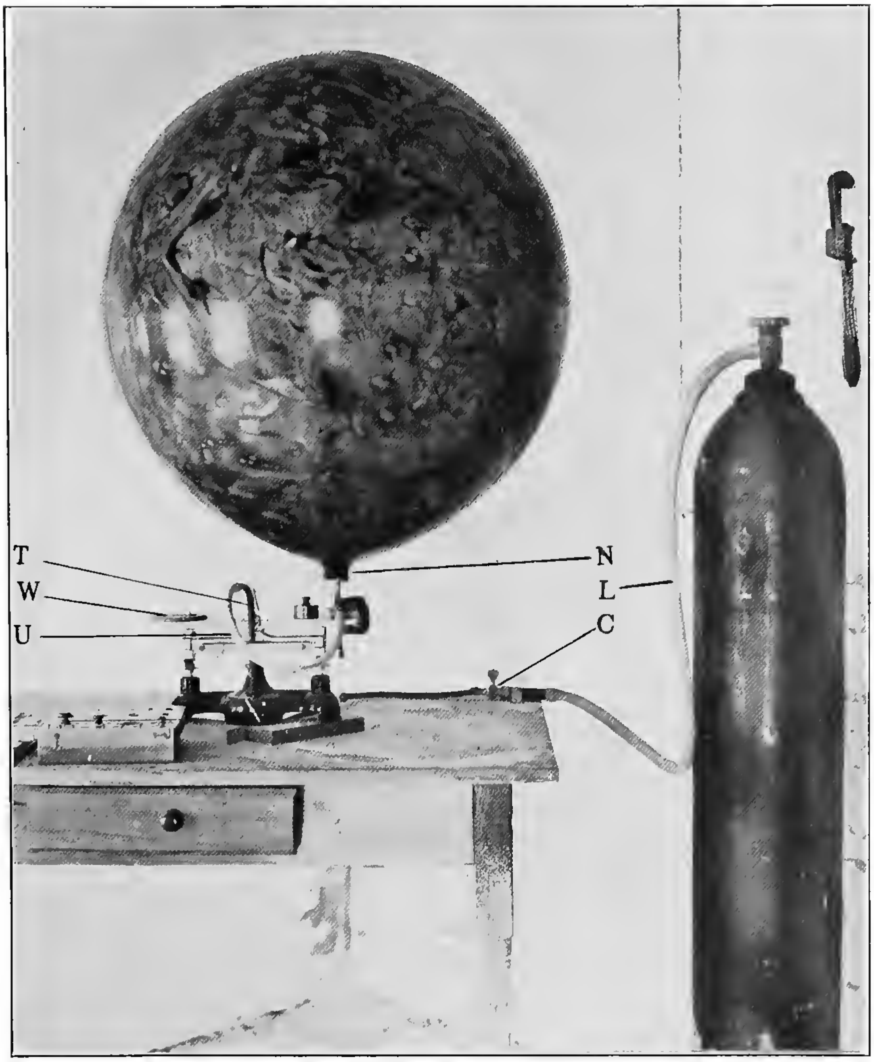


FIG. 44.—Balloon-filling apparatus used for "definite" inflation (*C*, threeway stopcock; *L*, hydrogen line; *N*, filler nozzle; *T*, lead tubing; *U*, rubber U-tube; *W*, counterweight).

fifth meridian time. Occasionally special observations will be requested, and these will be made at the times indicated. But whether morning, evening, or special, the procedure will be identically the same. Not all stations will telegraph both morning and evening observations, but each station will be instructed separately with respect to the observations that are to be telegraphed.

A pilot-balloon observation may be divided into three parts, (1) collection of data, (2) computation and plotting, and (3) reduction and tabulation.

The first part, the collection of data, is the making of the observation itself, and involves the taking and the recording of balloon data, meteorological data, and observed readings of azimuth and elevation angles.

Computation and plotting, the second part, is a connecting link between (1) and (3). It includes the work necessary to prepare the observed data for reduction and tabulation. There are various methods by which this may be accomplished, viz., the slide-rule method; the graphical method, and the logarithmic method.

The last part (3), covers the major portion of the work connected with the average pilot-balloon observation, namely, plotting the flight, determining the direction and velocity at the end of each minute, plotting the velocity-azimuth graph, and reading off and tabulating the values for the specified levels.

The single-theodolite observation requires the services of two men, the observer and the recorder. The materials necessary are the theodolite, balloons, balance and weights, supply of hydrogen, tape or string, rubber bands, measuring calipers, watch or timing apparatus, slide rule, plotting board, graphing board, clip board, ascensional rate tables, conversion tables, forms, art gum, and pencils, both hard and soft.

The observer is responsible for the setting of the theodolite, and the orientation on north or south, the meteorological data, and the proper placement of cross hairs over the balloon during the observation. The recorder is responsible for the preparation of the balloon, reading of angles at theodolite, recording of all data on Form No. 1110–Aer., Table 19, and the computations so far as possible during the observation.

The theodolite, balloons, balance, and weights have been already discussed. The hydrogen used for inflation is supplied, under considerable pressure, in strong steel cylinders. These cylinders when charged should be stored in a cool or at least well-shaded place, and entirely free from exposure to flame or glowing coals and embers. The watch is generally used for marking the time, though there are a few cases in which an idle "triple register" clock has been arranged as a time-interval clock. The slide rule, plotting board, etc., will be discussed in their turn.

To arrange the time-interval clock as mentioned above, run a wire through the binding post of both wind direction and sunshine brush and thence to the battery. From there it is carried to the place of observation, where it is connected to a buzzer, or bell, and passed through a switch, thence back to the ground post of the clock. By this arrangement the clock will give a double signal at the end of each minute. The signals, or the two buzzes, will be about five seconds apart. It should be so arranged that the first buzz will be a little long and quite loud, and the second buzz much shorter and as definitely short as can be successfully arranged. The first buzz will be known as the "warning" signal and the second buzz as the "read" signal. This "warning" signal will give ample time for the observer to center the balloon and the recorder to prepare for the reading of the angles. Without the interval clock it will be necessary to keep close watch of the time, in which case the "warning" signal will be called by the recorder about five seconds before the expiration of the minute, or the "read," signal. Generally the balloon is released on the full minute, therefore the "read" signal would occur at the sixtieth second and the "warning" signal on the fifty-fifth second.

Since the observer is entirely responsible for the data obtained by theodolite when the angles are carefully and accurately read, he will set up the instrument over the observation point, level, and orient as described in earlier paragraphs under "The Theodolite," section 2. Suppose this setting to be with an elevation angle of 1°.3 and the azimuth angle of the 45° horizontal vernier to be 345°.6 with zero of the base plate on north. (See Table 19.)

After setting of the theodolite is completed, the observer will note and record the current meteorological data comprising the amount, kind, and direction of movement of the clouds, the direction and velocity of movement of the surface wind, the current temperature and the wet bulb temperature, the pressure, and the relative humidity. Where a regular meteorological observation has been taken within 15 minutes of the actual starting time of the balloon ascension (time of balloon release) that meteorological observation may be used instead of taking another. But in the event that a period of more than 15 minutes of time has elapsed, a separate and complete meteorological observation will be made. The results of this meteorological observation and the settings of the theodolite will be entered in the respective spaces upon the work sheet, or Form No. 1110–Aer.

In the meantime the recorder will select the size and color of balloon to be used, weigh, inflate, and measure the free lift and ascertain the ascensional rate as instructed under "Inflation," section 3. Suppose the balloon selected is a 6-inch red, and it is to be given a definite inflation to attain an ascensional rate of 200 m/m. The weight of the balloon is found to be 38 grams. When referring to Table 28, we find that a free lift of 193.1 grams is required to give the inflated balloon an upward velocity of 200 m/m. Since the free lift of inflation is measured only in whole grams, this will be reduced to 193 grams and balloon inflated to that point. All of these data will be recorded in the proper spaces on Form No. 1110–Aer. as soon as they are determined.

TABLE 19.

[Form No. 1110–Aer.]

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

PILOT BALLOON ASCENSION REPORT.

Station (place of observation).
Ascension number, 2136.

Date, July 10, 1920.
Number of theodolites used, 1.

Starting time, 8:26 a. m.
75th meridian time, ...

Observation point, A. Altitude, 55.3 m.

Minute.	Elevation angle.	Azimuth angle.	Distance from observation point.	Altitude.	Wind direction.	Wind velocity.
	°	°	m.	m.		m. p. s.
0	1.3	345.6	Zero setting on north.			
1	16.7	203.4	800	240	222	8.6
2	25.6	221.7	960	460	242	8.6
3	21.35	225.1	1,736	680	233	11.3
4	21.35	222.6	2,272	890	205	9.6
5	21.2	217.2	2,840	1,100	195	10.0
6	21.05	213.8	3,380	1,300	194	10.0
7	20.7	210.2	3,968	1,500	196	9.8
8	20.65	209.5	4,508	1,700	206	6.2
9	21.9	208.5	4,728	1,900	156	3.0
10	23.95	205.9	4,732	2,100	114	7.1
11	25.95	199.2	4,724	2,300	108	10.8
12	27.9	190.3	4,720	2,500	105	12.0
13	29.2	183.0	4,832	2,700	80	14.0
14	33.3	169.5	4,420	2,900	68	17.8
15	35.1	155.7	4,408	3,100	72	16.2
16	35.6	144.7	4,612	3,300	73	12.8
17	35.85	137.3	4,840	3,500	67	13.2
18	35.5	127.4	5,180	3,700	67	15.2
19	34.3	120.0	5,720	3,900	66	16.8
20	32.65	111.3	6,400	4,100	80	19.6
21	29.2	108.6	7,680	4,300	81	19.3
22	27.95	103.3	8,480	4,500	63	18.4
	1.3	345.6	Checked.			

Theodolite number, 17396
Observer, Patrick Henry
Recorder, John Doe
Disappearance due to haze

Observation point, ... Altitude, ... m.

Minute.	Elevation angle.	Azimuth angle.	Distance from observation point.	Altitude.	Wind direction.	Wind velocity.
	°	°	m.	m.		m. p. s.
0			Zero setting on			

Theodolite number, ...
Observer, ...
Recorder, ...
Disappearance due to ....

Diameter at full lift—
Vertical, 80.0; hor. 74.0 cm.
Weight, 38 gm.
Free lift, 193 gm.
Total lift, 231 gm.

Rate of ascent from—
Tables, 200 m. p. m.
T-A curve, m. p. m.
Type of balloon, 6″ Red.

Clouds.	Amt.	Kind.	Dir.
Upper	1	Ci	WSW.
Inter			
Lower	1	Cu	NNE.

Surface wind direction, NNE.
velocity, 10 m/h. 4.5 m/s.
Temperature, 23°.3–18°.5 C.
Pressure, 1,017.9–1,021.7 mb.
Humidity, 62%.

Baseline, ...; length, ...
Azimuth, ...
Visibility, Good.
Sun, Bright.
Notes, ...
No ascension for—
a. m. Date p. m.
low clouds. 9. rain.

Now that all is in readiness for the observation, the ascension will be started, or the balloon will be released. The recorder will be provided with Forms No. 1110–Aer. on a clip board, hard pencil, slide rule, and watch. The observer will hold the inflated balloon near to and about level with the theodolite head, until the signal of "read" (or release) is pronounced by recorder or is given by the time-interval clock. If the time-interval clock is used the balloon will be held in readiness at the first buzz, and released on the second buzz. The exact time of release to the nearest minute is noted and recorded in the proper space at the top of Form No. 1110–Aer. If the watch alone is depended upon for time, then the recorder will be forced to watch the time and call out the signals "warning" and "read" as they occur. By the latter system of time marking the balloon will be placed in readiness at the signal "warning" from the recorder at the fifty-fifth second, and released at the following signal of "read," at the sixtieth second. Also the exact time of release is noted and entered upon Form No. 1110–Aer. Suppose the starting time to be 8:26 a. m. As the balloon rises and moves out from the station the observer will determine the direction of wind movement to the nearest of the 16 compass points, which he will call to the recorder, who will enter the same on Form No. 1110–Aer. Suppose this to be NNE. Note that the wind direction will be just opposite to that toward which the balloon moves.

As soon as the balloon has moved away from the observation point sufficiently, the observer will sight the main tube of the telescope upon the balloon, by means of ball and V sight, then throwing in both tangent screws *VT* and *HT*, figure 35, continue to sight balloon over the main tube while turning the tangent screws to keep the theodolite trained upon the balloon. Note that object end of telescope is always inclined toward the left as the observer looks through the front; that is, the elevation angle at *VV*, figure 35, must never be greater than 90 degrees. When the rate and character of motion to keep the balloon in line of sight have been attained, continue the movement, and quickly change the position of the eye to look through the telescope at front or eyepiece. If the rate of movement has been properly judged, the balloon will appear in the field near the intersection of the cross hairs. Thereafter the observer will keep the balloon in the field by suitable movement of the tangent screws.

When the surface wind velocity is low, oftentimes there will be much difficulty experienced in placing the balloon in the field of the theodolite. Under such conditions much assistance can be given by the recorder. The observer posts himself at the front of the telescope with hands placed on the respective disengaged tangent screws. The recorder, with one hand on the telescope standard and the other on the main tube of the telescope, will turn the telescope until the vertical plane of movement is in line with the balloon, and, holding in this position, will slowly turn the telescope over its vertical axis until the balloon comes into the field of the telescope. When this occurs, the observer will throw in the tangent screws and proceed as directed above.

Fifty-five seconds after the release of the balloon, a signal of "warning" will be given, either by the recorder or by the time interval clock. When this signal is given, the observer will bring the intersection of the cross hairs directly over the balloon and keep it there until the second signal of "read" is given, when the motion will be stopped to allow the reading of the angles. The recorder, at the "warning" signal, will post himself just behind the observer and a little to the right, so that he can easily see both elevation and azimuth verniers, and make a mental note of the degrees of each. Then at the signal "read," as quickly as possible after the motion of tangent screws has been stopped, the angles of elevation and azimuth will be read and recorded on Form No. 1110–Aer. Always read the azimuth angle from the same horizontal vernier by which the theodolite has been oriented.

Ordinarily the observer will read one angle and the recorder will read the other. Whether the observer reads the elevation angle or the azimuth angle depends largely upon the way the base plate is oriented. If the orientation setting is on the right horizontal vernier *HV*, figure 35, it is better for the observer to read the azimuth angle and the recorder the elevation angle, but if the orientation setting is on the 45° horizontal vernier *hv*, figure 35, then it is better for the observer to read the elevation angle and the recorder the azimuth angle. In any event, the observer should not attempt to read *either* angle during the first five minutes or more, for during this time the lateral movement of the balloon is so great in comparison with the field of the telescope that it is easily lost from the field, and this often results in the entire loss of time and material. The data for a minute or so might better be lost than to lose the balloon at this early stage. The recorder has nothing else to do at that time but read the angles.

To read either of the angles it is not necessary for the observer to remove his eye from the telescope tube, and thereby lose the focus of balloon, but he may read either angle with the other eye. To read, retain the eye in the position as though peering through telescope and cast the other eye upon the vernier to be read. A little practice will prove this to be as simple and easy as though reading with both eyes.

The observer will find that much relief is obtained, and much eye strain eliminated, by observing with both eyes open. Do not squint, or close the unused eye. A little practice will enable the observer to keep one eye at the instrument and read one angle with the other eye without difficulty. When he becomes proficient, even though the gaze of the one eye may be directed upon one or the other of the verniers, the other eye will gain and register an impression of the movement of the balloon, and should the balloon pass a little from the field during the reading, it may be regained readily by aid of the movement just mentally registered.

Many instances will arise, however, wherein the observer will be unable to read either angle due to the fact that the balloon movement is so rapid as to require his full attention. In such cases, the recorder will read both angles, reading that first which the observer indicates is changing the more rapidly. A reading should be missed rather than be the means of losing the balloon. During the first 2 to 4 minutes the balloon can generally be seen by the naked eye, and thus easily placed in the field again. In a few instances, principally when the balloon turns and comes back directly over the station, the balloon movement will be more rapid than can be followed by turning of the tangent screws. However, loss of the balloon can be prevented without much difficulty if the following instructions are closely followed. While grasping the horizontal tangent screws, *HT*, figure 35, between the thumb and forefinger of the right hand, extend the middle finger past the 45° horizontal vernier, *hv*, figure 35, to rest upon the threaded groove of the baseplate, *BP*, figure 35, just below the edge of the revolving plate of the telescope standard. Letting this act as a brake, carefully throw out the tangent screw and retain the finger so placed. It is unnecessary to release the hand-hold upon the knurled head of the tangent screw. It acts as a rest for the hand. In a similar manner the middle finger of the left hand is extended until the ball of the finger is placed over the small space between the back edge of the vertical circle, *VC*, figure 35, and the pivot bearing near the middle of vertical tangent screw. Exercise a firm pressure here, then throw out vertical tangent screw and shift the thumb and forefinger to grip the edge of vertical circle, *VC*, figure 35. The middle finger in each case acts as a brake, steadying the movement of the telescope through the respective planes. With the fingers so placed and a little careful judgment on the part of the observer, it is an easy matter to follow a balloon going overhead at a good rate of speed. When the rate of movement has diminished sufficiently, the tangent screws are gradually thrown in again and the ordinary procedure followed.

In *single-theodolite observations* the angles will be read to the nearest tenth of a degree (see description of vernier and figs. 36 and 37), and only at the completion of the minute as signaled by the time interval clock or the recorder. At the signal "warning" it is well to read the angles to the point of ascertaining the whole degrees, then the final reading or the reading to tenths of degrees can be made in much less time and directly at the "read" signal. It is practically necessary that the angles be read quickly and accurately. Comparatively small errors in reading angles can be detected when the run is carefully plotted. Thus the necessity for quick and accurate work.

As soon as the angles are read, the observer will bring the balloon near the center of the field by means of the tangent screws, where he will keep it until the following "warning" signal is given. In the meantime the recorder will enter the reading that he has made in the proper column on Form No. 1110–Aer., and opposite the corresponding minute. Suppose the azimuth angle for the first minute, read by the recorder from the 45° horizontal azimuth vernier, is 203°.4; this he will record in the column under azimuth angle and opposite 1 in the minute column. The observer then calls out the angle which he has read and the recorder enters this; e. g., 16°.7 in the column headed "Elevation angle."

During the time that is left between the readings the recorder will compute the values for the column headed "Distance from observation point" with the slide rule. Explanation of this process will be taken up in following sections. By doing the computation at this time fully 25 per cent of the working time of an observation will be saved, and permit an earlier filing of the coded message in the telegraph office. At the recurrence of the "warning" signal all other duties will be suspended and the full attention of both men given to the placing of balloon on cross hairs and the accurate determination of the angles. This same procedure obtains so long as the balloon can be kept in sight. When the balloon disappears, the observer will call out the reason for such disappearance and then check the setting and orientation of the theodolite. This reason of disappearance and the results of rechecking will be entered on Form No. 1110–Aer. in the proper spaces. Let Table 19 be the Form No. 1110–Aer. of an observation containing the above mentioned data.

When the orientation setting is checked there is seldom any change necessary to be made. When the change amounts to a few tenths of a degree there is little that can be done in the way of correction, unless it is evident that the setting has been in error throughout the flight. Corrections should be made to the azimuth angles when there is reason to believe that such corrections should be made. This will emphasize the need of care and attention to the minutest detail throughout the whole of the observational work.

The cause of disappearance will be recorded according to the following reasons. They stand in their order of frequency and relative importance.

1. Clouds:
   - Against.
   - In base of.
   - Obscured by.
2. Burst.
3. Distance.
4. Haze.
5. Sun.
6. Obscured by—
   - Tower.
   - Chimney.
   - Etc.
7. Overhead:
   - High elevation angle.
   - Rapid change of angles.
8. Accident:
   - Kicking of theodolite.
   - Allowed to pass off field.
   - Vibration of theodolite, etc.
9. Abandoned.

When the disappearance is due to clouds, it will be specifically stated whether against, in, or behind clouds. If this is not known, a statement to that effect should be made. If the balloon is seen to enter the base of clouds, particular attention will be given to the azimuth and elevation angles of the balloon, and the fractional part of the minute of the balloon's disappearance after the last minute reading. The product of this fraction of a minute into the rate of ascent, when added to the altitude of balloon for the last minute observed, will give the altitude of the cloud base. The direction and velocity of clouds is then computed in the same manner as for any other specific point of the projection. (See section 5.)

Disappearance due to distance will not occur during a short flight, except in rare cases where there is a very strong wind at the surface and aloft. A distance of 10 kilometers is the minimum value for this entry. Horizontal distances of less than that amount are due to other causes, possibly haze, fog, etc. Occasionally the balloon will run across the sun's disk, making observation impossible; however, such instances should be rare, since the theodolites now in use have a special eyepiece with pivoted disc of colored glass, permitting observation until the balloon actually begins to cross the sun. Other instances will occur when the balloon will be lost behind the anemometer tower, chimney, or other obstruction. At a properly selected station possessing low angle of obstructions this reason will be of small frequency. The entry will be made, "obscured by ----------." During periods of low surface wind velocity, the elevation angles for the first few minutes will be relatively high. In fact, the balloon may be directly overhead. The balloon may change its course and come back directly over the observation station. The change of the angles, especially the azimuth angle, will then be rapid. In case of disappearance due to either of these causes an explanatory note should be entered after the entry "Overhead." There will be a certain amount of loss due to accident, which is caused by the kicking or knocking of theodolite sufficiently to throw the balloon out of the field. This disappearance is due to carelessness, and with due attention to the work at hand will be eliminated altogether. Strong surface winds will sometimes throw the theodolite into such a state of vibration that the balloon can not be accurately placed at the cross hairs, and this will finally result in the loss of balloon altogether. An explanatory note must also accompany the entry of accident. There are but few cases when the balloon will be abandoned, principally to permit the early file of a coded message containing the observed data.

The checking of the setting and orientation is accomplished by setting the telescope of the theodolite upon the orientation point and noting the readings at the same verniers by which the theodolite was originally oriented. If there is no change within a few tenths of a degree, the readings will be entered in the proper columns on the second line under the last entry of observed angles, as "check." Otherwise, corrections will be made on the observed data. In this instance the setting at the end of the observation was identical with that of the initial orientation, 1°.3 elevation, and 345°.6, azimuth angle.

Double-theodolite observations require the cooperation of three, four, and sometimes more men, all depending upon the arrangement of station and scope of work at hand. The prevailing arrangement of double theodolite station requires four men for the observation work, an observer and a recorder posted at each station. Their respective duties are nearly identical with those in a single-theodolite observation.

Little or no slide-rule computation work is done while the observation is in progress. During the time that the primary station is preparing the balloon and setting the theodolite, those detailed for duty at the secondary station will have arrived at that station, set, and oriented their theodolite according to one of the methods set forth in "Orientation of theodolite," section 2.

Each station will be provided with a signal flag about 3 feet square, and attached to a short pole, or staff, to facilitate signaling to the other station. When all is ready at either station the signal flag will be exposed so that the men at the other station can see it. When both preparation signals are posted, all is in readiness for the ascent. The actual mode of signaling of the balloon release should be adopted and understood by all of the observers. Two methods are here given, both of which have been found to be very satisfactory. In the first, when the preparation signal at the primary station is answered by that of the secondary station, the recorder at the primary station, commencing one minute before the balloon is to be released, will wave the flag vigorously and in plain view of the observer at the secondary station for a period of 55 seconds. At the end of this time the flag is poised high above the head for the succeeding interval of five seconds, at the expiration of which the flag is brought down with a decided stroke. At the final downward stroke, the observer, who has been holding the balloon near the head of the instrument, will release it. The time of release will be noted and recorded at both stations, their time pieces having been compared before the flight. When the time pieces are not compared and set together previous to the flight, there is likely to be much inconvenience at the secondary station in regard to the watch time of warning and read signals. They may come at 21, 29, 51, or any other odd second.

Another method of signaling the release of the balloon is to expose the inflated balloon at arms' length above the head in full view of the observer at the secondary station. When all is in readiness for the release, the observer at the primary station will lower the balloon to the ground about 10 seconds before the time of release, where he will hold it for five seconds, at which time he will raise it to the initial position above the head. On the expiration of the minute, or on the sixtieth second, he will release the balloon. The recorder at each station will note and record the time of release as in the preceding method.

As soon as the balloon is released, the signal flags will be taken down at both stations by the recorder. The observers at both stations will immediately sight their theodolite upon the balloon and follow closely as instructed under single-theodolite observation. The observer at the secondary station will have little difficulty in this matter, since his theodolite is already trained upon the balloon at the primary station. When the balloon is released he has only to follow it by manipulation of the tangent screws. Location of the balloon at the primary station will be identical with that during a single-theodolite observation.

At each station the recorder will have to note the time and call signals for the readings which will be taken at the end of each successive minute from the time the balloon is released. The data at primary station will be entered on left-hand half of Form No. 1110–Aer., Table 20, and when that half of the sheet is filled up, a second sheet will be used. In single-theodolite work the second or right-hand half of the sheet would be used for the continuation of the data, but with the double-theodolite work the second half of the sheet is reserved for the entry of the data of the other station. Thus we have all the observed data for any one minute at both stations, on the same sheet and in the same lines. The data at the secondary station will be entered on the right-hand side of the sheet only. Form No. 1110–Aer. will provide for a single-theodolite run of 60 minutes, but only for a run of 30 minutes for double-theodolite work, Table 20. At the completion of the observation the data from the one station will be copied on the Form No. 1110–Aer. of the other.

TABLE 20.

[Form No. 1110-Aer.]

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

PILOT BALLOON ASCENSION REPORT.

Station (place of observation).
Ascension number, 1111.

Date, July 14, 1920.
Number of theodolites used, 2.

Starting time, 7 :25 a.
90th meridian time, ...

Observation point, A of A B. Altitude, 228.14 m.

Minute.	Elevation angle. °	Azimuth angle. °	Distance from observation point. m.	Altitude. m.	Wind direction.	Wind velocity. m. p. s.
0	0.0	0.0	Zero setting on north.			
1	31.1	43.5	400	242	56	6.9
2	28.2	56.5	840	450	82	8.4
3	26.4	72.0	1,320	656	93	11.9
4	21.4	79.3	2,160	850	89	13.7
5	19.6	81.6	2,930	1,044	89	11.7
6	19.2	83.1	3,555	1,240	89	10.4
7	19.0	83.8	4,160	1,435	94	11.7
8	18.2	86.2	4,975	1,635	101	12.9
9	17.6	88.3	5,650	1,795	97	13.3
10	16.9	88.9	6,510	2,005	90	16.1
11	16.3	88.7	7,600	2,225	87	18.0
			Check			

Theodolite number, 13394.
Observer, John Doe.
Recorder, Patrick Henry.
Disappearance due to: Obscured by St. Cu. cloud.

Observation point, B of A B. Altitude, 230.33 m.

Minute.	Elevation angle. °	Azimuth angle. °	Distance from observation point. m.	Altitude. m.	Wind direction.	Wind velocity. m. p. s.
0	0.0	0.0	Zero setting on north.			
1	7.1	314.3				
2	15.5	330.4				
3	25.3	349.4				
4	29.7	24.9				
5	28.0	45.1				
6	26.8	55.8				
7	25.1	62.0				
8	24.2	69.5				
9	22.8	74.9				
10	21.2	77.9				
11	19.8	79.4				
12	18.9	81.2				
13	18.3	83.6				
14	18.0	85.2				
		Check.				

Theodolite number, 12348.
Observer, James L. Jones.
Recorder, M. S. Smith.
Disappearance due to: Enter St. Cu. cloud.

Diameter at full lift—
Vertical, 75.5; hor., 71.0 cm.
Weight, 37.5 gm.
Free lift, 172.0 gm.
Total lift, 209.5 gm.

Rate of ascent from—
Tables, 191 m. p. m.
T-A curve, 202 m. p. m.
Type of balloon, C.-R.-6"

Clouds.	Amt.	Kind.	Dir.
Upper			
Inter	2	A. St	W.
Lower	8	St. Cu.	W.

Surface wind, direction, SW.
velocity, 4.5 m/s.
Temperature, 22°.5 C.
Pressure, 989.2 mb.
Humidity, 89%.

Base line, A. B.; length, 1781.86.
Azimuth, 122°.55.
Visibility, Fair.
Sun, Obscured.
Notes, Weather cloudy.

The balloon will be followed as long as it can be kept in sight. Never should it be abandoned at either station before disappearance, without strong reasons for doing so. However, as soon as the balloon is lost at either station the flag will be raised as a signal to the other station. In cases where the balloon is lost sight of at one station for an appreciably longer period than at the other, the remainder of the flight beyond the time of disappearance at the one station may be computed by the single-theodolite method.

Following the disappearance of the balloon, and before the theodolite is disturbed from its setting, a check of the levels and orientation will be made. Note that the azimuth bearing is read from the same vernier by which the theodolite was oriented. If there are no corrections to be made the "check" will follow in the second line after the last line of observed data. The data will then be plotted and reduced in the same way as in the making of a single-theodolite observation. The methods of plotting vary to some extent, however, and will be taken up in regular order in subsequent paragraphs.

In but few cases will slide-rule computations be performed during the double-theodolite observation. In many cases, however, it may be possible to do the computation and plotting while the flight is in progress. In such instances the computing work is generally carried on at a third point, which has telephonic communication with both observation stations. All three terminals of the line end in a head set, which allows free use of hands, and yet provides for the immediate use of the telephone. A time-interval system is easily installed in the telephone line, and will serve to mark the release of the balloon and the observation signals for each of the successive minutes, making it possible to read the angles at both stations at the same instant. Communication from the primary station will prepare the secondary station for the time of balloon release.

When the observing stations are connected by telephone, then an observation can be carried on with only three men. But if computation and plotting are carried on during the flight, then four or more men will be needed. The regular force of two men obtains at the primary station, where they perform their regular duties much the same as in a single-theodolite observation, with the exception that the recorder, speaking plainly, calls the observed data to the third party in the computing room. At the secondary station one man can easily observe the balloon and read the azimuth angle, which he calls to the computer over the telephone. Where this practice is carried on it is best to orient the theodolite by the right azimuth vernier. The computer, or the party in the computing room, receives and records all data from both stations, placing that of primary station on the left-hand half of sheet and that of the secondary station on the right-hand half of the sheet. He then immediately plots the data, or constructs the horizontal projection, before the lapse of the whole minute. The recorder at the primary station will receive and record the angle or angles reported by the secondary station. This will be the original record and should be rendered in carbon with data from both stations and on the same sheet or sheets.

At any convenient time during the ascension the visibility and condition of the sun will be noted and recorded according to the following scales:

Visibility scale.

Scale.	Descriptive term.	Limiting distance (meters).
0	Dense fog—prominent objects not visible at	50
1	Very bad—prominent objects not visible at	200
2	Bad—prominent objects not visible at	500
3	Very poor—prominent objects not visible at	1,000
4	Poor—prominent objects not visible at	2,000
5	Indifferent—prominent objects not visible at	4,000
6	Fair—prominent objects not visible at	7,000
7	Good—prominent objects not visible at	12,000
8	Very good—prominent objects not visible at	30,000
9	Excellent—prominent objects visible beyond	30,000

This scale is nearly self-explanatory. The distances can be laid off on a map of the section of the country, and prominent objects selected as the points of reference.

Sun brightness scale.

1. Brilliant—Of rare occurrence; atmosphere must be exceptionally clear; smooth surfaces and shiny objects glisten.
2. Bright—As in a normal clear sky.
3. Intermittent—Alternate sun and shadow; sky containing clouds of the bunch formation.
4. Through clouds—Sun quite dimmed by continuous clouds; grayish appearance.
5. Faint—Disk of sun barely visible through clouds of sheet formation, as Ci. St., A. St., or St.
6. Obscured—Sun completely hidden by any dense cloud layer.

This scale is also self-explanatory. In each case the sun brightness and the visibility will be entered on the Form, using for this purpose the appropriate terms rather than the numbers; e. g., "brilliant," "faint," "dense fog," etc.

Omission of an Ascension.—It sometimes happens that at the time of the scheduled pilot-balloon observation the weather conditions are such that an observer might carelessly or indifferently call off an ascension when it is really possible to make a satisfactory observation. For example, a light sprinkle of rain might be sufficient to give the observer the excuse for calling off the ascension, even when the drops are so few as to cause neither injury to the theodolite, discomfort to the observer, the early disappearance of the balloon, nor appreciable retardation in the ascensional rate of the balloon. Snow flurries of short duration often preclude an ascension at the scheduled time, when a very few minutes later an ascension would be easily possible and worth while. It is expected that an ascension will be made within 30 minutes of the scheduled time, either before or after, if weather conditions are such as not positively to forbid the making of an ascension. It is recognized that there are times when it would be a waste of balloon and gas to attempt an ascension; but, on the other hand, conditions must not be too easily and quickly dismissed as belonging to this class. In general, it may be said that an ascension should be made under all conditions except those which incur danger to the instrument, marked discomfort and possible injury to the health of the observers, or a loss of the balloon below 250 meters. If such conditions disappear within 30 minutes of the time of the scheduled observation the ascension should be made; and if it is judged that such conditions may occur at the time of observation, the ascension should be begun early, possibly as much as a half hour.

It is recognized that, in the last analysis, the question of omitting an ascension is one that must be decided locally, and that no ironclad rules can be set down in instructions. But it is a question that has a strong personal element, and is one that must be answered conscientiously by those concerned. Times when ascensions are likely to be omitted owing to unfavorable weather conditions are often those which would be of greatest scientific value. The observer should bear in mind at all times the value of the data he is securing and the many uses to which they may be put, and he should try to cultivate such a spirit of sincerity. This, coupled with good judgment, is certain to result in the satisfactory collection of aerological data.

5. COMPUTATION.

The second part in making an observation, or the computation, may be accomplished by either one of three methods; that is, by slide-rule method, graphical method, or by logarithmic computation. The computation of single-theodolite observations is nearly always done by means of the slide-rule method, though the graphical method is frequently used when men doing observation work are not proficient in manipulation of the slide rule. The slide-rule method saves much time when there is a limited period during which the observation must be completed, and for the same amount of time expended on either method will give results more closely comparable with the results by logarithms. The logarithmic method is seldom used in single-theodolite computation because of the time involved in the work. Practically the only use made of it is as a means of checking the computation by either of the other methods.

The slide-rule method provides a means whereby the observed data can be reduced during the observation itself for the construction of the horizontal projection immediately after the completion of the ascension, whereas by either of the other two methods the computation must be suspended until the making of the observation is complete, and by one of these until after the horizontal projection is made. By the graphical method more than the observed data is not determined until after the horizontal projection has been made.

Double-theodolite computation is generally accomplished either by the graphical method or by the logarithmic method. The slide rule is frequently used for the solving of the trigonometric formulæ when immediate general results are desired. The greatest accuracy is attained by the logarithmic method, though it involves considerably more time than the graphical method. Computation by logarithmic method is preferred, though the graphical method will be used frequently. All methods will be given full discussion in the following paragraphs.

Method I. (1). Single-theodolite computation, slide-rule method.—The slide rule used by the Weather Bureau for the computation of pilot-balloon observations is the K. & E. polyphase duplex slide rule. It is a 10-inch rule of mahogany, with the scales graduated upon a white celluloid base. The principle of the slide rule is purely logarithmic, and each scale is graduated after that principle, but the manipulation of it and the work done with it are purely mechanical and can be readily taken up without the slightest knowledge of logarithms.

The scales of the slide rule in general use for pilot-balloon computation are the tangent scale T, the sine scale S, and the associate scales of D and A. For single-theodolite computation, little but the T and the D scales will be used, and these in conjunction with the formula $\tan e = \frac{h}{d}$, will be sufficient.

e = the observed elevation angle for any one minute, which is found on T scale of central slide of rule.

h = the theoretical altitude or elevation of balloon at end of each minute. It is the product of ascensional rate into time in minutes from release of balloon. This value is found on the lower or D scale of the slide rule.

d = the horizontal distance from the observation point to a point directly underneath the balloon.

A complete manual of instructions is furnished with each slide rule, and for that reason but little attention need be given here to the manipulation of the slide rule. Therefore, special reference is made to sections 3 and 7, and to pages 2 and 16 of the "Mannheim and Polyphase Slide Rule Manual." The supplement at the end of the manual will give much information of practical interest.

Slide-rule computation for pilot-balloon work is affected to some extent by the elevation angle, which separates the work into two phases, namely, elevation angles less than 45° and elevation angles greater than 45°. While an explanation of computation involving an elevation angle of more than 45° is given early in section 7 of the manual, the direct application to pilot-balloon computation can be stated in simpler form, and will follow later. In ordinary computation, the elevation angle is less than 45°, and in such cases the procedure is simple enough.

To compute the value d from the formula, $\tan e = \frac{h}{d}$, where e is less than 45°, the runner of the slide rule is set at h, in meters, on the D scale of slide rule, and then central slide is moved until the elevation angle e (for the same minute) on scale T is brought under the hair line of runner. The value of d is then read from the D scale of slide rule under the index of the central slide. In some instances this will be the right index and at other times it will be the left index. With reference to data sheet for single-theodolite observation, Table 19, to compute the distance out for the first minute, set the runner of slide rule on 240 of the D scale, then adjust the central slide until 16°.7 (the elevation angle for the same minute) on the tangent scale is placed under the hair line of runner and coincident with 240 on the D scale. Under the right index of slide and on the D scale read 800 meters. Notice that the subdivisions on the T scale for angles less than 20° are equivalent to 5 minutes of arc and those subdivisions from 20° to 45° are equivalent to 10 minutes of arc, while the divisions of angles as read from the theodolite are in degrees and tenths of degrees. Therefore, it will be necessary to convert the tenths of degrees to minutes in order to make the settings of T scale accurate. This is a simple mental operation accomplished by multiplying the tenths of the angle by 6, the resulting product being the fractional part of the angle converted to minutes. This value found will be recorded on the Form No. 1110–Aer., in the column headed "Distance from observation point." Proceed with the remainder of the flight in the same way, making sure that each computation is made only on altitude and corresponding elevation angle.

When the elevation angle is above 45°, set the index of the T scale over h found on D scale, set the hair line of the runner over the elevation angle found on T scale, and read the value d under the hair line of runner on D scale. This value is the quantity sought, and is to be recorded in the corresponding space on Form No. 1110–Aer. As an example, suppose the elevation angle is 54°.9 and the altitude of the balloon is 600 meters. To compute the value of d for this case we would set the index of central slide over 600 on the D scale, then on the T scale of the central slide we would find the angle 54°.9 and place the hair line of the runner thereon. Under the hair line and on the D scale we would read off the value of d, or 422 meters. It will be noticed that the T scale provided only for angles of 45° or less, and since the function of an angle is equal to the cofunction of the complementary angle, the operation involves a reversal of the method when an angle of more than 45° is recorded. To simplify the settings when the angles are greater than 45°, let the 5° divisions of the tangent scale be re-marked beginning at the 40° division which will be designated as 50°; 30° will be 60°, etc. If these divisions are marked upon the celluloid surface of the rule in red ink, it will be found to assist greatly in the settings for angles greater than 45°. Let it be noticed and used as a check that the results of all slide-rule computations made on angles of elevation *less* than 45° will be *greater* than the h value on which the computation was made. Similarly, the results of all slide-rule computations made on angles of elevation *greater* than 45° will be *less* that the corresponding *h* factor.

Some difficulty is had in making the final close adjustments of the central slide during the computation. The following method, when closely followed, will eliminate any such trouble: Hold the rule between the thumb and first finger with one hand at either end of the slide rule so that the ball of the thumb and the tip of the first finger are placed over the seam of the slide rule between the rule itself and the central slide. Now, to make the setting, apply the principle of the parallel rule; that is, while firmly holding the rule as directed, extend one hand and arm while the other is drawn backward. This motion will cause the slide in the rule to move gradually and smoothly toward the end of rule which is being extended. Reversing the operation will drive it to the other end. By performing this movement slowly, the setting can be made as close as the eye is able to determine.

Plotting, or the construction of the horizontal projection.—Immediately after the observation is taken and computation is completed, the data will be plotted and reduced. The process of plotting is slightly different for the two methods, slide-rule computation and graphical method. As a matter of fact, the computation in the graphical method is preceded by the plotting or the construction of the horizontal projection. Plotting from logarithmic computation is identical with plotting from slide-rule computation, though more accurate, and also a much longer operation.

The plotting board in use throughout the service is the most practical apparatus of its kind which has yet come to our knowledge. After prolonged study of various methods this board was selected for its simplicity and accuracy. It consists of a drafting board about 42 inches square. Over the central area is glued a circular sheet of millimeter cross-section paper. At the center of the area, and set into the board, is a brass bearing and pin A, figure 45. From the center of this pin or post three distance scales are drawn: Scale AC is a single scale and so constructed that 1 cm. = 100 m.; AD is a double scale in black and red. The divisions on the black scale, or the right side of the scale base, are such that 1 cm. = 200 m., and the red scale, or that on the left side of the scale base, is equal to 1 cm. = 400 m. Let these scales be designated as 1, 2, and 4. The number of the scale will correspond to the number of hundred meters which 1 centimeter will equal. Let the lines on which the scales are graduated be known as the indices of the *d* scales, and let the scales themselves be known as *d*–1, *d*–2, and *d*–4. At a convenient distance from the center, and extending perpendicularly toward the right from each of the scale bases, are drawn altitude scales EF and GH. These scales are so constructed that they are homologous to the respective distance scales; that is, 1 cm. = 100 m., 1 cm. = 200 m., and 1 cm. = 400 m. Let these scales be known as 1–*h*, 2–*h*, and 4–*h*, respectively, to agree with the distance scales so designated. In the quadrant to the right of the scale base, and near the edge of the circular sheet of millimeter paper, is drawn a 90-degree arc, graduated in half degrees. This arc is to be used for the elevation setting when the projection is constructed by the graphical method. Over the circular area of paper and fastened to the brass pin as a center is placed a disk of frosted celluloid with the circumference graduated in half degrees. The subdivisions of half degrees are made to aid in determining settings of azimuth angles when projection is being made. A brass arm, AX, plays about the central pin and on the graduated 90-degree arc for the graphical computation, but is not used when the flight is plotted after the slide-rule computation. Its main use is in graphical projections of double-theodolite work.

To plot, or construct, the horizontal projection of the computed flight, the plotting board will be arranged with the scale selected, 1–*d*, 2–*d*, or 4–*d*, directly in front of the operator. The celluloid on plotting board is then cleared of all previous records by erasing the pencil marks with a piece of soft eraser or art gum. Note that only *soft* erasers are used for this purpose. The celluloid protractor is then revolved about the center until the observed azimuth angle for the minute to be plotted is found on the edge of the disk and placed over the index of the scale selected. Then taking the computed distance out for the same minute as a second factor, a point is plotted on the celluloid surface directly over this value found on the scale selected. The point is set off, or made more prominent, to distinguish it from any other point that may have been left upon the board, by encircling, or by marking with a small cross, letting the intersection come at the position of the point. The method of encircling is recommended. Only very soft and well-sharpened pencils will be used on the celluloid protractor. It is difficult to place a point accurately with a dull point, and a hard, or even a medium soft, pencil will not make a mark easily distinguished.

The average scale selected will be 2–*d* of the double scale AD, figure 45, or that in which 1 cm. = 200 m. Scale 1–*d*, AC, figure 45, will be chosen only when the wind movement for the first few minutes is comparatively small, the observation a short one, or the maximum distance out less than 5,000 meters. Observations of another character than these will be started upon the larger of the double scale, 2–*d*, and if necessary transferred to the smaller scale 4–*d*. As an example see horizontal projection for single-theodolite observation on figure 45, A, 1, 2, 3 . . . . 21, 22, designated by points inclosed with small circles. This is the horizontal projection for sample flight recorded on Form No. 1110–Aer., Table 19. The plot is to the scale 1 cm. = 200 m., or scale 2–*d*. The board is arranged so that this scale is directly in front of the operator, then the azimuth angle for the first minute 203°.4, is found on circumference of the celluloid disk which is revolved until this angle is placed over the scale base or index of scale used, AD, figure 45. The distance from the observation point for the same minute, 800, is then found on the scale 2–*d* and a point placed there directly over the scale base, with a soft pencil. Set off by marking with cross or encircling with a small circle, and number the point as 1. Proceed in the same manner with succeeding minutes 2, 3, 4, etc. Note that the setting of plotting board in this figure is for the third minute of the tabulated data; that is, the azimuth angle 225°.1 is set over the line AD, and point 3 is placed over the scale base on scale 2–*d* at a scale distance of 1,736 meters from the observation point. The point is inclosed by a circle and marked 3. Had the flight extended over a greater length of time, such that the maximum distance out would have exceeded 10,000 meters, the last two minutes on scale 2–*d* would have been plotted on scale 4–*d* with the same azimuth setting. The reason for this will be explained later. From the repetition of the two points the horizontal projection will be continued on 4–*d*. Had the

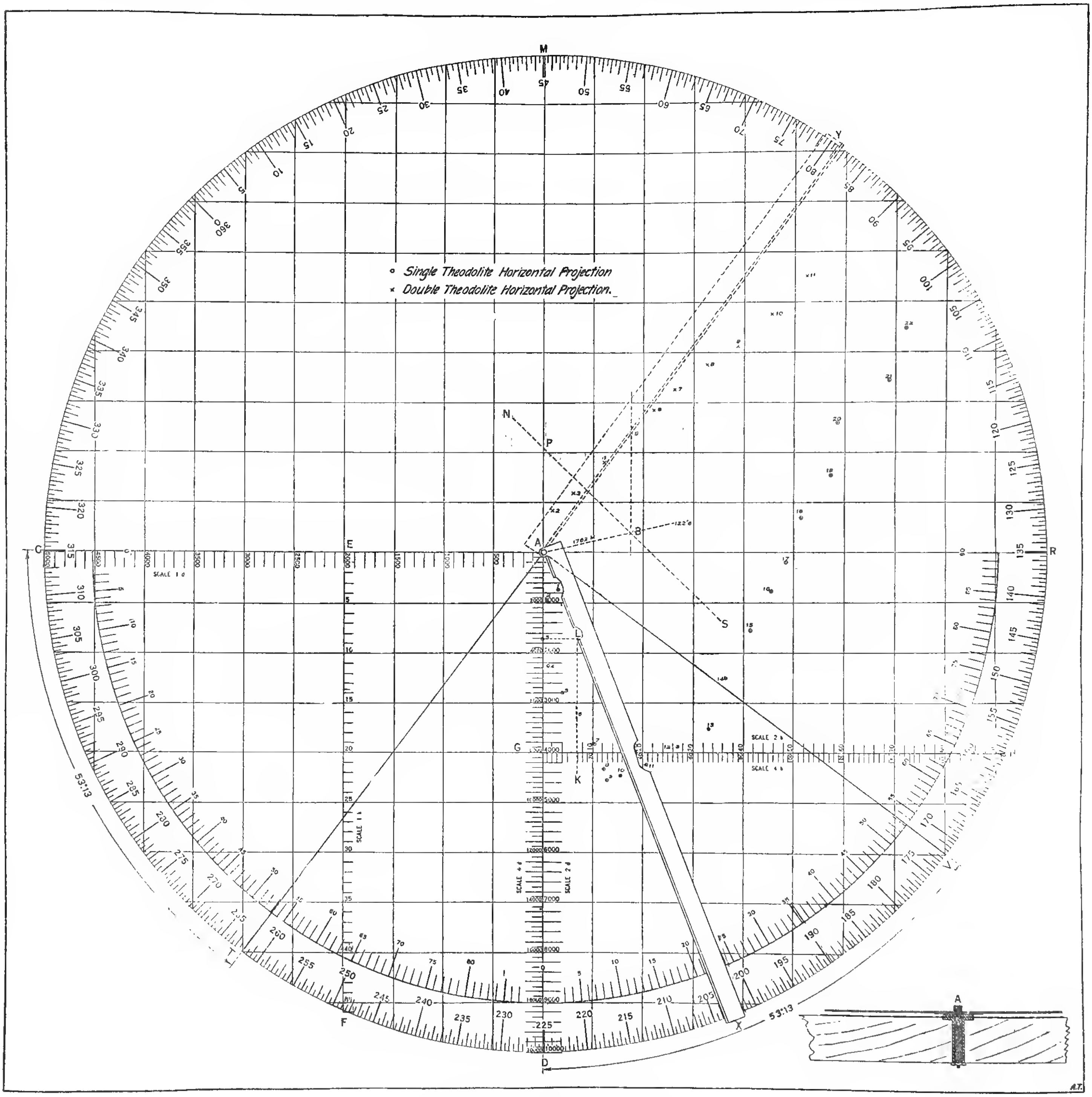


FIG. 45.—Single-theodolite plotting board.

flight been started on scale 1–*d*, the double plot would have taken in the last two points before 5,000 meters distance out, or points 16 and 17. That is, point 16 would have been plotted on both scale 1–*d*, and scale 2–*d*, the azimuth setting of 144°.7 obtaining on both scales. Likewise, point 17 would be repeated.

Method I. (2). Single-theodolite, graphical method.—If the graphical method is substituted for the slide-rule computation, then the plotting of the horizontal projection will be somewhat different, and will in truth precede the actual derivation of distance from observation point. Slide-rule computation during the observation will not be necessary. The only duties of the recorder will be to read and record any data pertaining to the observation. Directly after completion of the ascension, a horizontal projection of observed data will be made on the plotting board. By this method, the plotting board will be equipped with the brass arm, and arranged with a selected distance scale directly in front of the operator, as though plotting from slide-rule computation.

To plot or construct the horizontal projection for any minute, find the observed azimuth angle on edge of celluloid protractor and set this over the scale base selected, then set the beveled edge of the brass arm AX, at the observed elevation angle on the 90-degree arc in the quadrant of the circle, to the right of the azimuth index. Then, with the altitude of the balloon as the third factor, find this value on the altitude scale agreeing with the distance scale on which the horizontal projection is being made, and follow line through this point parallel to the scale base until it intersects the edge of the brass rule. From this point drop a line perpendicular to the line just run through the point on the elevation scale, to the scale base or index where a point will be placed, set off by circle or cross and numbered. Horizontal projection A, 1, 2, 3 . . . . 21, 22, figure 45, shows the setting for plotting of the third minute. Scale 2–*d* was selected for the plot. The azimuth setting of 225°.1, and elevation setting 21°.4, obtain, as may be seen from figure. Now on elevation scale corresponding to distance scale, in this case 2–*h*, the altitude for the same minute is found and a line run through this point parallel to distance scale index. Careful attention given to the millimeter lines of millimeter paper base will aid in running the parallels and perpendiculars in the plotting operation. The altitude for the third minute is 680 meters. Note that KL, figure 45, runs through 680 on scale 2–*h* and parallel to the scale base or index of scale 2–*d*. At the point of intersection, L, between this line KL and edge of brass arm, drop a perpendicular to the index of scale 2–*d*, and place the point 3. Note that L 3 is perpendicular to index 2–*d*. The points A, L, and 3 determine a right triangle, and with reference to formula $\tan\ e=\frac{h}{d}$, the base A 3 is equivalent to distance out, since 3 L is the altitude of balloon and angle 3 A L, the angular elevation.

When the observation is plotted by the graphical method three unknown values are to be determined from the horizontal projection instead of two as in the method by slide-rule computation. From the method under present discussion, distance from observation point, wind direction, and wind velocity must be determined, while by the slide-rule method only wind direction and wind velocity need be determined from the horizontal projection. To determine the distance from observation point of points plotted by the graphical method, revolve the protractor or celluloid disk until the point in question comes directly over the index of distance scale upon which horizontal projection is made, then read off the distance from the same scale. For example, to find the distance out for the third minute in plot A, 1, 2, 3 . . . . 21, 22, figure 45, bring the third point over the index scale 2–*d* and read the position of point 3 on scale 2–*d*. By this method the distance out seems to be about 1,725 meters against 1,736 by the slide-rule method. The general average of results obtained by the slide-rule method compares more closely with results obtained by logarithmic computation than do the results from the graphical method. Therefore, the slide-rule method should be used in preference to the graphical method. Not only is it more accurate but it is a much quicker method.

Method I. (3). Single-theodolite, slide-rule computation, graphical cosine plotting.—A third method of graphical plotting, convenient, speedy, and very accurate, if worked out carefully, is based upon the use of the natural cosine value of 0.6000, which reduces, graphically, the resulting horizontal distances to velocities in meters per second.

The protractor is prepared for this method of plotting by drawing a line, as AT or AV, figure 45, on the millimeter paper in the quadrant to the right of the index of each distance-out scale, so that it will make an angle with the scale base equal to 53°.13, or the angle whose natural cosine is 0.6000.

To construct the horizontal projection by this method, rotate the celluloid disk until the observed azimuth angle, on the edge of the disk, is set over the outer end of AT or AV, figure 45. Then, finding the distance from observation point on the *d* scale that has been selected, drop a perpendicular from this point and produce until it intersects the line AT or AV, where a point is placed and set off as described in the foregoing methods. Successive points for the remainder of the ascension are plotted in the same manner. The horizontal projection by this method is automatically reduced so that the straight-line distance between alternating points is divided by 12, which operation converts the horizontal distance traversed during a two-minute interval to velocities of wind movement in meters per second.

The observer should have some practice with this method and should become thoroughly familiar with it before attempting to make the projection of an actual observation. Much care must be taken in running the perpendiculars from the distance scale to the line AT or AV, figure 45. It will be noticed that the range of distance scale by this method is about 30 per cent less than the range of the distance scale of the two preceding methods. The particular advantage of this method lies in the speed with which the direction and velocity may be determined, as will be shown under determination of direction in "Reduction of data," section 6.

Method I. (4). Single-theodolite, logarithmic computation.—This form of computation for single-theodolite work involves the use of the same formula as that used in slide-rule computation, namely, $\tan e = \frac{h}{d}$, or $d = \frac{h}{\tan e}$. Any convenient table of logarithms to the fifth place may be used. As an example, suppose the balloon to be at an altitude h, of 400 meters, and the observed elevation angle (e) 34°.6, then the distance out, d, is found by subtracting log tan e from log 400;

$$\begin{array}{rl} \log 400 & = 2.60206 \\ -\log \tan 34°.6 & = 9.83876 \\ \hline \log d & = 2.76330 \\ d & = 579.83 \end{array}$$

and since we use the distance to the nearest whole meter, this is reduced to 580 meters, the distance out for that reading.

Double-theodolite computation.—While there are numerous methods of graphical computation for double-theodolite observations, the basic principle of all is the same. A series of triangles is formed and projected upon a horizontal plane where the required parts can be conveniently measured by the use of a properly divided scale. Some methods are simpler than others and still may be retained within the same limits of accuracy. Three graphical methods have been carefully studied out and favorably accepted for their accuracy, simplicity, and speed. Any complete graphical method necessitates the use of a graduated circle or protractor at either end of a scaled base line. Two of the graphical methods are adaptations of the single-theodolite plotting board, one of which involves the permanent alteration of plotting board, while the other, and that favored most, brings about only a temporary alteration of the board.

Method II. (1). Double-theodolite, graphical method.—The first of the above-mentioned schemes has been explained fully in the MONTHLY WEATHER REVIEW for April, 1919, page 222. Where all double-theodolite work is over one base line, or all base lines of a station are of the same length, this scheme is very satisfactory, but it is not well adapted to stations having a system of base lines of varied lengths, for, as the length of the base line varies, so must the scaled distance AB vary in proportion, and this variation is difficult to accomplish on a single-theodolite plotting board as it is now arranged, with its fixed center. However, the radial lines from station B might be drawn upon tracing paper, and a slot prepared along the 0°–180° line to receive the protractor pin and allow for adjustment of base-line length, but this is unsatisfactory, since much difficulty will be experienced in placing the auxiliary sheet and keeping it in place over the fixed millimeter paper. Unless the base line is laid off to comparatively small scale, the method will not provide for long runs, since it is difficult to alter the scale distance of the base line. Again, if the base-line scale is small, there will be considerable difficulty in plotting points and measuring velocities and directions for ascensions during periods of little wind movement.

For the above reasons the following method is given as the simplest and most applicable graphical method to be used with the single-theodolite plotting board. This method can be used for a base line of any bearing and any length within the limits of the distance scale on the protractor. The length of the base line may be changed or the scale of the same base line may be increased or decreased at will.

Method II. (2). Double-theodolite, graphical method.—The preparation of the single-theodolite plotting board for double-theodolite observations necessitates the use of a brass arm, and a point so placed as to represent the location of secondary station with reference to bearing and distance from primary station. To accomplish the location of this point, revolve the celluloid disk until the azimuth bearing of base line is placed over the index of the scale selected, then on that scale set a point at a distance from the center that will have a proper ratio to the distance from the secondary to the primary station. This point will mark the position of the secondary station, or station B. Place the brass arm over the central pivot, and the preparation is complete. As an example, let the horizontal projection, A, 1, 2 . . . . 10, 11, figure 45, be the representation of data for double-theodolite observation on Form No. 1110–Aer., Table 20. Note that the line AB is in the direction from A, of 122°.55, and that B is a point on that line a scale distance of 1,781.86 meters from A. For purposes of explanation, let *N–S* be the north-south line through the secondary station, or that just located.

To use the protractor, and to plot these data, let the center of the celluloid disk, figure 45, be the primary station, or station A, and the auxiliary point be the secondary station, or station B. The data from both stations must be reduced to the same origin of orientation points. For graphical plotting, both theodolites should be oriented with the zeros of base plates on north. Keep in mind the fact that all azimuth settings for station B will be made by rotating the celluloid disk until that setting, on its edge, is placed over the index of the scale selected. For a direction of north, south, or any other direction at station B, will be parallel, so far as this work is concerned, to the same direction at station A. Therefore the point A with its circumscribed arc of 360° may be used for setting any direction at station B. All azimuth settings at station A will be made with the beveled edge of the brass arm pivoted at the center of protractor.

To construct the horizontal projection for the data recorded on Form No. 1110–Aer., Table 20, rotate the celluloid disk until the azimuth reading at B, 314°.3, is set over the index of scale 2–*d*, and set the edge of the brass arm on the azimuth reading at A, 43°.5. Then, noting the position of point as located on protractor, pass an imaginary line through this point and parallel to the scale base or index of scale, letting it intersect the edge of the brass rule. At this point of intersection, place a point and set off by circle or cross. This last point fixed is the relative horizontal position of the balloon, and should be numbered as 1, 2, 3, etc. Proceed in the same manner with the remainder of the observation.

The fifth point in the horizontal projection A, 1, 2 . . . . 10, 11, figure 45, illustrates the principle involved. In the actual construction of this particular horizontal projection, the disk was turned through a half circle; that is, all of the points as plotted fell within the semicircumference MCD, and not in the semicircumference DRM. Most of these points fell within the quadrant CFD, rather than quadrant RYM, as represented in figure 45. But to represent these two horizontal projections upon the same figure without interference with one another, and yet to show the principles of each, and allow for comparison, the details of plotting the fifth point are laid out in quadrant RYM. When plotted, it fell in the same relative position in quadrant CFD. To gain a clear impression, reverse figure 45. The horizontal projection will then appear as it did in quadrant CFD, upon the plotting of the fifth point.

The observed azimuth reading for the fifth minute at B is 45°.1, which was located on the edge of the protractor and brought over the index of scale 2–*d* at D. The beveled edge of the brass arm is then set at 81°.6, the observed azimuth reading at A on the edge of the celluloid protractor. An imaginary line is then passed through the point B, parallel to the line AD. Where this line intersects the edge of the brass rule, a point is placed, and designated as 5, which is the relative position of the balloon on a horizontal plane, for the fifth minute. As a proof of the setting for station B, let an imaginary line be drawn through A, cutting the circumference at 0° and 180°, and let the line DA be produced through A to cut the circumference at M, and intersect the line *N–S*, at P. The angle 0°AM, then, is equal to angle PB5, for two angles whose respective sides are parallel are equal.

Method II. (*3*). *Double-theodolite, graphical method.*—The third graphical method of plotting necessitates the use of a large drafting board, table, or flat-top desk, upon which the base line is laid out to some convenient scale, and the observation points marked by inserting pegs to protrude above the surface of the board. About these pegs and upon semicircles circumscribed about them play a set of arms, by means of which the relative position of the balloon is found, and the distance away and elevation of balloon measured. Figure 46 represents such a plotting board. AB is the base line, 1,200 meters long, laid out to the scale 1 cm. = 200 m. CKF and EKD are graduated semicircles described about the observation points A and B, respectively. AK is the azimuth arm and elevation apparatus at station A, while BG is the azimuth arm at station B. The elevation apparatus at station A consists of an arc of 90°, KL, fixed at the extreme end of the azimuth arm AK. About the post A, and playing upon this arc KL, is the elevation arm KH. Still a fourth arm, or elevation scale PM, is

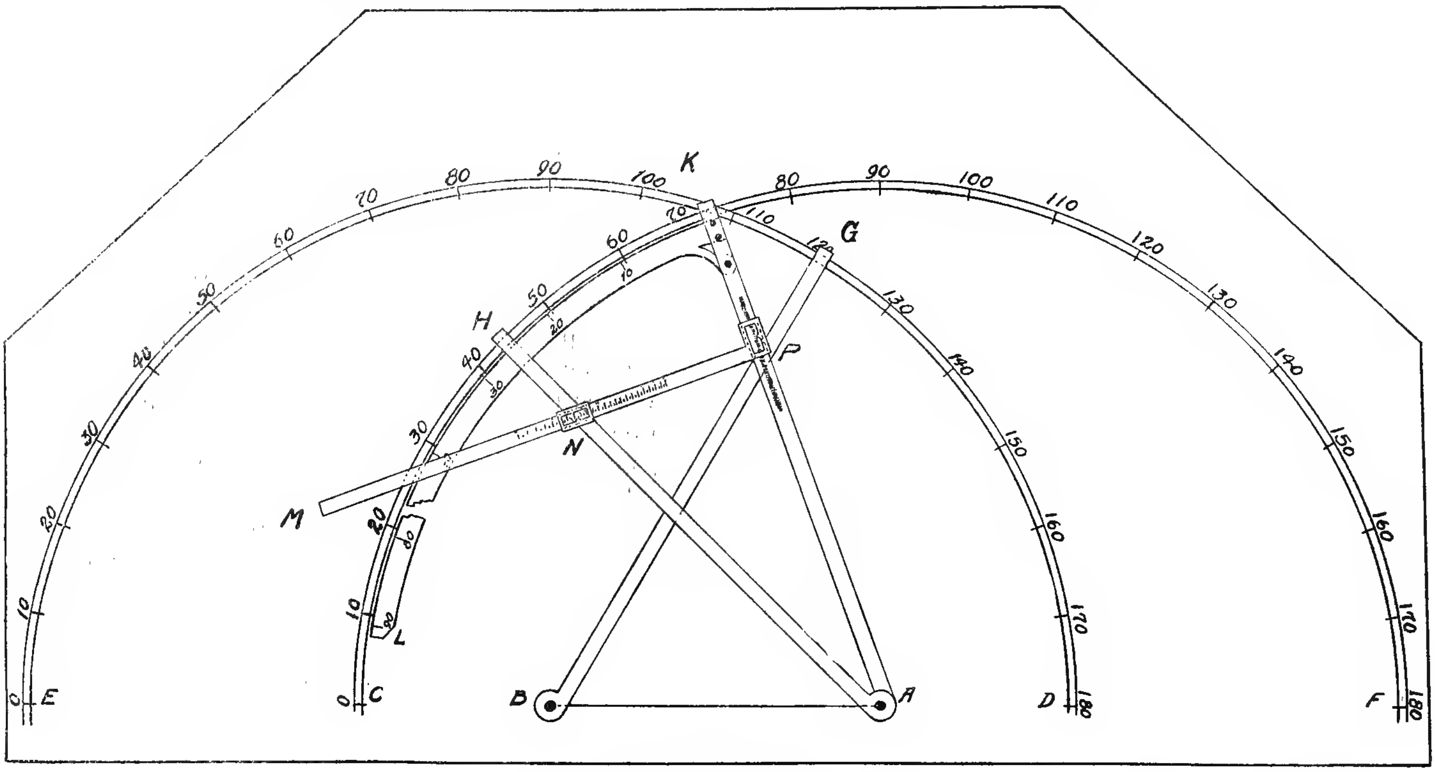


FIG. 46.—Plan of double-theodolite plotting board.

attached perpendicularly to the azimuth arm AK. This bar is graduated to the same scale upon which AB is laid out. A cursor, or runner N, indicates the elevation of balloon at each minute when all settings are correctly made.

As an example of the operation assume that the following data are obtained when the theodolites are set up by the method of base-line orientation, which is the most convenient orientation for this system of graphical plotting. Let the azimuth and elevation angles at station A, be 70° and 25°, respectively, and the azimuth angle at station B be 120°. To locate the points, set the arm AK on 70° of the arc CKF, and the arm BG on 120° of the arc EKD. It will be noticed that each of the azimuth arms is so constructed that a line along one edge would pass directly through the point about which it is placed. At the intersection of these edges a point will locate the horizontal position. Retaining the arms in this position, set the elevation arm AH on 25° of the arc KL, and set the elevation gage, PM, so that the right angle on the inside edge is coincident with the point of location. Finally, slide the runner to the position of N, or to the point of intersection of elevation arm and elevation gage. The position of the index along the graduated bar PM will give the elevation of the balloon, and the position of the index along the arm AK will give the distance out. The best application of this method is for stations provided with only a single base line. Where observation work is done over more than one base line, especially when these base lines are of varied lengths, additional posts will have to be set and semicircular arcs be drawn for each scaled length of each base line.

Method II. (4). Double-theodolite, logarithmic method.—This method of computation is used more extensively in double-theodolite computation than in single. To facilitate ease and accuracy of the work, the theodolites should be oriented by the base-line method. The principal of the computation is the sine formula in case 1, of trigonometric computation of triangles, wherein we have given one side and two angles, figure 47. At stations with well-selected base lines nearly all the computation can be worked with the formulæ—

$$d=\frac{b \sin B}{\sin C}, \tag{4}$$

$$\text{and } h=d \tan e; \tag{5}$$

wherein b = base-line length.
A = azimuth angle at station A.
B = azimuth angle at station B.
$C=180°-(A+B)$.
d = distance from station A.
d' = distance from station B.
h = altitude of balloon.
e = elevation angle at A.
e' = elevation angle at B.

Even with the most carefully selected base lines, instances will arise in which the balloon movement will be in a vertical plane nearly over and parallel to the base line. At such times, even though all angles during the observation are read to hundredths of degrees, they will not be close enough to avoid considerable error in the computation. To overcome this error as much as possible, the order in which the d and h factors are generally computed will be reversed, and the computation will then follow after one of the following pairs of formulæ:

$$h=\frac{b \tan e \sin B}{\sin (A+B)} \tag{6}$$

and

$$d=\frac{h}{\tan e} \tag{7}$$

or,

$$h=\frac{b \tan e \tan e'}{\tan e \pm \tan e'} \tag{8}$$

and No. (7) above. That is to say, the value of h will be computed by formula (6) or (8), and from the result obtained d will then be found by formula (7). Formulæ (6) and (7) will be used when the balloon is within an angle of 4° to 10° from base line at station A, and formulæ (8) and (7) will be used for angles from 0° to 4°. For angles of any other magnitude the formulæ (4) and (5) may be used. As an example of the application of each method, let the following data be computed by each pair of formulæ. The letter in parentheses after each line of the example will designate the order in which it has been found best to work the problem to save the most time and acquire the greatest accuracy.

Assume the elevation angle and the azimuth angle at station A to be 41°.3 and 172°.65, respectively, the corresponding angles at station B to be 49°.0 and 10°.42, the theodolites oriented by the base-line method, and the base line to be 1,781.86 meters. See figure 47. When the problem is computed by formulæ (4) and (5), we have:

$\log b$ =	3.25088	(*a*)
$+\log \sin B$ =	9.25721	(*b*)
	2.50809	(*e*)
$-\log \sin C$ =	9.48450	(*c*)
$\log d$ =	3.02359	(*f*)
$+\log \tan e$ =	9.94375	(*d*)
$\log h$ =	2.96734	(*g*)
h =	927.58 meters	(*h*)
d =	1055.8 meters	(*i*)

by formulæ (6) and (7) we have:

$\log b$ =	3.25088	(*a*)
$+\log \sin B$ =	9.25721	(*b*)
$+\log \tan e$ =	9.94375	(*c*)
	2.45184	(*e*)
$-\log \sin (A+B)$ =	9.48450	(*d*)
$\log h$ =	2.96734	(*f*)
$+\log \tan e$ =	9.94375	(*c*)
$\log d$ =	3.02359	(*g*)
d =	1055.8 meters	(*h*)
h =	927.58 meters	(*i*)

and by formulæ (8) and (7) we have:

$\log b =$	3.25088	(a)
$+\log \tan e =$	9.94375	(b)
$+\log \tan e' =$	0.06084	(c)
	3.25547	(e)
$-\log (\tan e \pm$ [3] $\tan e') =$	0.30726	(d)
$\log h =$	2.94821	(f)
$-\log \tan e =$	9.94375	(b)
$\log d =$	3.00446	(g)
$d =$	1010.3 meters	(h)
$h =$	887.58 meters	(i)
$\tan e =$	0.87852	(d_1)
$\tan e' =$	1.1504	(d_2)
$\tan e + \tan e' =$	2.02892	(d_3)
$\log (\tan e + \tan e') =$	0.30726	(d)

a difference in results will appear by working the same data with the two pairs of formulæ. Such differences when present appear in problems of azimuth angles less than 10°. Computations by the two pairs of formulæ on angles greater than 10° agree so closely that the computation will be done by the formulæ (4) and (5), these being the simpler.

When the logarithmic computation has been completed, the data are then plotted in the same manner as for a single-theodolite observation. A great deal of care should always be given to the plotting operation, for if this is done in a careless manner the data resulting therefrom will be considerably in error, and sometimes worthless.

The horizontal projection will nearly always be a smooth, even curve, though decided bends and shard

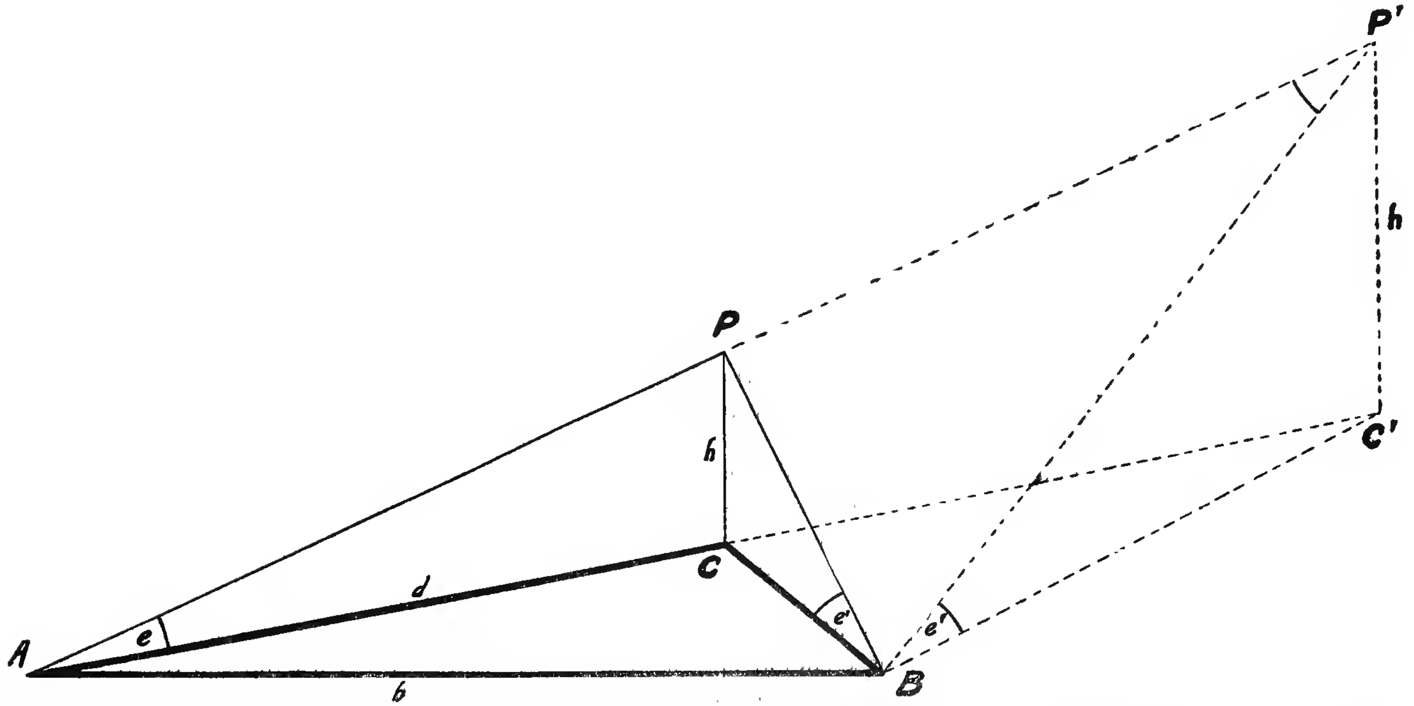


FIG. 47.—Plan of triangulation showing relative positions of balloon at P when balloon is between ends of base line, and at P' when balloon is beyond either end of base line.

It will be noticed that the values of d and h determined by these formulæ do not agree with the values obtained by the use of the two preceding pairs of formulæ. It must be taken into account that formulæ (8) and (7) use only the elevation angles for finding the altitude of balloon, and therefore the altitude, or h, factor would be the altitude of balloon were it in the vertical plane passing through the base line. For this reason formulæ (8) and (7) should be used only when the azimuth bearing of balloon is quite small, within 4° of base line. The results by the first two pairs of formulæ agree closely; in this case they are identical. But when the azimuth angles are small—that is, when the balloon is only a small angular distance from the direction of base line—

angles often exist. The difference between an actual bend of projection, even though it be sharp, and a wavering of projection due to poor data can generally be detected. In the single theodolite plot A, 1, 2 . . . . 21, 22, figure 45, the decided bend in projection at 8 to 10 minutes is well founded, but point 13 seems to be out the least bit. A smoother projection would be made were the point placed more nearly in line with the eleventh, twelfth, and fourteenth points. Likewise the twentieth point seems to be out decidedly. As a means of checking such points, refer to the data and check over the angles by the differences. Occasionally errors in reading angles will be detected. The errors occur principally during hasty readings and are generally either 5°.0 or 0°.5 in error. The frequency of errors of 2°.0 and 0°.2 comes next in order. In the case of the thirteenth point, increasing the elevation angle from 28°.3 to 28°.8,

[3] When the balloon is between the extremities of the base line, as at P, figure 47, the sum of the tangents will be used, and when the balloon is beyond either extremity of the base line, as P′, figure 47, the difference of the tangents will be used.

or by 0°.5, changes the distance out for the point from 4,832 meters to 4,730 meters, which brings point 13 in the same general curve of points 11, 12, and 14. In a similar manner the curve would be smoothed along the eighteenth to the twenty-first minute. Seldom will an actual observation present such an irregular curve, and with the careful observer there will be little need for checking and corrections. Roughness of horizontal projection is generally indicative of carelessness and error.

6. REDUCTION OF DATA.

The immediate result of the horizontal projection is to furnish us with a plan of the horizontal movement of the balloon throughout the period during which it was followed by the observer. On a very much smaller scale, each point represents the actual horizontal position of the balloon at the time when the angles were read on the theodolite. Now, then, since the balloon is traveling with the wind, both in direction and velocity, and since we have a scaled plan of the horizontal movement before us, to measure the wind velocity and direction it is only necessary to measure the velocity of movement and direction of movement of the balloon from the scaled plan and substitute the movement of the balloon for the movement of the wind. Scales corresponding to *d*–1, *d*–2, *d*–4 are supplied with the plotting boards for the measurement of the velocities. The direction is taken directly from the board in most cases, as will be explained.

The wind data for any point or minute represent the mean and resultant of the conditions over a two-minute interval of time, extending from the beginning of the preceding minute to the end of the following minute, thus placing the minute in question between these limits. In using the wind velocity scales, particular attention must be given that the wind scale used is that corresponding to the scale upon which the plot was made. If the projection is constructed upon the scale of 1 cm.= 200 m., then the wind scale of the same base should be used. In applying the wind scale always apply it to alternating points, or connect the points on either side of the one being measured, from 0 to 2, from 1 to 3, and from 2 to 4, etc. The zero of the wind scale will be placed on the earlier of the three points under consideration, and the graduated edge will then be adjusted until it coincides with the last of the three points. Note that the point being measured is the point between. At the point of coincidence between the set scale and the last of the group, the velocity for the intermediate point will be read off to tenths of meters per second. Thus, the reading of the velocity for the first, second, and third points will be read from the coincidence of points 2, 3, and 4, with the edge of the scale, when applied to the respective groups 0 to 2, 1 to 3, and 2 to 4, etc. As an example, the wind velocities measured from the single-theodolite horizontal projection A, 1, 2 . . . . 21, 22, figure 45, when measured by wind velocity scale 2–*w*, and applied from A to 2, 1 to 3, 2 to 4, etc., give velocities of 8.0, 8.6, and 11.3 meters per second, respectively. Figure 48 shows a section of the plotting board and a portion of ascension No. 2136, from Table 19, with the application of wind scale to the horizontal projection in measuring the velocity for the seventh minute. Note that the zero of the scale is coincident with the sixth point of the projection, while the reading of velocity measurement, 9.8 meters per second, is taken coincident with the eighth point along the edge of the scale. The figure also shows the placement of same points for the determination of direction, as will be explained later. If the horizontal projection is constructed by the graphical cosine method, the velocity of movement will be determined at the same setting as that by which the direction is determined, using the centimeter divisions of the millimeter paper as a scale.

To determine the velocity for the last point, 22, since there is not a point placed beyond to mark the limitation of the succeeding minute, we may either place an auxiliary point in a position which would approximately satisfy the character of the last portion of the projection, and measure as before, or we may apply the scale to the last minute interval, that is, from 21 to 22, and double the scale reading. This last scheme is sufficiently accurate when that part of the projection is nearly a straight line and the points are evenly spaced; but when even a general curve prevails, the auxiliary point should be placed. It is also used in determining the *direction* for the last point.

Measurement of the wind direction is no more difficult than measurement of the wind velocity, though until thoroughly understood is more confusing. The direction to be determined, like the velocity, is the mean or resultant direction from the point or minute in question, for the two-minute interval extending from the beginning of the previous minute to the end of the succeeding minute; thus, the direction of the wind for the first, second, third, etc., minutes will be the resultant direction between the points 0 to 2, 1 to 3, 2 to 4, etc., respectively.

To measure the resultant direction for point 1, it is only necessary to rotate the protractor until the points 0 to 2 are on the same straight line. For instance, set both of these points over the scale base or index line of scale, and read the direction in degrees from the edge of the protractor over the index of the scale. To determine the direction for succeeding minutes 2, 3, 4, etc., rotate the protractor until the preceding and succeeding points to that being determined are arranged on the same straight line parallel to the scale base. That is, to measure the direction of point 2, arrange the points 1 and 3 so that they are in the same imaginary line parallel to the index of distance scale. For point 3, arrange 2 and 4 on the imaginary parallel line. Note that the later numbered minute is always toward the operator when determining these directions, otherwise the directions will be 180° in error. Read the direction of movement in whole degrees from the edge of the protractor over the same index of distance scale as for the first minute. In general it may be stated, to find the wind direction for any one minute rotate the protractor until the adjacent points of horizontal projection on either side, with the latest numbered point of the group toward the operator, are directly over the scale base or a line parallel to the scale base and read the direction in degrees on the edge of the protractor coincident with the index line of the scale base.

A south wind will be designated as 0°, west as 90°, north as 180°, and east 270°, etc. Since the balloon travels with the wind, it is nearly always moving away from the observer, and owing to the fact that angles of azimuth are read on opposite side of instrument from balloon, it has been found better to set the zero of base plate on north when orienting the theodolite for an observation. This is well borne out when determining the direction of wind movement from the plotting board, as described just above. When the theodolite has been oriented with zero of base plate on north, the resulting direction of points will be read from index of scale base on the near edge of the board; but when the theodolite is oriented with the zero of base plate on south, then it will be necessary to read the direction from the opposite edge of the board and over the scale base produced, as at M, figure 45. Note that the latter is more difficult to accomplish since the figures of the graduated celluloid disk are inverted, while by the north orientation they appear directly in front of the operator and are right side up.

As an example, the directions for points 1, 2, 3, etc., of horizontal projection *A*, 1, 2 . . . . . 21, 22, figure 45, were determined by rotating the celluloid disk until A and 2, 1 and 3, 2 and 4, etc., were on the scale base AD, or a line parallel to AD, and the directions read at the index of the scale at D, to the nearest whole degree. Thus for the first minute we get 222°, or the observed azimuth reading of point 2. For the second point, when points 1 and 3 are placed on a line parallel to AD, we get 242°, read from edge of protractor over the same index of scale base at D. Had the theodolite been set up with the zero of base plate on south, then the directions would have been read from the opposite side of the board, otherwise there would have been an error of 180°. Figure 48 illustrates the arrangement of horizontal projection of figure 45, for the determination of the direction for the seventh point. Note that the points 6 and 8 are arranged on the same line parallel to the scale base AD. The direction of movement 197 is taken in whole degrees from the index of the scale at D of the figure.

Some observers may prefer to apply the wind scale to points for velocity, then, using this as a straight edge to aid in arranging points on the line parallel to scale base, immediately determine the direction for the same minute. The ease of determination of the latter is gained only through the loss of time in changing from one system to the other.

From a horizontal projection constructed by *method I (3)* the cosine method, the direction and velocity of wind movement are determined at a single setting. The initial procedure is identical with that for determination of the wind direction alone by either of the first two methods given, but the setting of the celluloid disk for the point to be determined is not disturbed until the velocity for that point has also been determined. To accomplish the latter, the centimeter divisions on the millimeter paper are used as a velocity scale, the values of the divisions depending upon the distance scale used. Whether the distance scale is *d*–1, *d*–2, or *d*–4, the centimeter divisions of the velocity scale are equal to the magnitude of the distance used, divided by 200. This is obvious from the fact that the distance-out scale is given in hundreds of meters per centimeter, and that velocities are measured in meters per second over a two-minute interval. Upon this principle where the centimeter divisions of distance-out scale are equal to 100, 200, and 400 meters, the centimeter divisions on the millimeter paper, when used as a velocity scale, will be equal to the factors of 0.5, 1.0, and 2.0, respectively. While the celluloid disk is set for the determination of the direction, note the number of whole and fractional centimeter divisions along a straight line between the limiting points of the two-minute interval and parallel to scale base. Multiply the number so determined by the velocity factor corresponding to the distance scale used; the result is the velocity in meters per second. Much care must be taken that the proper factor, 0.5, 1.0, or 2.0, is applied to the centimeter divisions. The disk is then rotated to the setting for the determination of the subsequent points and the same procedure followed throughout.

Whether the plot be of a single-theodolite or a double-theodolite observation, the same method of determining the wind direction and velocity is used, so long as the horizontal projection is made upon the rotating protractor. However, if the horizontal projection has been plotted by means of double arm and elevation apparatus, then it would have been necessary to apply a T square and protractor to the plot in order to determine the direction.

As the observer determines and calls out the wind velocities and directions, the recorder will enter these data in their respective columns and spaces on Form No. 1110–Aer. It is well to call the fifth, tenth, etc., minutes as the observer comes to them in the determination of velocity and direction. This will eliminate many errors and much annoyance which might be experienced at the end of a long observation when it is occasionally found that the data given are one or more minutes short of the tabulated data. Let the data in the direction and velocity column of Form No. 1110–Aer., Tables 19 and 20, be the results determined in this manner from the tabulated data, and horizontal projections A, 1, 2 . . . . 21, 22, and A, 1, 2 . . . . 10, 11, figure 45, respectively.

Next in order in reducing data will be the preparation of Form No. 1115–Aer., or velocity and direction graph, from which the data to be telegraphed are derived. Various methods for plotting this graph have been devised. A simple apparatus which has proved to be both accurate and speedy is constructed as follows: It consists of an 11 by 13 inch clip board, upon which is mounted a celluloid or hard bristol-board backing C, figure 49. Along the left edge of the celluloid backing is fixed a strip of the same material E, to act as an altitude scale and guide for the triangle. This scale is fastened only at each extreme end and is graduated for every 100 meters to coincide with the altitude lines of Form No. 1115–Aer. On the celluloid backing perpendicular to the edge of the altitude scale at the zero point is drawn a horizontal line to act as a base line in placing the Form No. 1115–Aer. on the board. A celluloid triangle is then graduated along one of the perpendicular edges to coincide with the principal divisions of the Form No. 1115–Aer. This when placed on celluloid back,

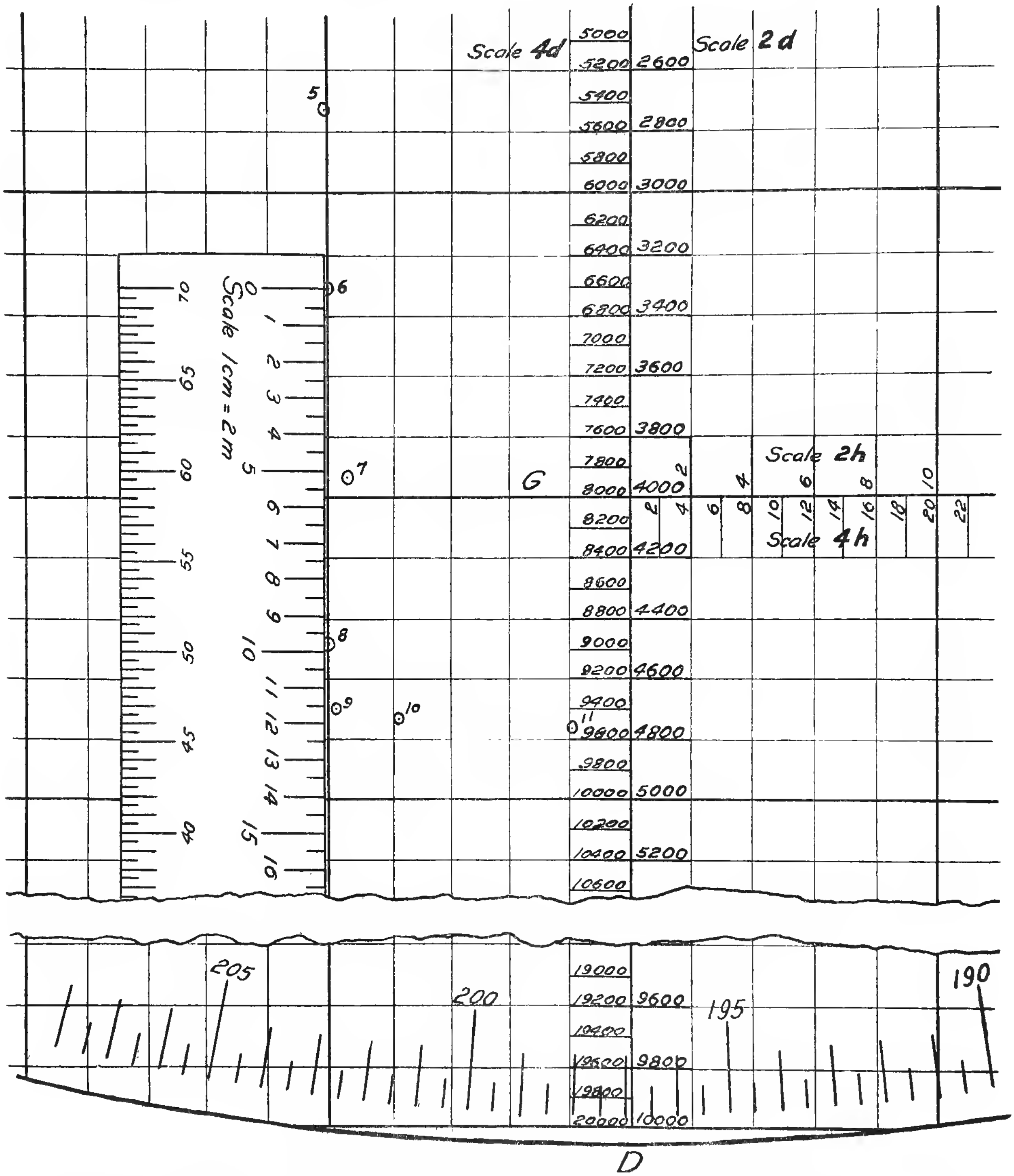


Fig. 48.—Section of plotting board, showing setting of horizontal projection for determination of direction and velocity for the seventh point.

with the other perpendicular side running along the edge of the altitude scale, affords a simple, accurate, and quick method of plotting both velocity and direction at the same setting for any one minute.

arrange the Form so that the heavy line at the bottom edge and the left end of cross-section area are coincident with the right angle formed by the horizontal base line and the edge of the altitude scale on the board. While

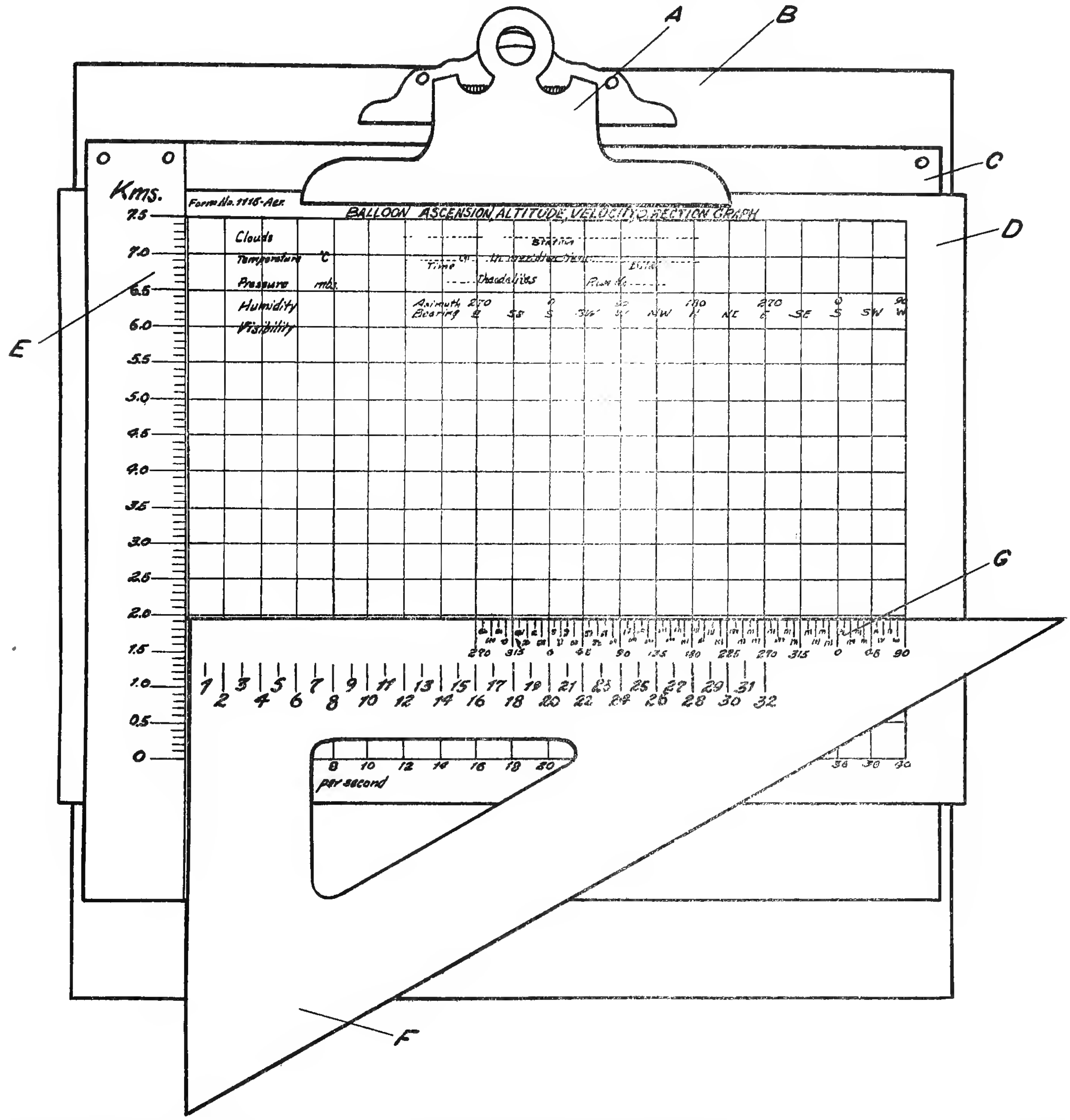


FIG. 49.—Graphing board for construction of Form No. 1115–Aer. (*A*, spring clip; *B*, clip board; *C*, hard celluloid surface riveted on clip board; *D*, Form No. 1115–Aer. set with zero altitude corresponding to zero on *E*; *E*, altitude scale corresponding to horizontal lines on Form No. 1115–Aer., graduated to every 100 meters; *F*, celluloid triangle for setting at proper altitude; *G*, direction scale corresponding to vertical lines on Form No. 1115–Aer. graduated to every 9 degrees).

To use this graphing board, or to construct the velocity azimuth graph from the data recorded on Form No. 1110–Aer., place the Form No. 1115–Aer. on the graphing board with the left end of Form under the altitude scale; holding firmly in this position, depress the spring clip A and allow the top edge of the Form to pass under this; when released this will firmly hold the Form in place. Apply the triangle with the graduated edge along the horizontal lines of the Form; and when the second perpendicular edge is against the edge of the altitude scale, see that the main graduations on the triangle are coincident with those on the Form.

To construct the graph, set the triangle at the zero elevation, and by means of the graduated edge plot the values of the velocity and direction for the surface conditions. Then move the triangle to the next level, 150, 175, 200, etc., meters, or whatever it may be, and plot the values for that level. The remainder of the data for the observation will be plotted in like manner. At each setting of the triangle, both velocity and direction will be plotted for that level. In flights which extend over 7,500 meters in altitude, it will be necessary to construct another curve for the data above that level. See section 8 on the rendition of forms.

The graphs for both single- and double-theodolite observations, on Form No. 1115–Aer., figure 50, were plotted by this method. For the single-theodolite observation, the triangle was set at zero elevation and the surface velocity, 4.4 m. p. s., was plotted by placing a pencil point directly on the bottom line of the cross-section area. With the same setting of the triangle, the surface direction, NNE., was plotted. The triangle was then moved along the altitude scale until the horizontal edge was near the altitude for point 1, in this case 240 meters, and the velocity of 8.0 m. p. s. and the direction of 222° were then plotted directly on the 240-meter line without moving the triangle. The data for 3, 4, etc., minutes for the remainder of the observation were plotted in the same manner. Note that each vertical line of the form represents 0.2 of one meter per second on velocity curve, and 4½ degrees on direction curve.

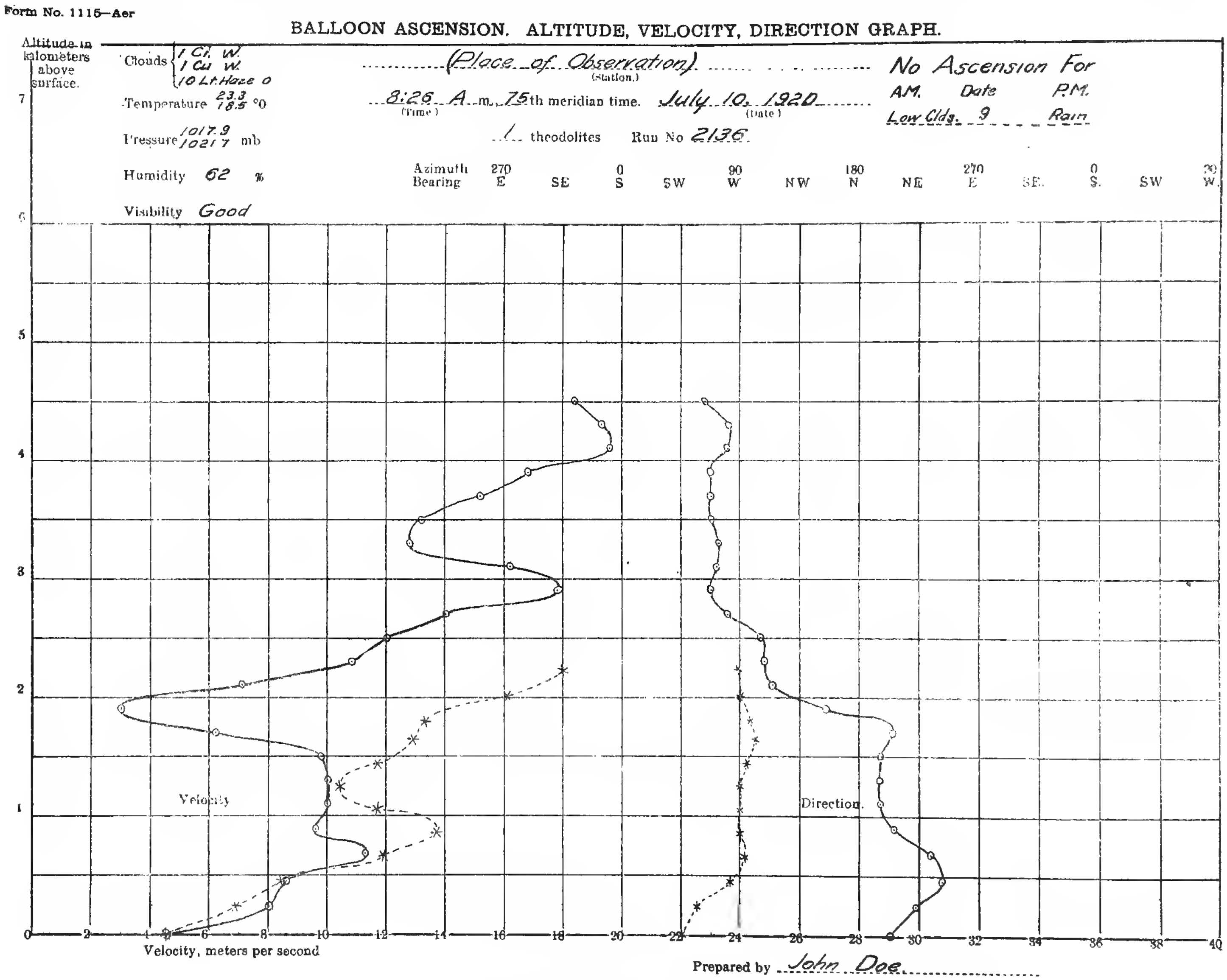


FIG. 50.—Sample of velocity-direction graph, Form No. 1115–Aer.

When all points have been plotted, a line is drawn to *connect all points* of the plot and join them in a smooth curve. Decided irregularities and bumps in either the velocity curve or the direction curve are to be checked over by reference to data on Form No. 1110–Aer., to see that no error has been made in the computation or reduction. In the velocity curve of the single-theodolite graph, figure 50, a peculiar kink occurs at the elevation of 600 meters. From the graph it appears that the point should be in line with the two on either side. The velocity curve is likely to be more irregular than the direction curve; in fact it may be said that the actual direction curve will nearly always be smooth, though the irregularities, when at all present, are generally very prominent.

When the results of the observation are to be telegraphed, the data will be taken from the graph for the specified levels, recorded in their respective spaces on Form No. 1116–Aer., Table 21, coded, and filed in the telegraph office. To code the message see section 7.

In determining the wind for the various levels from Form No. 1115–Aer., figure 50, it will be noticed that each 250 meters in altitude is designated by one or another of the slightly heavier horizontal lines. These lines will act as an index for the required levels. The telegraphic data will give both velocity and direction for the surface, 250, 500, 1,000, 1,500, 2,000, 3,000, and 4,000 meter levels, and the maximum altitude when more than 4,000 meters. To obtain these data from the Form No. 1115–Aer., use the altitude scale at the left as a guide, and, where the respective curves cross these 250, 500, etc., meter level lines, read off the values corresponding to the scale to which the graph was plotted. The velocity will be taken off to the nearest whole meter per second, and the direction will be taken off to the nearest 16 compass points, *N*, *NNE*, *NE*, etc. Note that each of the heavier vertical lines of Form crossing the velocity curve represents 1 meter per second, while each of the heavier vertical lines of Form crossing the direction curve represents one of the 16 compass points.

With the completion of the telegraphic message these data, with a few additional levels, are likewise entered in their proper places on Form No. 1114–Aer., Table 22, or the monthly tabulated summary. One sheet is used for the tabulation of the morning observations and a second is used for the tabulation of the evening observations. Upon the completion of this tabulation work, entries will then be made on Form No. 1112–Aer., Table 23, Form No. 1113–Aer., Table 25, when such data occur, and Form Fo. 1111–Aer., Table 24, when so desired by the station official. For the rendition of these and other Forms see section 8.

All Forms and material will then be filed in some convenient place, well known to all the observing force in any manner concerned with the balloon work. At the conclusion of each week's observations, Sunday a. m., to Saturday p. m., inclusive, Forms Nos. 1110–Aer., 1112–Aer., and 1115–Aer. will be mailed to the Aerological Division at the Central Office. Forms Nos. 1113–Aer. and 1114–Aer., for both a. m. and p. m., will be mailed at the end of the month. Form No. 1116–Aer. will not be mailed to the Central Office, but will be retained at the station. All Forms must be filled out completely as instructed under section 8, and promptly mailed. Forms Nos. 1110, 1112, 1113, 1114, and 1115 Aer. should be made in duplicate, and the second copy kept on file at the station to provide against entire loss of data in the mails.

[Form No. 1116–Aer.] TABLE 21.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

PILOT BALLOON TELEGRAPHIC SUMMARY.

Ascension number, 2136. Date, July 10, 1920. Time, 8:26 a. m.

Distinguishing code word.	Distinguishing time word.	Even (ai). Surface.		Odd (eo). 250 meters.		Even (ai). 500 meters.	
		Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.
Station. Washington.	a. m. 10th Carbuncle.	NNE.	4	NE.	8	ENE.	9
		Biped.		Deacon.		Diplomacy.	

Odd (eo). 1,000 meters.		Even (ai). 1,500 meters.		Odd (eo). 2,000 meters.		Even (ai). 3,000 meters.		Odd (eo). 4,000 meters.	
Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.
NNE.	10	NNE.	10	NW.	4	WSW.	18	WSW.	19
Bogbull.		Bibulous.		Sealegs.		Nimbose.		Nobody.	

Maximum altitude.	Even (ai). Maximum altitude.		Clouds.			Cloud altitude. m.	Visibility.
	Direction.	Velocity.	Amt.	Kind.	Dir.		
4,500 Tuggers.	WSW. Nimbose.	18	1 1	Ci. Cu.	W. W.	....	Good. Seven.
			Cubby, cirrum.				

State of weather
(To be sent only in case of no run.)

(Signed) HENRY.

[Form No. 1114-Aer.]

TABLE 22.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

WIND DIRECTION AND VELOCITY (m. p. s.).

Station (place of observation). Month, July, 1920. Base, 55.3 meters. Time, 8 a. m.

Day.	Altitude, meters. Surface.		250		500		750		1,000		1,500		2,000		2,500		3,000		3,500		4,000		4,500		5,000		6,000		7,000	
	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity	Direction.	Velocity.	Direction.	Velocity.
1	nnw.	3	nne.	4	nne.	4	nne.	5	n.	5	nnw.	6	wnw.	7	wnw.	9	wnw.	14	w.	14	w.	11	w.	14						
2	s.	4	sse.	7	sse.	10	s.	10																						
3	wnw.	4	wnw.	8	wnw.	11	nw.	14	nw.	16	nw.	13																		
4	wnw.	7	nw.	8	nw.	9	wnw.	10	wnw.	11	wnw.	12	wnw.	22																
5	wnw.	3	nw.	5	n.	9	nne.	10	n.	9	n.	8	nw.	11	nw.	15	nw.	16	nw.	18	nw.	19								
6	ssw.	1	sw.	8	ssw.	10	s.	9	s.	8	sw.	7	wsw.	8	wnw.	7														
7	No ascension, due to low clouds.																													
8	nnw.	4	nw.	8	nw.	9	wnw.	10	wnw.	11	wsw.	8	wsw.	17	wsw.	18														
9	nw.	1	nw.	4	nw.	6	nw.	7	nw.	7	wnw.	9	wnw.	10	w.	12	w.	15	wsw.	20	wsw.	22	wsw.	20						
10	nne.	4	ne.	8	ene.	9	ne.	11	nne.	10	nne.	10	nw.	4	wnw.	12	wsw.	18	wsw.	13	wsw.	19	wsw.	18						
11	sse.	1	s.	3	sse.	5	sse.	7	sse.	8	ese.	7	ese.	3																
12	ssw.	3	sw.	4	sw.	5																								
13	nnw.	1	n.	4	n.	4	nne.	3	n.	2	wnw.	4	wnw.	4	wnw.	5	wnw.	7	w.	8	w.	9	w.	7	w.	9	w.	3	nw.	7
14	s.	2	sw.	6	sw.	8	sw.	7	sw.	8	wsw.	8																		
15	Calm.	...	w.	5	w.	6	w.	7	w.	9	w.	8	w.	9	w.	11	w.	14												
16	w.	3	wnw.	6	nw.	7	nw.	6	nw.	6	nw.	5																		
17	ne.	4	ene.	3	ne.	5	nne.	5	wnw.	7	wnw.	11																		
18	se.	(?)	Disappeared in stratus cloud at about 300 meters. Wind light.																											
19	ssw.	4	sw.	7	wsw.	10																								
20	nw.	3	nnw.	6	n.	6	n.	3	nnw.	2																				
21	Calm.	...	ssw.	1	sw.	1	ssw.	1	wnw.	1																				
22	sw.	1	sw.	1	sw.	2	ssw.	3	ssw.	3	w.	1	w.	3	w.	6	nw.	2	nnw.	3	wnw.	7	wnw.	9	wnw.	8	w.	8	wnw.	8
23	ssw.	1	wsw.	2	wnw.	4	wnw.	7	wnw.	7	wnw.	6	w.	8	w.	9	w.	8	w.	9	w.	11								
24	sw.	2	wsw.	7	w.	12	wnw.	16	wnw.	17	wnw.	19	wnw.	18																
25	ne.	4	ne.	10	ne.	10	ene.	5	ne.	2	wnw.	7	wnw.	11	w.	10														
26	n.	4	nne.	5	nne.	6	ne.	7	ne.	7	n.	8	n.	11	nnw.	9	nw.	8	wnw.	9	wnw.	11	wnw.	11	wnw.	12	wnw.	16		
27	n.	4	n.	7	n.	7	n.	7	n.	8	nne.	7	nne.	8	nne.	8	nne.	8	n.	9	nnw.	8	nnw.	10	nw.	10	nnw.	10		
28	ne.	2	ne.	4	ne.	5	ene.	7	ene.	8	e.	8	ene.	7	ne.	7	ene.	6	ene.	3	nw.	3	nw.	4	nw.	4	wnw.	8		
29	sw.	1	sw.	3	sw.	4	wsw.	3	w.	2	se.	2	e.	2	e.	2	ese.	1	nnw.	1	n.	2	n.	3	wnw.	5	nw.	2	w.	4
30	ssw.	2	wsw.	5	w.	6	w.	6	w.	5	wnw.	5	w.	5	wnw.	5	w.	7	wnw.	9	wnw.	10	wnw.	13	wnw.	15	w.	17		
31	sw.	1	wsw.	6	wsw.	7	w.	8	w.	8	wsw.	7	wsw.	8	sw.	7	sw.	6	sw.	9	w.	10	w.	9						

Prepared by John Doe, assistant.

TABLE 23.

[Form No. 1112-Aer.]

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

WEEKLY SUMMARY OF AEROLOGICAL OBSERVATIONS WITH PILOT BALLOONS.

Station (place of observation). Week ending July 10, 1920.

Date.	Number of ascension.	Starting time.	Number of theodolites.	Length of observation.	Disappearance due to—	Mean diameter.	Weight.	Free lift.	Total lift.	Ascension rate. Tables.	Ascension rate. Time-altitude curve.	Type of balloon.	Temperature.	Pressure.	Humidity.	Sun.	Predominant clouds.
				Min.		cm.	g.	g.	g.	m.p.m.	m.p.m.		° C.	mb.	%		
4 a.	2125	8:39 a.	1	12	Haze.	76.0	35	189	224	200	....	6″ Unc.	23.3	1,004.4	65	Bright.	Few A. St. NW.; few Cu. NW.
4 p.	2126	3:17 p.	1	22	Haze.	77.5	37	192	229	200	....	6″ red.	24.4	1,007.1	39	Bright.	1 Ci. NW.; 3 Ci. St. NW.; 2 Ci. Cu. NW.
5 a.	2127	8:18 a.	1	20	Distance.	74.0	30	183	213	200	....	6″ Unc.	18.3	1,012.5	59	Bright.	None.
5 p.	2128	3:16 p.	2	17	Burst.	80.0	45	202	247	200	....	6″ red.	25.0	1,011.9	39	Bright.	2 Ci. St. W.; 2 Cu. NW.
6 a.	2129	8:26 a.	1	13	A. St. Clds.	75.5	31	184	215	200	....	6″ red.	19.4	1,014.2	76	Through clouds.	Few Ci. Cu. NW.; 8 A. St. WNW.
6 p.	2130	3:11 p.	1	12	Eclipsed by clouds.	77.5	32	185	217	200	....	6″ red.	25.6	1,011.7	57	Through clouds.	5 A. St. W.
7a.	None	8a.	Low clouds.			....	....	....	....	....	....	....	....	....	....	....	10 St. WSW.
7 p.	2131	3:21 p.	1	5	Cu. cloud.	77.5	42	198	240	200	....	6″ red.	31.1	1,004.7	59	Through clouds.	7 Cu. WNW.
8 a.	2132	8:23 a.	2	12	Against Ci. Cu.	74.5	30	183	213	200	....	6″ Unc.	23.3	1,011.8	65	Bright.	4 Ci. St. WSW.
8 p.	2133	3:31 p.	1	15	Haze.	76.5	38	193	231	200	....	6″ red.	26.7	1,012.5	50	Bright.	2 Cu. W.
9 a.	2134	8:27 a.	1	23	Haze.	75.0	30	183	213	200	....	6″ Unc.	25.6	1,014.9	61	Bright.	Few St. Cu. NW.
9 p.	2135	3:09 p.	2	15	Haze.	73.5	27	179	206	200	....	6″ Unc.	31.1	1,013.5	34	Bright.	Few St. Cu. W.; 2 St. W.
10 a.	2136	8:26 a.	1	22	Haze.	76.0	38	193	231	200	....	6″ red.	23.3	1,017.9	62	Bright.	1 Ci. W.; 1 Cu. W.; 10 Lt. Haze 0.
10 p.	2137	3:07 p.	1	9	Cloud.	76.0	34	188	222	200	....	6″ Unc.	30.0	1,015.9	39	Through clouds.	2 Cu. NE.

Notes:

PATRICK HENRY, *Meteorologist,*
Official in Charge.

[Form No. 1111-Aer.] TABLE 24.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

Station (place of observation). (75th meridian time.)

Time, 8:26 a. m. WIND-ALOFT REPORT. Date, July 10, 1920.

Altitude.	Direction.	Velocity.	Remarks.
m.		*m. p. s.*	
Surface	nne.	4	
250	ne.	8	
500	ene.	9	
750	ne.	11	
1,000	nne.	10	
1,250	nne.	10	
1,500	nne.	10	
1,750	nne.	5	
2,000	nw.	4	
2,250	wnw.	10	
2,500	wnw.	12	
2,750	wsw.	15	
3,000	wsw.	18	
3,250	wsw.	13	
3,500	wsw.	13	
3,750	wsw.	16	
4,000	wsw.	19	
4,250	w.	20	
4,500	wsw.	18	

(Signed) PATRICK HENRY, *Meteorologist.*

[Form No. 1113-Aer.] TABLE 25.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

MONTHLY REPORT OF CLOUD ALTITUDES FROM PILOT BALLOON ASCENSIONS.

Station (place of observation). Month, July, 1920.

Date.	Cloud type.	Altitude.	Direction.	Velocity.	Remarks.
		m.		*m. p. s.*	
2	Cu.	800	s.	10.0	8:21 a. m.
3	St. Cu.	2,000	wnw.	16.4	3:31 p. m.
6	A. St.	2,600	wnw.	6.8	8:39 a. m.
10	Cu.	1,800	n.	0.2	3:16 p. m.
11	St.	1,400	sse.	8.5	3:14 p. m.
12	St.	450	sw.	4.8	8:22 a. m.
15	St. Cu.	2,200	w.	9.5	8:32 a. m.
15	Cu.	1,750	w.	12.0	3:50 p. m.
17	A. Cu.	2,000	wnw.	11.0	8:34 a. m.
18	St.	300	s.	8.0	8:17 a. m.
18	St. Cu.	1,000	ssw.	10.2	3:40 p. m.
19	St.	600	wsw.	11.0	8:24 a. m.
19	A. Cu.	3,800	wsw.	16.0	3:37 p. m.
20	Cu.	1,600	ene.	2.5	3:40 p. m.
24	St. Cu.	1,100	sse.	2.0	3:14 p. m.
25	St. Cu.	2,800	w.	9.1	8:48 a. m.

(Signed) PATRICK HENRY, *Official in Charge.*

7. CODING THE MESSAGE.

The greatest care must be exercised in coding the telegraphic message and preparing an accurate legible copy for the telegraph office. Each telegraphic message will be a report of the observation for which it stands, and will regularly include in the order of mention, so far as available, the name of the station; time of observation, the wind velocity, and wind direction at the surface, 250, 500, 1,000, 1,500, 2,000, 3,000, and 4,000 meter levels; the maximum altitude reached; the velocity and direction of wind for the maximum altitude when this is greater than 4,000 meters; clouds in amount, kind, and direction; the cloud altitude when known, and the surface visibility. When an observation is not made due to low clouds, mist, fog, rain, snow, etc., such information will be telegraphed in place of the regular message.

For the present only the above-mentioned altitudes will be sent in the telegraphic message. The 4,000-meter altitude word, when that altitude is attained, will be the last word sent indicating wind direction and velocity, except when the maximum altitude is greater than 4,000 meters, in which case the 4,000-meter altitude word will be followed by a wind word expressing the direction and velocity of the maximum altitude. The code words expressing the wind conditions are divided into two classes: Class 1, words possessing the characteristic vowels *a* or *i* in the first syllable; class 2, those possessing the characteristic vowels *e* or *o*, in the first syllable. Class 1 is used for the even-numbered words in the message after the time word, namely, second, fourth, sixth, and eighth words; class 2 for the odd-numbered words in the message after the time word, namely, third, fifth, seventh, and ninth.

The complete coded message for an observation may be divided into four distinct sections: (1) Designation, (2) time, (3) wind data, and (4) miscellaneous data, as follows:

Section.	Signification.	Characterized by—	Order of word in message.
(1) Designation.	Station.	Name of station sending message.	First.
(2) Time.	Observation, a. m., p. m., or special.	C or H, date and time word, or "Special eleven," etc.	Second.
(3) Wind data.	Velocity and direction at surface:	First syllable containing: a or i.	Third.
	250 meters.	e or o.	Fourth.
	500 meters.	a or i.	Fifth.
	1,000 meters.	e or o.	Sixth.
	1,500 meters.	a or i.	Seventh.
	2,000 meters.	e or o.	Eighth.
	3,000 meters.	a or i.	Ninth.
	4,000 meters.	e or o.	Tenth.
(4) Miscellaneous.	Maximum altitude.	T words.	Eleventh.
	Maximum altitude wind data.	Wind words in a or i.	Twelfth.
	Predominating clouds.	C words.	Thirteenth.
	Cloud altitude.	T words.	Fourteenth.
	Visibility.	Numbers.	Fifteenth.

Section 1 will consist of the telegraphic name of the station from which the message is sent. Section 2 will signify the time of observation, whether regular a. m. or p. m. or special. When the observation, being telegraphed, is the regular a. m. or p. m. observation one of the regular date and time words (commencing with *C* or *H*) will be used. If the observation is a special one, then the word expressing the hour nearest to which the observation was made with the word "Special" will replace the time and date word. Thus a special observation taken at 10:40 or 11:25 would be indicated in the message by the words "Special eleven," instead of the *C* or *H* date and time word. Section 3 will consist of the wind data in code for specified levels. The number of the words in this section will vary to some extent with the length of the observation. The maximum number of words for this section is eight, and for observations for less than 4,000 meters in altitude will decrease accordingly. For instance, a message for an observation of 1,600 meters in altitude would contain wind data for five levels only, that is, surface to 1,500-meter level inclusive.

If, for any reason, data are not available at an intermediate level, the word "Missing" will be inserted in the proper place so as to preserve the regular sequence of coded words. This does not mean that "Missing" will be sent, for instance, for the 3,000 and 4,000 meter levels when the observation extended to only 2,000 meters. This information is conveyed by the absence of further data in that section, and by the word expressing the maximum altitude. Section 4 will consist of code words for miscellaneous data. The number of the words in this section will also vary, but the first and last will always be present. The first word will give the maximum altitude attained in the observation. When the maximum altitude is more than 4,000 meters, the maximum altitude word will be followed by a code word of class 1, or the even group, and will express the velocity and direction at that level. When there are clouds, the third word of this section will signify the amount, kind, and direction. When the altitude of the clouds is known, this coded information immediately follows. The last word of the coded message will express the visibility by number according to scale. Thus, dense fog will be expressed by the word "Zero," poor by the word "Four," indifferent by the word "Five," etc. In many instances this last section will consist of only the first and last words. Frequently the maximum altitude word and the cloud altitude word will be identical. The cloud altitude word should not be given unless the altitude of the cloud base has been definitely established.

The code is founded on the principles of the regular Weather Bureau code, and with slight modifications, fulfills all needs completely. The significant letters *B*, *D*, *F*, *G*, *M*, *N*, *R*, and *S* have the same numerical value as in the regular code, such as: $B=10$, $D=20$, $F=30$, etc., the value between the even 10 values being denoted by the vowels *u*, *a*, *e*, *i*, and *o*, corresponding to 0, 2, 4, 6, and 8, respectively, as in the regular code. In directions, the significant letters, *B*, *D*, *F*, etc., are modified by significant vowels such that each letter denotes one or two directions according to the vowel that follows it; for example, *Ba*, and *Be* correspond, respectively, to the even and odd classes of words denoting north; and *Bi*, and *Bo* correspond, respectively, to the even and odd classes of words denoting north-northeast.

Each wind word of the message, section 3, indicates the wind velocity and direction at a particular altitude. The position of the word and the character of the first syllable signify the altitude at which such data were observed. The first word of this section, taken from the even group of words, or class 1, the first syllable of which ends in either *a* or *i*, denotes the conditions at the surface. The second word of the section taken from the odd group, or class 2, the first syllable of which ends in either *e* or *o*, denotes the conditions for the 250-meter level. Likewise, the third, fourth, fifth, sixth, seventh, and eighth words alternating from the odd group to the even group, designate the wind conditions for the succeeding levels, 500, 1,000 meters, etc.

The direction from which the wind is blowing is denoted by the first two letters of the first syllable of each of the wind words, and is recorded to the nearest one of the 16 compass points. This first syllable is made up of one of the code consonants *B*, *D*, *F*, etc., followed by one of the four vowels *a*, *e*, *i*, or *o*. These vowels are divided into two classes, *a* and *i* in the first class characterizing the even group of wind words, or the surface, 500, 1,500, 3,000 meter and maximum-altitude levels; *e* and *o* in the second class characterizing the odd group of wind words, or 250, 1,000, 2,000, and 4,000 meter levels. Let it be noted that wind words characterized by *a* and *i*, designate directions at the eight compass points, e. g., N., NE., E., etc., while *e* and *o* designate directions at the intermediate compass points, e. g., NNE., ENE., ESE., etc. The

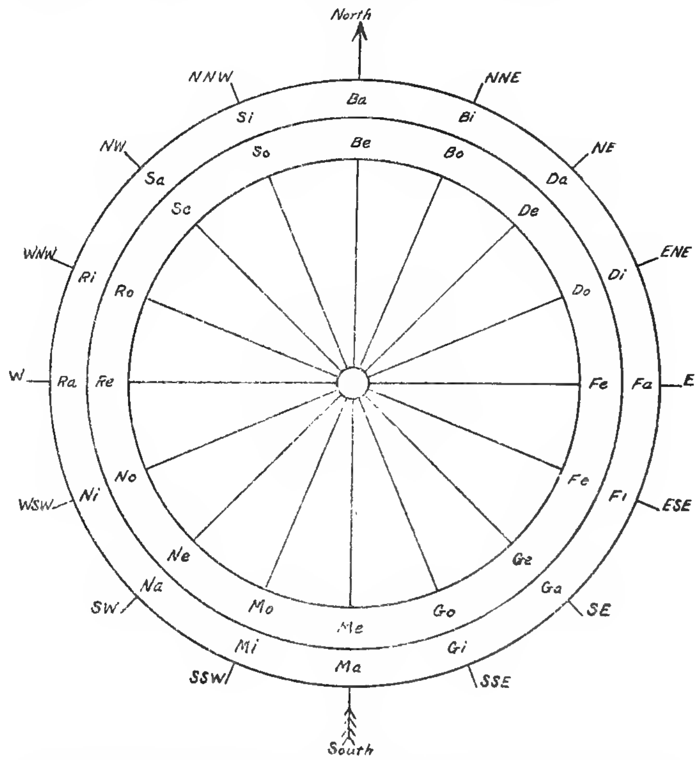


Fig. 51.—Graphical representation of wind words of balloon code. (The outer circle is the even-word code direction; the inner circle is the odd-word code direction.)

accompanying diagram, figure 51, indicates the direction denoted by the various combinations of consonants and vowels in the first syllable of the wind word, for both classes of wind words. For example, a wind word beginning with *Da* indicates a wind from the northeast, *Ni* a wind from the west-southwest, and these two combinations would only be found in words of the first class of even-order words. A wind word beginning with *Fe* denotes a wind from the east, *Mo* from the south-southwest, and these would only be found in words of the second class or odd-order of words.

A message properly made out will contain a succession of wind words alternately of class 1 (characteristic vowel *a* or *i*) and class 2 (characteristic vowel *e* or *o*). The wind words are divided into these two classes, which alternate in the message, for the reason that should one of the wind words of the message be omitted in transmission, the omission may be readily detected.

The wind velocity, or rate of movement in meters per second, is denoted by the second syllable of the wind word, wherein the first consonant is immediately followed by a vowel. The numerical values of the consonants and vowels have already been explained. The various combinations of these consonants and vowels make it possible to express any velocity from 1 to 89 meters per second. However, the code provides for a velocity up to and including 50 meters per second only. Should the telegraphic data include velocities greater than 50 meters per second, code words may be coined according to the above principles, to designate the actual velocities.

The odd values of the velocities are expressed by the presence of the letter *y* in the word, which increases the even value of the velocity, as expressed in the second syllable, by 1. This is illustrated by the word "bathday," expressing a velocity of 23 meters per second, while the word "bagdad" containing the same combination of consonant and vowel, *da*, expresses a velocity of 22 meters per second, the direction in each case being from the north. A velocity of 1 meter per second is expressed by a word whose second syllable contains the letter *y*, but which has no other translatable value; thus, the word "daily" expresses a velocity of 1 meter per second from the northeast. When the velocity is less than 0.5 meter per second, the word "us," indicating calm, will be used.

Maximum altitude, or the height at which the balloon is lost to sight, is given in an altitude word which immediately follows the last wind word in section 3 of the message. The altitude is reported to the nearest 100 meters, and for this reason code words are given for each 100 meters from 100 to 15,000. All of the altitude words, whether maximum altitude or cloud altitude words, begin with *T* and are followed directly by the vowel *a*, *u*, or *y*. Altitudes under 10,000 meters will be expressed by words beginning with *Tu* or *Ty*, and altitudes greater than 10,000 meters will begin with *Ta*. In the second syllable a consonant followed by a vowel indicates the altitude in hundreds and thousands of meters, the same numerical value being assigned to the respective vowels and consonants in this syllable as in the wind words. In the altitude words, the odd value of the altitudes is indicated by a final *s* in the word. This increases the even value of the altitude word by 100 meters. For instance, *Bi* in the second syllable of the altitude word denotes an altitude of 1,600 meters, but with the presence of the terminating *s* it denotes an altitude of 1,700 meters. Let the following examples set forth the principles outlined above:

Tusks	= 100 meters.	Tucksy	= 8, 000 meters.
Turcoman	= 800 meters.	Tape	=10, 400 meters.
Turfy	= 3, 000 meters.	Tabards	=11, 300 meters.
Tyfus	= 3, 100 meters.		

The kind, direction, and amount of the predominating clouds will be coded in the word immediately following the maximum altitude wind word, with the exception that where the maximum altitude is less than 4,000 meters the cloud word will immediately follow the maximum altitude word itself. This type of word always begins with the letter *C*. The second letter of the word characterizes the type of cloud according to the following scheme:

Cu for cirrus, or cirro-stratus.
Ca for cirro-cumulus, or alto-cumulus.
Ce for alto-stratus.
Ci for cumulus.
Co for strato-cumulus.
Ch for stratus.
Cl, Cr } for nimbus, or cumulo-nimbus.

In the second syllable a vowel following a consonant indicates the amount of clouds observed, as follows:

u or y=one tenth or less.
a=two or three tenths.
e=four or five tenths.
i=six or seven tenths.
o=eight, nine, or ten tenths.

The consonant preceding this vowel gives the direction to the nearest one of the eight compass points, from which the clouds are moving, thus:

b from north.	m from south.
d from northeast.	n from southwest.
f from east.	r from west.
g from southeast.	s from northwest.

Ordinarily only the predominating clouds will be included in the telegraphic message. However, when two or more types of clouds are equally distributed over the sky, a word for each type will be included in the message. When two or more kinds of clouds are reported, the directions reported will be those of the respective kinds; the amount reported will be the amount observed of each general type.

No ascension.—In case no regular ascension is made, for any reason, such as rain, snow, sleet, mist, haze, fog, or smoke, etc., the message will be filed in the regular order as though the ascension had been made. The reason for no ascension, followed by the word "none," will be substituted for the regular wind data of the message in section 3. Much of the data in section 4 will then necessarily be omitted. Cloudiness will be expressed as usual, with the exception of rain, snow, sleet, and mist, when it will be omitted. If a successful ascension equivalent to 250 meters in elevation is made, the state of the weather will not be reported, but the message will be sent in the regular form. By reference to subsequent portions of the code, there will be found little difficulty in the coding of the message. When coded, the message should be carefully checked and verified before submitting to the telegraph office. The observation on which it is based should be made promptly and as nearly as possible, at the scheduled time, and the calculation of data should be accomplished as rapidly as accuracy will permit. It is important that the message be sent as soon as possible after the observation has been completed. Each station will be informed of the observations that are to be telegraphed and the message for these data must not be omitted whether an ascension has been made or not.

Stations that are instructed to telegraph only one of their daily observations will file a message at the regular time whether or not a successful ascension is made. If an ascension is made, the data will be coded and telegraphed in the regular manner. If an ascension is not made because of "rain," "snow" "low clouds," etc., the message will give this information, followed by the coded data for the immediately preceding observation. If the latter was not made, the reason for its omission will also be stated. Each portion of the message will be preceded by the proper time word.

The proper coding of a typical pilot balloon message is given below. The data enciphered in section 3 are those obtained in the single-theodolite projection A, 1, 2 . . . . 21, 22, figure 45.

(Station)	(Time)	(Surface)	(250)	(500)	(1,000)
Washington	Carbuncle	Biped	Deacon	Diplomacy	Bogbull
		(NNE 4)	(NE 8)	(ENE 9)	(NNE 10)

(1,500)	(2,000)	(3,000)	(4,000)	(Maximum altitude)
Bibulous	Sealegs	Nimbose	Nobody	Tuggers
(NNE 10)	(NW 4)	(WSW 18)	(WSW 19)	(4,500)

(Maximum altitude wind)	(Cloud)	(Cloud)	(Visibility)
Nimbose	Cubby	Cirrum	Seven
(WSW 18)	(1 Ci. W)	(1 Cu. W)	(Good)

The enciphered data of the double theodolite observation obtained from the projection A, 1, 2 . . . . 10, 11, figure 41, will appear as follows:

(1)	(2)	(3)	(4)	(5)	(6)
(Station)	Camber	Naked	Novity	Rancourously	Rebanish

(7)	(8)	(11)	(13)	(15)
Rabate	Redbird	Tyndall	Control	Six

Due to the fact that the length of the observation was insufficient to provide data for more than the 2,000-meter level, a full 15-word message can not be submitted. Note that the words (9), (10), (12), and (14) are omitted.

A message, filed from a station regularly telegraphing only one daily observation, but reporting the current and preceding observations, when the former has resulted in failure, will take the following form:

(1)	(2)	(3)	(15)	(2)	(3)	(3)	(15)
Ithaca	Coach	Raining	Four	Hold	Raining	Foggy	One

The complete code used in telegraphing pilot-balloon observations is given in the following pages.

CODE FOR TIME AND DATE WORDS.

Date.	A. M.	P. M.
1	Coach	Hold
2	Canvas	Hazard
3	Collar	Holland
4	Cave	Hale
5	Cobble	Hockey
6	Calico	Hacking
7	Colic	Hoodwink
8	Cavort	Halcyon
9	Colon	Hollow
10	Carbuncle	Hamburg
11	Combustion	Hobby
12	Cabal	Hatband
13	Cobalt	Hopback
14	Camber	Habeas
15	Corbet	Hornbeak
16	Cabin	Habit
17	Combine	Hornbill
18	Caboose	Harbor
19	Cockboat	Hobo
20	Caducean	Handy
21	Conduct	Honduras
22	Cadaver	Halfday
23	Cordage	Houdah
24	Cadet	Hades
25	Code	Hoiden
26	Caddie	Hading
27	Codicil	Hoarding
28	Candor	Haddock
29	Condole	Hoodoo
30	Capful	Harmful
31	Coiffure	Hogfur

(Ca=even dates, a. m. Ha=even dates, p. m.) (Co=odd dates, a. m. Ho=odd dates, p. m.)

NOTE.—In date words in which the vowel in the first syllable is "o," the value of the second syllable is increased by one (1).

CODE FOR WIND ALOFT REPORT.

NORTH.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Balky.	26	Bandit
2	Bacca	27	Bandily
3	Bavaroy	28	Bandon
4	Bachelor	29	Bandory
5	Barley	30	Bagful
6	Bacillus	31	Banfully
7	Baycliff	32	Bafak
8	Bacon	33	Badfairy
9	Balcony	34	Barfee
10	Backbur	35	Baffetay
11	Banbury	36	Baffin
12	Barbara	37	Barfishy
13	Backbay	38	Barnfork
14	Babel	39	Backfoyer
15	Bayberry	40	Baguette
16	Babish	41	Badguy
17	Baybinky	42	Bargain
18	Backbone	43	Baygate
19	Bathboy	44	Banger
20	Baldus	45	Badgerly
21	Baydull	46	Banging
22	Bagdad	47	Baggily
23	Bathday	48	Bagoas
24	Baden	49	Baggory
25	Badenfly	50	Barmuck

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Bevy	26	Bedim
2	Beware	27	Bedirty
3	Belady	28	Bedote
4	Beheld	29	Bedoughy
5	Beaver	30	Befurred
6	Bewilder	31	Beakfully
7	Beylik	32	Befall
8	Below	33	Befancy
9	Beworry	34	Befetter
10	Bedbug	35	Beltferry
11	Bedbuggy	36	Befit
12	Beanbag	37	Beficiary
13	Beyball	38	Before
14	Berber	39	Bendfoy
15	Bearberry	40	Beguile
16	Berbice	41	Beguilingly
17	Bellbirdy	42	Bengal
18	Benbow	43	Beggarly
19	Bellboy	44	Beget
20	Bedust	45	Bergerly
21	Bedusky	46	Begirdle
22	Bedaub	47	Beggingly
23	Beanday	48	Begotton
24	Bedew	49	Begodly
25	Bedewy	50	Bemuffle

NNE.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Billy	26	Bildiment
2	Biparous	27	Bidingly
3	Bicavity	28	Bidon
4	Biped	29	Bidogyn
5	Biweekly	30	Bifurcate
6	Billing	31	Bifuzzy
7	Biliary	32	Bifacial
8	Billow	33	Bigfay
9	Bijoutry	34	Biferous
10	Bibulous	35	Biferey
11	Bibulously	36	Bifilar
12	Bibasic	37	Bifixity
13	Bibacity	38	Biforine
14	Bibber	39	Bifogy
15	Bilberry	40	Bitguard
16	Bitbinder	41	Bigguy
17	Bibbitary	42	Bigamist
18	Bilbo	43	Bigamy
19	Bigboy	44	Biggest
20	Billduck	45	Bigeyed
21	Bidumpy	46	Biggin
22	Biddable	47	Bigilpey
23	Birthday	48	Bigot
24	Bidder	49	Bigotry
25	Bindery	50	Bismuth

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Boldly	26	Boddice
2	Bogland	27	Bodily
3	Bolary	28	Bordon
4	Bolero	29	Bodocity
5	Bowyer	30	Boastful
6	Bovine	31	Bokfury
7	Boligny	32	Boldface
8	Bologna	33	Bookfancy
9	Boycott	34	Bouffe
10	Bogbull	35	Bofelty
11	Bondbuyer	36	Bonfire
12	Bobance	37	Bowfishy
13	Bombay	38	Boxford
14	Bonbekir	39	Bofoxy
15	Bogberry	40	Bogus
16	Bobbin	41	Boldguy
17	Bobbishly	42	Bogardus
18	Bobolink	43	Boggarty
19	Bourbony	44	Bourgeon
20	Boddum	45	Bogey
21	Bogduty	46	Bougie
22	Bondage	47	Boggify
23	Boundary	48	Bogota
24	Border	49	Bowgory
25	Bouldery	50	Bomund

CODE FOR WIND ALOFT REPORT—Continued.

NE.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Dally	26	Dandiness
2	Dacapo	27	Dandify
3	Daylark	28	Daddock
4	Dauntless	29	Dadoxylon
5	Dacey	30	Darkful
6	Davit	31	Dayfue
7	Daylily	32	Dartfall
8	Dacort	33	Dayfairy
9	Daylost	34	Dafer
10	Dabuh	35	Dayfelony
11	Darkbully	36	Daffish
12	Daba	37	Daffishly
13	Dampbay	38	Daffodil
14	Dabber	39	Daffocky
15	Daubery	40	Daguerre
16	Daubing	41	Daygull
17	Dabistisy	42	Dagart
18	Dagsbora	43	Daygalley
19	Daybook	44	Dangerous
20	Darkdull	45	Dangerfully
21	Dawduffy	46	Dagging
22	Dardanelle	47	Dagiggly
23	Darkday	48	Dagonism
24	Dander	49	Daggory
25	Daydeck	50	Damusa

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Deadly	26	Dedicate
2	Decant	27	Dedicatory
3	Delay	28	Dedona
4	Deceit	29	Dedory
5	Decency	30	Dearthful
6	Decipher	31	Defusedly
7	Deviltry	32	Deface
8	Deadlock	33	Defanatory
9	Decoy	34	Defeat
10	Debutant	35	Defensory
11	Denbury	36	Defiance
12	Debase	37	Deficiency
13	Debasingly	38	Deform
14	Debel	39	Deformity
15	Dewberry	40	Dengue
16	Debited	41	Degumy
17	Debility	42	Degarnish
18	Debonair	43	Degaranty
19	Deckboy	44	Degender
20	Deduct	45	Degeneracy
21	Deducibly	46	Deggins
22	Dedalous	47	Degilpey
23	Dedactyl	48	Dego
24	Dedentian	49	Degotey
25	Deadeye	50	Demulsion

ENE.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Dippy	26	Disdip
2	Dilate	27	Didickey
3	Dilatory	28	Disdoes
4	Dice	29	Disdoily
5	Dickey	30	Diffuse
6	Diligent	31	Diffusedly
7	Disciplinary	32	Diffame
8	Dipolar	33	Disfamily
9	Diplomacy	34	Differ
10	Disburse	35	Differently
11	Digbury	36	Difficult
12	Disbark	37	Diffidently
13	Dibasicity	38	Difform
14	Diabet	39	Difformity
15	Dibberly	40	Disgulf
16	Disbind	41	Disgustedly
17	Disbindery	42	Digamouse
18	Disbowel	43	Digalaxy
19	Disbordy	44	Digest
20	Didus	45	Dingey
21	Dingdully	46	Digit
22	Disdain	47	Digitately
23	Didactyl	48	Dingo
24	Diadem	49	Diagonally
25	Didelphyd	50	Dismusk

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Dolly	26	Dodipoll
2	Dockage	27	Dowdishy
3	Doorway	28	Dodo
4	Dover	29	Dodoggy
5	Donkey	30	Doomful
6	Docking	31	Doubtfully
7	Docity	32	Dogface
8	Dolomite	33	Dogfamily
9	Dolorously	34	Doffea
10	Dobule	35	Downferry
11	Dollbuggy	36	Dolfin
12	Dogbane	37	Dogfishery
13	Donbay	38	Dogfox
14	Dogbee	39	Dotfollery
15	Dombey	40	Dogguard
16	Doorbind	41	Dockgully
17	Dobicy	42	Dogal
18	Dogbolt	43	Doggayly
19	Doughboy	44	Dogged
20	Dogdull	45	Doggery
21	Dotduly	46	Doggish
22	Dockdam	47	Doggishly
23	Dogday	48	Dongola
24	Doder	49	Dongory
25	Dodecagyn	50	Dortmund

CODE FOR WIND ALOFT REPORT—Continued.

EAST.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Fancy	26	Fading
2	Facade	27	Fadingly
3	Fallacy	28	Fardon
4	Father	29	Fardory
5	Facety	30	Faithful
6	Fakir	31	Farfully
7	Facially	32	Fanfare
8	Favor	33	Falfastly
9	Falconry	34	Farfetch
10	Fabulous	35	Farferity
11	Fabulously	36	Fairfield
12	Fabaceous	37	Falfishy
13	Farbay	38	Fanfoot
14	Fabella	39	Fallforty
15	Fabery	40	Fagundus
16	Fabian	41	Fatgully
17	Fabingy	42	Fagan
18	Fadboil	43	Fagally
19	Fatboy	44	Fadge
20	Fardug	45	Faggery
21	Faydub	46	Fagine
22	Fandango	47	Fawngilly
23	Farday	48	Fagots
24	Fade	49	Fagopye
25	Fadedly	50	Farmulate

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Feckly	26	Fendille
2	Fellable	27	Fedity
3	Fellary	28	Fedora
4	Feeble	29	Fedoddy
5	Feathery	30	Fearfun
6	Feline	31	Fearfully
7	Felicity	32	Feefarn
8	Feloid	33	Fewfalsity
9	Felony	34	Feafer
10	Febus	35	Fellferry
11	Fearbunny	36	Fersfield
12	Fearbabe	37	Fearfitty
13	Fellbary	38	Fenfowl
14	Fellbear	39	Fefolly
15	Fenberry	40	Ferguson
16	Febing	41	Felgully
17	Fewbiggy	42	Feugar
18	Fenboat	43	Fegarcy
19	Feedboy	44	Felger
20	Fenduck	45	Fegemetry
21	Feyndunce	46	Fengite
22	Feudal	47	Fegility
23	Feudary	48	Fengower
24	Federal	49	Feargodly
25	Federacy	50	Femur

ESE.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Fiky	26	Fiendish
2	Fiscal	27	Fiendishly
3	Filatory	28	Fido
4	File	29	Fixdoggy
5	Fippenny	30	Fitful
6	Fixing	31	Fiendfully
7	Filiety	32	Fishfag
8	Fico	33	Fibfancy
9	Filosy	34	Fife
10	Ficksburg	35	Fifedity
11	Filbury	36	Fifield
12	Finback	37	Fillfinny
13	Fieldbay	38	Firmfoot
14	Fiberless	39	Fiforay
15	Fibbery	40	Figure
16	Fishbite	41	Figurantly
17	Figbiddy	42	Fillgap
18	Fimboro	43	Figary
19	Fillboggy	44	Fidget
20	Fiducial	45	Fidgety
21	Fiduciary	46	Figgist
22	Fidalgo	47	Figginy
23	Fidairy	48	Figoal
24	Fides	49	Figgoody
25	Fidelity	50	Filmuck

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Folly	26	Folding
2	Forward	27	Fordity
3	Forway	28	Fordo
4	Force	29	Foddory
5	Foley	30	Formful
6	Folio	31	Foolfully
7	Foliosity	32	Footfall
8	Follow	33	Foxfairy
9	Forlornly	34	Forfeit
10	Forbush	35	Fogferry
11	Forbuy	36	Forficula
12	Forbade	37	Fobfinely
13	Forbarely	38	Fourfold
14	Forbear	39	Forfootedly
15	Forbearingly	40	Fourgun
16	Forbidden	41	Foygun
17	Forbiddingly	42	Forgave
18	Forbore	43	Foxgamy
19	Footboy	44	Foge
20	Fondulac	45	Forgery
21	Fonduly	46	Forging
22	Foldage	47	Forgivingly
23	Foxday	48	Forgotten
24	Folders	49	Forgoingly
25	Fordedly	50	Formula

CODE FOR WIND ALOFT REPORT—Continued.

SE.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		*m. p. s.*	
1	Gainly	26	Gaddish
2	Galago	27	Gaddingly
3	Gallantry	28	Gador
4	Galena	29	Gaydoily
5	Galley	30	Gastful
6	Gallot	31	Gasfumy
7	Gapingly	32	Garfall
8	Gallop	33	Garfairy.
9	Galloway	34	Gaffer
10	Gadbush	35	Gayfeather
11	Gaynburg	36	Gasfitter
12	Garbage	37	Gayfiny
13	Gabatay	38	Gafol
14	Gaberdine	39	Gadfolly
15	Garbelay	40	Gangue
16	Gambit	41	Gaygurgle
17	Gaybine	42	Gargarize
18	Gambol	43	Garganey
19	Gaboy	44	Gage
20	Gadus	45	Gaugey
21	Gaduinly	46	Gaging
22	Gardant	47	Gargily
23	Gayday	48	Gargol
24	Gardening	49	Gargoyle
25	Gardenly	50	Gamut

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		*m. p. s.*	
1	Gelly	26	Gelding
2	Gelatine	27	Gendizzy
3	Gelably	28	Gemdore
4	Gehenna	29	Geardotty
5	Geleemy	30	Gerful
6	Gelid	31	Gemfury
7	Gelidly	32	Gerfalcon
8	Gecko	33	Gemfancy
9	Gerholdy	34	Geffers
10	Geburah	35	Genfenny
11	Geltbuy	36	Gelfin
12	Gebang	37	Gemfiry
13	Gebarny	38	Gessford
14	Gebber	39	Gefozzy
15	Gembelfry	40	Gegum
16	Getbid	41	Gemgurry
17	Gerbilly	42	Gewgaw
18	Gemsbok	43	Gesgally
19	Gadbony	44	George
20	Geddum	45	Geogenously.
21	Gemduly	46	Georgian
22	Gendarme	47	Getgilpy
23	Gendarmory	48	Geldgold
24	Genderless	49	Geogony
25	Geodesy	50	Gemmush

SSE.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		*m. p. s.*	
1	Gilpy	26	Giddiness
2	Gila	27	Giddily
3	Giglay	28	Girdon
4	Give	29	Gigdotty
5	Gilery	30	Ginfume
6	Gilian	31	Girthfumy
7	Girlishly	32	Giffard
8	Gillote	33	Girdfarcy
9	Giglotry	34	Girtfeld
10	Gibbus	35	Gigfeyn
11	Gibusly	36	Gilfillan
12	Gimbal	37	Girdfinny
13	Gilbakery	38	Gilford
14	Gibbering	39	Gilfoy
15	Ginbeddy	40	Girdgup
16	Gibier	41	Gipgulfy
17	Gibingly	42	Gigantic
18	Gibbons	43	Gingaly
19	Gibbosity	44	Ginger
20	Gindump	45	Gingerly
21	Gigdually	46	Gingival
22	Gildale	47	Gingingy
23	Gipdarky	48	Gigot
24	Gilder	49	Gillgoby
25	Gigdecky	50	Gimmut

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		*m. p. s.*	
1	Godly	26	Gordian
2	Gocart	27	Godify
3	Goodpay	28	Gondola
4	Gopher	29	Gondolary
5	Gopey	30	Godful.
6	Golling	31	Godfury
7	Goblinary	32	Godfather
8	Golore	33	Godfairy
9	Golory	34	Gofer
10	Gobum	35	Goldfelly
11	Gotbusy	36	Goffish
12	Goodbar	37	Goldfinny
13	Gobangy	38	Goldfoil
14	Gobelin	39	Goforbay
15	Godberty	40	Gorgus
16	Gobbing	41	Gotguay
17	Godbilly	42	Gongar
18	Goldbound	43	Gogally
19	Gobony	44	Gorged
20	Golddust	45	Gorgeously
21	Gongduty	46	Goggin
22	Goddard	47	Goldgildy
23	Goddary	48	Gorgon
24	Golden	49	Goldgoby
25	Goldenly	50	Gomut

CODE FOR WIND ALOFT REPORT—Continued.

SOUTH.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Mashy	26	Madia
2	Macadam	27	Maddingly
3	Malay	28	Madonna
4	Majestic	29	Mandory
5	Macey	30	Marful
6	Making	31	Manfully
7	Machinery	32	Marfa
8	Major	33	Madfay
9	Mahogany	34	Magfell
10	Marbull	35	Macfeely
11	Mawkbury	36	Maxfield
12	Marbach	37	Mayfish
13	Mackbay	38	Malform
14	Madbee	39	Mayfowl
15	Maybe	40	Magus
16	Mabin	41	Mainguy
17	Maybird	42	Margarite
18	Marlboro	43	Margay
19	Maybog	44	Magenta
20	Manduke	45	Mangery
21	Malmduchy	46	Magic
22	Madam	47	Magically
23	Maday	48	Maggot
24	Maiden	49	Madgoying
25	Maidenly	50	Mamugue

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Mealy	26	Medical
2	Medlar	27	Mediacy
3	Melancholy	28	Meadow
4	Meeken	29	Mendogey
5	Methenyl	30	Meanful
6	Mexico	31	Meedfully
7	Melissyl	32	Medfast
8	Melon	33	Menfaggy
9	Melody	34	Meanfelt
10	Meanbull	35	Medfelly
11	Medbury	36	Medfield
12	Mealbag	37	Meanfilly
13	Membarry	38	Medford
14	Member	39	Menfoxy
15	Mealberry	40	Mergus
16	Membine	41	Mealgunny
17	Merbilly	42	Megapode
18	Melbourne	43	Megalonyx
19	Messboy	44	Merge
20	Medusa	45	Meagerly
21	Medullary	46	Merging
22	Medal	47	Meangilly
23	Meanday	48	Mergot
24	Meander	49	Mengoodly
25	Medeny	50	Meanmug

SSW.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Micky	26	Minding
2	Mica	27	Middingy
3	Midway	28	Misdoubt
4	Millet	29	Misdodgy
5	Miley	30	Mindful
6	Midwinter	31	Mightfully
7	Military	32	Misfall
8	Milo	33	Misfairy
9	Milogy	34	Misfeign
10	Milburn	35	Milfelony
11	Misbury	36	Misfit
12	Milbach	37	Milfiggy
13	Midbaby	38	Misform
14	Misbear	39	Misfoolery
15	Milberry	40	Misguide
16	Misbirth	41	Misguy
17	Milbilly	42	Misgave
18	Misborn	43	Midgalley
19	Midboy	44	Misget
20	Misdude	45	Milgentry
21	Mixduly	46	Misgiven
22	Mida	47	Misgiddy
23	Midday	48	Misgovern
24	Milden	49	Misgory
25	Mildewy	50	Mimulus

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Monthly	26	Modius
2	Mackade	27	Modify
3	Mohairy	28	Modoc
4	Mole	29	Modocry
5	Monkey	30	Mournful
6	Molino	31	Morfurry
7	Mollify	32	Moffat
8	Mohocks	33	Morfarcy
9	Moochooey	34	Moffette
10	Messbunker	35	Mossfelty
11	Mossburly	36	Moorfish
12	Morband	37	Moldfinny
13	Mossbay	38	Moorfowl
14	Mobbed	39	Morfondly
15	Moberly	40	Morgue
16	Mobilize	41	Mogully
17	Mockbilly	42	Morgan
18	Morbose	43	Morgay
19	Mobocracy	44	Monger
20	Module	45	Morgently
21	Modulantly	46	Mogilno
22	Mordant	47	Mossgilly
23	Monday	48	Mongolian
24	Mode	49	Montgomery
25	Modesty	50	Momus

CODE FOR WIND ALOFT REPORT—Continued.

SW.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Nancy	26	Nadir
2	Nazarene	27	Naidinay
3	Navally	28	Nandow
4	Naked	29	Nadobby
5	Naively	30	Nailful
6	Narcissus	31	Natfumy
7	Napkinly	32	Nagfair
8	Napoleon	33	Nafady
9	Nauscopy	34	Nafe
10	Nabull	35	Natferry
11	Naybuff	36	Narfin
12	Nailball	37	Nanfiggy
13	Nabasye	38	Narford
14	Nabbed	39	Nafolly
15	Nabetony	40	Nangull
16	Nabbing	41	Nagually
17	Nabilgy	42	Nagasaki
18	Nabob	43	Nagany
19	Nanboy	44	Nagged
20	Nandu	45	Naggemy
21	Naydual	46	Nargil
22	Nadab	47	Naggingly
23	Nabdaddy	48	Nalgonda
24	Narden	49	Nagory
25	Nadecyl	50	Namur

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Nearly	26	Neddiness
2	Nevada	27	Needily
3	Neyland	28	Newdorp
4	Nearness	29	Neadonary
5	Necessary	30	Neckfur
6	Nervine	31	Needfully
7	Negligency	32	Nefarious
8	Nervous	33	Nefariously
9	Neckyoke	34	Neife
10	Nebulous	35	Needfelly
11	Nebuly	36	Newfield
12	Nebat	37	Nestfinny
13	Neahbay	38	Newfound
14	Nebeb	39	Nefoamy
15	Nedberry	40	Negus
16	Nesbit	41	Negundory
17	Nebilly	42	Negative
18	Neighbor	43	Negatory
19	Neighborly	44	Negget
20	Newdune	45	Nelgentry
21	Neyducat	46	Neginoth
22	Nedar	47	Negirthy
23	Netdarky	48	Negotiate
24	Nedder	49	Newgory
25	Newderby	50	Nemuel

WSW.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Nightly	26	Niding
2	Nirvana	27	Nidify
3	Nipay	28	Nidor
4	Niles	29	Nidorosity
5	Nicely	30	Nigful
6	Niblic	31	Nightfully
7	Nihility	32	Nightfall
8	Nilod	33	Nifalcy
9	Niloscopy	34	Niffert
10	Nimbus	35	Nifferny
11	Nigbuy	36	Nightfire
12	Niband	37	Niffilly
13	Nibally	38	Nightfog
14	Niobe	39	Niffodly
15	Nisberry	40	Nigua
16	Nibbing	41	Nigully
17	Nibbirdy	42	Niggard
18	Nimbose	43	Niggardly
19	Nilbody	44	Niger
20	Nidus	45	Nidgery
21	Nidusly	46	Niggish
22	Nidal	47	Nilgilly
23	Nidary	48	Nightgown
24	Nide	49	Nipgory
25	Niddery	50	Nismur

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Nobly	26	Nodding
2	Norval	27	Noddingly
3	Nopalry	28	Nodose
4	Novel	29	Nodosity
5	Nocently	30	Nonfulfill
6	Novice	31	Noyfully
7	Novity	32	Nofar
8	Norwood	33	Nonfancy
9	Novology	34	Nonfeance
10	Nobbut	35	Nonfedity
11	Noybulb	36	Northfield
12	Noback	37	Nonfidelity
13	Nonbaby	38	Norfolk
14	Norbeck	39	Nonfoxy
15	Nobelay	40	Noguera
16	Nobile	41	Noygust
17	Nobility	42	Nougat
18	Noboat	43	Nogaray
19	Nobody	44	Nogent
20	Nodular	45	Nongentry
21	Noyduct	46	Noggins
22	Nodation	47	Nogiddy
23	Noonday	48	Nogo
24	Nodded	49	Nongoodly
25	Nodewy	50	Nomus

CODE FOR WIND ALOFT REPORT—Continued.

WEST.

Class 1 (even) words.
Altitudes: 0, 250, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Racy	26	Radiant
2	Rampart	27	Radially
3	Railway	28	Random
4	Rake	29	Rathdowny
5	Raillevy	30	Rashful
6	Racing	31	Rapfully
7	Racially	32	Rainfall
8	Racoon	33	Rainfarry
9	Rancorously	34	Raffed
10	Rambuse	35	Rackferly
11	Rawbundy	36	Raffinose
12	Rabate	37	Raffiay
13	Rambady	38	Radford
14	Rabbeting	39	Rayfoily
15	Raspberry	40	Raguled
16	Rabid	41	Ranguly
17	Rabbitry	42	Ragamuffin
18	Rawbone	43	Ragabashy
19	Ramboy	44	Raggedness
20	Radula	45	Raggery
21	Radulately	46	Raging
22	Radama	47	Ragingly
23	Randandy	48	Ragout
24	Raider	49	Ragouty
25	Radey	50	Ramusio

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Rely	26	Reading
2	Recall	27	Readily
3	Recarry	28	Redoubt
4	Reflect	29	Redolently
5	Recently	30	Refute
6	Recipe	31	Redfury
7	Recipiency	32	Refasten
8	Reflow	33	Realfairy
9	Reenjoy	34	Refer
10	Rebuff	35	Refectory
11	Rebury	36	Refining
12	Rebanish	37	Refinery
13	Reedbay	38	Reform
14	Rebelled	39	Refortify
15	Redberry	40	Regular
16	Redbird	41	Regularly
17	Redbindery	42	Regard
18	Rebound	43	Regally
19	Reembody	44	Regent
20	Reduced	45	Reagency
21	Redundancy	46	Region
22	Rendable	47	Registry
23	Reddaisy	48	Regorge
24	Redemption	49	Regorgify
25	Redely	50	Remus

WNW.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		m. p. s.	
1	Richly	26	Ridicule
2	Riparian	27	Ridingly
3	Rivalry	28	Ridotto
4	Ripest	29	Ringdotty
5	Ripely	30	Rightful
6	Risking	31	Rightfully
7	Rickishly	32	Rightface
8	Richohet	33	Rigfally
9	Ridlory	34	Rifeness
10	Ribull	35	Rifelly
11	Ribbuoy	36	Richfield
12	Ribald	37	Rifibby
13	Ribandry	38	Rinford
14	Ribbed	39	Riforay
15	Ribbery	40	Rigum
16	Ribbing	41	Ringusly
17	Ribbingly	42	Rigadoon
18	Ribbon	43	Ribgalley
19	Ribbonry	44	Ridgeless
20	Ridum	45	Riggerdy
21	Riftdungy	46	Rigid
22	Riddance	47	Rigidity
23	Ridably	48	Rigor
24	Riderless	49	Rigorously
25	Ridently	50	Rimula

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		m. p. s.	
1	Ropy	26	Rounding
2	Roulade	27	Rodiya
3	Roadway	28	Rondo
4	Rover	29	Rodomonty
5	Rockery	30	Roomful
6	Roving	31	Rollfully
7	Rockingly	32	Roofage
8	Rococo	33	Rofairy
9	Roloway	34	Roofer
10	Roebuck	35	Rockferry
11	Robustly	36	Roofing
12	Roband	37	Rockfilmy
13	Rockbay	38	Rockfoot
14	Roadbed	39	Rollfoggy
15	Robbery	40	Rogue
16	Robins	41	Roguishly
17	Rockbibby	42	Rogation
18	Roborant	43	Rogatory
19	Rollboy	44	Roger
20	Rondure	45	Rogentry
21	Roydub	46	Rouging
22	Rondache	47	Rogimpy
23	Rodaily	48	Rockgoat
24	Rodent	49	Rogory
25	Roundelay	50	Romulus

CODE FOR WIND ALOFT REPORT—Continued.

NW.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		*m. p. s.*	
1	Saucy	26	Sardine
2	Sacar	27	Sandily
3	Salary	28	Sardonic
4	Save	29	Sardony
5	Saddlery	30	Sackful
6	Savior	31	Sackfurry
7	Saliency	32	Safable
8	Saloon	33	Sacfancy
9	Sallowy	34	Safeguard
10	Sabula	35	Safety
11	Sabulosity	36	Saltfish
12	Sabbath	37	Saffirey
13	Sabbathry	38	Sanford
14	Saber	39	Sanfoldy
15	Sagbelly	40	Sanguine
16	Sabine	41	Sadguy
17	Sabianry	42	Sagamore
18	Sambo	43	Sagacity
19	Saboray	44	Sagenite
20	Sadducee	45	Sandgelly
21	Sandusky	46	Saginaw
22	Sandal	47	Sagittary
23	Sadday	48	Sargon
24	Saddest	49	Sagoinly
25	Sanderay	50	Samuel

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		*m. p. s.*	
1	Seepy	26	Sedition
2	Sealark	27	Seditiously
3	Secancy	28	Seldom
4	Sealegs	29	Seadotty
5	Secrecy	30	Seafur
6	Servile	31	Seafully
7	Sealily	32	Serfage
8	Seahog	33	Seafairy
9	Sepoy	34	Seaferns
10	Seabum	35	Selferry
11	Sebundy	36	Seafish
12	Seabate	37	Selfishly
13	Sebaciously	38	Seafoam
14	Seabean	39	Seafolly
15	Seaberry	40	Seagull
16	Seabird	41	Selfguy
17	Seabilgy	42	Segar
18	Seaborne	43	Seagalley
19	Seaboy	44	Sergeant
20	Seduce	45	Sengelly
21	Sedulity	46	Sedging
22	Sedan	47	Seagirty
23	Sedately	48	Seagod
24	Sederunt	49	Seggony
25	Sedentary	50	Semuncial

NNW.

Class 1 (even) words.
Altitudes: 0, 500, 1,500, 3,000.

m. p. s.		*m. p. s*	
1	Sickly	26	Siding
2	Silvan	27	Sidinky
3	Sikay	28	Siddow
4	Silence	29	Sidoily
5	Silently	30	Sinful
6	Silcilian	31	Sinfully
7	Sickishly	32	Sitfast
8	Sillock	33	Sinfancy
9	Siloy	34	Simferne
10	Sibulk	35	Sifferny
11	Sickbully	36	Siffian
12	Sitzbath	37	Sifilety
13	Sibary	38	Sixfold
14	Siberian	39	Sifony
15	Sibbendy	40	Singular
16	Sibilant	41	Singularly
17	Sibilancy	42	Singapore
18	Sibboleth	43	Sigarety
19	Sickboy	44	Singer
20	Sidulate	45	Siggerly
21	Signduty	46	Singing
22	Sirdar	47	Sigillary
23	Sibday	48	Sillgo
24	Sideral	49	Sigourney
25	Sideway	50	Simulate

Class 2 (odd) words.
Altitudes: 250, 1,000, 2,000, 4,000.

m. p. s.		*m. p. s.*	
1	Soapy	26	Sodium
2	Solar	27	Sordity
3	Solary	28	Southdown
4	Solenoid	29	Sodomy
5	Solemnity	30	Songful
6	Solid	31	Soulfully
7	Sociably	32	Sofa
8	Solon	33	Soulfalacy
9	Socoury	34	Sofett
10	Soapbubble	35	Sopfelly
11	Soyburg	36	Sofism
12	Sorbate	37	Sofinny
13	Sobaly	38	Soulfoot
14	Somber	39	Sowfolly
15	Soberly	40	Sogun
16	Songbird	41	Soygurt
17	Sobbingly	42	Southgate
18	Soboles	43	Southgary
19	Sobolery	44	Sorgen
20	Sodupe	45	Sogery
21	Soydux	46	Songish
22	Sodamide	47	Sogify
23	Sodality	48	Sorgo
24	Soldering	49	Soulgoody
25	Sordesy	50	Solmuth

CODE FOR ALTITUDE OF CLOUDS AND BALLOONS.

m		m		m		m	
100	Tusks	4,100	Tunguses	8,100	Tursus	12,100	Tardus
200	Tuscany	4,200	Tugaloo	8,200	Tutsan	12,200	Tardation
300	Tuckahoes	4,300	Tygarts	8,300	Tussahs	12,300	Tardacious
400	Turtle	4,400	Tuggerah	8,400	Tusseiner	12,400	Tadde
500	Tumbles	4,500	Tuggers	8,500	Tussers	12,500	Tandems
600	Tucking	4,600	Turgid	8,600	Tussicular	12,600	Tardily
700	Tulips	4,700	Turgidness	8,700	Tursins	12,700	Tardiness
800	Turcoman	4,800	Tungo	8,800	Tussock	12,800	Tardo
900	Turcois	4,900	Turngourds	8,900	Tysonites	12,900	Tarldons
1,000	Tubule	5,000	Tumult	9,000	Tufty	13,000	Taffy
1,100	Tubulous	5,100	Tumulous	9,100	Tutuilas	13,100	Taffys
1,200	Tubal	5,200	Turnman	9,200	Tutary	13,200	Tafa
1,300	Turbans	5,300	Turmalines	9,300	Turntables	13,300	Tafallas
1,400	Tube	5,400	Tumefy	9,400	Tutelary	13,400	Tafeta
1,500	Tuberous	5,500	Tumefies	9,500	Tutelages	13,500	Tafferels
1,600	Turbid	5,600	Tumid	9,600	Tutti	13,600	Tafi
1,700	Turbidness	5,700	Tumidness	9,700	Tuitions	13,700	Tafias
1,800	Tyboe	5,800	Tumor	9,800	Tutoring	13,800	Tarfork
1,900	Turbots	5,900	Turmoils	9,900	Tutors	13,900	Talfords
2,000	Turfdum	6,000	Tunny	10,000	Tally	14,000	Taguan
2,100	Turdulis	6,100	Turnus	10,100	Talks	14,100	Tagus
2,200	Tyndall	6,200	Tunable	10,200	Tankard	14,200	Taganet
2,300	Tyndarus	6,300	Tunas	10,300	Tallages	14,300	Tagals
2,400	Tysdell	6,400	Turney	10,400	Tape	14,400	Tangent
2,500	Tydeus	6,500	Tunnels	10,500	Tales	14,500	Targets
2,600	Tundish	6,600	Tuning	10,600	Talking	14,600	Tangible
2,700	Tuditanus	6,700	Turnips	10,700	Tapis	14,700	Taggings
2,800	Tudor	6,800	Turnover	10,800	Talcose	14,800	Tagolanda
2,900	Tudorous	6,900	Turnouts	10,900	Talons	14,900	Tagouts
3,000	Turfy	7,000	Turung	11,000	Tabular	15,000	Talmud
3,100	Tyfus	7,100	Tyrus	11,100	Tabulates		
3,200	Turfan	7,200	Tyrannical	11,200	Tabasco		
3,300	Tuffas	7,300	Tyrants	11,300	Tabards		
3,400	Turfed	7,400	Turret	11,400	Taber		
3,500	Turfers	7,500	Tureens	11,500	Tabernacles		
3,600	Tuficani	7,600	Turio	11,600	Tabid		
3,700	Turfings	7,700	Tyrians	11,700	Tabidness		
3,800	Tuffoon	7,800	Tyro	11,800	Taboo		
3,900	Tyfoons	7,900	Tyrones	11,900	Taborets		
4,000	Tuggy	8,000	Tucksy	12,000	Tardy		

CODE FOR AMOUNT, KIND, AND DIRECTION OF CLOUDS.

Direction moving from—	One tenth or less.	Two or three tenths.	Four or five tenths.	Six or seven tenths.	Eight, nine, or ten tenths.
			CIRRUS OR CIRRO-STRATUS—CU.		
North	Cubby	Cuban	Cubeb	Cubic	Cupboard.
Northeast	Cutduck	Cudahy	Cudden	Cudding	Curdog.
East	Cuffy	Cufa	Curfew	Curfish	Curfoot.
Southeast	Cutgull	Cupgall	Cudgel	Curgill	Cutgown.
South	Cumulate	Cushman	Culmen	Culminate	Cupmore.
Southwest	Cutnut	Cunard	Cunette	Cunning	Cunot.
West	Curry	Curate	Currency	Cupric	Culrow.
Northwest	Curtsy	Cupsail	Curser	Cursing	Cursory.
			CIRROC-UMULUS—CA.		
North	Carbuncle	Cabal	Campbell	Carbine	Carbon,
Northeast	Candy	Cadaver	Cadet	Cardinal	Caddo.
East	Canful	Carfare	Cafe	Catfish	Canform.
Southeast	Catgut	Cargason	Cage	Caging	Cargo.
South	Calmy	Carman	Camel	Camille	Camon.
Southwest	Canuck	Canal	Canner	Canine	Canoe.
West	Carrying	Caramel	Careen	Carrion	Carroll.
Northwest	Catsup	Cassada	Cause	Casing	Cassock.

CODE FOR AMOUNT, KIND, AND DIRECTION OF CLOUDS—Continued.

Direction moving from—	One tenth or less.	Two or three tenths.	Four or five tenths.	Six or seven tenths.	Eight, nine, or ten tenths.
ALTO-STRATUS—CE.					
North	Cebu	Cebal	Cerbera	Cerbit	Cellbox.
Northeast	Cedule	Cedar	Cedent	Cedive	Cedose.
East	Ceffy	Cefalu	Ceffel	Cellfish	Celfoil.
Southeast	Ceggum	Cellgage	Ceggert	Ceggick	Cellgown.
South	Cemmure	Celtman	Cement	Cepmist	Cemoin.
Southwest	Cernum	Cenation	Ceneda	Cenity	Cenotaph.
West	Centrule	Central	Ceremony	Centrist	Cedron.
Northwest	Censure	Cessant	Cessement	Cession	Censor.
CUMULUS—CI.					
North	Cimbud	Cimbal	Cibert	Cimbia	Cilborn.
Northeast	Ciddy	Cinda	Cider	Cidick	Cindow.
East	Ciffum	Cifax	Cilfern	Cinfix	Cinfoot.
Southeast	Ciggum	Cigar	Cigent	Ciggish	Cingold.
South	Cirmul	Cimar	Cimeter	Cimid	Cimone.
Southwest	Cinura	Cinnamon	Cisney	Cimnit	Cilnot.
West	Cirrum	Citrate	Cipreal	Citrine	Citron.
Northwest	Cissy	Cissail	Ciselure	Cissing	Cirsome.
STRATO-CUMULUS—CO.					
North	Combustion	Combat	Combed	Coalbin	Coalbox.
Northeast	Conduct	Cordage	Code	Codding	Condole.
East	Confuse	Confab	Confer	Confide	Comfort.
Southeast	Cowgut	Coalgate	Congeal	Cogging	Congo.
South	Commute	Command	Comedy	Coming	Common.
Southwest	Connubial	Coinage	Cockney	Cognizant	Cognomen.
West	Corrupt	Contract	Congregate	Contrite	Control.
Northwest	Consult	Corsage	Consent	Consist	Consort.
STRATUS—CH.					
North	Chubby	Chainball	Chamber	Childbirth	Checkbook.
Northeast	Churchdue	Chadam	Chide	Chendi	Chaldon.
East	Chaffy	Chufa	Chafer	Chaffing	Chaffo.
Southeast	Chagull	Chigga	Change	Chugging	Chagon.
South	Chummy	Chapman	Charmed	Chemical	Chamon.
Southwest	Chestnut	China	Channel	Churning	Chignon.
West	Cherub	Charade	Children	Chagrin	Chapron.
Northwest	Choisy	Chainsaw	Chisel	Chasing	Chauson.
NIMBUS OR CUMULO-NIMBUS—CL OR CR.					
North	Cloudburst	Cribbage	Clubbed	Climbing	Crossbow.
Northeast	Cloddy	Classday	Crude	Credit	Cladonia.
East	Cleffy	Clockface	Crowfeet	Clopfish	Clubfoot.
Southeast	Clergy	Clubgate	Cringe	Clogging	Clackgoose.
South	Clammy	Climate	Claimer	Criminal	Clamor.
Southwest	Cranny	Clampnail	Cleaner	Clannish	Crinoline.
West	Cleary	Clara	Claret	Clarify	Clubroom.
Northwest	Clumsy	Crusade	Crossed	Classify	Crimson.

CODE FOR VISIBILITY.

Descriptive term.	Limiting distance.	Code words.
	Meters.	
Dense fog—prominent objects not visible at	50	Zero.
Very bad—prominent objects not visible at	200	One.
Bad—prominent objects not visible at	500	Two.
Very poor—prominent objects not visible at	1,000	Three.
Poor—prominent objects not visible at	2,000	Four.
Indifferent—prominent objects not visible at	4,000	Five.
Fair—prominent objects not visible at	7,000	Six.
Good—prominent objects not visible at	12,000	Seven.
Very good—prominent objects not visible at	30,000	Eight.
Excellent—prominent objects visible beyond	30,000	Nine.

8. FORMS AND REDUCTION TABLES.

The Forms to be used in pilot-balloon work are 1110–Aer., 1111–Aer., 1112–Aer., 1113–Aer., 1114–Aer., 1115–Aer., and 1116–Aer.

Form No. 1110–Aer., Table 19, is for the recording of all data in any way connected with the observation. The heading must be carefully made out and the remaining spaces filled in so far as possible. The observation point, altitude (of observing point), and zero setting, whether on north or south, will be given on each Form. The names of the observer and the recorder should not be omitted. Particular attention is to be given to the recording of the disappearance of the balloon. When it is due to clouds, it will be stated distinctly whether against, into, or behind them. The balloon data and the meteorological data will be entered in complete form in each case. The wind direction and velocity at the surface will be recorded to the nearest one of the 16 compass points and in meters per second. The temperature (both dry and wet bulb readings) is to be recorded in degrees and tenths centigrade. For the conversion of Fahrenheit temperatures, see Table 29. Both station and sea-level pressure will be entered in millibars. See Table 31. Base line, length, and azimuth will be recorded only in double-theodolite work. Visibility and sun will be recorded according to scale as set forth near the end of section 4. Form No. 1110–Aer. will be rendered only when an ascension is made. In the event that one or more observations result in no ascension, this information will be entered on the succeeding Form in the space for notes, under the heading

No ascension for,
a. m. Date p. m.

If the space is insufficient, refer to the back of sheet and enter the data there, referring thereto by entry in notes.

Form No. 1111–Aer., Table 24, is for station use and is designed for the convenience of the Official in Charge. Rendition of this Form will depend upon the need for such data, at the discretion of the Official in Charge.

Form No. 1112–Aer., Table 23, is a summary of the week's work, from the a. m. observation of Sunday to the p. m. observation of Saturday, inclusive. An entry on this Form must be made for each scheduled observation during that period—that is, an entry must be made for the a. m. and p. m. observation during the week. A single line must be left blank between each entry. When an ascension is made, the entry will consist of the data taken from Form No. 1110–Aer. Note that entry for the tenth a. m. agrees with the data on Form No. 1110–Aer., Table 19. In the event of no ascension, due to low clouds, etc., the entry for the observation will state the reason why. See entry for the seventh a. m., Table 23. No ascension was made at that time, due to low clouds. Entries will also be made for special observations.

Form No. 1113–Aer., Table 25, is for the reporting of known cloud altitudes for the month. Much care should be taken in selecting data for this Form. Questionable data should not be recorded, or, if recorded, should be so indicated in space under "remarks."

Form No. 1114–Aer., Table 22, is a monthly summary for all observations for specified levels. One Form is used for summarizing a. m. observations, and a second is used for summarizing the p. m. observations. Care must be taken that data for an a. m. observation are not recorded on the p. m. Form. For a regular ascension these data will be taken from Form No. 1115–Aer. Note that data in the space for a. m. of the 10th agree with those on Form No. 1115–Aer., figure 49, for the single-theodolite graph. When the observation results in no ascension, the reason will be entered in the corresponding space on this Form; thus, no observation on the a. m. of the 7th, due to low clouds, is recorded on the a. m. sheet and in the space for that date. When the ascension extends over 10,000 meters in altitude, the data for each kilometer above that level will be entered on the reverse side of the sheet. In this event it will be signified in the corresponding space under "remarks."

Form No. 1115–Aer., figure 49, is a graphical representation of the data obtained from the ascension. The construction of the graphs themselves has already been explained in section 6. The heading should agree in all details with Form No. 1110–Aer., Table 19. Special attention will be given to date, time, and ascension number. The meteorological data in the upper left-hand corner of the Form should agree with those on the Form No. 1110–Aer. Form No. 1115–Aer. will be rendered only when an ascension is made. When the observation results in no ascension, the reason for the same will be entered in the upper right-hand corner of the succeeding Form under

No ascension for,
a. m. Date p. m.

Form No. 1116–Aer., Table 21, is for the station file, and is designed to assist the observer in accurately coding the telegraphic report. The data for the specified levels are derived from Form No. 1115–Aer., and entered on first blank line of Form No. 1116–Aer. The coded information is then entered on the second blank line. This Form will be rendered for each observation that is telegraphed. When the regular telegraphic observation results in no ascension, due to low clouds, etc., this information will replace the regular data and be entered in the space under "state of the weather."

From the above we see that an observation resulting in no ascension, due to low cloud, rain, snow, etc., is noted on each of the required Forms, or the reason for no ascension will be entered upon Forms Nos. 1110–Aer., 1112–Aer., 1114–Aer., 1115–Aer., and 1116–Aer. in each case. All Forms will be rendered promptly and with a view to accuracy and legibility.

Table 26, "Rate of Ascent in Meters per Minute," is for the determination of ascensional rates of balloons inflated by "indefinite method," explained in section 3. The argument "free lift" (l), ranging from 55 grams to 650 grams at intervals of 5 grams, will be found in the vertical column at the extreme left of the table; the weight of the balloon (w), ranging from 10 grams to 90 grams at intervals of 2 grams, along the first horizontal line heading each column. Table 26a, supplementary to Table 26, gives ascensional rates for values of w and l most commonly in use, viz., 16 to 40 and 75 to 250 grams, respectively, both w and l being given at intervals of 1 gram. Thus no interpolation is necessary.

Table 27, "Altitude Time Tables for Various Rates of Ascent," gives the altitude of the balloon at any minute from 1 to 40 for ascensional rates of each 10 meters from 150 meters per minute to 270 meters per minute, inclusive. This table has its specific application for balloons inflated by indefinite inflation. Each column contains multiples of the ascensional rate and minute of time in succession. Note the additive correction for the first five minutes.

Table 28, "Free Lift for Definite Inflation," gives the amount of free lift required to attain a definite ascensional rate of 140, 160, 180, 200, 220, 240, and 260 meters per minute for any weight of balloon from 15 to 60 grams, inclusive.

Table 29 aids in the conversion of Fahrenheit temperatures in degrees and tenths to centigrade degrees and tenths. The range of the table in Fahrenheit temperature is from $-36°$ to 100° by tenths of degrees. Note that each column of centigrade temperatures is arranged with two columns of Fahrenheit temperatures, one on either side. The values in the centigrade column when associated with the Fahrenheit column on the left are as they appear in print, but when associated with the Fahrenheit column on the right the value is reversed. That is, 5°.0 C. when associated with 41° F. is above zero, but, when associated with 23° F., is below zero. The tenths of Fahrenheit degrees are converted by noting the ending of the centigrade temperature for the whole Fahrenheit degree, finding this in the column headed "P. P.," and moving down the scale the number of spaces equivalent to the number of tenths of degrees to be converted. For instance, a temperature of 58°.8 F. is equivalent to 14°.9 C. Opposite the whole degree 58 and in the C. column is found 14°.44. The ending .44 is found in column "P. P." Since the tenths of a degree to be converted are 8, we move down the column 8 spaces and there find .89; this when substituted for the ending .44 of the C. value 14.44 gives us the temperature 14.89, or 14°.9 C. Likewise any Fahrenheit temperature within the limits stated can be converted to degrees and tenths of the centigrade scale.

Tables 30 and 31 are self-explanatory.

TABLE 26.—*Rate of ascent, in meters per minute, for given weight (w) and free lift (l).*

l.	w.																			
	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
50	150.8	148.7	146.8	144.9	143.1	141.4	139.7	138.1	136.6	135.2	133.8	132.3	131.0	129.8	128.5	127.4	126.2	125.0	124.0	122.9
55	154.8	152.8	151.0	149.2	147.5	145.8	144.2	142.7	141.2	139.8	138.4	137.1	135.8	134.5	133.3	132.1	131.0	129.9	128.8	127.8
60	158.4	156.6	154.8	153.1	151.5	149.9	148.3	146.9	145.4	144.0	142.7	141.4	140.1	138.9	137.7	136.6	135.4	134.4	133.3	132.3
65	161.9	160.1	158.4	156.8	155.2	153.6	152.1	150.7	149.3	148.0	146.7	145.4	144.2	143.0	141.8	140.7	139.6	138.5	137.5	136.4
70	165.0	163.3	161.7	160.1	158.6	157.1	155.7	154.3	152.9	151.6	150.4	149.1	147.9	146.8	145.6	144.5	143.4	142.4	141.4	140.4
75	168.0	166.4	164.8	163.3	161.8	160.4	159.0	157.7	156.4	155.1	153.8	152.6	151.5	150.3	149.2	148.1	147.1	146.0	145.0	144.0
80	170.8	169.2	167.7	166.3	164.9	163.5	162.1	160.8	159.5	158.3	157.1	155.9	154.8	153.6	152.6	151.5	150.5	149.5	148.5	147.5
85	173.4	171.9	170.5	169.1	167.7	166.4	165.1	163.8	162.6	161.3	160.2	159.0	157.9	156.9	155.8	154.7	153.7	152.7	151.7	150.8
90	176.0	174.5	173.1	171.7	170.4	169.1	167.8	166.6	165.4	164.2	163.1	162.0	160.9	159.8	158.8	157.7	156.7	155.8	154.8	153.9
95	178.3	176.9	175.6	174.3	173.0	171.7	170.6	169.2	168.1	167.0	165.8	164.8	163.7	162.6	161.6	160.6	159.6	158.7	157.7	156.8
100	180.6	179.3	177.9	176.7	175.4	174.2	173.0	171.8	170.7	169.6	168.5	167.4	166.4	165.3	164.3	163.3	162.4	161.4	160.5	159.6
105	182.8	181.5	180.2	179.0	177.7	176.5	175.4	174.2	173.1	172.0	171.0	169.9	168.9	167.9	166.9	166.0	165.0	164.1	163.2	162.3
110	184.9	183.6	182.4	181.1	180.0	178.8	177.7	176.6	175.5	174.4	173.4	172.3	171.3	170.4	169.4	168.5	167.5	166.6	165.7	164.8
115	186.9	185.6	184.4	183.2	182.1	181.0	179.9	178.8	177.7	176.7	175.7	174.7	173.7	172.7	171.8	170.9	169.9	169.0	168.2	167.3
120	188.8	187.6	186.4	185.3	184.2	183.1	182.0	180.9	179.9	178.9	177.9	176.9	175.9	175.0	174.1	173.2	172.3	171.4	170.5	169.7
125	190.7	189.5	188.4	187.3	186.2	185.1	184.0	183.0	182.0	181.0	180.0	179.1	178.2	177.3	176.4	175.4	174.5	173.6	172.8	171.9
130	192.4	191.3	190.2	189.1	188.0	187.0	186.0	185.0	184.0	183.0	182.0	181.1	180.2	179.3	178.4	177.5	176.6	175.8	174.9	174.1
135	194.2	193.1	192.0	191.0	189.9	188.9	187.9	186.9	185.9	185.0	184.1	183.2	182.2	181.3	180.4	179.6	178.7	177.9	177.0	176.2
140	195.9	194.8	193.7	192.7	191.7	190.7	189.7	188.7	187.8	186.8	185.9	185.0	184.1	183.2	182.4	181.5	180.7	179.9	179.1	178.3
145	197.5	196.4	195.4	194.4	193.4	192.4	191.5	190.6	189.5	188.6	187.8	186.9	186.0	185.2	184.3	183.5	182.6	181.8	181.0	180.2
150	......	198.0	197.0	196.0	195.1	194.1	193.2	192.2	191.3	190.4	189.5	188.6	187.8	187.0	186.1	185.3	184.5	183.7	182.9	182.2
155	......	199.6	198.6	197.6	196.7	195.7	194.8	193.9	193.0	192.1	191.3	190.4	189.6	188.7	187.9	187.1	186.3	185.5	184.8	184.0
160	......	201.1	200.2	199.2	198.3	197.3	196.4	195.5	194.7	193.8	193.0	192.1	191.3	190.5	189.7	188.9	188.1	187.3	186.5	185.8
165	......	202.6	201.6	200.7	199.8	198.9	198.0	197.1	196.3	195.4	194.6	193.7	192.9	192.1	191.3	190.6	189.8	189.0	188.3	187.5
170	......	204.0	203.1	202.2	201.3	200.4	199.5	198.7	197.8	197.0	196.2	195.3	194.5	193.8	193.0	192.2	191.4	190.7	190.0	189.2
175	......	......	204.5	103.6	202.7	201.9	201.0	200.2	199.3	198.5	197.7	196.9	196.1	195.3	194.6	193.8	193.1	192.3	191.6	190.9
180	......	......	205.9	205.0	204.1	203.3	202.4	201.6	200.8	200.0	199.2	198.4	197.6	196.8	196.1	195.4	194.6	193.9	193.2	192.5
185	......	......	207.2	206.4	205.6	204.7	203.9	203.0	202.2	201.4	200.7	199.9	199.1	198.4	197.6	196.9	196.2	195.5	194.7	194.0
190	......	......	208.6	207.7	206.9	206.0	205.2	204.4	203.6	202.9	202.1	201.3	200.6	199.8	199.1	198.4	197.7	197.0	196.3	195.6
195	......	......	209.8	209.0	208.2	207.4	206.6	205.8	205.0	204.2	203.5	202.7	202.0	201.3	200.6	199.9	199.1	198.4	197.7	197.1
200	......	......	......	210.3	209.5	208.7	207.9	207.1	206.3	205.6	204.8	204.1	203.4	202.7	201.9	201.2	200.5	199.9	199.2	198.5
205	......	......	......	211.4	210.6	209.9	209.2	208.4	207.6	206.9	206.2	205.4	204.6	204.0	203.3	202.6	201.9	201.3	200.6	199.9
210	......	......	......	212.8	212.0	211.2	210.4	209.7	208.9	208.2	207.5	206.8	206.0	205.3	204.7	204.0	203.3	202.6	202.0	201.3
215	......	......	......	214.0	213.2	212.4	211.6	210.9	210.2	209.5	208.7	208.0	207.3	206.7	206.0	205.3	204.6	204.0	203.3	202.7
220	......	......	......	215.1	214.4	213.6	212.9	212.2	211.4	210.7	210.0	209.3	208.6	207.9	207.3	206.6	205.9	205.3	204.6	204.0
225	......	......	......	......	215.5	214.8	214.1	213.4	212.7	212.0	211.2	210.5	209.9	209.2	208.5	207.9	207.2	206.6	205.9	205.3
230	......	......	......	......	216.6	215.9	215.2	214.5	213.8	213.1	212.4	211.7	211.1	210.4	209.7	209.1	208.4	207.8	207.2	206.6
235	......	......	......	......	217.7	217.0	216.3	215.7	215.0	214.3	213.6	212.9	212.2	211.6	210.9	210.3	209.7	209.0	208.4	207.8
240	......	......	......	......	218.8	218.1	217.4	216.7	216.1	215.4	214.7	214.1	213.4	212.8	212.1	211.5	210.9	210.3	209.6	209.0
245	......	......	......	......	220.0	219.2	218.5	217.8	217.2	216.5	215.9	215.2	214.6	213.9	213.3	212.7	212.0	211.4	210.8	210.2

l.	w.																			
	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88
50	121.9	120.9	119.9	118.9	118.0	117.1	116.2	115.4	114.6	113.7	112.9	112.2	111.4	110.7	109.9	109.2	......	......	......	......
55	126.7	125.7	124.8	123.8	122.9	122.0	121.1	120.3	119.5	118.6	117.9	117.1	116.3	115.6	114.8	114.1	......	......	......	......
60	131.2	130.3	129.3	128.4	127.5	126.6	125.7	124.9	124.0	123.2	122.4	121.6	120.9	120.1	119.4	118.7	......	......	......	......
65	135.4	134.5	133.5	132.6	131.7	130.8	130.0	129.1	128.3	127.5	126.7	125.9	125.2	124.4	123.7	123.0	......	......	......	......
70	139.4	138.4	137.5	136.6	135.7	134.8	134.0	133.1	132.3	131.5	130.7	129.9	129.2	128.4	127.7	127.0	......	......	......	......
75	143.1	142.1	141.2	140.3	139.4	138.6	137.7	136.9	136.1	135.3	134.5	133.7	133.0	132.2	131.5	130.8	130.1	......	......	......
80	146.5	145.6	144.7	143.8	142.9	142.1	141.2	140.4	139.6	138.8	138.0	137.3	136.6	135.8	135.1	134.4	133.7	......	......	......
85	149.8	148.9	148.0	147.1	146.3	145.4	144.6	143.8	143.0	142.2	141.4	140.7	139.9	139.2	138.5	137.8	137.1	......	......	......
90	152.9	152.0	151.2	150.3	149.4	148.6	147.8	147.0	146.2	145.4	144.7	143.9	143.2	142.5	141.7	141.0	140.4	......	......	......
95	155.9	155.0	154.1	153.3	152.4	151.6	150.8	150.0	149.2	148.5	147.7	147.0	146.3	145.5	144.8	144.1	143.5	......	......	......
100	158.7	157.8	157.0	156.1	155.3	154.5	153.7	152.9	152.2	151.4	150.7	149.9	149.2	148.5	147.8	147.1	146.4	145.8	......	......
105	161.4	160.6	159.7	158.9	158.1	157.3	156.5	155.7	154.9	154.2	153.4	152.7	152.0	151.3	150.6	149.9	149.3	148.6	......	......
110	164.0	163.1	162.3	161.5	160.7	159.9	159.1	158.4	157.6	156.9	156.1	155.4	154.7	154.0	153.3	152.7	152.0	151.3	......	......
115	166.5	165.6	164.8	164.0	163.2	162.4	161.7	160.9	160.2	159.4	158.7	158.0	157.3	156.6	155.9	155.3	154.6	154.0	......	......
120	168.8	168.0	167.2	166.4	165.6	164.9	164.1	163.4	162.6	161.9	161.2	160.5	159.8	159.1	158.4	157.8	157.1	156.5	......	......
125	171.1	170.3	169.5	168.7	168.0	167.2	166.5	165.7	165.0	164.3	163.6	162.9	162.2	161.5	160.9	160.2	159.6	158.9	158.3	......
130	173.3	172.5	171.7	171.0	170.2	169.5	168.7	168.0	167.3	166.6	165.9	165.2	164.5	163.8	163.2	162.5	161.9	161.3	160.6	......
135	175.4	174.7	173.9	173.1	172.4	171.6	170.9	170.2	169.5	168.8	168.1	167.4	166.7	166.1	165.4	164.8	164.2	163.5	162.9	......
140	177.5	176.7	176.0	175.2	174.5	173.7	173.0	172.3	171.6	170.9	170.2	169.6	168.9	168.3	167.6	167.0	166.3	165.7	165.1	......
145	179.5	178.7	178.0	177.2	176.5	175.8	175.1	174.4	173.7	173.0	172.3	171.7	171.0	170.4	169.7	169.1	168.5	167.9	167.2	......
150	181.4	180.6	179.9	179.2	178.5	177.7	177.0	176.4	175.7	175.0	174.3	173.7	173.0	172.4	171.8	171.1	170.5	169.9	169.3	168.7
155	183.3	182.5	181.8	181.1	180.4	179.6	179.0	178.3	177.6	176.9	176.3	175.6	175.0	174.4	173.7	173.1	172.5	171.9	171.3	170.7
160	185.1	184.3	183.6	182.9	182.2	181.5	180.8	180.2	179.5	178.8	178.2	177.5	176.9	176.3	175.7	175.0	174.4	173.8	173.2	172.7
165	186.8	186.1	185.4	184.7	184.0	183.3	182.6	182.0	181.3	180.7	180.0	179.4	178.8	178.1	177.5	176.9	176.3	175.7	175.2	174.6
170	188.5	187.8	187.1	186.4	185.7	185.1	184.4	183.7	183.1	182.4	181.8	181.2	180.6	179.9	179.3	178.7	178.2	177.6	177.0	176.4
175	190.2	189.5	188.8	188.1	187.4	186.8	186.1	185.5	184.8	184.2	183.5	182.9	182.3	181.7	181.1	180.5	179.9	179.3	178.8	178.2
180	191.8	191.1	190.4	189.7	189.1	188.4	187.8	187.1	186.5	185.9	185.2	184.6	184.0	183.4	182.8	182.2	181.7	181.1	180.5	180.0
185	193.4	192.7	192.0	191.3	190.7	190.0	189.4	188.8	188.1	187.5	186.9	186.3	185.7	185.1	184.5	183.9	183.4	182.8	182.2	181.6
190	194.9	194.2	193.6	192.9	192.2	191.6	191.0	190.4	189.7	189.1	188.5	187.9	187.3	186.7	186.1	185.6	185.0	184.4	183.9	183.3
195	196.4	195.7	195.1	194.4	193.8	193.1	192.5	191.9	191.3	190.7	190.1	189.5	188.9	188.3	187.7	187.2	186.6	186.0	185.5	184.9
200	197.8	197.2	196.5	195.9	195.3	194.6	194.0	193.4	192.8	192.2	191.6	191.0	190.4	189.9	189.3	188.7	188.2	187.6	187.1	186.5
205	199.3	198.6	198.0	197.4	196.7	196.1	195.5	194.9	194.3	193.7	193.1	192.5	191.9	191.4	190.8	190.2	189.7	189.2	188.6	188.1
210	200.7	200.0	199.4	198.8	198.2	197.5	196.9	196.3	195.7	195.2	194.6	194.0	193.4	192.9	192.3	191.7	191.2	190.6	190.1	189.6
215	202.0	201.4	200.8	200.2	199.5	198.9	198.3	197.7	197.2	196.6	196.0	195.4	194.9	194.3	193.8	193.2	192.7	192.1	191.6	191.1
220	203.4	202.7	202.1	201.5	200.9	200.3	199.7	199.1	198.5	198.0	197.4	196.8	196.3	195.7	195.2	194.6	194.1	193.6	193.0	192.5
225	204.7	204.1	203.4	202.8	202.2	201.6	201.1	200.5	199.9	199.3	198.8	198.2	197.7	197.1	196.6	196.0	195.5	195.0	194.4	193.9
230	205.9	205.3	204.7	204.1	203.6	203.0	202.4	201.8	201.2	200.7	200.1	199.6	199.0	198.5	197.9	197.4	196.9	196.3	195.8	195.3
235	207.2	206.6	206.0	205.4	204.8	204.2	203.7	203.1	202.5	202.0	201.4	200.9	200.3	199.8	199.3	198.7	198.2	197.7	197.2	196.7
240	208.4	207.8	207.2	206.7	206.1	205.5	204.9	204.4	203.8	203.3	202.7	202.2	201.6	201.1	200.6	200.1	199.5	199.0	198.5	198.0
245	209.6	209.0	208.5	207.9	207.3	206.8	206.2	205.6	205.1	204.5	204.0	203.4	202.9	202.4	201.9	201.3	200.8	200.3	199.8	199.3

TABLE 26.—*Rate of ascent, in meters per minute, for given weight (w) and free lift (l)*—Continued.

l.	w.																			
	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58
250	220.3	219.6	218.9	218.2	217.6	217.0	216.3	215.7	215.1	214.5	213.8	213.2	212.6	212.0	211.4	210.8	210.2	209.7	209.1	208.5
255	221.3	220.7	220.0	219.3	218.7	218.1	217.4	216.8	216.2	215.6	214.9	214.3	213.7	213.1	212.6	212.0	211.4	210.8	210.3	209.7
260	222.4	221.7	221.0	220.4	219.8	219.1	218.5	217.9	217.3	216.7	216.0	215.4	214.9	214.3	213.7	213.1	212.5	212.0	211.4	210.9
265	223.4	222.7	222.1	221.4	220.8	220.2	219.6	218.9	218.3	217.7	217.1	216.6	216.0	215.4	214.8	214.2	213.7	213.1	212.6	212.0
270	224.4	223.7	223.1	222.4	221.8	221.2	220.6	220.0	219.4	218.8	218.2	217.6	217.0	216.5	215.9	215.3	214.8	214.2	213.7	213.1
275		224.7	224.1	223.4	222.8	222.2	221.6	221.0	220.4	219.8	219.3	218.7	218.1	217.5	217.0	216.4	215.9	215.3	214.8	214.2
280		225.7	225.0	224.4	223.8	223.2	222.6	222.0	221.4	220.9	220.3	219.7	219.2	218.6	218.0	217.5	216.9	216.4	215.9	215.3
285		226.6	226.0	225.4	224.8	224.2	223.6	223.0	222.4	221.9	221.3	220.7	220.2	219.6	219.1	218.5	218.0	217.4	216.9	216.4
290		227.6	227.0	226.4	225.8	225.2	224.6	224.0	223.4	222.9	222.3	221.7	221.2	220.6	220.1	219.6	219.0	218.5	218.0	217.4
295		228.5	227.9	227.3	226.7	226.1	225.5	225.0	224.4	223.8	223.3	222.7	222.2	221.6	221.1	220.6	220.0	219.5	219.0	218.5
300			228.8	228.2	227.6	227.1	226.5	225.9	225.4	224.8	224.3	223.7	223.2	222.6	222.1	221.6	221.0	220.5	220.0	219.5
305			229.7	229.1	228.6	228.0	227.4	226.9	226.3	225.8	225.2	224.7	224.1	223.6	223.1	222.5	222.0	221.5	221.0	220.5
310			230.6	230.0	229.5	228.9	228.3	227.8	227.2	226.7	226.2	225.6	225.1	224.6	224.0	223.5	223.0	222.5	222.0	221.5
315			231.5	230.9	230.4	229.8	229.3	228.7	228.2	227.6	227.1	226.6	226.0	225.5	225.0	224.5	224.0	223.4	223.0	222.4
320			232.4	231.8	231.2	230.7	230.1	229.6	229.1	228.5	228.0	227.5	226.9	226.4	225.9	225.4	224.9	224.4	223.9	223.4
325				232.6	232.1	231.6	231.0	230.5	230.0	229.4	228.9	228.4	227.9	227.4	226.8	226.3	225.8	225.3	224.8	224.3
330				233.5	233.0	232.4	231.9	231.4	230.8	230.3	229.8	229.3	228.8	228.2	227.7	227.2	226.7	226.3	225.8	225.3
335				234.4	233.8	233.3	232.7	232.2	231.7	231.2	230.7	230.2	229.6	229.1	228.6	228.2	227.7	227.2	226.7	226.2
340				235.2	234.6	234.1	233.6	233.1	232.5	232.0	231.5	231.0	230.5	230.0	229.5	229.0	228.5	228.1	227.6	227.1
345				236.0	235.5	234.9	234.4	233.9	233.4	232.9	232.4	231.9	231.4	230.9	230.4	229.9	229.4	229.0	228.5	228.0
350					236.3	235.8	235.2	234.7	234.2	233.7	233.2	232.7	232.2	231.7	231.3	230.8	230.3	229.8	229.4	228.9
355					237.1	236.6	236.0	235.6	235.0	234.6	234.0	233.6	233.1	232.6	232.1	231.6	231.2	230.7	230.2	229.7
360					237.9	237.4	236.8	236.4	235.9	235.4	234.9	234.4	233.9	233.4	232.9	232.5	232.0	231.5	231.1	230.6
365					238.7	238.2	237.6	237.2	236.7	236.2	235.7	235.2	234.7	234.2	233.8	233.3	232.8	232.4	231.9	231.4
370					239.4	238.9	238.4	237.9	237.4	237.0	236.5	236.0	235.5	235.1	234.6	234.1	233.7	233.2	232.7	232.3
375						239.7	239.2	238.7	238.2	237.8	237.3	236.8	236.3	235.9	235.4	234.9	234.5	234.0	233.6	233.1
380						240.5	240.0	239.5	239.0	238.5	238.1	237.6	237.1	236.6	236.2	235.7	235.3	234.8	234.4	233.9
385						241.2	240.7	240.2	239.8	239.3	238.8	238.4	237.9	237.4	237.0	236.5	236.1	235.6	235.2	234.7
390						242.0	241.5	241.0	240.5	240.1	239.6	239.1	238.7	238.2	237.8	237.3	236.9	236.4	236.0	235.5
395						242.7	242.2	241.7	241.3	240.8	240.4	239.9	239.4	239.0	238.5	238.1	237.6	237.2	236.8	236.3
400							242.9	242.5	242.0	241.6	241.1	240.6	240.2	239.7	239.3	238.8	238.4	238.0	237.5	237.1
405							243.7	243.2	242.7	242.3	241.8	241.4	240.9	240.5	240.0	239.6	239.2	238.7	238.3	237.9
410							244.4	243.9	243.5	243.0	242.6	242.1	241.7	241.2	240.8	240.4	239.9	239.5	239.0	238.6
415							245.1	244.6	244.2	243.7	243.3	242.8	242.4	242.0	241.5	241.1	240.6	240.2	239.8	239.4
420							245.8	245.3	244.9	244.4	244.0	243.6	243.1	242.7	242.2	241.8	241.4	241.0	240.5	240.1
425								246.0	245.6	245.2	244.7	244.3	243.8	243.4	243.0	242.6	242.1	241.7	241.3	240.8
430								246.7	246.3	245.8	245.4	245.0	244.5	244.1	243.7	243.3	242.8	242.4	242.0	241.6
435								247.4	247.0	246.5	246.1	245.7	245.2	244.8	244.4	244.0	243.6	243.1	242.7	242.3
440								248.1	247.6	247.2	246.8	246.4	245.9	245.5	245.1	244.7	244.2	243.8	243.4	243.0
445								248.8	248.3	247.9	247.5	247.0	246.6	246.2	245.8	245.4	245.0	244.5	244.1	243.7

l.	w.															
	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
250	208.0	207.4	206.8	206.3	205.8	205.2	204.7	204.2	203.6	203.1	202.6	202.1	201.6	201.1	200.6	200.1
255	209.1	208.6	208.1	207.5	207.0	206.4	205.9	205.4	204.9	204.4	203.9	203.4	202.8	202.4	201.9	201.4
260	210.3	209.8	209.2	208.7	208.2	207.6	207.1	206.6	206.1	205.6	205.1	204.6	204.1	203.6	203.1	202.6
265	211.5	210.9	210.4	209.9	209.3	208.8	208.3	207.8	207.3	206.8	206.3	205.8	205.3	204.8	204.3	203.8
270	212.6	212.1	211.5	211.0	210.5	210.0	209.5	208.9	208.4	207.9	207.4	207.0	206.5	206.0	205.5	205.0
275	213.7	213.2	212.6	212.1	211.6	211.1	210.6	210.1	209.6	209.1	208.6	208.1	207.6	207.2	206.7	206.2
280	214.8	214.3	213.8	213.2	212.7	212.2	211.7	211.2	210.7	210.2	209.7	209.2	208.8	208.3	207.8	207.4
285	215.9	215.3	214.8	214.3	213.8	213.3	212.8	212.3	211.8	211.3	210.9	210.4	209.9	209.4	209.0	208.5
290	216.9	216.4	215.9	215.4	214.9	214.4	213.9	213.4	212.9	212.4	212.0	211.5	211.0	210.5	210.1	209.6
295	218.0	217.4	216.9	216.4	215.9	215.4	215.0	214.5	214.0	213.5	213.0	212.6	212.1	211.6	211.2	210.7
300	219.0	218.5	218.0	217.5	217.0	216.5	216.0	215.5	215.0	214.6	214.1	213.6	213.2	212.7	212.2	211.8
305	220.0	219.5	219.0	218.5	218.0	217.5	217.0	216.6	216.1	215.6	215.2	214.7	214.2	213.8	213.3	212.9
310	221.0	220.5	220.0	219.5	219.0	218.5	218.1	217.6	217.1	216.6	216.2	215.7	215.3	214.8	214.4	213.9
315	222.0	221.5	221.0	220.5	220.0	219.5	219.1	218.6	218.1	217.7	217.2	216.7	216.3	215.8	215.4	215.0
320	222.9	222.4	221.9	221.5	221.0	220.5	220.0	219.6	219.1	218.7	218.2	217.8	217.3	216.9	216.4	216.0
325	223.9	223.4	222.9	222.4	222.0	221.5	221.0	220.6	220.1	219.6	219.2	218.7	218.3	217.8	217.4	217.0
330	224.8	224.3	223.8	223.4	222.9	222.4	222.0	221.5	221.1	220.6	220.2	219.7	219.3	218.8	218.4	218.0
335	225.7	225.2	224.8	224.3	223.8	223.4	222.9	222.5	222.0	221.6	221.1	220.7	220.2	219.8	219.4	218.9
340	226.6	226.2	225.7	225.2	224.8	224.3	223.9	223.4	223.0	222.5	222.1	221.6	221.2	220.8	220.3	219.9
345	227.5	227.1	226.6	226.1	225.7	225.2	224.8	224.3	223.9	223.4	223.0	222.6	222.1	221.7	221.3	220.8
350	228.4	227.9	227.5	227.0	226.6	226.1	225.7	225.2	224.8	224.4	223.9	223.5	223.1	222.6	222.2	221.8
355	229.3	228.8	228.4	227.9	227.5	227.0	226.6	226.1	225.7	225.3	224.8	224.4	224.0	223.6	223.1	222.7
360	230.1	229.7	229.2	228.8	228.3	227.9	227.5	227.0	226.6	226.2	225.7	225.3	224.9	224.4	224.0	223.6
365	231.0	230.5	230.1	229.6	229.2	228.8	228.3	227.9	227.5	227.0	226.6	226.2	225.8	225.4	224.9	224.5
370	231.8	231.4	230.9	230.5	230.1	229.6	229.2	228.8	228.3	227.9	227.5	227.1	226.6	226.2	225.8	225.4
375	232.7	232.2	231.8	231.3	230.9	230.5	230.0	229.6	229.2	228.8	228.4	227.9	227.5	227.1	226.7	226.3
380	233.5	233.0	232.6	232.2	231.7	231.3	230.9	230.5	230.0	229.6	229.2	228.8	228.4	228.0	227.6	227.2
385	234.3	233.9	233.4	233.0	232.6	232.1	231.7	231.3	230.9	230.5	230.0	229.6	229.2	228.8	228.4	228.0
390	235.1	234.7	234.2	233.8	233.4	232.9	232.5	232.1	231.7	231.3	230.9	230.5	230.1	229.6	229.3	228.9
395	235.9	235.4	235.0	234.6	234.2	233.8	233.3	232.9	232.5	232.1	231.7	231.3	230.9	230.5	230.1	229.7
400	236.7	236.2	235.8	235.4	235.0	234.6	234.1	233.7	233.3	232.9	232.6	232.1	231.7	231.3	230.9	230.5
405	237.4	237.0	236.6	236.2	235.8	235.4	234.9	234.5	234.1	233.7	233.3	232.9	232.5	232.1	231.7	231.3
410	238.2	237.8	237.4	236.9	236.5	236.1	235.7	235.3	234.9	234.5	234.1	233.7	233.3	232.9	232.5	232.1
415	239.0	238.5	238.1	237.7	237.3	236.9	236.5	236.1	235.7	235.3	234.9	234.5	234.1	233.7	233.3	232.9
420	239.7	239.3	238.9	238.5	238.1	237.6	237.2	236.8	236.5	236.1	235.7	235.3	234.9	234.5	234.1	233.7
425	240.4	240.0	239.6	239.2	238.8	238.4	238.0	237.6	237.2	236.8	236.4	236.0	235.6	235.3	234.9	234.5
430	241.2	240.8	240.4	240.0	239.6	239.2	238.8	238.4	238.0	237.6	237.2	236.8	236.4	236.0	235.7	235.3
435	241.9	241.5	241.1	240.7	240.3	239.9	239.5	239.1	238.7	238.3	238.0	237.6	237.2	236.8	236.4	236.0
440	242.6	242.2	241.8	241.4	241.0	240.6	240.2	239.8	239.5	239.1	238.7	238.3	237.9	237.5	237.2	236.8
445	243.3	242.9	242.5	242.1	241.7	241.4	241.0	240.6	240.2	239.8	239.4	239.0	238.7	238.3	237.9	237.6

TABLE 26.—*Rate of ascent, in meters per minute, for given weight (w) and free lift (l)*—Continued.

l.	w.																
	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68
450	249.0	248.6	248.1	247.7	247.3	246.9	246.5	246.0	245.6	245.2	244.8	244.4	244.0	243.6	243.2	242.8	242.4
455	249.6	249.2	248.8	248.4	248.0	247.5	247.1	246.7	246.3	245.9	245.5	245.1	244.7	244.3	243.9	243.6	243.2
460	250.3	249.9	249.5	249.0	248.6	248.2	247.8	247.4	247.0	246.6	246.2	245.8	245.4	245.0	244.6	244.2	243.8
465	250.9	250.5	250.1	249.7	249.3	248.9	248.5	248.1	247.7	247.3	246.9	246.5	246.1	245.7	245.3	244.9	244.5
470	251.6	251.2	250.8	250.3	249.9	249.5	249.1	248.7	248.3	247.9	247.5	247.2	246.8	246.4	246.0	245.6	245.2
475	....	251.8	251.4	251.0	250.6	250.2	249.8	249.4	249.0	248.6	248.2	247.8	247.4	247.0	246.7	246.3	245.9
480	....	252.4	252.0	251.6	251.2	250.8	250.4	250.0	249.6	249.2	248.9	248.5	248.1	247.7	247.3	247.0	246.6
485	....	253.0	252.7	252.2	251.8	251.5	251.1	250.7	250.3	249.9	249.5	249.1	248.8	248.4	248.0	247.6	247.2
490	....	253.7	253.3	252.9	252.5	252.1	251.7	251.3	250.9	250.5	260.2	249.8	249.4	249.0	248.6	248.3	247.9
495	....	254.3	253.9	253.5	253.1	252.7	252.3	251.9	251.6	251.2	250.8	250.4	250.0	249.7	249.3	248.9	248.6
500	....	....	254.5	254.1	253.7	253.3	253.0	252.6	252.2	251.8	251.4	261.0	250.7	250.3	249.9	249.6	249.2
505	....	....	255.1	254.7	254.3	253.9	253.6	253.2	252.8	252.4	252.1	251.7	251.3	250.9	250.6	250.2	249.8
510	....	....	255.7	255.3	254.9	254.6	254.2	253.8	253.4	253.0	252.7	252.3	251.9	251.6	251.2	250.8	250.5
515	....	....	256.3	255.9	255.5	255.2	254.8	254.4	254.0	253.7	253.3	252.9	252.6	252.2	251.8	251.5	251.1
520	....	....	256.9	256.5	256.1	255.8	255.4	255.0	254.6	254.3	253.9	253.5	253.2	252.8	252.4	252.1	251.7
525	....	....	257.5	257.1	256.7	256.4	256.0	255.6	255.2	254.9	254.5	254.2	253.8	253.4	253.0	252.7	252.4
530	....	....	258.1	257.7	257.3	256.9	256.6	256.2	255.8	255.5	255.1	254.7	254.4	254.0	253.7	253.3	253.0
535	....	....	258.6	258.3	257.9	257.5	257.2	256.8	256.4	256.0	255.7	255.3	255.0	254.6	254.3	253.9	253.6
540	....	....	259.2	258.8	258.5	258.1	257.7	257.4	257.0	256.6	256.3	255.9	255.6	255.2	254.9	254.5	254.2
545	....	....	259.8	259.4	259.0	258.7	258.3	258.0	257.6	257.2	256.9	256.5	256.2	255.8	255.5	255.1	254.8
550	....	....	260.3	260.0	259.6	259.2	258.9	258.5	258.2	257.8	257.4	257.1	256.7	256.4	256.0	255.7	255.4
555	....	....	260.9	260.5	260.2	259.8	259.4	259.1	258.7	258.4	258.0	257.7	257.3	257.0	256.6	256.3	256.0
560	....	....	261.4	261.1	260.7	260.4	260.0	259.6	259.3	259.0	258.6	258.2	257.9	257.6	257.2	256.9	256.5
565	....	....	262.0	261.6	261.3	260.9	260.6	260.2	259.9	259.5	259.2	258.8	258.5	258.1	257.8	257.4	257.1
570	....	....	262.5	262.2	261.8	261.5	261.1	260.8	260.4	260.1	259.7	259.4	259.0	258.7	258.4	258.0	257.7
575	....	....	263.1	262.7	262.4	262.0	261.7	261.3	261.0	260.6	260.3	259.9	259.6	259.3	258.9	258.6	258.2
580	....	....	263.6	263.3	262.9	262.6	262.2	261.9	261.5	261.2	260.8	260.5	260.2	259.8	259.5	259.1	258.8
585	....	....	264.2	263.8	263.5	263.1	262.8	262.4	262.1	261.7	261.4	261.0	260.7	260.4	260.0	259.7	259.4
590	....	....	264.7	264.3	264.0	263.6	263.3	263.0	262.6	262.3	261.9	261.6	261.3	260.9	260.6	260.3	259.9
595	....	....	265.2	264.9	264.5	264.2	263.8	263.5	263.2	262.8	262.5	262.1	261.8	261.5	261.1	260.8	260.5
600	....	....	265.7	265.4	265.0	264.7	264.4	264.0	263.7	263.4	263.0	262.7	262.4	262.0	261.7	261.4	261.0
605	....	....	266.2	265.9	265.6	265.2	264.9	264.5	264.2	263.9	263.5	263.2	262.9	262.6	262.2	261.9	261.6
610	....	....	266.8	266.4	266.1	265.7	265.4	265.1	264.7	264.4	264.1	263.7	263.4	263.1	262.8	262.4	262.1
615	....	....	267.3	266.9	266.6	266.3	265.9	265.6	265.3	264.9	264.6	264.3	263.9	263.6	263.3	263.0	262.6
620	....	....	267.8	267.4	267.1	266.8	266.4	266.1	265.8	265.4	265.1	264.8	264.5	264.1	263.8	263.5	263.2
625	....	....	268.3	267.9	267.6	267.3	266.9	266.6	266.3	266.0	265.6	265.3	265.0	264.7	264.3	264.0	263.7
630	....	....	268.8	268.4	268.1	267.8	267.4	267.1	266.8	266.5	266.2	265.8	265.5	265.2	264.9	264.5	264.2
635	....	....	269.3	268.9	268.6	268.3	268.0	267.6	267.3	267.0	266.6	266.3	266.0	265.7	265.4	265.1	264.8
640	....	....	269.8	269.4	269.1	268.8	268.4	268.1	267.8	257.5	267.2	266.8	266.5	266.2	265.9	265.6	265.3
645	....	....	270.2	269.9	269.6	269.3	269.0	268.6	268.3	268.0	267.7	267.4	267.0	266.7	266.4	266.1	265.8
650	....	....	270.7	270.4	270.1	269.8	269.4	269.1	268.8	268.5	268.2	267.8	267.5	267.2	266.9	266.6	266.3

l.	w.										
	70	72	74	76	78	80	82	84	86	88	90
450	242.1	241.7	241.3	240.9	240.5	240.1	239.8	239.4	239.0	238.6	238.3
455	242.8	242.4	242.0	241 6	241.2	240 9	240.5	240.1	239.8	239.4	239.0
460	243 5	243.1	242.7	242.3	242.0	241.6	241.2	240.8	240.5	240.1	239.8
465	244.2	243.8	243.4	243.0	242.6	242.3	241.9	241.6	241.2	240.8	240.4
470	244.8	244.5	244.1	243.7	243.4	243.0	242.6	242.2	241.9	241.5	241.2
475	245.5	245.2	244.8	244.4	244.0	243.7	243.3	242.9	242.6	242.2	241.9
480	246.2	245.8	245.5	245.1	244.7	244.4	244.0	243.6	243.3	242.9	242.6
485	246.9	246.5	246.1	245.8	245.4	245.0	244.7	244.3	244.0	243.6	243.2
490	247.5	247.2	246.8	246.4	246.1	245.7	245.4	245.0	244 6	244.3	243.9
495	248.2	247.8	247.5	247.1	246.7	246.4	246.0	245.7	245.3	245.0	244.6
500	248.8	248.5	248.1	247.8	247.4	247.0	246.7	246.3	246.0	245.6	245.3
505	249.5	249.1	248.8	248.4	248.0	247.7	247.3	247.0	246.6	246.3	245.9
510	250.1	249.8	249.4	249.0	248.7	248.3	248.0	247.6	247.3	247.0	246.6
515	250.8	250.4	250.0	249.7	249.3	249.0	248.6	248.3	248.0	247.6	247.3
520	251.4	251.0	250.7	250.3	250.0	249.6	249.3	248.9	248.6	248.2	247.9
525	252.0	251.6	251.3	250.9	250.6	250.2	249.9	249.6	249.2	248.9	248.6
530	252.6	252.3	251.9	251.6	251.2	250.9	250.5	250.2	249.8	249.5	249.2
535	253.2	252.9	252.5	252.2	251.8	251.5	251.2	250.8	250.5	250.1	249.8
540	253.8	253.5	253.1	252.8	252.4	252.1	251.8	251.4	251.1	250.8	250.4
545	254.4	254.1	253.7	253.4	253.0	252.7	252.4	252.0	251 7	251.4	251.0
550	255.0	254.7	254.3	254.0	253.6	253.3	253.0	252.7	252.3	252.0	251.6
555	255.6	255.2	254.9	254.6	254.2	253.9	253 6	253.2	252.9	252.6	252.3
560	256.2	255.8	255.5	255.2	254.8	254.5	254.2	253.9	253.5	253 2	252.9
565	256.8	256.4	256.1	255.8	255.4	255.1	254.8	254.4	254.1	253.8	253.5
570	257.3	257.0	256.7	256.3	256.0	255.7	255.4	255.0	254.7	254.4	254.1
575	257.9	257.6	257.2	256.9	256.6	256.3	256.0	255.6	255.3	255.0	254.6
580	258.5	258.2	297.8	257.5	257.2	256.8	256.5	256.2	255.9	255.6	255.2
585	259.0	258.7	258.4	258.1	257.7	257.4	257.1	256.8	256.5	256.1	255.8
590	259.6	259.3	259.0	258.6	258.3	258.0	257.7	257.3	257.0	256.7	256.4
595	260.2	259.8	259.5	259.2	258.8	258.5	258.2	257.9	257.6	257.3	257.0
600	260.7	260.4	260.1	259.7	259.4	259.1	258.8	258.5	258.2	257.8	257.5
605	261.2	260.9	260.6	260.3	260.0	259.6	259.3	259.0	258.7	258.4	258.1
610	261.8	261.5	261.2	260.8	260.5	260.2	259.9	259.6	259.3	259.0	258.6
615	262.3	262.0	261.7	261.4	261.1	260.8	260.4	260.1	259.8	259.5	259.2
620	262.9	262.5	262.2	261.9	261.6	261.3	261.0	260.7	260.4	260.0	259.8
625	263.4	263.1	262.8	262.4	262.1	261.8	261.5	261.2	260.9	260.6	260.3
630	263.9	263.6	263.3	263.0	262.7	262.4	262.1	261.7	261.4	261.1	260.8
635	264.4	264.1	263.8	263.5	263.2	262.9	262.6	262.3	262.0	261.7	261.4
640	265.0	264.6	264.3	264.0	263.7	263.4	263.1	262.8	262.5	262.2	261.9
645	265.5	265.2	264.8	264.5	264.2	263.9	263.6	263.3	263.0	262.7	262.4
650	266.0	265.7	265.4	265.1	264.8	264.5	264.2	263.8	263.6	263.2	263.0

TABLE 26a.—*Rate of ascent, in meters per minute, for weight (w) and free lift (l).*

l.	w.																									
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
75	164	163	163	162	161	160	160	159	158	158	157	156	156	155	164	154	153	153	152	152	151	150	150	149	149	148
76	165	164	163	162	162	161	160	160	159	158	158	157	156	156	155	154	154	153	153	152	152	151	150	150	149	149
77	165	164	164	163	162	162	161	160	160	159	158	158	157	156	156	155	155	154	153	153	152	152	151	150	150	149
78	166	165	164	164	163	162	162	161	160	160	159	158	158	157	156	156	155	155	154	153	153	152	152	151	151	150
79	166	166	165	164	164	163	162	162	161	160	160	159	158	158	157	156	156	155	155	154	154	153	152	152	151	151
80	167	166	166	165	164	163	163	162	161	161	160	160	159	158	158	157	157	156	155	155	154	154	153	153	152	152
81	168	167	166	166	165	164	163	163	162	161	161	160	160	159	158	158	157	157	156	155	155	154	154	153	153	152
82	168	167	167	166	165	165	164	163	163	162	161	161	160	160	159	158	158	157	157	156	155	155	155	154	153	153
83	169	168	167	167	166	165	165	164	163	163	162	161	101	160	160	159	158	158	157	157	156	156	155	155	154	153
84	169	169	168	167	167	166	165	164	164	163	163	162	161	161	160	160	159	158	158	157	157	156	156	155	155	154
85	170	169	168	168	167	166	166	165	164	164	163	163	162	161	161	160	160	159	158	158	157	157	156	156	155	155
86	170	170	169	168	168	167	166	166	165	164	164	163	163	162	161	161	160	160	159	158	158	157	157	156	156	155
87	171	170	169	169	168	168	167	166	166	165	164	164	163	163	162	161	161	160	160	159	159	158	158	157	156	156
88	171	171	170	169	169	168	167	167	166	166	165	164	164	163	163	162	161	161	160	160	159	159	158	158	157	156
89	172	171	170	170	169	169	168	167	167	166	165	165	164	164	163	162	162	161	161	160	160	159	159	158	158	157
90	172	172	171	170	170	169	169	168	167	167	166	165	165	164	164	163	163	162	161	161	160	160	159	159	158	158
91	173	172	171	171	170	170	169	168	168	167	167	166	165	165	164	164	163	163	162	161	161	160	160	159	159	158
92	173	173	172	171	171	170	170	169	168	168	167	167	166	165	165	164	164	163	163	162	161	161	160	160	159	159
93	174	173	173	172	171	171	170	169	169	168	168	167	167	166	165	165	164	164	163	163	162	162	161	161	160	159
94	174	174	173	172	172	171	171	170	169	169	168	168	167	166	166	165	165	164	164	163	163	162	162	161	161	160
95	175	174	174	173	172	172	171	170	170	169	169	168	168	167	166	166	165	165	164	164	163	163	162	162	161	161
96	175	175	174	174	173	172	172	171	170	170	169	169	168	167	167	166	166	165	165	164	164	163	163	162	162	161
97	176	175	175	174	173	173	172	171	171	170	170	169	169	168	167	167	166	166	165	165	164	164	163	163	162	162
98	176	176	175	174	174	173	173	172	171	171	170	170	169	169	168	167	167	166	166	165	165	164	164	163	163	162
99	177	176	176	175	174	174	173	172	172	171	171	170	170	169	168	168	167	167	166	166	165	165	164	164	163	163
100	177	177	176	175	175	174	174	173	172	172	171	171	170	170	169	168	168	167	167	166	166	165	165	164	164	163
101	178	177	177	176	175	175	174	174	173	172	172	171	171	170	169	169	168	168	167	167	166	166	165	165	164	164
102	178	178	177	176	176	175	175	174	173	173	172	172	171	171	170	169	169	168	168	167	167	166	166	165	165	164
103	179	178	177	177	176	176	175	174	174	173	173	172	172	171	171	170	169	169	168	168	167	167	166	166	166	165
104	179	178	178	177	177	176	175	175	174	174	173	173	172	172	171	170	170	169	169	168	168	167	167	166	166	166
105	180	179	178	178	177	177	176	175	175	174	174	173	173	172	172	171	170	170	169	169	168	168	167	167	167	166
106	180	179	179	178	178	177	176	176	175	175	174	174	173	173	172	171	171	170	170	169	169	168	168	167	167	167
107	180	180	179	179	178	177	177	176	176	175	175	174	174	173	172	172	171	171	170	170	169	169	168	168	168	167
108	181	180	180	179	178	178	177	177	176	176	175	175	174	174	173	172	172	171	171	170	170	169	169	168	168	167
109	181	181	180	180	179	178	178	177	177	176	176	175	174	174	173	173	172	172	171	171	170	170	169	169	168	168
110	182	181	181	180	179	179	178	178	177	177	176	176	175	174	174	173	173	172	172	171	171	170	170	169	169	168
111	182	182	181	180	180	179	179	178	177	177	176	176	175	175	174	174	173	173	172	172	171	171	170	170	169	169
112	183	182	181	181	180	180	179	179	178	177	177	176	176	175	175	174	174	173	173	172	172	171	171	170	170	169
113	183	182	182	181	181	180	180	179	178	178	177	177	176	176	175	175	174	174	173	173	172	172	171	171	170	170
114	183	183	182	182	181	181	180	180	179	178	178	177	177	176	176	175	175	174	174	173	173	172	172	171	171	170

l.	w.																									
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
115	184	183	183	182	182	181	181	180	179	179	178	178	177	177	176	176	175	175	174	174	173	173	172	172	171	171
116	184	184	183	183	182	181	181	180	180	179	179	178	178	177	177	176	176	175	175	174	174	173	173	172	172	171
117	185	184	184	183	182	182	181	181	180	180	179	179	178	178	177	177	176	176	175	175	174	174	173	173	172	172
118	185	184	184	183	183	182	182	181	181	180	180	179	179	178	178	177	177	176	176	175	175	174	174	173	173	172
119	185	185	184	184	183	183	182	182	181	181	180	180	179	178	178	177	177	176	176	175	175	175	174	174	173	173
120	186	185	185	184	184	183	183	182	182	181	180	180	179	179	178	178	177	177	176	176	175	175	175	174	174	173
121	186	186	185	185	184	183	183	182	182	181	181	180	180	179	179	178	178	177	177	176	176	175	175	175	174	174
122	187	186	186	185	184	184	183	183	182	182	181	181	180	180	179	179	178	178	177	177	176	176	175	175	175	174
123	187	186	186	185	185	184	184	183	183	182	182	181	181	180	180	179	179	178	178	177	177	176	176	175	175	175
124	187	187	186	186	185	185	184	184	183	183	182	182	181	181	180	180	179	179	178	178	177	177	176	176	175	175
125	188	187	187	186	186	185	185	184	184	183	183	182	182	181	181	180	180	179	179	178	178	177	177	176	176	175
126	188	188	187	187	186	185	185	184	184	183	183	182	182	181	181	180	180	180	179	179	178	178	177	177	176	176
127	189	188	188	187	186	186	185	185	184	184	183	183	182	182	181	181	180	180	180	179	178	178	178	177	177	176
128	189	188	188	187	187	186	186	185	185	184	184	183	183	182	182	181	181	180	180	179	179	178	178	177	177	177
129	189	189	188	188	187	187	186	186	185	185	184	184	183	183	182	182	181	181	180	180	179	179	178	178	177	177
130	190	189	189	188	188	187	186	186	185	185	184	184	184	183	183	182	182	181	181	180	180	179	179	178	178	177
131	190	190	189	188	188	187	187	186	186	185	185	184	184	183	183	182	182	181	181	181	180	180	179	179	178	178
132	190	190	189	189	188	188	187	187	186	186	185	185	184	184	183	183	182	182	181	181	181	180	180	179	179	178
133	191	190	190	189	189	188	188	187	187	186	186	185	185	184	184	183	183	182	182	181	181	181	180	180	179	179
134	191	191	190	190	189	188	188	187	187	186	186	185	185	185	184	184	183	183	182	182	181	181	181	180	180	179
135	192	191	190	190	189	189	188	188	187	187	186	186	185	185	185	184	184	183	183	182	182	181	181	180	180	180
136	192	191	191	190	190	189	189	188	188	187	187	186	186	185	185	184	184	184	183	183	182	182	181	181	180	180
137	192	192	191	191	190	190	189	180	188	188	187	187	186	186	185	185	184	184	183	183	183	182	182	181	181	180
138	193	192	191	191	190	190	189	189	189	188	188	187	186	186	186	185	185	184	184	183	183	182	182	182	181	181
139	193	192	192	191	191	190	190	189	189	188	188	187	187	186	186	185	185	185	184	184	183	183	182	182	182	181
140	193	193	192	192	191	191	190	190	189	189	188	188	187	187	186	186	185	185	185	184	184	183	183	182	182	182
141	194	193	192	192	191	191	190	190	190	189	189	188	188	187	187	186	186	185	185	185	184	184	183	183	182	182
142	194	193	193	192	192	191	191	190	190	189	189	189	188	188	187	187	186	186	185	185	184	184	184	183	183	182
143	194	194	193	193	192	192	191	191	190	190	189	189	188	188	188	187	187	186	186	185	185	184	184	184	183	183
144	195	194	194	193	193	192	192	191	191	190	190	189	189	188	188	187	187	186	186	186	185	185	184	184	183	183
145	195	194	194	193	193	192	192	191	191	191	190	190	189	189	188	188	187	187	186	186	186	185	185	184	184	184
146	195	195	194	194	193	193	192	192	191	191	190	190	189	189	189	188	188	187	187	186	186	186	185	185	184	184
147	196	195	194	194	194	193	193	192	192	191	191	190	190	189	189	189	188	188	187	187	186	186	185	185	185	184
148	196	195	196	194	194	193	193	192	192	192	191	191	190	190	189	189	188	188	188	187	187	186	186	185	185	185
149	196	196	195	195	194	194	193	193	192	192	191	191	190	190	190	189	189	188	188	187	187	187	186	186	185	185
150	197	196	196	195	195	194	194	193	193	192	192	191	191	190	190	190	189	189	188	188	187	187	187	186	186	185
151	197	196	196	195	195	194	194	193	193	193	192	192	191	191	190	190	189	189	189	188	188	187	187	186	186	186
152	197	197	196	196	195	195	194	194	193	193	192	192	192	191	191	190	190	189	189	189	188	188	187	187	186	186
153	198	197	197	196	196	195	196	194	194	193	193	192	192	191	191	191	190	190	189	189	188	188	188	187	187	186
154	198	197	197	196	196	195	195	194	194	194	193	193	192	192	191	191	190	190	190	189	189	188	188	188	187	187

TABLE 26a.—*Rate of ascent, in meters per minute, for weight* (*w*) *and free lift* (*l*)—Continued.

l.	w.																									
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
155	198	198	197	197	196	196	195	195	194	194	193	193	193	192	192	191	191	190	190	190	189	180	188	188	188	187
156	198	198	197	197	197	196	196	195	195	194	194	193	193	192	192	192	191	191	190	190	189	189	189	188	188	187
167	199	198	198	197	197	196	196	195	195	194	194	194	193	193	192	192	192	191	191	190	190	189	189	189	188	188
158	199	199	198	198	197	197	196	196	195	195	194	194	194	193	193	192	192	191	191	191	190	190	189	189	189	188
169	199	199	198	198	197	197	197	196	196	195	195	194	194	193	193	193	192	192	191	191	191	190	190	189	189	189
160	200	199	199	198	198	197	197	196	196	196	195	195	194	194	193	193	193	192	192	191	191	190	190	190	189	189
161	200	199	199	199	198	198	197	197	196	196	195	195	195	194	194	193	193	192	192	192	191	191	190	190	190	189
162	200	200	199	199	198	198	198	197	197	196	196	195	195	194	194	194	193	193	192	192	192	191	191	190	190	190
163	201	200	200	199	199	198	198	197	197	197	196	196	195	195	194	194	193	193	193	192	192	191	191	191	190	190
164	201	200	200	199	199	199	198	198	197	197	196	196	196	195	195	194	194	193	193	193	192	192	191	191	191	190
165	201	201	200	200	199	199	198	198	198	197	197	196	196	195	195	195	194	194	193	193	193	192	192	191	191	191
166	202	201	200	200	200	199	199	198	198	197	197	197	196	196	195	195	194	194	194	193	193	192	192	192	191	191
167	202	201	201	200	200	199	199	199	198	198	197	197	196	196	196	195	195	194	194	194	193	193	192	192	192	191
168	202	202	201	201	200	200	199	199	198	198	198	197	197	196	196	196	195	195	194	194	193	193	193	192	192	192
169	202	202	202	201	200	200	200	199	199	198	198	198	197	197	196	196	195	195	195	194	194	193	193	193	192	192
170	203	202	202	201	201	200	200	199	199	199	198	198	197	197	197	196	196	195	195	195	194	194	193	193	193	192
171	203	203	202	202	201	201	200	200	199	199	199	198	198	197	197	196	196	196	195	195	194	194	194	193	193	192
172	203	203	202	202	201	201	200	200	200	199	199	198	198	198	197	197	196	196	196	195	195	194	194	194	193	193
173	204	203	203	202	202	201	201	200	200	200	199	199	198	198	198	197	197	196	196	196	195	195	194	194	193	193
174	204	203	203	202	202	202	201	201	200	200	199	199	199	198	198	197	197	197	196	196	195	195	195	194	194	193
175	204	204	203	203	202	202	201	201	201	200	200	199	199	198	198	198	197	197	197	196	196	195	195	195	194	194
176	204	204	204	203	203	202	202	201	201	200	200	200	199	199	198	198	198	197	197	196	196	196	195	195	194	194
177	205	204	204	203	203	203	202	202	201	201	200	200	200	199	199	198	198	198	197	197	196	196	196	195	195	194
178	206	204	204	204	203	203	202	202	201	201	201	200	200	199	199	199	198	198	197	197	197	196	196	196	195	195
179	205	205	204	204	203	203	203	202	202	201	201	200	200	200	199	199	198	198	198	197	197	197	196	196	195	195
180	206	205	205	204	204	203	203	202	202	202	201	201	200	200	200	199	199	198	198	198	197	197	197	196	196	195
181	206	105	205	104	204	204	203	203	202	202	202	201	201	200	200	199	199	199	198	198	198	197	197	196	196	196
182	206	206	205	205	204	204	203	203	203	202	202	201	201	201	200	200	199	199	199	198	198	197	197	197	196	196
183	206	206	205	205	205	204	204	203	203	202	202	202	201	201	200	200	200	199	199	199	198	198	197	197	197	196
184	207	206	206	205	205	204	204	204	203	203	202	202	202	201	201	200	200	200	199	199	198	198	198	197	197	197
185	207	206	206	206	205	205	204	204	203	203	203	202	202	201	201	201	200	200	200	199	199	198	198	198	197	197
186	207	207	206	206	205	205	205	204	204	203	203	203	202	202	201	201	201	200	200	199	199	199	198	198	198	197
187	207	207	206	206	206	205	205	204	204	204	203	203	202	202	202	201	201	200	200	200	199	199	199	198	198	198
188	208	207	207	206	206	205	205	205	204	204	203	203	203	202	202	202	201	201	200	200	200	199	199	198	198	198
189	208	207	207	207	206	206	205	205	205	204	204	203	203	203	202	202	201	201	201	200	200	200	199	199	198	198
190	208	208	207	207	206	206	206	205	205	204	204	204	203	203	203	202	202	201	201	201	200	200	199	199	199	198
191	208	208	208	207	207	207	206	206	205	205	204	204	204	203	203	202	202	202	201	201	200	200	200	199	199	199
192	209	208	208	207	207	207	206	206	205	205	205	204	204	203	203	203	202	202	202	201	201	200	200	200	199	199
193	209	208	208	208	207	207	206	206	206	205	205	204	204	204	203	203	203	202	202	201	201	201	200	200	200	199
194	209	209	208	208	207	207	207	206	206	205	205	205	204	204	204	203	203	202	202	202	201	201	201	200	200	200

l.	w.																									
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
195	209	209	209	208	208	207	207	207	206	206	205	205	205	204	204	204	203	203	202	202	202	201	201	201	200	200
196	210	209	209	208	208	208	207	207	206	206	206	205	205	205	204	204	203	203	203	202	202	202	201	201	200	200
197	210	210	209	209	208	208	207	207	207	206	206	206	205	205	204	204	204	203	203	203	202	202	202	201	201	200
198	210	210	209	209	209	208	208	207	207	207	206	206	205	205	205	204	204	204	203	203	202	202	202	201	201	201
199	210	210	210	209	209	208	208	208	207	207	206	206	206	205	205	205	204	204	204	203	203	202	202	202	201	201
200	211	210	210	210	209	209	208	208	207	207	207	206	206	206	205	205	204	204	204	203	203	202	202	202	202	201
201	211	211	210	210	209	209	208	208	208	207	207	207	206	206	205	205	205	204	204	204	203	203	203	202	202	202
202	211	211	210	210	210	209	209	208	208	208	207	207	206	206	206	205	205	205	204	204	204	203	203	203	202	202
203	211	211	211	210	210	209	209	209	208	208	207	207	207	206	206	206	205	205	205	204	204	203	203	203	202	202
204	212	211	211	210	210	210	209	209	208	208	208	207	207	207	206	206	205	205	205	204	204	204	203	203	203	202
205	212	211	211	211	210	210	210	209	209	208	208	208	207	207	206	206	206	205	205	205	204	204	204	203	203	203
206	212	212	211	211	211	210	210	209	209	209	208	208	207	207	207	206	206	206	205	205	205	204	204	204	203	203
207	212	212	212	211	211	210	210	210	209	209	208	208	208	207	207	207	206	206	206	205	205	205	204	204	204	203
208	213	212	212	211	211	211	210	210	210	209	209	208	208	208	207	207	207	206	206	205	205	205	204	204	204	203
209	213	212	212	212	211	211	211	210	210	209	209	209	208	208	208	207	207	206	206	206	205	205	205	204	204	204
210	213	213	212	212	212	211	211	210	210	210	209	209	208	208	208	207	207	207	206	206	206	205	205	205	204	204
211	213	213	213	212	212	211	211	211	210	210	210	209	209	208	208	208	207	207	207	206	206	206	205	205	205	204
212	214	213	213	212	212	212	211	211	211	210	210	209	209	209	208	208	208	207	207	207	206	206	206	205	205	204
213	214	213	213	213	212	212	212	211	211	210	210	210	209	209	209	208	208	208	207	207	206	206	206	205	205	205
214	214	214	213	213	213	212	212	211	211	211	210	210	210	209	209	208	208	208	207	207	207	206	206	206	205	205
215	214	214	214	213	213	212	212	212	211	211	211	210	210	210	209	209	208	208	208	207	207	207	206	206	206	205
216	215	214	214	213	213	213	212	212	212	211	211	210	210	210	209	209	209	208	208	208	207	207	207	206	206	206
217	215	214	214	214	213	213	212	212	212	211	211	211	210	210	210	209	209	209	208	208	208	207	207	206	206	206
218	215	215	214	214	213	213	213	212	212	212	211	211	211	210	210	210	209	209	208	208	208	207	207	207	206	206
219	215	215	215	214	214	213	213	213	212	212	212	211	211	211	210	210	209	209	209	208	208	208	207	207	207	206
220	215	215	215	214	214	214	213	213	213	212	212	211	211	211	210	210	210	209	209	209	208	208	208	207	207	207
221	216	215	215	215	214	214	213	213	213	212	212	212	211	211	211	210	210	210	209	209	208	208	208	207	207	207
222	216	216	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	209	209	209	208	208	208	207	207
223	216	216	215	215	215	214	214	214	213	213	212	212	212	211	211	211	210	210	210	209	209	209	208	208	208	207
224	216	216	216	215	215	215	214	214	214	213	213	212	212	212	211	211	211	210	210	210	209	209	209	208	208	208
225	217	216	216	216	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	210	209	209	208	208	208
226	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	211	211	211	210	210	210	209	209	209	208	208
227	217	217	216	216	216	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	210	209	209	209	208
228	217	217	217	216	216	216	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	210	209	209	209
229	218	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	209	209	209
230	218	217	217	217	216	216	216	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	210	209	209
231	218	218	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	210	209
232	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	210
233	218	218	218	217	217	217	216	216	216	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210	210
234	219	218	218	218	217	217	216	216	216	216	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210	210

46329—21——8

TABLE 26a.—*Rate of ascent, in meters per minute, for weight (w) and free lift (l)*—Continued.

l.	w.																									
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
235	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	212	211	211	211	210
236	219	219	218	218	218	217	217	217	216	216	216	215	215	214	214	214	213	213	213	212	212	212	212	211	211	211
237	219	219	219	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	212	211	211	211
238	220	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	212	211	211
239	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	214	214	214	214	213	213	213	212	212	212	211
240	220	220	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	212	212
241	220	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212	212	212
242	220	220	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	214	214	214	214	213	213	213	212	212
243	221	220	220	220	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213	213	212
244	221	220	220	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213	212
245	221	221	220	220	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213	213
246	221	221	220	220	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	214	213	213
247	221	221	221	220	220	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213	213
248	222	221	221	221	220	220	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214	213
249	222	221	221	221	220	220	220	219	219	219	218	218	218	217	217	217	216	216	216	216	215	215	215	214	214	214
250	222	222	221	221	221	220	220	220	219	219	219	218	218	218	217	217	217	216	216	216	215	215	215	214	214	214

TABLE 27.—*Altitude time tables for various rates of ascent.*

[Ascensional rate in meters per minute.]

Minutes.	140	150	160	170	180	190	200	210	220	230	240	250	260	270
1	168	180	192	204	216	228	240	252	264	276	288	300	312	324
2	322	345	368	391	414	437	460	483	506	529	552	575	598	621
3	476	510	544	578	612	646	680	714	748	782	816	850	884	918
4	623	668	712	756	801	846	890	934	979	1,024	1,068	1,112	1,157	1,202
5	770	825	880	935	990	1,045	1,100	1,155	1,210	1,265	1,320	1,375	1,430	1,485
6	910	975	1,040	1,105	1,170	1,235	1,300	1,365	1,430	1,495	1,560	1,625	1,690	1,755
7	1,050	1,125	1,200	1,275	1,350	1,425	1,500	1,575	1,650	1,725	1,800	1,875	1,950	2,025
8	1,190	1,275	1,360	1,445	1,530	1,615	1,700	1,785	1,870	1,955	2,040	2,125	2,210	2,295
9	1,330	1,425	1,520	1,615	1,710	1,805	1,900	1,995	2,090	2,185	2,280	2,375	2,470	2,565
10	1,470	1,575	1,680	1,785	1,890	1,995	2,100	2,205	2,310	2,415	2,520	2,625	2,730	2,835
11	1,610	1,725	1,840	1,955	2,070	2,185	2,300	2,415	2,530	2,645	2,760	2,875	2,990	3,105
12	1,750	1,875	2,000	2,125	2,250	2,375	2,500	2,625	2,750	2,875	3,000	3,125	3,250	3,375
13	1,890	2,025	2,160	2,295	2,430	2,565	2,700	2,835	2,970	3,105	3,240	3,375	3,510	3,645
14	2,030	2,175	2,320	2,465	2,610	2,755	2,900	3,045	3,190	3,335	3,480	3,625	3,770	3,915
15	2,170	2,325	2,480	2,635	2,790	2,945	3,100	3,255	3,410	3,565	3,720	3,875	4,030	4,185
16	2,310	2,475	2,640	2,805	2,970	3,135	3,300	3,465	3,630	3,795	3,960	4,125	4,290	4,455
17	2,450	2,625	2,800	2,975	3,150	3,325	3,500	3,675	3,850	4,025	4,200	4,375	4,550	4,725
18	2,590	2,775	2,960	3,145	3,330	3,515	3,700	3,885	4,070	4,255	4,440	4,625	4,810	4,995
19	2,730	2,925	3,120	3,315	3,510	3,705	3,900	4,095	4,290	4,485	4,680	4,875	5,070	5,265
20	2,870	3,075	3,280	3,485	3,690	3,895	4,100	4,205	4,510	4,715	4,920	5,125	5,330	5,535
21	3,010	3,225	3,440	3,655	3,870	4,085	4,300	4,515	4,730	4,945	5,160	5,375	5,590	5,805
22	3,150	3,375	3,600	3,825	4,050	4,275	4,500	4,725	4,950	5,175	5,400	5,625	5,850	6,075
23	3,290	3,525	3,760	3,995	4,230	4,465	4,700	4,935	5,170	5,405	5,640	5,875	6,110	6,345
24	3,430	3,675	3,920	4,165	4,410	4,655	4,900	5,145	5,390	5,635	5,880	6,125	6,370	6,615
25	3,570	3,825	4,080	4,335	4,590	4,845	5,100	5,355	5,610	5,865	6,120	6,375	6,630	6,885
26	3,710	3,975	4,240	4,505	4,770	5,035	5,300	5,565	5,830	6,095	6,360	6,625	6,890	7,155
27	3,850	4,125	4,400	4,675	4,950	5,225	5,500	5,775	6,050	6,325	6,600	6,875	7,150	7,425
28	3,990	4,275	4,560	4,845	5,130	5,415	5,700	5,985	6,270	6,555	6,840	7,125	7,410	7,695
29	4,130	4,425	4,720	5,015	5,310	5,606	5,900	6,195	6,490	6,785	7,080	7,375	7,670	7,965
30	4,270	4,575	4,880	5,185	5,490	5,705	6,100	6,405	6,710	7,015	7,320	7,625	7,930	8,235
31	4,410	4,725	5,040	5,355	5,670	5,985	6,300	6,615	6,930	7,245	7,560	7,875	8,190	8,505
32	4,550	4,875	5,200	5,525	5,850	6,175	6,500	6,825	7,150	7,475	7,800	8,125	8,450	8,775
33	4,690	5,025	5,360	5,695	6,030	6,365	6,700	7,035	7,370	7,705	8,040	8,375	8,710	9,045
34	4,830	5,175	5,520	5,865	6,210	6,555	6,900	7,245	7,590	7,935	8,280	8,625	8,970	9,315
35	4,970	5,325	5,680	6,035	6,390	6,745	7,100	7,455	7,810	8,165	8,520	8,875	9,230	9,585
36	5,110	5,475	5,840	6,205	6,570	6,935	7,300	7,665	8,030	8,395	8,760	9,125	9,490	9,855
37	5,250	5,625	6,000	6,375	6,750	7,125	7,500	7,875	8,250	8,625	9,000	9,375	9,750	10,125
38	5,390	5,775	6,160	6,545	6,930	7,315	7,700	8,085	8,470	8,855	9,240	9,625	10.010	10,395
39	5,530	5,925	6,320	6,715	7,110	7,505	7,900	8,295	8,690	9,085	9,480	9,875	10,270	10,665
40	5,670	6,075	6,480	6,885	7,290	7,695	8,100	8,505	8,910	9,315	9,720	10,125	10,530	10,935

TABLE 28.—*Free lift for definite inflation, for rates of ascent 140, 160, 180, 200, 220, 240, and 260 meters per minute.*

Rates of ascent	140	160	180	200	220	240	260
w.	l.	l.	l.	l.	l.	l.	l.
15	43.8	68.6	106.0	161.1	240.4	....	....
16	44.8	69.8	107.3	162.6	242.1	....	....
17	45.7	71.0	108.7	164.2	243.8	....	....
18	46.7	72.2	110.0	165.7	245.5	....	....
19	47.6	73.3	111.4	167.2	247.1	....	....
20	48.5	74.4	112.7	168.7	248.7	....	....
21	49.4	75.5	114.0	170.1	250.3	....	....
22	50.3	76.5	115.3	171.6	251.9	....	....
23	51.2	77.6	116.5	173.1	253.5	....	....
24	52.0	78.7	117.8	174.5	255.1	....	....
25	52.8	79.7	119.0	175.9	256.6	....	....
26	53.6	80.7	120.2	177.3	258.2	....	....
27	54.4	81.7	121.4	178.7	259.7	....	....
28	55.2	82.7	122.6	180.0	261.2	....	....
29	56.0	83.7	123.8	181.4	262.7	....	....
30	56.8	84.7	125.0	182.7	264.2	376.9	....
31	57.6	85.6	126.2	184.0	265.7	378.5	....
32	58.3	86.6	127.3	185.4	267.2	380.1	....
33	59.1	87.5	128.5	186.7	268.6	381.7	....
34	59.8	88.5	129.6	188.0	270.1	383.3	....
35	60.6	89.4	130.7	189.3	271.5	384.9	....
36	61.3	90.3	131.8	190.6	273.0	386.5	....
37	62.0	91.2	132.9	191.9	274.4	388.1	....
38	62.7	92.1	134.0	193.1	275.8	389.6	....
39	63.4	93.0	135.0	194.4	277.2	391.2	....
40	64.1	93.9	136.1	195.6	278.6	392.7	547.0
41	64.8	94.8	137.1	196.8	280.0	394.2	548.6
42	65.5	95.6	138.2	198.1	281.4	395.8	550.3
43	66.2	96.5	139.2	199.3	282.8	397.3	551.9
44	66.9	97.3	140.3	200.5	284.2	398.8	553.5
45	67.6	98.2	141.3	201.7	285.5	400.3	555.1
46	68.2	99.0	142.3	202.9	286.9	401.8	556.7
47	68.9	99.9	143.3	204.1	288.2	403.3	558.3
48	69.5	100.7	144.3	205.3	289.6	404.8	559.9
49	70.2	101.6	145.4	206.5	290.9	406.2	561.5
50	70.8	102.4	146.4	207.6	292.2	407.7	563.1
51	71.4	103.2	147.4	208.8	293.5	409.2	564.7
52	72.1	104.0	148.3	209.9	294.8	410.6	566.3
53	72.7	104.8	149.3	211.0	296.1	412.1	567.8
54	73.4	105.6	150.2	212.2	297.4	413.5	569.4
55	74.0	106.3	151.2	213.3	298.7	414.9	570.9
56	74.6	107.1	152.1	214.4	300.0	416.3	572.4
57	75.2	107.9	153.1	215.6	301.3	417.7	574.0
58	75.8	108.7	154.0	216.7	302.6	419.1	575.5
59	76.4	109.4	155.0	217.8	303.8	420.5	577.0
60	77.0	110.2	155.9	218.9	305.1	421.9	578.6

TABLE 29.—*Degrees Fahrenheit into degrees centigrade.*

°F	°C.	°F.	°F.	°C.	°F.	P. P.	
31	−0.56	33	66	18.89	− 2	.1	0.06
32	.00	32	67	19.44	− 3	.2	.11
33	.56	31	68	20.00	− 4	.3	.17
34	1.11	30	69	20.56	− 5	.4	.22
35	1.67	29	70	21.11	− 6	.5	.28
36	2.22	28	71	21.67	− 7	.6	.33
37	2.78	27	72	22.22	− 8	.7	.39
38	3.33	26	73	22.78	− 9	.8	.44
39	3.89	25	74	23.33	−10	.9	.50
40	4.44	24	75	23.89	−11	1.0	.56
41	5.00	23	76	24.44	−12	1.1	.61
42	5.56	22	77	25.00	−13	1.2	.67
43	6.11	21	78	25.56	−14	1.3	.72
44	6.67	20	79	26.11	−15	1.4	.78
45	7.22	19	80	26.67	−16	1.5	.83
46	7.78	18	81	27.22	−17	1.6	.89
47	8.33	17	82	27.78	−18	1.7	.94
48	8.89	16	83	28.33	−19	1.8	1.00
49	9.44	15	84	28.89	−20		
50	10.00	14	85	29.44	−21		
51	10.56	13	86	30.00	−22		
52	11.11	12	87	30.56	−23		
53	11.67	11	88	31.11	−24		
54	12.22	10	89	31.67	−25		
55	12.78	9	90	32.22	−26		
56	13.33	8	91	32.78	−27		
57	13.89	7	92	33.33	−28		
58	14.44	6	93	33.89	−29		
59	15.00	5	94	34.44	−30		
60	15.56	4	95	35.00	−31		
61	16.11	3	96	35.56	−32		
62	16.67	2	97	36.11	−33		
63	17.22	1	98	36.67	−34		
64	17.78	0	99	37.22	−35		
65	18.33	− 1	100	37.78	−36		

TABLE 30.—*Miles per hour into meters per second.*

m. p. h.	m. p. s.	m. p. h.	m. p. s.	m. p. h.	m. p. s.	m. p. h.	m. p. s.
1	.45	19	8.5	37	16.5	55	24.6
2	.89	20	8.9	38	17.0	56	25.0
3	1.3	21	9.4	39	17.4	57	25.5
4	1.8	22	9.8	40	17.9	58	25.9
5	2.2	23	10.3	41	18.3	59	26.4
6	2.7	24	10.7	42	18.8	60	26.8
7	3.1	25	11.2	43	19.2	61	27.3
8	3.6	26	11.6	44	19.7	62	27.7
9	4.0	27	12.1	45	20.1	63	28.2
10	4.5	28	12.5	46	20.6	64	28.6
11	4.9	29	13.0	47	21.0	65	29.1
12	5.4	30	13.4	48	21.5	66	29.5
13	5.8	31	13.9	49	21.9	57	30.0
14	6.3	32	14.3	50	22.4	68	30.4
15	6.7	33	14.8	51	22.8	69	30.8
16	7.2	34	15.2	52	23.2	70	31.3
17	7.6	35	15.6	53	23.7		
18	8.0	36	16.1	54	24.1		

TABLE 31.—*Inches into millibars.*

Inches.	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0 09
29.0	982.1	982.4	982.7	983.1	983.4	983.7	984.1	984.4	984.8	985.1
29.1	85.4	85.8	86.1	86.5	86.8	87.1	87.5	87.8	88.2	88.5
29.2	88.8	89.2	89.5	89.8	90.2	90.5	90.9	91.2	91.5	91.9
29.3	92.2	92.6	92.9	93.2	93.6	93.9	94.2	94.6	94.9	95.3
29.4	95.6	95.9	96.3	96.6	97.0	97.3	97.6	98.0	98.3	98.6
29.5	999.0	999.3	999.7	1,000.0	1,000.4	1,000.7	1,001.0	1,001.4	1,001.7	1,002.0
29.6	1,002.4	1,002.7	1,003.1	03.4	03.7	04.1	04.4	04.7	05.1	05.4
29.7	05.8	06.1	06.4	06.8	07.1	07.5	07.8	08.1	08.5	08.8
29.8	09.1	09.5	09.8	10.2	10.5	10.8	11.2	11.5	11.9	12.2
29.9	12.5	12.9	13.2	13.5	13.9	14.2	14.6	14.9	15.2	15.6
30.0	1,015.9	1,016.3	1,016.6	1,016.9	1,017.3	1,017.6	1,018.0	1,018.3	1,018.6	1,019.0
30.1	19.3	19.6	20.0	20.3	20.7	21.0	21.3	21.7	22.0	22.4
30.2	22.7	23.0	23.4	23.7	24.0	24.4	24.7	25.1	25.4	25.7
30.3	26.1	26.4	26.8	27.1	27.4	27.8	28.1	28.4	28.8	29.1
30.4	29.5	29.8	30.1	30.5	30.8	31.2	31.5	31.8	32.2	32.5
30.5	1,032.9	1,033.2	1,033.5	1,033.9	1,034.2	1,034.5	1,034.9	1,035.2	1,035.6	1,035.9
30.6	36.2	36.6	36.9	37.3	37.6	37.9	38.3	38.6	38.9	39.3
30.7	39.6	40.0	40.3	40.6	41.0	41.3	41.7	42.0	42.3	42.7
30.8	43.0	43.3	43.7	44.0	44.4	44.7	45.0	45.4	45.7	46.1
30.9	46.4	46.7	47.1	47.4	47.8	48.1	48.4	48.8	49.1	49.5