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A REPORT ON TWO PILOT BALLOON ASCENTS

MADE AT

SHOEBURYNESS,

BY

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A REPORT ON TWO PILOT BALLOON ASCENTS MADE AT SHOEBURYNESS.

By N. K. Johnson, B.Sc., A.R.C.Sc.

The following report deals with two pilot balloon ascents which were made at Shoeburyness on 18th February, 1920. The results obtained from these two ascents are of considerable interest from several points of view. In the first place, they indicate very clearly the limitations and uncertainty of the single-theodolite method of observation. On the other hand, they give a very fair idea of the accuracy obtainable in determining upper wind velocities and directions by the double-theodolite method.

In addition to this, a considerable amount of information is afforded on the structure of the upper atmosphere, notably in regard to the existence of ascending vortices of air, and in regard to the question of gustiness.

The balloons used for the ascents were 90-inch undyed india-rubber balloons weighing 31 grams each; and both were filled to give a rate of ascent of 500 feet per minute on the Dines' formula :—

$$V=276 \frac{L^{\frac{1}{2}}}{(W+L)^{\frac{1}{3}}}$$

The first balloon was released at 10 hours 25 minutes, and was observed for 74 minutes. At the end of 48 minutes it had attained a height of 26,400 feet. At this point it appears to have developed a leak, for it sank continuously to 12,800 feet, when it disappeared by immerging into a light bank of haze. The sudden manner in which the upward velocity was changed to a downward motion seems to show quite clearly that the fabric of the balloon must have given way at a weak spot, thus allowing the hydrogen to escape through the hole so formed.

The second balloon was released at 11 hours 50 minutes, and was followed for 116 minutes. In 64 minutes it rose to a height of 32,000 feet—in excellent agreement with the rate of ascent given by the Dines' formula. At this point it ceased to rise, and maintained a practically uniform height until the 93rd minute, when it commenced to fall slowly, having sunk to 27,000 feet when it was lost to view in distance.

Both balloons were followed by means of two Cary $1\frac{1}{2}$ inch aperture theodolites, situated at the ends of a base line 4,290 feet long; and also by means of a Barr and Stroud 2 metre base rangefinder placed immediately beside the home-station theodolite.

The angles between the optical and geometrical axes of the two theodolites were afterwards measured, and the necessary corrections were applied to all the observed readings.

It is interesting to note that the colour of both balloons was white, and that no filters were used on the theodolites.

The theodolite mountings at Shoeburyness are cemented into the top of brick pillars. Unfortunately, the cement setting at the out-station had become cracked, and the results indicate that slight movements must have occurred in this theodolite. Reference to this, however, will be made later.

The orientation of the base line was also unfortunate in view of the subsequent behaviour of the balloons. The surface wind was almost at right angles to the base line, but it veered considerably with height, and the effective base line was consequently much foreshortened. In fact, in the case of the second balloon the path turned and actually re-crossed the continuation of the base line. The accuracy of the results is therefore not as great as it might have been, although, as will be seen later, it is still very good.

The observations for the first twenty minutes of each ascent were originally reduced by the Wedderburn semi-graphical method; but the whole of both ascents was subsequently reduced by the slide rule method for the sake of uniformity. The method of reduction consists first in solving the horizontal triangle formed by the two theodolites and the projection of the balloon on the ground. The two angular elevations then enable two independent determinations of the balloon's height to be made, and the closeness of their agreement affords a check upon the accuracy of the observations.

Owing to the shifting of one of the theodolites, already referred to, it was found that there was a very consistent discrepancy between the two calculated values of the height, amounting to almost exactly 1 per cent. of the height. Since this discrepancy is so strikingly consistent, it follows that the actual error of observation must be considerably less than 1 per cent. Occasional errors may be due to small temporary movements of the out-station theodolite. It is considered that the irregularities in the path of No. 2 balloon in the neighbourhood of 55, 80 and 85 minutes may be attributed to this cause.

With regard to the portion of the second trajectory which crosses the base line, it was found that the height of the balloon was practically the same before and after traversing this region. The observations in this neighbourhood were therefore reduced by assuming the height to remain constant. This method gives far better consistency amongst the value of the wind velocity and direction than the other method, as the latter method has to make use of the very small angle subtended by the base line at the balloon during this period.

The results obtained from the rangefinder are very much less accurate than those given by the two theodolites. This, of course, is to be expected, both owing to the very much shorter base of the rangefinder, and also on account of the extreme difficulty in accurately "splitting" a moving point object.

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All the main features of each ascent are, however, clearly shown by the rangefinder observations. In particular, the rangefinder shows that the height does remain constant during the time that the second balloon is crossing the base line; and, in addition, the horizontal distances given by the rangefinder over this period confirm the shape of this portion of the trajectory.

It should be pointed out, however, that both the heights and the distances given by the rangefinder are consistently low by about 10 per cent. The cause of this has not yet been explained. The zero of the instrument was carefully checked both by using the moon, and also by ranging on a stationary object at a known distance. This matter is still under investigation.

In obtaining the results which follow, no use has been made of the rangefinder observations beyond that referred to in the penultimate paragraph.

Turning now to the actual results, these are represented in the series of curves which follows. Figures 1 to 4 relate to the first balloon, and figures 5 to 8 to the second.

We will consider No. 1 balloon first. Fig. 1 shows the path of the balloon projected on to the ground. The origin is the home-station, and the position of the out-station is marked by the circle containing a cross. Numbers placed along the curve indicate the position of the balloon after that number of minutes. The surface wind at the commencement was 11 feet per second from 174 degrees.

The outstanding peculiarity of this curve is the existence in it of two complete loops—one right-handed and the other left-handed. It should be noted that the maximum height of the balloon occurred at V, which is situated midway between the two loops. The meaning of all this will be dealt with after figure 6 has been discussed.

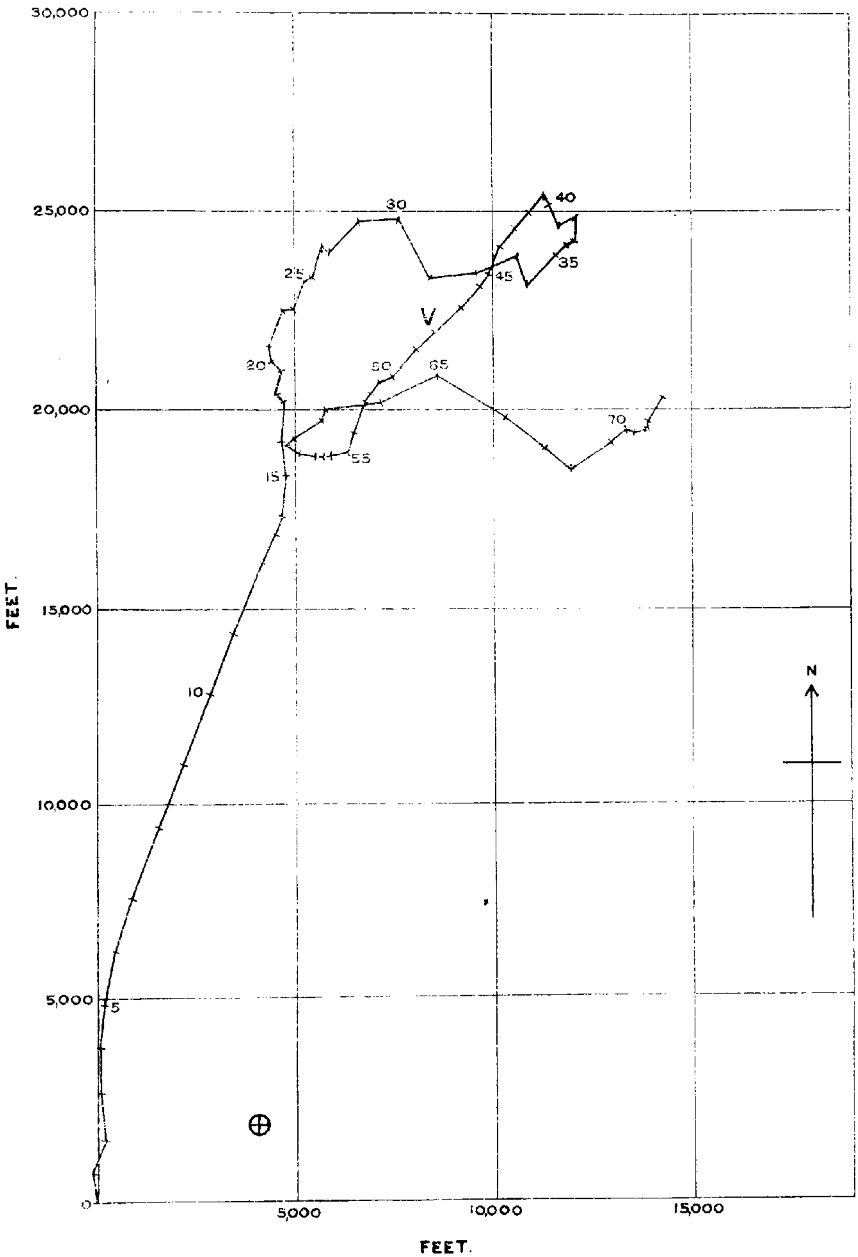
The positions at the 28th, 34th and 39th minutes appear to be irregular, and are probably due to small errors of observation. In this connection it may be pointed out that an error of 0·1 degree in the azimuth readings of both theodolites would shift the position at the 34th minute to midway between the positions at the 33rd and 35th minutes.

The horizontal distance to the balloon when it was lost was 25,000 feet, or 7½ kilometres.

In Figure 2 the height of the balloon is plotted against time. The sharpness with which the vertex is defined is very apparent.

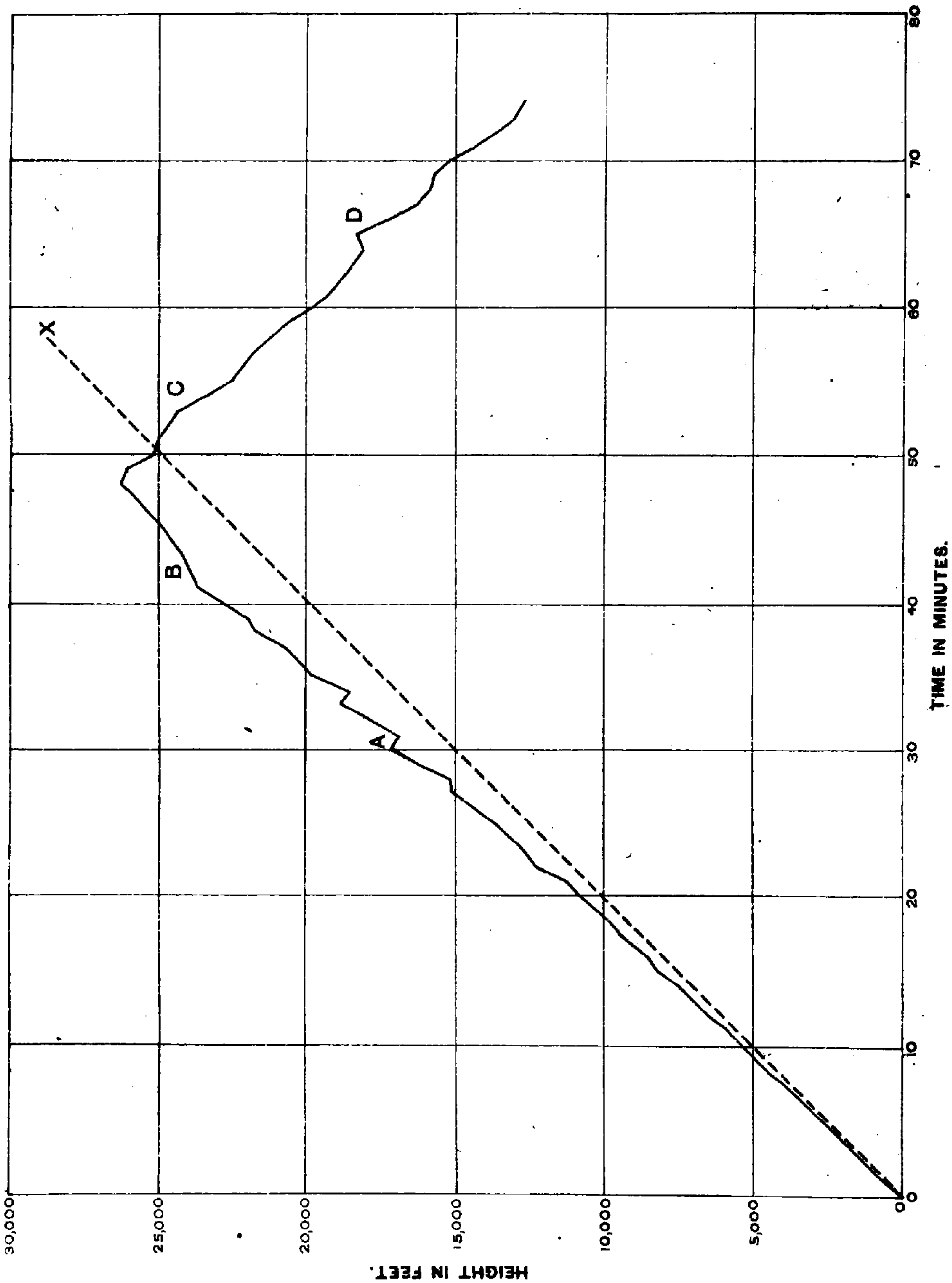
The regions AB and CD represent the positions at which the loops in the path occur, and it is at once seen they embrace the same layer of atmosphere, and that the left hand loop occurs as the balloon is ascending and the right hand loop as it falls.

The line OX indicates a uniform rate of ascent of 500 feet per minute. For the first eleven minutes the rate of ascent is uniform, and equal to 530 feet per minute. From this point

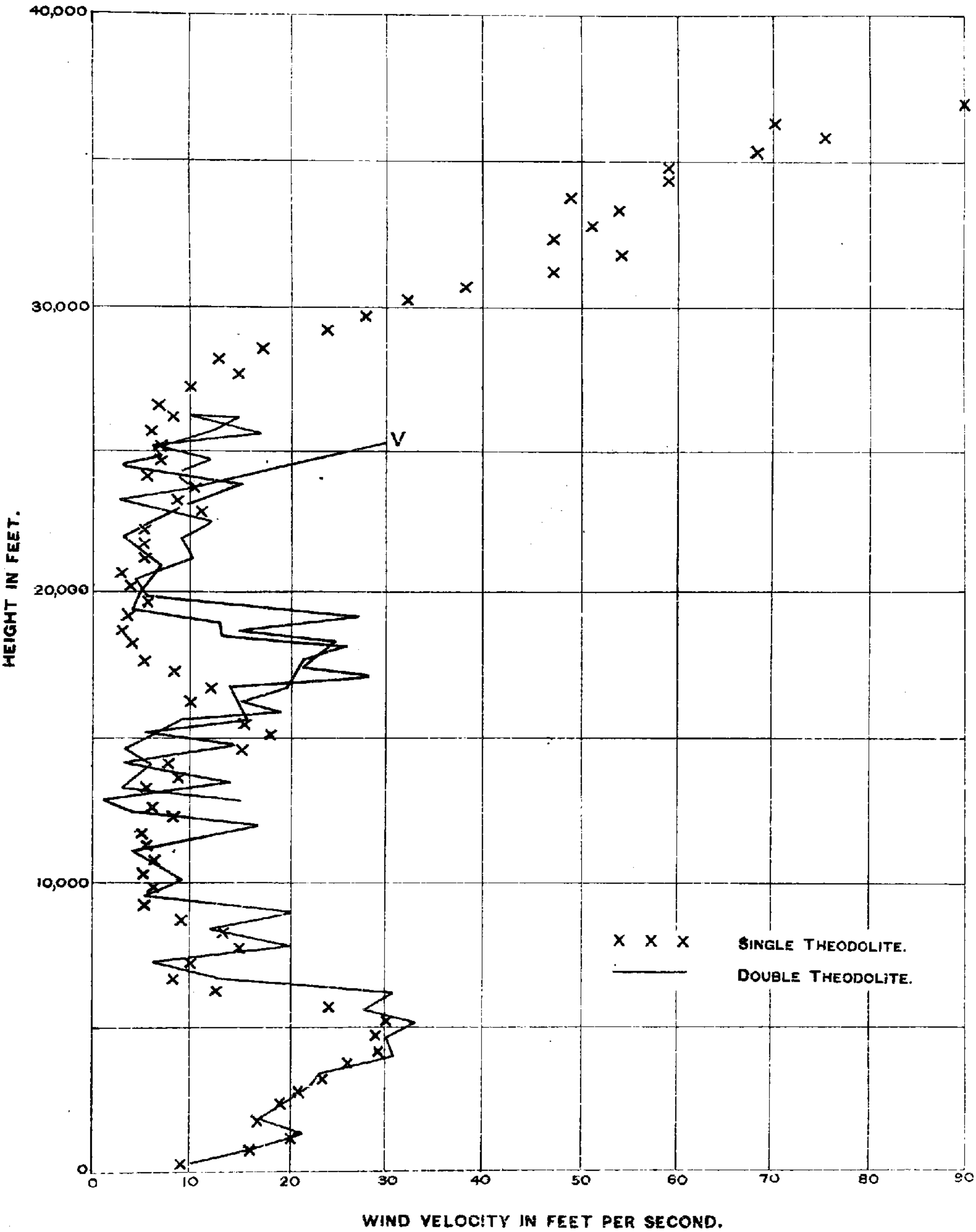


No. 1 Balloon. The Path of the Balloon projected on to the Ground.

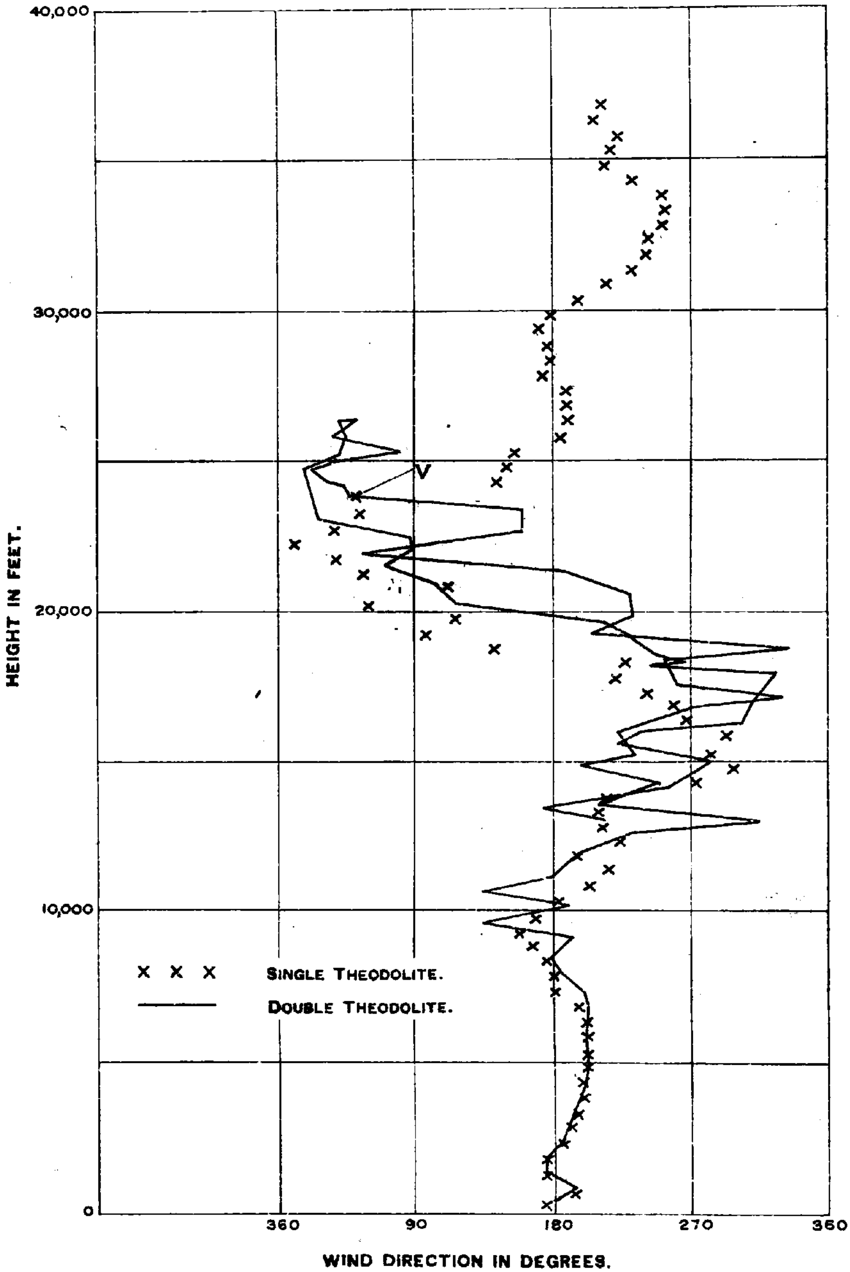
Figure 2.



No. 1 Balloon. The Rate of Ascent of the Balloon.



No. 1 Balloon. Distribution of Wind Velocity with Height.



No. 1 Balloon. Distribution of Wind Direction with Height.

it increases in velocity until the 41st minute. Over this interval the mean rate of ascent is 597 feet per minute. After the 41st minute the rate of ascent falls off suddenly to 383 feet per minute until the vertex is reached at the 48th minute.

The calculated heights for the 31st and 34th minutes may be due to small errors of observation, although the occurrence of a similar irregularity at the same altitude on the descending branch of the curve would indicate that the effect is probably genuine. It may be noted that at V the balloon is 2,400 feet above the height calculated from the free lift given to the balloon.

Figure 3 shows the distribution of wind velocity with height. The line curve gives the velocities and heights obtained from the two theodolite method of observation; and the crosses represent the values obtained by reducing the home-station observations as a single theodolite ascent, assuming a uniform rate of ascent of 500 feet per minute.

The agreements between the two up to 5,000 feet is excellent. From there up to 24,000 feet the balloon gains appreciably on the theoretical rate of ascent; and, although the computed velocity curve is of the original shape, yet the individual velocities are all too small, and are all represented as occurring at heights less than their true heights.

It will be observed that the gustiness from 7,000 feet up to 19,000 feet is very considerable, and that the single theodolite method does not record this fact. The crosses form a much smoother curve than the continuous line.

The close agreement between the ascending and descending portions of the continuous curve is noteworthy, as it affords an excellent means of determining the order of accuracy that is obtainable in the two theodolite method of wind measurement. It should be remembered, however, that the gustiness prevailing at the time was very considerable, and in making the comparison mean values for the velocity ought to be taken.

It follows from this that when upper wind measurements are utilised for such purposes as the reduction of artillery shooting trials, gustiness, as measured in the vertical direction, ought to be smoothed out in order to obtain representative values for the wind velocity at various heights.

The chief value of Figure 3 lies in the information it gives after the 48th minute. The two theodolites and the rangefinder show that after this time the balloon is falling, and consequently we have no information as to the wind above 25,400 feet. The single-theodolite method, on the other hand, assumes that the balloon continues to rise to a height of 37,000 feet, at which altitude it shows a wind velocity of 90 feet per second. Both the altitudes and the velocities given by the single-theodolite method after the 48th minute are, of course, fictitious; and are, in addition, hopelessly in error. Thus, this method indicates a velocity at 33,000 feet of 53 feet per second; the actual velocity at this height as given by the two-theodolite method in the second ascent is 30 feet per second. The direction is also more than 100 degrees wrong (see Figures 3 and 7).

The danger of the single-theodolite method, especially when used for long ascents, is well exemplified by the present case.

In this connection, it may be remarked that a cursory glance through the Upper Air Supplements issued with the Daily Weather Report, reveals a considerable number of instances in which the wind velocities up to moderate heights maintain quite a low value, whilst at great heights the velocity increases enormously. One is tempted to wonder how many of these determinations were made by the single-theodolite method.

The counterpart of Figure 3 is found in Figure 4, in which the wind direction at increasing heights is shown. As before, the continuous curve shows the double-, and the crosses the single-theodolite results. As with the velocities, the agreement up to 6,000 feet is excellent; but above that point the directions given by the single-theodolite method lag considerably behind the true heights. After the vertex is reached, this method gives the fictitious directions shown in the curve, and these correspond to the fictitious velocities of Figure 3.

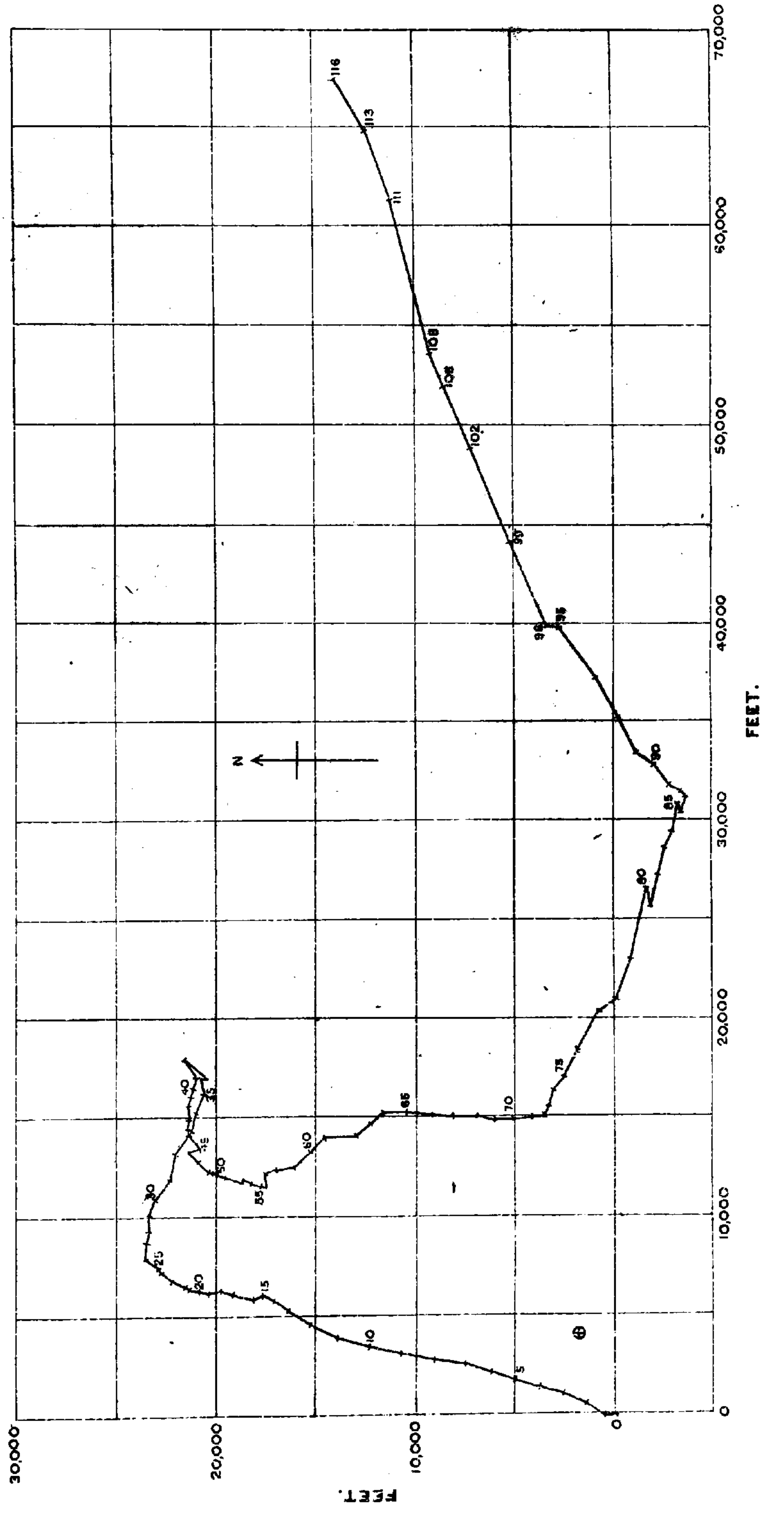
Corresponding with the irregular fluctuations in the wind velocities between the heights of 7,000 and 19,000 feet, the wind directions over the same region are seen to fluctuate also to a very marked extent.

The agreement between the ascending and descending portions of the two-theodolite curve should be noted.

On the ascending portion, between the heights of 18,000 and 24,000 feet, the wind is seen to "back" a complete turn. Reference to Figures 1 and 2 show that this represents the closed loop formed between the 32nd and 45th minutes. On the other hand, on the descending portion of the curve between the same heights the wind "veers" a complete turn, corresponding to the right-hand loop described between the 53rd and 64th minutes.

Turning now to the second balloon, Figure 5 is a projection of its path on the same scale as Figure 1. The agreement between the two up to the 48th minute is patent. In particular, the loop occurs again at the same time, and at very nearly the same position in space. Unlike the first balloon, the second continued to rise after this time, and from this point the two paths diverge. As this balloon did not descend through the 23,000 to 18,000 feet layer again, the right handed loop is missing.

It is interesting to note that at the 72nd minute the angular elevation of the balloon reached a maximum; from the home-station it was 64·0 degrees, and from the out-station 70·4 degrees. When the balloon was lost to view at 116 minutes, the elevations were still both above 21 degrees. Its horizontal distance from the home-station was then 69,000 feet, or just over 21 kilometres.



No. 2 Balloon. The Path of No. 2 Balloon projected on to the Ground.

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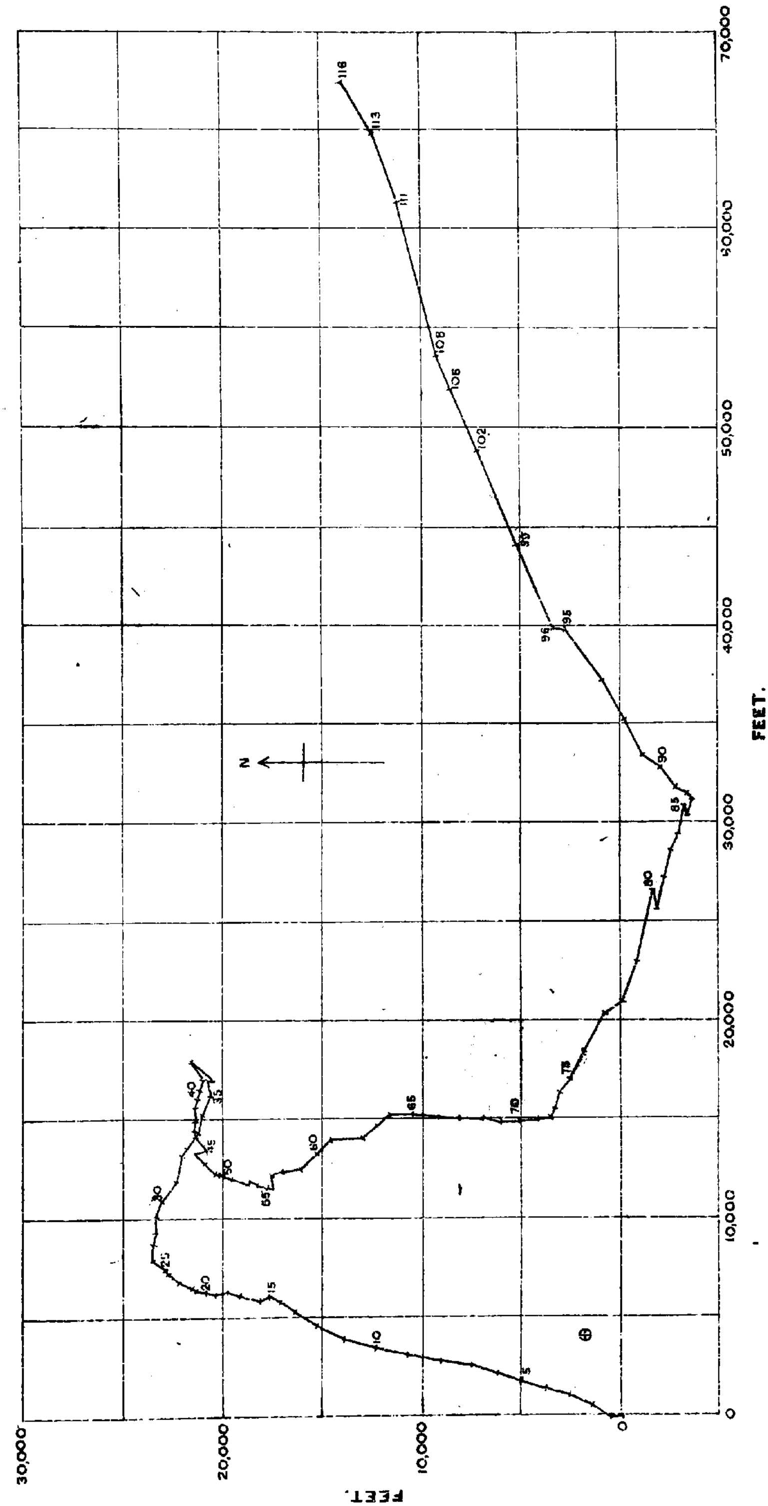
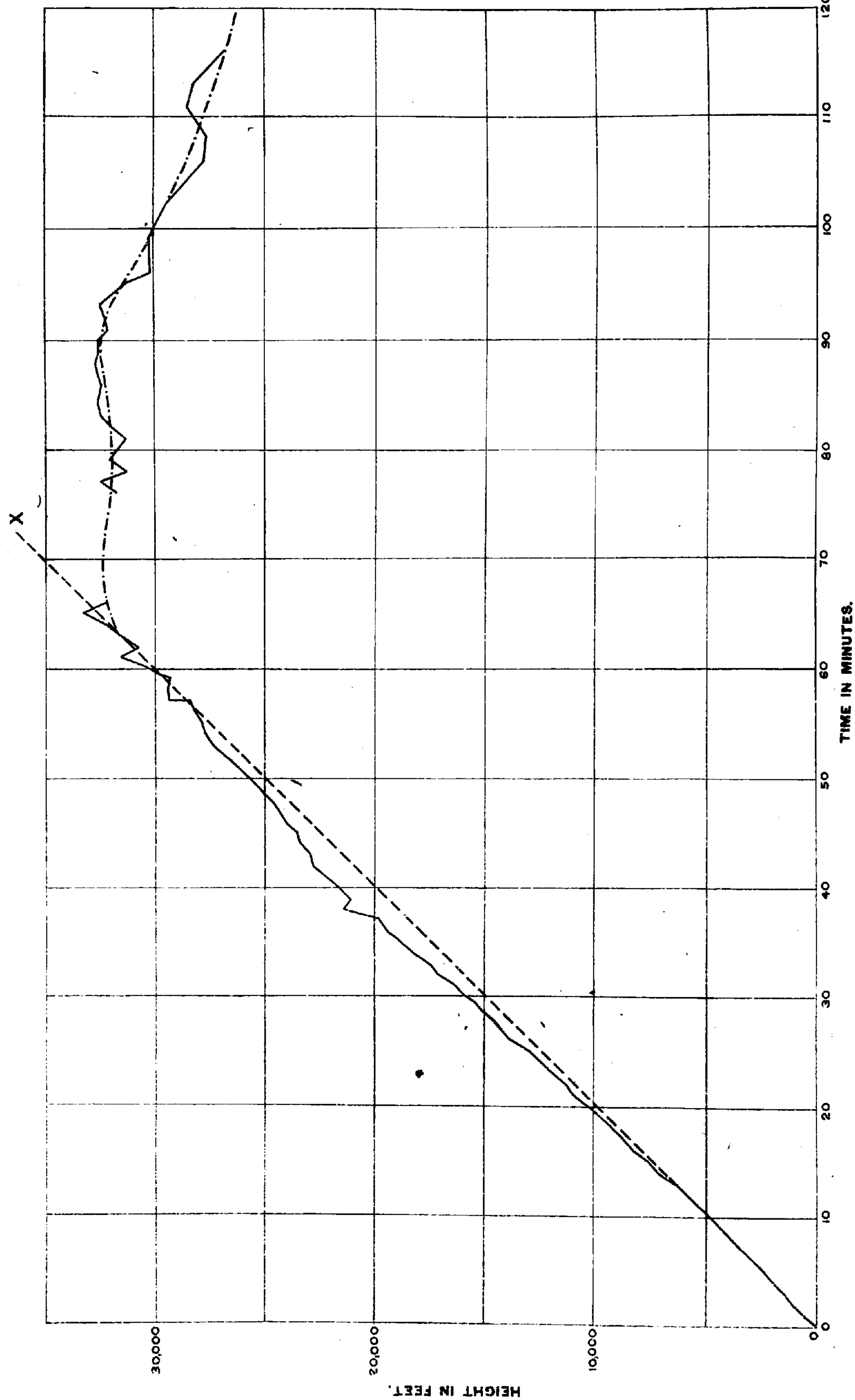
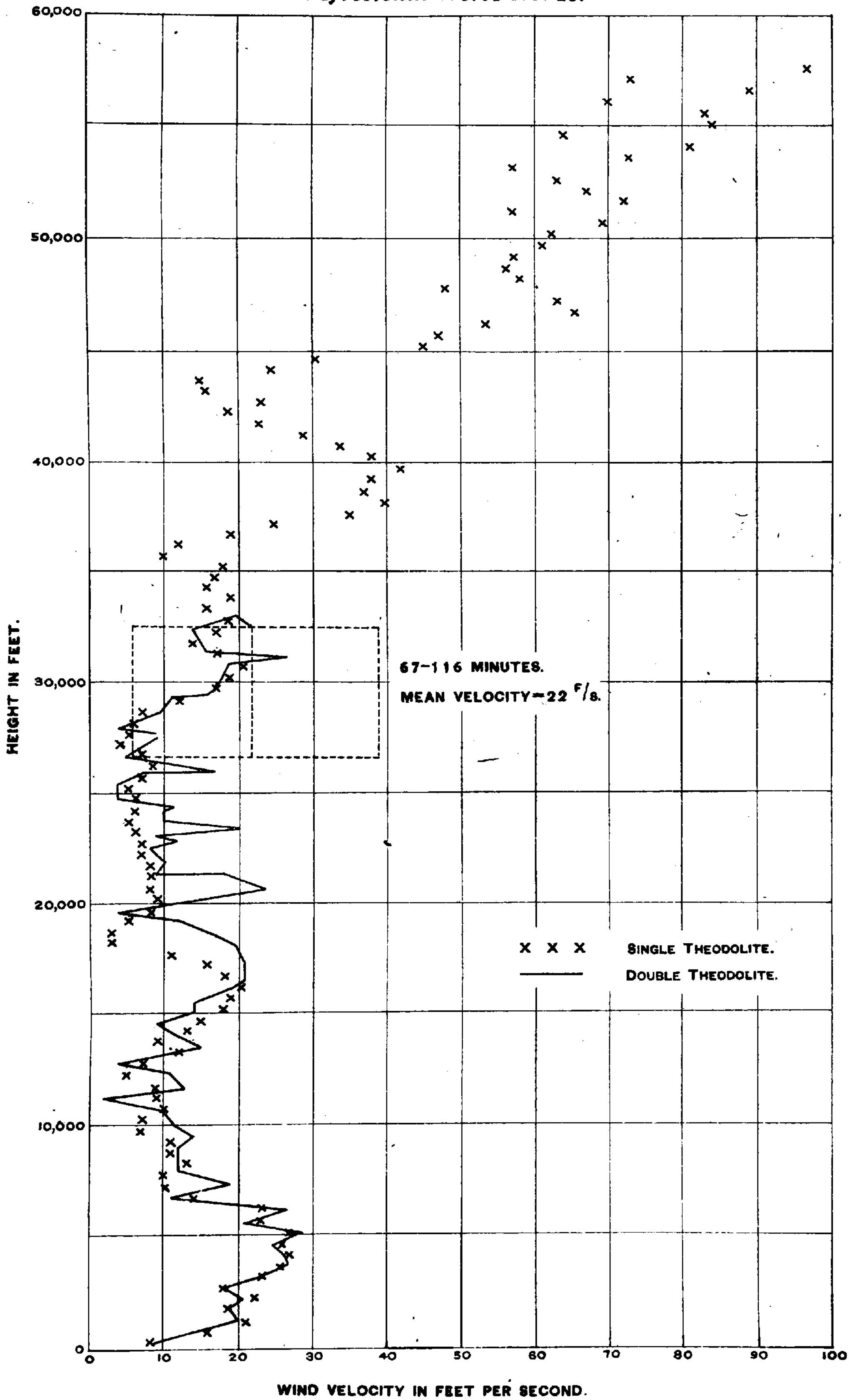


No. 2 Balloon. **The Path of No. 2 Balloon projected on to the Ground.**



No. 2. Balloon. The Rate of Ascent.



No. 2 Balloon. The Distribution of Wind Velocity with Height.

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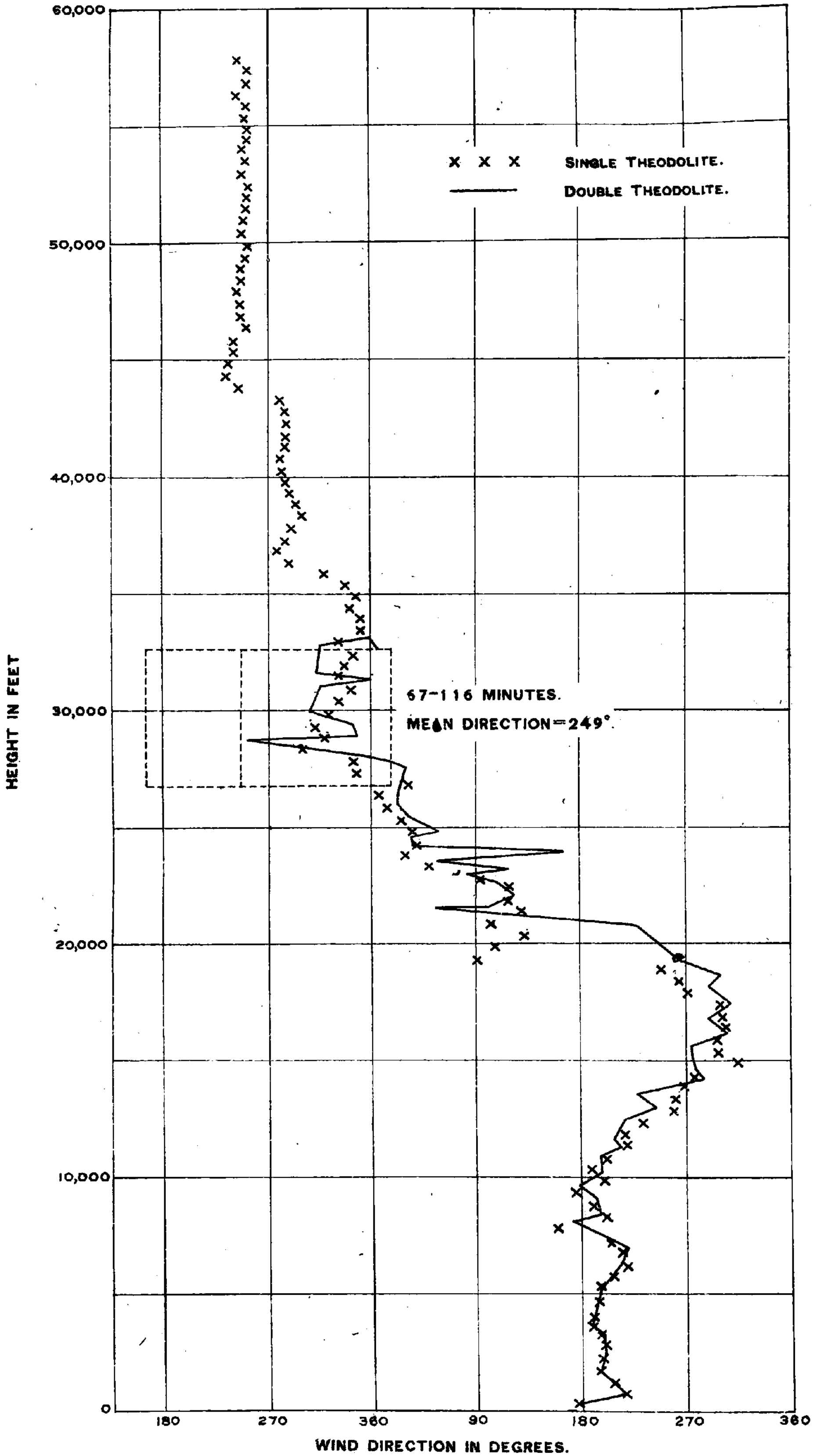

No. 2 Balloon. The Distribution of Wind Direction with Height.

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By this time the angle subtended by the base line at the balloon was about 0·8 degree. From the 98th minute onwards this angle was always less than 2 degrees, and an error of 0·1 degree in either azimuth reading makes a large error in the calculated position of the balloon. For this reason, after the 96th minute, only about every third observation is shown, those being selected which lie most nearly on what is obviously the true path.

The rate of ascent of the second balloon is shown in Fig. 6. Up to 13 minutes the vertical velocity is exactly 500 feet per minute. From there until the 42nd minute it is increased to a mean value of 552 feet per minute; and from thence on to the 64th minute its mean value is 427 feet per minute.

By this time it had attained a height of about 32,000 feet, which it maintained sensibly constant until the 93rd minute, when it commenced to sink slowly, becoming lost to view at about 27,000 feet.

The irregular nature of the curve from the 55th to the 65th minutes, and from the 75th to the 80th minutes, must be attributed partly to possible movement of the out-station theodolite, and partly to the small angle which the base line subtends at the balloon over this period. It is considered that the former is the more likely cause. The irregularities around 110 minutes are due to the second cause. The re-appearance at a height of about 20,000 feet of a similar irregularity to that shown in Fig. 2 indicates that this effect is undoubtedly real.

A comparison of the rates of ascent with those obtained for the first balloon shows clearly that the air between 18,000 and 23,000 feet possesses a steady upward movement. The velocity according to the first balloon is 1·1 feet per second.

The paths of both balloons show, moreover, that the air in this region is moving in a circular track. The combination of these two movements implies the existence of a large vortex, by which the air is rising at a rate of about 1 foot per second.

The mean horizontal velocity of the two balloons describing the three circular tracks is 11·3 feet per second.

The variation of wind velocity with height is illustrated in Figure 7. After attaining a vertex of about 33,000 feet the balloon fell slowly to about 27,000 feet. In order not to confuse the diagram a rectangle has been drawn, which represents by its confines the extreme velocities and heights concerned during the downward movement. The mean of all the velocities over the minute intervals represented by the rectangle is shown by the dotted vertical line.

Up to 26,000 feet, Fig. 7 is almost a replica of Fig. 3. Indeed, the fidelity with which the wind structure is reproduced affords a good illustration of the accuracy of the pilot balloon method for its determination, The rapid space variations in the wind velocity which Fig. 3 shows to have existed between 7,000 feet and 19,000 feet, are seen in Fig. 7 to have become smoothed out an hour and a half later. The general shape of the curve is nevertheless accurately maintained even over this region.

The velocities given by the single-theodolite method of reduction for heights above 33,000 feet are again imaginary. According to this method, the velocity at 58,000 feet is 97 feet per second. Both the height and the velocity are, of course, fictitious.

Apart from what has been said above, the remarks made in connection with Fig. 3 refer equally to Fig. 7

Fig. 8 shows the variation of wind direction with height, and is in many respects a duplicate of Fig. 4. As in Fig. 7, the results for the downward portion of the balloon's track are represented by a rectangle, and the mean direction during this time is indicated as before by the dotted line.

Referring to the region between 7,000 feet and 19,000 feet, it should be observed that not only have the fluctuations in velocity subsided, but also the large variations in the direction have become almost entirely smoothed out.

In conclusion, a short statement will be made of the weather conditions prevailing at the time.

The conditions were typically anticyclonic—light surface winds with a clear, deep blue sky. The visibility upwards was generally excellent, although both balloons encountered at times patches of haze.

The pressure distribution at the time in question was as follows:—Shoeburyness, where the ascents were made, was situated in the north-west corner of a well-defined anticyclone centred over Southern Austria. Another, and rather better defined, anticyclone centred over Iceland, extended nearly to the British Isles. Situated nearly symmetrically about the line joining these two " highs " were two " lows," one over Northern Scandinavia and the other off the south-west corner of Portugal. A " wedge " extended from the latter in a north-east direction across the north-west region of the British Isles.

Thus Shoeburyness was to be found nearly at the " neutral point " produced by these four systems.