Tables 7 and 8, and Sections 27, 28, and 29 of the Book 'Aerology', Which Deal With Pilot Balloon Observations

Aerologiya

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TABLE 7

Pilot Balloon No 57

Date 6 March hour 6 minutes 45

Casing No 20

Free lifting force 238 gr Length of circumference 253 cm

Vertical velocity 223 m/min

Correction Multiplier 0.96 Corrected for density 214 m/min

Base No Point No

Pressure 746.2 mm, 994.9 mb

Temperature: by dry - 3.0

by wet - 3.6

Humidity: relative 86%

absolute 4.2 mm

Verification of the ShT theodolite system

angle	before ascent direct sight	before ascent inverted sight	after ascent direct sight	after ascent inverted sight
horizontal				
vertical				

	before ascent	after ascent
Cloudiness: amount of gen/lower and form		
Wind: (by vane): direction and velocity		

Reason for stopping observation entered Ac

Wind at standard altitudes

Over land surface

km	velocity	direction

Above sea level

km	velocity	direction

The Balloon went in direction

Form and height of clouds, into which balloon (in moment of fogging) entered over land surface ~~and~~ ~~above~~ sea level

Signature of observers:

TABLE 8

Moment of release 6 hours 45 min. Correction $\Delta\delta$ = - 0.8°

(Mean solar time)

Minutes	ANGLE hori-zontal readings	ANGLE verti-cal readings	Altitude of balloon over land surface	Verti-cal velo-city w	ΔW	Altitude ave. layer over land sur. level	Altitude above sea level	Wind direc-tion	Wind velo-city
0.5									
1.0									
1.5									
2.0									
2.5									
3.0									
4									
5									
6									
7	covered by Frst								
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
19 min 48 sec fogging in Ac									
20 min	350.8	19.7							
21 min 0.5 sec. lost in Ac									

27. Errors in the Method of Pilot Balloon Observations from One Point

The method of pilot balloon observations from one point, as also other methods, makes it possible to determine the speed and direction of the wind with a certain degree of accuracy depending on the size of errors in the obtained results. Knowing the size of these errors permits us to judge the area of application of this method and to avoid large errors in the utilization of the results obtained.

Inasmuch as the wind velocity and direction are determined by the size and direction of the segments between the projections of the pilot balloon, then, consequently, the errors in the determination of the positions of the projections will result in errors in the determination of the wind velocity and direction. The position of the projections in turn depends on the values of the coordinates of the pilot balloon, i.e., azimuths, vertical angles, and altitudes. In this manner, the errors in the determination of the wind velocity and direction depend on the errors of the basic values forming the foundation of the method, namely, the azimuth, the vertical angle and the altitude.

In studying the question of errors and the determination of the wind velocity and direction, those errors in the determination of angular coordinates which are accidental are taken into account, assuming that the systematic errors are considered by means of corresponding corrections. The error in the determination of the altitude of the pilot balloon is considered to be dependent on the error in the determination of the vertical velocity, assuming that the interval of time from the moment of release of the pilot balloon to the reading is correct.

Let us look at the effect of errors in the determination of coordinates of the pilot balloon upon the relative error in the determination of the wind.

Let us assume that at some moment of time t_1 the horizontal projection of the pilot balloon is at point C_1, and at the next moment of time t_2 -- at point C_2 (Figure 37). The segment $C_1C_2 = l$ represents the displacement of the pilot balloon for the interval of time $t_2 - t_1$. The velocity of the wind for layer $H_2 - H_1$ is therefore determined by

[diagram page 80]

Figure 37. The effect of error in the determination of azimuths.

The relation for the distance between projection l to the interval of time $t_2 - t_1$ is:

[formula page 81].

The relative error in the determination of the wind velocity, assuming that the error in the determination of $t_2 - t_1$ is equal to zero, may be expressed in the form:

[formula page 81]. (50)

In this manner the determination of the relative error in the magnitude of the wind velocity is reduced to the determination of the relative errors in the horizontal displacements of the balloon.

Let us look at the errors in the determination of the wind velocity and direction which depend on the errors in the determination of azimuths.

Let us assume first of all that the errors in the determination of azimuths at moments t_1 and t_2 are equal in size and sign and equal to $\triangle\alpha$. Then the projections C_1 and C_2 will appear at points C_1' and C_2' and the triangle OC_1C_2 whose angle φ is equal to the difference of the azimuths will take up the position $OC_1'C_2'$, and the segment C_1C_2 will turn through the angle $\triangle\alpha$. In this manner the constant error $\triangle\alpha$ in the determination of the wind velocity will not show any effect, and the error in the determination of the direction will be equal to the constant error $\triangle\alpha$.

Such an error may appear in the case of an incorrect orientation of the theodolite. If the theodolite is oriented with an error of about 1 to 2 degrees then the determination of the direction will not be affected.

If the errors in the determination of azimuths are different, this case may be reduced to that where one of the azimuths is determined correctly and the other with an error equal to the difference of errors in the determination of both azimuths. In Figure 38 the segment $C_1C_2 = l$ represents the actual displacement of the balloon, and segment C_1C_2', the displacement due to error $\triangle\alpha$ in the determination of the value of angle α_2. Dropping a perpendicular from point C_2 to segment C_1C_2' we may state that the error in the determination of value l will be equal to the magnitude of segment rC_2'.

From the right angle triangle rC_2C_2' it follows that

[formula page 81],

where L_2 is the distance from the point of observation O to the projection C_2 and γ is the angle $C_1C_2'O$. Besides that it may be approximately assumed that $C_2C_2' = L_2 \Delta \alpha_2$.

[diagram page 81]

Figure 38. Computation of errors in the wind velocity and direction due to errors in the determination of the azimuths.

Replacing $\Delta \alpha_2$ by $\Delta \varphi$ we will obtain for the absolute and relative errors in the determination of the wind the expressions

[formula page 82],)
)　　(51)
[formula page 82],)

where $\Delta \varphi$ is the error in the measurement of the differences of the azimuths.

The error in direction will be obtained, after determining angle $\Delta \mu$, by segments C_1C_2 and C_1C_2'. By utilizing the triangle $C_1C_2C_2'$, we can state

[formula page 82].

In view of the small value of $\Delta \mu$, let us substitute $\Delta \mu$ approximately for $\sin \Delta \mu$ and, besides, $L_2 \Delta \varphi$ for C_2C_2'. Then,

[formula page 82].　　(52)

The expressions (51) and (52) show that inasmuch as the relative error in the determination of the wind velocity is $\delta u = \frac{\Delta l}{l}$, then the eerror in the wind direction $\Delta \mu$ increases with the increase of $\Delta \varphi$ and the relation $\frac{L_2}{l}$ and, in addition depends on the size of the angle γ.

Let us study the errors in the determination of the wind velocity and direction which depend on the errors in the determination of the vertical angles. In Figure 39, the triangles POC and P_1OC_1 represent pilot balloon triangles in which OC is the distance to the projection of the balloon in a correct determination of the vertical angle, and OC_1, the distance obtained with an error caused by an error in the determination of the vertical angle $\Delta \delta$.

From studying the triangle OP_1P it follows that

[formula page 82].

[diagram page 82]

Figure 39. The effect of errors in the determination of the vertical angle.

The value OP may be represented as $\frac{OC}{\cos\delta}$, or in the form of $\frac{L + L}{\cos\delta}$. Disregarding in the numerator of this expression the value Δ L, and also the value $\Delta \delta$ in $\sin(\delta + \Delta \delta)$, the preceding relation may be restated in the form

[formula page 82],

from where

[formula page 83]. (53)

In formula (53), in view of the small value of angle $\Delta\delta$, we shall substitute the angle itself for its sine. It determines the effect of the errors in the measurement of the vertical angle on the error in the determination of the distance to the projection of the pilot balloon. It is not difficult to see that in the given L and $\Delta\delta$, its maximum value for ΔL is reached at small magnitudes of δ or near 90 degrees. Inversely, the minimum value for ΔL takes place when angle δ is close to 45 degrees.

Let us assume that errors in the determination of the vertical angles effect the determination of distances to projections C_1 and C_2, i.e., the length of segments OC_1 and OC_2 (Figure 40), in such a manner that

[formula page 83]

or, as follows from formula (53)

[formula page 83] (54)

Evidently, in this case the triangles OC_1C_2 and $OC_1'C_2'$ are similar. The segment $C_1'C_2'$ represents the distance between the projections, obtained with error rC_2'. The magnitude of this error may be determined by the relation

[formula page 83].

[diagram page 83]

Figure 40. The effect of error in the determination of vertical angles.

Replacing $\frac{\Delta L_2}{L_2}$ by $\frac{\Delta \delta_2}{\sin 2 \delta_2}$, from the relation (54), we obtain

[formula page 83].

At a sufficient distance of the balloon, the value rC_2' will be inconsequential, because the relation $\frac{\Delta L_2}{L_2} = \frac{\Delta \delta_2}{\sin 2 \delta_2}$ will be small.

As a result of the fact that under a normal value of δ, for a great distance of the balloon, the values δ_1 and δ_2 will be close to each other, then, in order to satisfy the relation (54), it is necessary that $\Delta \delta_1$ and $\Delta \delta_2$ be sufficiently close to each other both according to magnitude and sign. Consequently, if the conditions under which errors $\Delta \delta_1$ and $\Delta \delta_2$ are equal, are met, then the results of the above stated arguments are correct, i.e., the error in the determination of the wind velocity will be small and it can be disregarded.

From the similarity between triangles OC_1C_2 and $OC_1'C_2'$ it follows that the error in the wind direction in this case is equal to zero.

In this manner the effect of the error in the determination of the vertical angle upon the error in the determination of the wind, may be reduced even in this case, when one of the angles δ is determined correctly and the other with an error equal to the difference of errors of both vertical angles.

[formula page 84].

[diagram page 84]

Figure 41. The computation of errors in the wind velocity and direction due to the errors in the determination of the vertical angle.

In Figure 41, C_1C_2' represents the distance between projections, obtained with error rC_2, inasmuch as the correct value of balloon displacement is represented by segment C_1C_2. It is not difficult to see that the magnitude of the error rC_2 may be determined from triangle $rC_2'C_2$:

Turning to formula (53) and replacing ΔL_2 by $\frac{2L_2 \Delta \delta}{\sin 2\delta}$, we obtain an expression for the absolute error in the determination of the wind velocity:

[formula page 84], (55)

where $\Delta \delta$ is the error in the measurement of the difference of the vertical angles.

For the relative error in the determination of the wind velocity, the following formula will serve:

[formula page 84]. (56)

For the determination of the error in the wind direction, let us utilize the triangle $C_1C_2C_2'$. It is evident that

[formula page 84]

Replacing $\sin \Delta \mu$ by $\Delta \mu$ and considering C_1C_2' approximately equal to 1, we will find that

[formula page 84]

or, in accordance with expression (53),

[formula page 84]. (57)

From formulas (56) and (57) it is evident that other conditions being equal, the minimum error in the wind velocity and direction will occur when δ = 45 degrees.

Inasmuch as the errors in the determination of azimuths and the vertical angles are independent from one another, the maximum error in the determination of the wind velocity may be obtained by summing the errors due to mechanical errors and errors in the determination of other angles, considering that the sign of the errors is the same.

Then from formulas (51) and (55) and (56) we will obtain

[formula page 85], (58)

[formula page 85]. (59)

Exactly in the same way, for the maximum error in the wind direction which depends on the errors in α and δ, we will obtain

[formula page 85]. (60)

From formulas (59) and (60) we can see that the relative error in the determination of the wind velocity and the error in the wind direction increases with the increase of the relation $\frac{L_2}{l}$, i.e., according to the distance of the balloon from the point of release or according to its altitude, and with a decrease of l -- the displacement of the balloon along the horizontal.

In order that the errors in the determination of the wind velocity and the direction remain constant according to the distance of the balloon, it is necessary to increase the value of 1, i.e., the intervals of time for which the wind velocity and direction are calculated.

Let us study two separate cases. Let us suppose that the pilot balloon recedes from the observer in the direction L_2. In this case $\gamma = 0$, and the formulas (59) and (60) take on the form

[formula page 85],)
[formula page 85].) (61)

If, on the other hand, the pilot balloon circles the point of release, i.e., $\gamma = 90$ degrees, then the same formulas take on the form

[formula page 85],)
[formula page 85].) (62)

Supposing that $\Delta \varphi = \Delta \delta$ and comparing the formulas for the errors in the stated separate cases, we may conclude that in the given relation $\frac{L_2}{1}$ the wind velocity may be determined with a greater amount of accuracy in sharp winds and altitudes than in cases of inconsequential changes in the direction. On the other hand, if the pilot balloon recedes from the point of release, changing its direction but little, the error in the direction of the wind will be less than in cases when the pilot balloon circles the place of release. Turning to formulas (59) and (60) and assuming that $\pm \Delta \varphi = \pm \Delta \delta$, it is possible to determine the value of $\frac{L_2}{1}$ in dependence on γ

and δ, in order to obtain the wind velocity and direction with the given error. Accepting the error in the measurement of angles to be equal to ±0.05 degree, and considering that the possible error in $\Delta \varphi$ and $\Delta \alpha$ is equal to the sum of possible errors in each of their readings, i.e. ±0.1 degree, it is possible to construct a table for the magnitudes of the relation $\frac{L_2}{l}$. Table 9 is constructed with the assumption that $\delta \mu$ = 10 percent, and table 10, that $\Delta \mu$ = 10 degrees.

TABLE 9

Values of $\frac{L_2}{l}$ depending on γ and δ, corresponding to errors $\delta \mu$ = 10 percent.

TABLE 10

Values of $\frac{L_2}{l}$ depending on γ and δ, corresponding to errors $\Delta \mu$ = 10 degrees.

These tables answer the question as to which values of the relation $\frac{L_2}{l}$ in dependence on γ and δ should be taken in order to obtain the necessary degree of accuracy in the determination ofthe wind velocity and direction.

It is evident that a decrease of the errors of $\delta \mu$ and $\delta \mu$ demands an increase in the accuracy of the determination of angles of balloon displacement. On the other hand, other conditions being equal, the decrease in the same errors is tied up with the decrease of the relation $\frac{L_2}{l}$, i.e., with great distances of the balloon, the time intervals for which the wind velocity and direction are determined should be increased (and consequently also l).

The error in the determination of the third coordinate of the balloon, i.e., the altitude, depends on the error in the determination of its vertical velocity, inasmuch as the error in the determination of time may be considered inconsequential. The main source of the error in the determination of the vertical error is the deviation of the true vertical velocity from the computed value using the coefficient of the air resistance.

If by W, as is usual, we designate the computed vertical velocity of the pilot balloon, accepting it as constant, and by W_1 -- the real mean vertical velocity during time t_1 of balloon ascent, then the absolute and relative errors in the determination of the altitude H_1 may be obtained by using the expression $\Delta H_1 = (W_1 - W)\, t_1$ and $\frac{\Delta H_1}{H_1} = \frac{W_1 - W}{W_1}$.

The errors in the determination of the altitude are reflected in the determination of the distance to the projection without changing the angles between them. From Figure 42 it is evident that $\Delta L = \Delta H \operatorname{ctg} \delta$. In this manner the errors in the determination of the altitudes call forth errors in the determination of the distance to the projection and, consequently, in the determination of wind velocity and direction.

From the geometrical relations it can be shown that if the real vertical velocity W_τ in the layer $H_2 - H_1$, during time interval $\tau = t_2 - t_1$, is equal in size to W_1, then the relative error in the determination of the wind will be conditioned by the relative error in the determination of the altitude, in such a way that

[formula page 87] (63)

and, consequently,

[formula page 87]. (64)

[diagram page 87]

Figure 42. The influence of errors on the determination of the altitude of the pilot balloon.

The deviation $W_1 - W$, in this case, does not directly affect the direction of the wind.

If, however, $W_{\tau} \neq W_1$, which, as a rule, is encountered in practice, then to the errors determined by formulas (63) and (64) are added also the errors due to the deviation of W_{τ} from W_1. They may be obtained from the geometrical relations resulting from Figure 41. Actually, the errors in the determination of the altitude H_2 are

[formulas page 87]

and

[formulas page 87].

Arguing analogically on the matter of the value of errors in the vertical angles, we may also here utilize the relation flowing from Figure 41, in accordance with which

[formula page 87].

Substituting in this formula in place of $\triangle L_2$ the above obtained expression and going over to $\triangle u$, we can state

[formula page 88] (65)

and

[formula page 88] (66)

For the determination of the error in direction (Figure 41) let us utilize the relation

[formula page 88].

Inasmuch as $C_2C_2' = \triangle L_2$ and l_1 and sin $O\mu$ may be substituted by l and $\triangle \mu$, we will obtain

[formula page 88] (67)

From formulas (63), (64), (66) and (67) it follows that, other conditions being equal the errors in the determination of the wind velocity and direction increase with the increase of errors in the determination of the vertical velocity of the pilot balloon.

An analysis of the tables compiled on the basis of formulas (66) and (67) shows that errors due to the incorrectness of the vertical movement of the pilot balloon have a great bearing in the determination of the wind velocity and a lesser in the determination of its direction.

In a particular case, when the pilot balloon ascends with a constant velocity different from the calculated, the wind velocities will be determined with either an increase or decrease proportionate to the increase or decrease of the true vertical velocity over the computed (64). The direction of the wind will be obtained correctly.

The above formulas determine in the main the errors in the wind velocity and direction resulting from the errors in the determination of azimuths, the vertical angles and altitudes of the pilot balloons.

Differentiating the resulting formulas with respect to the two component vectors of the wind and the direction of the wind, V. M. Mikhel obtained full formulas of errors in the determination of the wind by the method of pilot balloon observations from one point, taking into consideration all factors influencing the accuracy in the determination of the wind.

In addition to the members depending on the errors in the determination of the main coordinates, members connected with the indirect errors are included, such as for example those due to the relation of the obtained velocity and direction to an incorrectly determined altitude of the center of the layer, with errors due to the addition of a point over the point of observation of the wind, factually measured at a distance L from it. Besides, the full formulas take into account the errors resulting from the assumption that the projection of the balloon travels not along a curve but along a straight line; errors due to the centering of the wind in a layer that is too thick; errors due to the variability of the wind vector with time and others.

In addition to errors connected with the measurement of the coordinates of the pilot balloon and indirect errors, errors in the

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processing of the observations also reflect on the end results of the determination of the wind velocity and the direction.

28. Deviations of the True Vertical Velocity of the Pilot Balloon from the Calculated, and the Reasons Therefor

From the preceding it can be seen that one of the reasons for errors in the determination of the wind velocity and direction is the non-coincidence of the true vertical velocity of the pilot balloon with the estimated tabular velocity.

Experiments in the determination of the actual vertical velocity, both in closed locations and in the ascent of the pilot balloon in the atmosphere, have shown that for pilot balloons having one and the same values of casing weight and free lifting force, the vertical velocities are different, notwithstanding the fact that the conditions of the experiments excluded the presence of vertical movements of the wind.

One of the basic reasons for this deviation must be the fact that the coefficient c in the formula for the resistance of the air is not constant. In paragraph 3 we had already spoken about the fact that the coefficient c is determined by Reynold's number: $Re = \frac{\sigma DW}{\eta}$. In Figure 43, curves characterizing the dependence of c on the values of Re, as obtained by experiments in an aerodynamic tunnel, are shown.

The right curve represents the change of c with various values of Re in a quiet flow of air, the left dashed curve gives the dependence of c on Re during turbulent conditions. The curves show that c changes little up to a certain critical value of Re, after which in a certain range of values of Re c quickly decreases.

With a further increase of Re the value of c again becomes practically constant, even though less than prior to the critical value of Re.

A comparison of curves obtained for various conditions of the air shows that in turbulent air the values of c corresponding to the same values of Re appear smaller than in still air. In this, the range of values of Re, under which a sharp decrease of c occurs, is displaced in the direction of smaller values of Re.

An analogous character of changes in c depending on Re was obtained in experiments in the study of air resistance to the balloons in the free atmosphere.

The aerodynamic resistances of the air to a balloon studied have shown that there is a definite relation between the change in the resistance and the distribution of the pressure along the surface of the balloon in its rear area.

In the flow of the air about the balloon forces of a negative pressure directed in an opposite direction to the movement of the balloon, are formed as a result of the cessation of the flow from the surface of the balloon and the establishment of a vortex area. In turbulent flow the magnitude of this negative pressure appears to be less than in a smooth flow. This is explained by the fact that in a turbulent condition the points of cessation of flow are displaced toward the rear area of the balloon, which conditions the decrease of the negative pressure.

Inasmuch as the full aerodynamic resistance experienced by the balloon is composed of frontal and rear pressures and the magnitude of the first of these does not depend on the condition of the air, the full resistance in turbulent air is less than in still air.

Under conditions of a free atmosphere, turbulent formations of magnitudes which are commensurate with the thickness of the limiting layer of the balloon will have an effect on the magnitude of resistance.

From the above-stated it follows that the differences in the values of the vertical velocity obtained for balloons of the same dimensions and the same lifting force may be explained by the influence of a varying degree of turbulence of the air upon which the value of coefficient c depends.

Experimental research on the distribution of pressure forces upon the balloon conducted by S. I. Troitskiy and S. I. Molchanov serves as a good confirmation of the change of resistance as a function of the character of the air flow. In the mentioned experiments a wooden sphere was placed before the inflow of an aerodynamic tunnel. The sphere contained an opening into which a micro-gauge was placed, by means of which the pressure was measured. The sphere could be turned around the vertical axis in such a manner that it was possible to study the changes in pressure along the equator of the sphere. The experiments were conducted at one and the same velocity both in even and turbulent air flow.

The results of the measurements have shown that the entire resistance experienced by the sphere in a turbulent flow was less than in an even one, due to the decrease in the rear resistance in turbulent air.

The indicated experiments are applicable to the movement of the balloon in the free atmosphere, though the character of dependence of the coefficient of resistance on the degree of turbulence have not yet been fully studied.

If we were to take into account the influence of turbulence upon the change of the magnitude of c, then from Figure 43 we may also draw conclusions on the conduct of the pilot balloon in dependence on Re. As we can see, the difference in the values of c for turbulent and still air at a value of Re $> 3 \cdot 10^5$ is considerably less than in the range of values for Re from $2 \cdot 10^5$ to $3 \cdot 10^5$. In the case where the balloon is released when the value of Re is in the vicinity of the latter values, the coefficient c will sharply change with the passage of the balloon into quieter layer, even with an unchanged Re, which will result in a corresponding change in the vertical velocity. Conversely, if Re lies beyond the limits of $3 \cdot 10^5$, the change in the condition of the air affects the value of c very little. Therefore the vertical velocities of large balloons used for the ascent of radiosondes, to which large values of Re apply, are practically constant.

[diagram page 89]

Figure 43. The dependence of the value of the coefficient of resistance c on the Reynolds number.

The first attempts at an explanation of the deviation of the actual vertical velocity from the tabular velocity were based on the hypothesis of rising currents. However, these ideas did not receive support when they were scrutinized from the point of view of the deviation from the mean vertical velocity separately for the warm and cold seasons. In the lowest layers these deviations in the cold season appeared even larger than in the warm, even though for the development of the vertical movements the conditions of the warm season are more conducive.

Interesting results in the changes of the vertical velocity were obtained at the Pavlovsk aerological observatory in the release of loaded balloons from kites at an altitude of 400 to 600 meters. It appeared that even in the case of falling balloons, the deviation of the true vertical velocity from the calculated velocity had a positive sign, which clearly contradicted the hypothesis of rising currents.

As for the experiments in aerodynamic tunnels and the experiments in the study of the vertical velocity in conditions of the free atmosphere, both have shown that turbulence is the main source of deviation of the true vertical velocity from the calculated.

The distribution of the true vertical velocity of the pilot balloons at various altitudes may be obtained from the data of base line pilot balloon observations. In base line observations the altitude of the pilot balloon is computed trigonometrically independently of any assumptions on the magnitude of the vertical velocity.

In figure 44 the results of such an experiment, conducted at the Pavlovsk observatory, are represented. Along the axis of the abscissa, the deviations of the true vertical velocity from the tabular values are plotted in percentages, while along the axis of ordinates the altitude in kilometers is shown. The thin curve gives the theoretical path of the vertical velocity as a function of the changes in the density of the air according to formula (22). The thick curve shows the mean value of deviation of the vertical velocity from its calculated values for all cases of observation of the balloon above 8 kilometers.

A comparison of the curves shows that in the lower layer up to an altitude of 2 kilometers the greatest deviation of the true vertical velocity from the calculated velocity is observed, and the magnitude of the deviation increases proportionately to its closeness to the surface of the earth. An explanation for this phenomenon must be sought in the increased turbulence of the air in the lower layers.

[diagram page 91]

Figure 44. Deviations of the true vertical velocity from the tabular velocity.

In the interval of altitudes from 2 to 12 kilometers, the path of the true vertical velocity differs little from the path of the calculated velocity.

The results obtained for the lower layer found support in the experiments for the region of Borispole (near Kiev).

A detailed analysis of the results of the observations at Pavlovsk and Borispole shows an increase of deviation during daylight hours in comparison with morning, as well as an increase in deviation with an increase of wind velocity. It is evident that these results confirm the assumption that the turbulence is the basic cause for the deviation of the true vertical velocity from the calculated velocity. In particular cases these deviations may reach quite large proportions.

Let us suppose that we are determining the mean wind velocity for the lower layer, using the calculated vertical velocity W. Then we can state that

[formula page 92]

and

[formula page 92].

where u is the wind velocity.

Inasmuch as the true vertical velocity as a result of turbulence is greater than the calculated, the determination of the wind velocity according to a lesser vertical velocity will give a lesser value to the wind velocity. The error obtained in this is partly erased in the case of an increase in wind velocity with altitude, because a lessening in wind velocity refers to a decreased altitude. But in the case of a decrease in wind velocity with altitude, the error in its determination increases sharply.

In addition to turbulence, other factors influence the vertical velocity.

A considerable effect may be provided by vertical air movements. Vertical currents of convectional origin under equal conditions are developed mainly in the lower layers up to 1 to 2 kilometers, and depending on their direction they may show an effect on the vertical velocity both in the sense of its increase and in its decrease. This influence is especially noticeable with the existence of Cb and Cu cong. clouds.

In mountainous regions, due to the conditions of the flow of air around impediments, both forced ascents and drops of air also bring about a considerable deviation of the vertical velocity from the tabular velocity. In some places this influence of local conditions is so great that making pilot balloon observations from one point must be replaced by base line observations.

The presence of vortices in the atmosphere on a scale commensurate with the dimensions of the pilot balloon bring about the deviation of the balloon through turbulent formations upward or downward depending on the displacement of the vortex. With the formation of a vortex of great dimensions, the vertical velocity may experience great deviations depending on whether the balloon happens into the ascending or descending branches of the vortex.

Among the less important causes for errors in the vertical displacement of the balloon we shall point out:

(1) the difference in the temperature of the hydrogen in the balloon and the surrounding air;

(2) the deviation of the balloon from the spherical form;

(3) differences in the texture of the surface of the casings;

(4) the appearance of flaws in the casing;

(5) rotation and somersaulting of the balloon.

The rotation and somersaulting of the balloon, in general, increases the resistance of its movement. A weight on its appendix brings about an increase in the stability of the balloon and an increase in its vertical velocity under the same free lifting force.

A comparison of the vertical velocities obtained according to base line observations with calculated velocities furnishes the possibility of compiling correction tables to the calculated vertical velocities for the lower layer of the atmosphere, for example, up to an altitude of 1 kilometer above the surface of the earth. However, their application is limited to comparable geographic conditions, character of the relief and wind pattern in those regions where the given correction table is to be used.

In this, the use of the tables must take into consideration those peculiarities in the deviations which are tied in with the season, time of day and dimensions of the balloon.

In any case, due to considerable deviations, in magnitude and sign, in the vertical velocities of separate pilot balloons, it is more sensible to use the tables for mean values of altitudes obtained from a great number of observations. For example, with the aid of the tables giving mean deviations it is possible to correct the data for the average altitude of the clouds of the lower stratum.

A detailed comparative study of determinations of the wind velocity and direction according to one point and base line observations has shown that the errors in the method of observations from one point are in practice not great when applied under conditions of a level locality with a moderate wind. In regions having a complex relief, however, this method gives doubtful results and must be replaced by the more accurate base line method.

29. Method of Determining the Altitude of a Pilot Balloon According to its Angular Dimensions

As we have seen, the greatest errors in the determination of the wind direction and the velocity are the result of errors in the determination of the altitude of the pilot balloon, which are due to the assumption of the constancy of the vertical velocity. The greatest deviations of the true vertical velocity from the calculated velocity are observed in the lower layers of the atmosphere. It is therefore considered reasonable to apply a method improving the accuracy of the determination of altitude of the pilot balloon in observations from one point, even though its application is limited to the lower layers of the atmosphere.

The principle of such a method is that the angular size of the diameter of the balloon, or a string with two marks suspended from it, called a base, is measured. For this a micrometer scale is placed in the eyepiece of the telescope of the theodolite, which allows the measurements of angles with great accuracy (up to 1 minute). With the aid of the angles measured in this manner as well as the known sizes of the diameter or the suspended base and the values of the vertical angles, it is possible to obtain the altitude of the balloon which is used in the determination of the vertical velocity.

M. M. Pomortsev used a similar method for the determination of the altitude of a free aerostat while checking a barometric formula. He measured the angular size of the diameter of the aerostat or the guide rope suspended from the aerostat, and then compared the values of the altitudes obtained by the barometric formula with those obtained by computing the values from the measurement data.

Let us study the method of determining the altitudes of the pilot balloon by the measurement of angular sizes of the diameter of the balloon as suggested by V. M. Mikhel.

Let O (Figure 45) be the point of observation, P -- the pilot balloon, D = ab -- its diameter, ε -- the angular size of the balloon, δ -- the vertical angle, H -- the height of the balloon above the surface of the ground and r -- the inclined distance of the balloon.

From triangle Oab we have $r = \frac{D}{\varepsilon}$.

For the determination of height H let us use triangle OPC. It is evident that

[formula page 94]

or, in view of the smallness of $\frac{\varepsilon}{2}$ in comparison with δ,

[formula page 94].

Substituting the above obtained expression for r, we will obtain

[formula page 94] (68)

[formula page 94] (69)

where C is the length of the circumference of the balloon at altitude H.

Because the diameter or the circumference at altitude H enter into formula (68) and (69) it follows that changes in these values in relation to those measured on the ground with the aid of the previously stated relation should be taken into account:

[formula page 94].

In any case the dimensions of the diameter of the balloon, as calculations show, vary but little if we keep in mind the determination of altitudes near 500 meters. For pilot balloons of type No 20 filled normally this change will be about 2 to 3 percent.

[formula page 94]

Figure 45. The determination of the altitude of a pilot balloon using its angular dimensions.