lated from the case and from each other. The outer half of the junction box, carrying plugs, is connected by lead-covered cables to the recording apparatus and current supply, and the joint between the two halves sealed with a soft rubber gasket.

The vertical shaft carrying the rotor is provided at the top with an annular ball bearing of the self-alining type, and at the bottom with a deep grove annular ball bearing which also carries the thrust load. A light oil developed by the General Electric Co. for use in watt-hour meters was selected for lubrication. This oil is used because it remains fluid at very low temperatures, as determined by tests by several persons, including the writer, who for a period of several years, worked in cooperation with Mr. B. W. St. Clair of the Lynn works of the General Electric Co., and to whom he is indebted for the oil.

Figure 8 is a schematic diagram, showing the reduction gearing for operating the electrical contacts for recording purposes. A single pitch worm mounted on the lower end of the main vertical shaft engages a 100-tooth worm wheel. Six pins projecting from the face of this wheel operate an electrical contact which gives a signal for each one-thirtieth mile. The shaft on which this 100-tooth wheel is mounted also carries a single-pitch worm which engages a 50-tooth worm wheel on which are mounted 10 pins which give a contact for each mile, 1 mile being recorded for each 500 turns of the rotor. The space between 2 of these 10 pins is made solid to make a long contact for identifying every tenth mile on the record.

Because freezing of the oil film and moisture on the electrical contacts was a source of trouble in the early experiments, a vacuum contact switch, supplied by the Burgess Laboratories, Inc., was selected for the 1-mile recording contact. Since the adoption of this device no trouble whatever has been experienced in their operation under the extreme conditions of temperature encountered.

Uncertainty which the writer felt over a set of anemometer readings made by him during the eclipse of 1932, led to the adoption of a Veeder counter for a visual recorder.

In the early consideration of design it seemed advisable to sacrifice, to some extent, the accuracy at low-wind velocities in order to obtain certainty of operation under the extreme conditions likely to be encountered on Mount Washington. A very recent critical examination of the anemometer, after 14 months of operation, showed no appreciable deterioration.

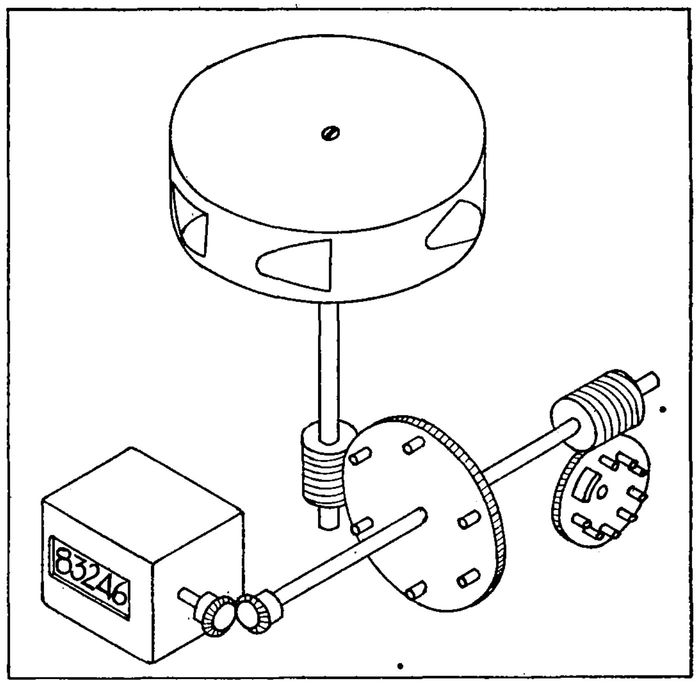

FIGURE 8.—Schematic view of gear system and Veeder counter. In order to indicate tenth of miles the angular motion is stepped down 2 to 1 inside the counter.

The writer takes this opportunity to acknowledge the kind cooperation of the staff of the Mount Washington Observatory in designing the anemometer, and to thank them for their careful handling of it. He wishes also to thank Mr. H. S. Shaw for maintaining a nightly radiotelephone schedule between Mount Washington and his home, and for his help in many other ways in this project.

PART III

THE CALIBRATION OF THE MOUNT WASHINGTON, N.H., HEATED ANEMOMETER AND THE ANALYSIS OF ITS RECORD OF APRIL 11-12, 1934

By CHARLES F. MARVIN

[Weather Bureau, Washington, July 1934]

When Mr. Mann's perfected anemometer (p. 189) was finished and ready for station use it was first sent to the Bureau of Standards to be tested. Two series of tests of its performance were made during November 1933. One run under a turbulence of about 0.5 percent, comprising a range of velocities from 11.6 miles per hour, just above the starting speed of the rotor, to 143.4 miles per hour, was made in the small 36-inch wind tunnel; the other, under about the same small turbulence, was made in the 54-inch wind tunnel. In view of the relatively small size and compact form of the rotor little or no blocking or other effect depending on the size of the tunnel could be expected, and the agreement between these tests was very close and highly satisfactory.

The calibration-curve representing these tests in the form shown in figure 9–A, as furnished by the United States Bureau of Standards, has been used by the Mount Washington Observatory for the reduction of all the station records.

After the great April 1934 storm and the reading of Mr. Pagliuca's paper on it at the April 1934 meeting of the American Meteorological Society, comments at the Weather Bureau and elsewhere on the accuracy of the reduction of the record led Dr. C. F. Brooks, Director of the Blue Hill Observatory, to send Mr. Pagliuca to Washington in June with the instrument for new tests. The primary object of these tests was to ascertain: (1) Any change since the previous tests in the ordinary performance of the instrument; (2) effects of inclining the axis forward or backward from the vertical; and (3) whether the run of the rotor was much or little affected by turbulence in the test wind stream.

The results of these tests may be stated briefly, in order, as follows:

(1) *Ordinary performance.*—Although neither change by use and exposure nor any alterations or injury that could affect the run of the rotor has been known to occur since the first test, nevertheless the second tests in both

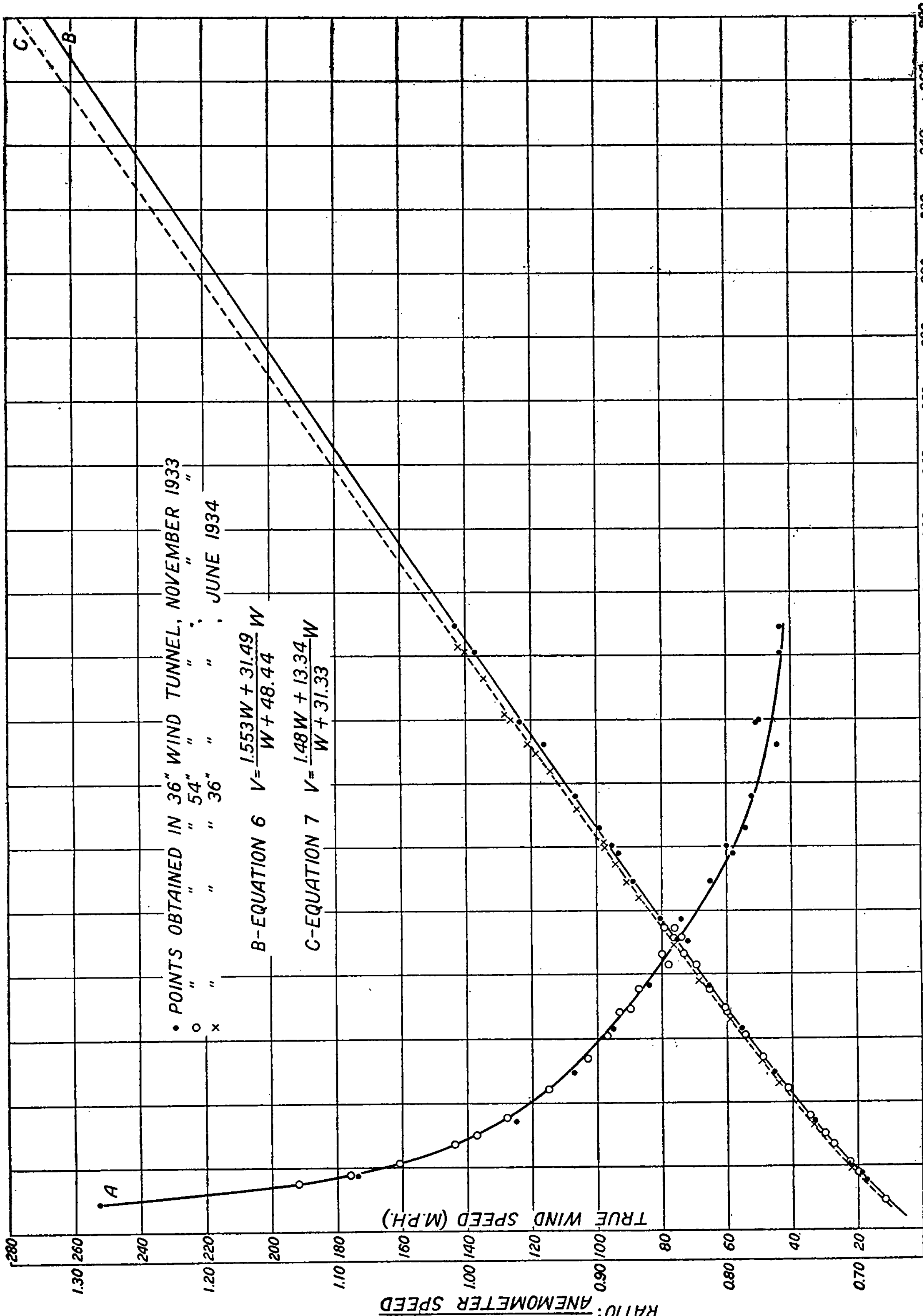

FIGURE 9.—Calibration curves for heated anemometer no. 2. A, Ration curve W/V and original observations dated November 1933 as furnished by Bureau of Standards. B, Hyperbola and same observations as in ratio curve A, Marvin's equation 6. C, Hyperbola by equation 7 of text with observation derived from June test data in 36-inch wind tunnel at the Bureau of Standards.

tunnels indicate that the rotor now seems to run more slowly at all wind speeds and show an as yet unexplained small difference (in general, under 3 percent) between the results of the two tests in the 3-foot (high-speed) wind tunnel. This means that if the past records are corrected on the basis of the new tests the true wind velocities, computed for the record would be somewhat higher than heretofore claimed.

Inasmuch as the original tests in both tunnels agree with entire satisfaction, and further, since we are necessarily dependent upon the tests in the small tunnel for the high velocities, and since, fortunately, the difference between the first and second tests in the small tunnel range under 3 percent, especially at velocities over 40 to 50 miles per hour, true wind speed, it is believed to be both conservative and best to continue to reduce future observations by the original calibration data until further opportunity arises for investigating the cause of the small discrepancies affecting the new tests.

Concerning these discrepancies, it may be remarked that the weight and moment of inertia of this particular rotor are relatively quite high. Moreover, the wind-driving torque is much smaller than for the ordinary 4-inch or 5-inch cup anemometers. These characteristics combine to make this rotor more sensitive to disturbing influences than the conventional cup wheels, notwithstanding that friction has been eliminated quite as fully as possible by high-grade efficient ball bearings. Therefore, the small change in performance may be due to some unnoticed change in the form or condition of the external surfaces of the rotor.

(2) *Effects related to inclination of axis.*—The tests to show the effects of tilting the axis of the rotor forward and backward in the wind stream were all made in the 54-inch tunnel, as were also the several tests with the axis vertical. These tests, of course, are strictly comparable and show that:

(*a*) Tilting the axis forward so that the wind stream impinges downward upon the rotor from above has very little effect as compared with the effects which were found with the wind stream flowing upward against the under side of the rotor. This is an aerodynamic effect and must be independent of possible friction, because the ball-bearing system is correctly designed to permit the rotor to turn with little friction in either case.

(*b*) Tilting the axis forward progressively decreases the run of the rotor until an inclination of about 7° is reached, when the effect apparently is a maximum, after which the relative run increases.

(*c*) At the maximum of effect and for a true wind speed of about 74 miles per hour, the ratio, true divided by indicated wind, was found to be 13 percent greater than when the axis is vertical.

(*d*) Tilting the axis backward speeded up the run of the rotor by an amount which, at true wind speed of about 75 miles per hour, appears to be quite proportional to the angle of tilt.

(*e*) For a tilt of 11⅓° the ratio, true divided by indicated wind, was about 70 percent of its value with the axis vertical.

(*f*) The critical examination of rime formations near the place of exposure of the anemometer at Mount Washington indicates that the air stream driving the rotor is so nearly perpendicular to its axis that no correction for inclination should be applied to the records.

(3) *Effects due to turbulence.*—Tests made in the 54-inch wind tunnel showed that when the turbulence was 2.7 percent the speed of the rotor was only about 1½ percent greater than when the turbulence was 0.7 percent. Therefore since the effect of turbulence is so small, and since so little is yet known as to the amount and nature of the so-called "fine-grained turbulence" in the free air, no attempt should be made to take any further account of it.

COMPUTATION AND EXTRAPOLATION OF TEST DATA

In view of the foregoing it seems quite unnecessary to analyze or discuss more minutely in this paper the results of the new tests except to show how the normal performance data may be analytically treated to provide a sound basis for the evaluation, in terms of true wind speeds, of very high indicated velocities. Experience shows that natural winds blow at speeds quite above the highest artificial values attained in any wind tunnel that has been suitable or available for anemometer testing. Until higher speed tunnels are available, extrapolation of test data is a necessity, and no argument is required to prove the superiority of extrapolation by means of an equation which accurately fits the test data over a wide speed range as compared with extrapolation by the extension of hand-drawn curves.

When the great difference in the form and open arrangement of arms and cups of the ordinary 3- or 4-cup wheels are contrasted with the compact rotor of the heated anemometer, equally great differences might be expected in the law of performance of the two types of rotor. The writer, however, has been much pleased and surprised to find that the hyperbolic equation which he has found represents so well the performance of a great variety of ordinary cup-wheel-forms over a wide range of speeds, also represents in a highly satisfactory way the run of the heated rotor.

In compliance with requests of Mr. Pagliuca to do so for the benefit of the observatory staff, the derivation of the parameters of the hyperbolic equation from the original test data on the no. 2 anemometer is presented with sufficient fullness below.

For reasons given more fully in the article in the MONTHLY WEATHER REVIEW April 1934, page 116, the 34 original test values have been combined into 10 group means of true wind, W, and indicated wind, V, on the basis of 500 rotor turns per indicated mile. Values of N, free from small arithmetical inaccuraces, were then computed by the equation $N=500\ \Sigma V \div \Sigma W$ in which ΣV and ΣW are the sums from which the group means are computed. Table 1 gives the 10 group mean values of W and N. These constitute the 10 observation equations by means of which the unknown parameters, a, b, and f of the full hyperbolic equation, $f+Wb+Na+NW=0$ are to be evaluated.

TABLE 1.—*Group mean observations and derived data from original tests made in November 1933, by the Bureau of Standards on Mount Washington heated anemometer no. 2*

	Observations		Derived data				
	W	N	NW	W^2	N^2	NW^2	N^2W
	14.3	421	6,020.3	204.49	177,241	86,090.29	2,534,546.3
	20.2	466	9,574.8	408.04	224,676	193,410.96	4,538,455.2
	31.2	509	15,880.8	973.44	259,081	495,480.96	8,083,327.2
	45.4	544	----------	----------	----------	----------	----------
	57.9	566	----------	----------	----------	----------	----------
	68.4	586	----------	----------	----------	----------	----------
	78.0	598	----------	----------	----------	----------	----------
	94.4	627	----------	----------	----------	----------	----------
	117.3	647	----------	----------	----------	----------	----------
	140.2	660	----------	----------	----------	----------	----------
Sums	667.3	5,624	403,123.6	60,088.79	3,218,108	37,632,990.90	245,655,263.2

It is scarcely necessary to remark that every digit in table 1 must be scrupulously exact, and that all digits must be retained in computing the derived data. Unnecessary digits should be dropped at the end of, not during, the analysis.

First compute the values of NW for which a modern calculating machine is best. The values of W^2 and N^2 are next entered from tables of squares, or otherwise. Then form values of NW^2 and $N^2 W$ by multiplying W^2 by N and then N^2 by W. When the values are all entered they should be rigorously checked, thus: multiply NW first by W, then by N. These operations completely check every value of the derived data. All that then remains to be done is to form the sums of each of the columns. By the least-square methods these sums furnish the coefficients for the three so-called "normal" equations whose solution gives the desired values of the three parameters.

The normal equations are:

$$\begin{array}{lllll} \text{For} & f, & 10f & +Wb \quad +Na & +NW=0 \\ \text{For} & b, & Wf & +W^2b \quad +NWa & +NW^2=0 \\ \text{For} & a, & Nf & +NWb+N^2a & +N^2W=0 \end{array}$$

Supplying the numerical coefficients from the sums in table 1 these become,

$$\begin{array}{l} 10.0f+667.30b \quad +5{,}624.0a \quad +403{,}123.6 \quad =0 \\ 667.3f+60{,}088.79b \quad +403{,}123.6a \quad +37{,}632{,}990.9 \quad =0 \\ 5{,}624.0f+403{,}123.60b+3{,}218{,}108.0a+245{,}655{,}263.2=0 \end{array}$$

Dividing each of these equations by the coefficient of f therein gives:

$$f+66.7300b \quad +562.400a \quad +40{,}312.4=0 \qquad (1)$$
$$f+90.0476b \quad +604.111a \quad +56{,}395.9=0 \qquad (2)$$
$$f+71.6792b \quad +572.210a \quad +43{,}679.8=0 \qquad (3)$$

Subtracting (1) from (2) and (3) gives

$$23.3176b+41.711a \quad +16{,}083.5=0$$
$$4.9492b+9.810a \quad +3{,}367.4 \quad =0$$

Dividing by the coefficients of b gives

$$b+1.78882a \quad +689.757=0 \qquad (4)$$
$$b+1.98214a \quad +680.393=0 \qquad (5)$$
$$.19332a \quad - \quad 9.364=0$$
$$a=+48.4378$$

Substituting a in equations 4 and 5 gives the folowing two values of b: $=-776.403$ and -776.403. The agreement is perfect. Substituting a and b in equations 1, 2, and 3 gives three values of $f=-15{,}744.4$, $-15{,}744.5$ and $-15{,}744.5$. The nearly perfect agreement here also indicates that there was no arithmetical error in the calculations, and the final equation solved for N becomes

$$N=\frac{776.4W+15{,}744}{W+48.44}$$

The relation $NW=500V$ gives

$$V=\frac{1.553W+31.49}{W+48.44}W \qquad (6)$$

Equation 6[1] is believed to be the most refined evaluation of the original test data from the runs made in the two wind tunnels in November of 1933. This equation, or a table of values of true and indicated speed based thereon, is recommended by the writer for use in correcting all Mount Washington wind records derived by use of the heated anemometer no. 2. The corresponding equation derived from the recent June tests in the 36-inch tunnel is

$$V=\frac{1.48W+13.34}{W+31.33}W \qquad (7)$$

It is important to show how very small are the residuals between the observed and calculated values by these two equations. They are given in table 2.

TABLE 2.—*The observed and calculated values of V for the two sets of group mean observations representing tests at the Bureau of Standards on the Mount Washington heated anemometer no. 2.*

Tests in November 1933, in both tunnels. Equation 6				Tests in June 1934, in 36-inch tunnel only. Equation 7			
W	V_o	V_c	V_o-V_c	W	V_o	V_c	V_c-V_o
14.3	12.09	12.23	+.14	22.3	19.20	19.27	+0.07
20.2	18.86	18.50	−.36	38.9	39.60	39.27	−.33
31.2	31.76	31.32	−.44	54.2	59.42	59.28	−.14
45.4	49.32	49.34	+.02	72.4	83.76	84.09	+.33
57.9	65.49	66.10	+.61	88.9	106.46	107.14	+.68
68.4	80.19	80.61	+.42	96.5	118.53	117.88	+.65
78.0	93.43	94.14	+.71	110.4	137.77	137.65	−.12
94.4	118.29	117.69	−.60	119.9	150.97	151.25	+.28
117.3	151.71	151.19	−.52	127.1	160.98	161.60	+.62
140.2	185.00	185.20	+.20	134.6	172.80	172.40	−.40
				141.2	182.06	181.93	−.13

The curve figure 9–B, plotted from accurately calculated values of equation 6 furnishes an excellent graphic extension of test data by which extrapolated corrections of extreme wind records may safely be made.

ANALYSIS OF WIND VELOCITY RECORD

Figure 2 is a photographic reproduction of the velocity portion of the original automatic wind velocity record from 12:10 p.m., April 11, to 3:05 p.m. April 12, 1934. This picture is presented in two parts in order to preserve the full scale (15 inches between marginal lines).

To make the record of single miles readily legible when the velocity is high, the miles of wind movement are recorded by the so-called zig-zag mechanism of the Weather Bureau multiple register. Each step in the zig-zag path which in the ordinary usage represents a rainfall of one-hundredth of an inch, or that the sun was shining at the time, now represents one mile of indicated wind movement, 500 cup turns. From crest to crest, or hollow to hollow of the trace, there are always exactly 10 steps. However, owing to the use of a so-called "bridge" pin (see fig. 7) for the purpose of automatically recording miles in groups of ten, the actual wind movement from crest to crest, or hollow to hollow, of the record, is always 11, not 10, miles. The passage of the bridge pin is clearly apparent in records of light and moderate winds, but can be discerned only with difficulty at some places in the present record.

Mr. Pagliuca has already stated on page 187 the general features of this splendid record of such a remarkable wind. The chief object of the present analysis is to critically evaluate the maximum wind travel in 5 minutes which occurred shortly after noon of April 12 in the place indicated by the letter M. Emphasis is placed on the maximum travel in 5 minutes, because it is standard practice at regular Weather Bureau stations to record this datum as a sort of gust velocity, although greater

[1] Equations 6 and 7 when solved for W require a complicated radical expression which cannot be computed accurately except with great difficulty. Values of V for exact integral values of W are accurately and rapidly computed to several decimal places if necessary from equations like 6, from which tables of true and indicated velocities may be computed by transposition and interpolation.

gusts of shorter duration are also recognized. The accurate timing of single miles in such a record as that shown is, of course impossible, and the irregularity in the record caused by the registration of the passage of the "bridge" pin further limits refined measurements of the record simply to timing as accurately as possible the crests and hollows during the period of extreme velocities. In order to employ a method which would single out the greatest wind travel in a 5-minute period and which at the same time would be free from any personal bias, the writer chose the following: A standard millimeter scale was clamped down on a clear photographic copy of the record. The zero was placed at the noon line, and the scale alined parallel to the slope of the record, then with the aid of a piece of celluloid engraved with a fine transverse reference line, the scale readings given in table 3 were made of several crests and hollows before and after the place of maximum travel.

TABLE 3.—*Millimeter scale readings on crests and hollows of a portion of zig-zag wind trace like fig. 2 from noon to 12:30 p.m. Apr. 12*

Crest $N°$	Scale reading:	Diff. single 11 miles	Sums 22 miles	Hollow $N°$	Scale	Diff. single 11 miles	Sums 22 miles
0	1.9			.5	3.6		
1	5.1	3.2		1.5	6.6	3.0	
2	8.3	3.2	6.4	2.5	9.5	2.9	5.9
3	11.1	2.8	6.0	3.5	12.7	3.2	6.1
4	14.1	3.0	5.8	4.5	16.0	3.3	6.5
5	17.3	3.2	6.2	5.5	19.2	3.2	6.5
6	20.4	3.1	6.3	6.5	22.0	2.8	6.0
7	23.0	2.6	5.7	7.5	24.5	2.5	5.3
8	25.7	2.7	5.3	8.5	27.2	2.7	5.2
9	28.8	3.1	5.8	9.5	30.1	2.9	5.6
10	31.9	3.1	6.2	10.5	33.1	3.0	5.9
11	34.5	2.6	5.7	11.5	36.0	2.9	5.9
12	37.5	3.0	5.6	12.5	39.1	3.1	6.0
13	40.7	3.2	6.2	13.5	42.0	2.9	6.0
14	43.5	2.8	6.0	14.5	45.0	3.0	5.9
15	46.9	3.4	6.2	15.5	48.0	3.0	6.0

1 hour=65.1 mm. 5m=5.4 mm.

It is clear from the table that at the time of the maximum there was a sustained high movement represented by at least four double 22-mile groups having a time space ranging from 5.2, 5.3 up to 5.7 mm. Since a space of 5.4 mm. represents a time interval of 5 minutes, the maximum travel in 5 minutes must have ranged between at least 20.9 and at most 22.8 indicated miles, that is, 251 or 274 indicated miles per hour. By the November tests of 1933 (equation 6) these indicated speeds correspond to true hourly speeds of 184 and 199 miles per hour. By the June 1934 tests in the 3-foot tunnel (equation 7) the corresponding hourly movements are slightly higher, that is, 187 and 204 miles.

In the case of the still higher gusts timed by stopwatch, permitting reading time to hundredths of seconds, it is stated the shortest elapsed time was 1.17 seconds for an indicated travel of one-tenth mile, that is, 308 miles hourly movement, which corresponds to a true wind of 221 miles per hour by the November 1933 calibration, and 225 miles by the June 1934 test.

Great confidence is justified in the verity of these results, especially the 5-minute travel, because of the perfect character of the automatic record, the sustained movement during the maximum, the excellent fit of the hyperbolic equation to the test observations, and finally, the sound character of the extrapolation of corrections to extreme wind speeds.

FURTHER CONCLUSIONS FROM ADDITIONAL OBSERVATIONS IN THE FREE AIR OVER SAN DIEGO, CALIF.

By DEAN BLAKE

[Weather Bureau, San Diego, Calif., 1934]

Because of their importance to aviation, their domination of climatic conditions in the regions affected, and the challenge they present, the fogs and overcast skies, and the concomitant temperature inversions that occur along the California coast during the summer, are the subject of considerable discussion and speculation. In spite of what has been written already, there remains a fruitful field open to research and investigation. Writers, too, are far from any sort of agreement as to their causes, and most of the conclusions that have been reached are based upon an insufficient amount of data.

This paper is in the nature of a supplementary discussion to others that have appeared, and is offered as an aid in the clearing up of some disputed points, by the presentation of additional data, made available through the courtesy of the aerological office at the Naval Air Station, San Diego, Calif. In it attempts are also made to couple various phases of the phenomena with the results of recent investigations, particularly with the findings from free air observations. With the accumulation of data, and the attainment of greater accuracy in aerological records, due largely to changes in technique, and an improvement in the aerographs in use, it has become possible to analyze many more statistics, and to draw much more accurate conclusions.

Several quite complete descriptions of the inversion and its attendant cloud stratum have been published, Byers, (1) and Anderson, (2) in particular, going into detail. All writers agree that it is a summer phenomenon limited to the littoral regions. It is characterized by the regular occurence of overcast skies during the greater part of the night and in the early morning; a decrease in temperature and an increase in relative humidity to the top of a relatively thin layer of air; and an increase in temperature and a rapid decrease in relative humidity for several hundred meters beyond, after which the normal lapse rate is approximated, and the humidity remains fairly constant but low.

The inland invasion of the vapor-laden stratum depends upon the elevation of the land contiguous to the ocean. Where a mountain range parallels the immediate coast without an opening, an effective barrier is offered, but where there are no elevations in its way, it penetrates well into the interior. Airways reports in San Diego County show that low clouds or fogs are prevalent in the early morning hours at least 40 miles inland, if there are no obstacles to prevent the sea breeze from carrying the moist air that far, but where mountains with an elevation of several thousand feet skirt the shore line, they are normally confined to the coastal areas.