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Evaluating Winds Aloft by a Simplified Field Technique

MELVIN K. HULL

ABSTRACT: A field technique for evaluating winds aloft is described. It can be used at remote places--even at the site of a wildfire. It has proved accurate as any known single theodolite technique, and is time-saving because the winds aloft are evaluated in miles per hour from direct readout. The tools required are much lower in cost, more portable, and more multi-purpose than any other known technique.

On-the-spot measurements of wind direction and speed are needed in operations to suppress wildland fires and to carry out prescribed burning. Evaluations of winds aloft also are useful in studying problems of air pollution and in predicting the effects of explosive blasts.

For less than $7 you can compile a field kit that can be used at remote places to evaluate winds aloft accurately after observations are taken. This price does not include the necessary observation tools, such as balloons, helium, theodolite, and timer. Requiring little hauling space, this field technique kit weighs less than 2 pounds; the conventional plotting board used in evaluating winds aloft weighs more than 30 pounds (fig. 1).

The field technique kit consists of four items:

- Set of horizontal distance tables with built-in conversions.
- Sheet of specially printed 11- by 17-inch plotting paper mounted on a clipboard.
- 12-inch triangular engineer drafting scale with 10, 20, 30, 40, 50, and 60 divisions to the inch.
- 12-inch folding parallel rule.

Field workers can be trained quickly how to use these simple tools. The plotting paper can serve as a permanent record of measurements.

A similar kit was developed by Dewitt Allen, of the University of California Lawrence Radiation Laboratory, Livermore. He uses it to evaluate wind speeds in knots, for problems in predicting the effects from blasts. His tools are the same, except for a "Paraline," which he prefers to the parallel rule, and for the horizontal distance tables.

Horizontal Distance Tables

I developed horizontal distance tables to obtain measurements in miles per hour. This particular unit is required in computing fire

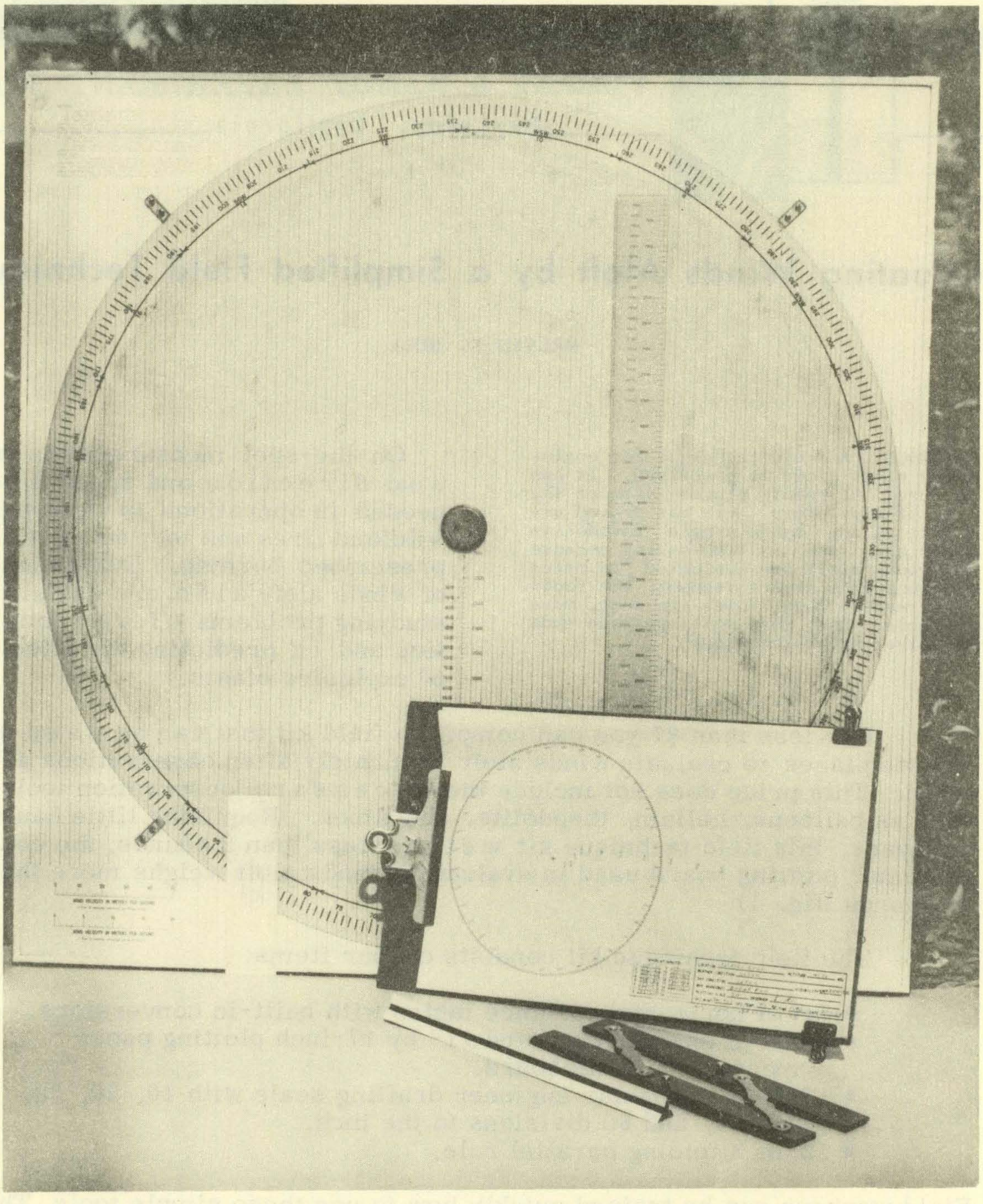
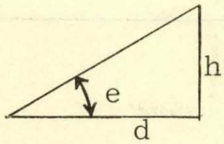


Figure 1.--Field technique kit (foreground) compared to plotting board. One other item in the kit--horizontal distance tables--is not shown.

danger indexes, and is preferred at the site of a wildfire because the fire suppression team is most familiar with this unit.

These tables are needed to obtain wind speeds from direct read-out on the drafting scale. For any single theodolite evaluation, compute the horizontal distance (d) by dividing the height of the balloon (h) by the tangent of the observed elevation angle (e).



$$d = \frac{h}{\tan e} \qquad (1)$$

The balloon height is a function of the balloon ascent rate, which is considered essentially constant above the turbulent layer. But to correct for low-level turbulence, increase the ascent rate during the first 4 to 5 minutes--depending on the balloon size. If the ascent rate is measured in feet, height (h) and horizontal distance (d) also are in feet.

Horizontal distance tables can be developed with conversions to obtain miles per hour from direct read-out on the drafting scale. The horizontal distance with conversions (d*) is computed as follows:

$$d^* = \frac{d \times 60}{5,280} \qquad (2)$$

in which (d) is the horizontal distance in feet and when divided by 5, 280 expresses horizontal distance in miles. The 60 then converts the distance between 1-minute measurements to miles per hour.

A typical horizontal distance table with built-in conversions is shown in figure 2. Data are for a 30-gram balloon rising at the standard rate and observed at half-minute intervals for the first 7 minutes. For example, with an observed elevation angle of 51. 1 degrees for the 5th minute the horizontal distance is 29. 7. The same answer can be obtained using formulas (1) and (2) in which h = 3,248 feet and e is 51. 1 degrees.

Plotting Balloon Position Points

Balloon position points represent the horizontal position of the balloon in flight. Plot these points on the specially printed plotting paper by measuring with the drafting scale. The plotting paper has a compass circle, with a center mark, printed on the left side. Use the compass circle to plot the observed azimuth angle of the balloon position and later to obtain wind direction. Its center mark represents the observation point. For each time interval, plot balloon position points by measuring horizontal distance from the center mark and in a direction on the compass circle representing the observed azimuth angle.

Number the compass circle in degrees in such a way as to insure that all balloon position points can be plotted within the longest dimensions of the paper. Scanning all azimuth angles will indicate how this can be done.

Next, select an appropriate decade scale (10 to 60) on the drafting scale, one that will insure plotting all balloon points on the paper with large enough single unit spacing for maximum accuracy. The decade scale selected must be used throughout the entire process.

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TIME-SINCE-RELEASE =	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	MIN.
BALLOON ALTITUDE =	354	709	1033	1358	1683	2008	2340	2627	2943	3248	3544	3840	4136	4432	FEET
ELEV.ANGLE															
50.0	33	67	98	129	160	191	223	250	280	309	337	366	394	422	
50.1	33	67	98	129	159	190	222	249	279	308	336	364	392	421	
50.2	33	67	97	128	159	190	221	248	278	307	335	363	391	419	
50.3	33	66	97	128	158	189	220	247	277	306	334	362	390	418	
50.4	33	66	97	127	158	188	219	246	276	305	333	360	388	416	
50.5	33	66	96	127	157	188	219	246	275	304	331	359	387	415	
50.6	33	66	96	126	157	187	218	245	274	303	330	358	386	413	
50.7	32	65	96	126	156	186	217	244	273	302	329	357	384	412	
50.8	32	65	95	125	155	186	216	243	272	301	328	355	383	410	
50.9	32	65	95	125	155	185	216	242	271	299	327	354	381	409	
51.0	32	65	95	124	154	184	215	241	270	298	326	353	380	407	
51.1	32	65	94	124	154	184	214	240	269	297	324	352	379	406	
51.2	32	64	94	124	153	183	213	240	268	296	323	350	377	404	
51.3	32	64	94	123	153	182	213	239	267	295	322	349	376	403	
51.4	32	64	93	123	152	182	212	238	266	294	321	348	375	402	
51.5	31	64	93	122	152	181	211	237	266	293	320	347	373	400	
51.6	31	63	93	122	151	180	210	236	265	292	319	345	372	399	
51.7	31	63	92	121	151	180	210	235	264	291	318	344	371	397	
51.8	31	63	92	121	150	179	209	234	263	290	316	343	369	396	
51.9	31	63	92	121	149	178	208	234	262	289	315	342	368	394	
52.0	31	62	91	120	149	178	207	233	261	288	314	340	367	393	
52.1	31	62	91	120	148	177	207	232	260	287	313	339	365	392	
52.2	31	62	91	119	148	176	206	231	259	286	312	338	364	390	
52.3	31	62	90	119	147	176	205	230	258	285	311	337	363	389	
52.4	30	62	90	118	147	175	204	229	257	284	310	336	361	387	
52.5	30	61	90	118	146	175	204	229	256	283	309	334	360	386	
52.6	30	61	89	117	146	174	203	228	255	282	307	333	359	385	
52.7	30	61	89	117	145	173	202	227	254	281	306	332	358	383	
52.8	30	61	89	117	145	173	201	226	253	280	305	331	356	382	
52.9	30	60	88	116	144	172	201	225	252	279	304	330	355	380	
53.0	30	60	88	116	144	171	200	224	252	278	303	328	354	379	
53.1	30	60	88	115	143	171	199	224	251	277	302	327	352	378	
53.2	30	60	87	115	143	170	198	223	250	276	301	326	351	376	
53.3	29	60	87	115	142	170	198	222	249	275	300	325	350	375	
53.4	29	59	87	114	142	169	197	221	248	274	299	324	349	374	
53.5	29	59	86	114	141	168	196	220	247	273	298	322	347	372	
53.6	29	59	86	113	141	168	196	220	246	272	296	321	346	371	
53.7	29	59	86	113	140	167	195	219	245	271	295	320	345	369	
53.8	29	58	85	112	139	167	194	218	244	270	294	319	343	368	
53.9	29	58	85	112	139	166	193	217	243	269	293	318	342	367	

Figure 2.--Sample of horizontal distance tables. Decimal points are omitted in such tables. Elevation angles are in degrees and tenths.

Finally, measure horizontal distance with the scale, and then plot and label each balloon point (figs. 3, 4). An example is the record of a pilot balloon run made at the Coyote Fire, at Santa Barbara, Calif., on September 28, 1964 (fig. 3). Observation time interval was 1 minute. The azimuth angles indicated that about 70 degrees should be numbered on the compass circle to the right of the center mark. The last observation (15 minutes) showed horizontal distance of 217.4. The 20-decade scale is most appropriate since its maximum range can represent 240 units. For the 5th minute, the observed elevation angle of 51.1 degrees yielded a horizontal distance of 29.7 from the tables shown in figure 2. The observed azimuth angle was 57 degrees.

Figure 4 shows how the 5th minute balloon position point is plotted from the center mark with the scale in an azimuth direction of 57 degrees on the compass circle. Each division on the scale equals a unit of horizontal distance. Figure 4 illustrates measurement of the distance 29.7. The 5th minute is then marked and labeled. All balloon points through 15 minutes in figure 3 were similarly marked and labeled.

Evaluating the Winds

To evaluate the average wind speed for a particular balloon point, measure from the preceding balloon point to the subsequent balloon point. The same decade scale is used as that used for measuring balloon position points. If the balloon position points are plotted for half-minute time intervals, the wind speed measurement is direct read-out in miles per hour. If 1-minute time intervals are used, divide the measurement by 2 because the measurement is for a 2-minute period.

Figure 5 is an example of measuring from the 6th minute to the 8th minute to obtain the average wind speed for the 7th minute. The scale reads 34.8 units. The measurement is for a 2-minute time interval and therefore must be divided by 2. The average wind speed then is 17.4 miles per hour for the 7th minute at a height of 4,432 feet above the release point or 9,124 feet above mean sea level (see fig. 3).

Obtain the wind direction in a similar manner with the parallel rule. Align the rule from the preceding balloon point to the subsequent balloon point and then bring it through the center mark, with care to prevent slippage. Read wind direction from the compass circle in the direction from which the balloon moved.

An example of getting the wind direction for the 7th minute is shown in figure 6. Alignment is made with the parallel rule from the 6th minute point to the 8th minute point and then brought through the center mark. The wind direction reads 253 degrees on the compass circle. This is the wind direction at a height of 4,432 feet above the release point or 9,124 feet.

WINDS ALOFT COMPUTATION SHEET

Location POTRERO SECO — Surface Weather CLEAR

Altitude 4692 FEET MSL — Dry Bulb 77°F — Wet Bulb 52°F

Date 9/28/64 — R. H. 17% — Dew Point 29°F

Start Time 1346 PDT — Xerometer

Reason Terminated END OF RUN — Wind direction & speed SW 4-6

Observer MUTCH & CHURAK — Pressure — Radiation

Remarks AT FIRE CAMP-6MILES NE FROM FIRE EDGE — Cloud Condition CLEAR "

Weather Condition CLEAR-VISIBILITY UNRESTRICTED

Time Min.	HT.A.G. 30G (Feet)	Elev 0.0°	AZ. 0.0°	Dist. Out	Wind Dir.	Wind Spd.	Time Min.	HT.A.G. 30G (Feet)	Elev 0.0°	AZ. 0.0°	Dist. Out	Wind Dir.	Wind Spd.
0.5	354						12.5	7688					
1.0	709	37.3	88.5	10.5	258	08	13.0	7984	27.6	71.1	173.5	256	22
1.5	1033						13.5	8280					
2.0	1358	45.8	78.1	15.0	218	05	14.0	8576	26.3	71.8	197.1	259	23.
2.5	1683						14.5	8872					
3.0	2008	51.3	64.3	18.2	204	06	15.0	9168	25.6	72.9	217.4	262	20
3.5	2340						15.5	9464					
4.0	2627	52.3	55.8	23.0	226	06	16.0	9760					
4.5	2943						16.5	10056					
5.0	3248	51.1	57.0	29.7	249	08	17.0	10352					
5.5	3544						17.5	10648					
6.0	3840	48.1	60.9	39.1	253	13	18.0	10944					
6.5	4136						18.5	11240					
7.0	4432	42.6	64.5	54.7	253	18	19.0	11536					
7.5	4728						19.5	11832					
8.0	5024	37.8	66.4	73.6	253	20	20.0	12128					
8.5	5320						20.5	12404					
9.0	5616	34.0	68.2	94.6	254	21	21.0	12720					
9.5	5912						21.5	13016					
10.0	6208	31.4	69.2	115.5	253	20	22.0	13312					
10.5	6504						22.5	13608					
11.0	6800	29.8	69.9	134.9	254	20	23.0	13904					
11.5	7096						23.5	14200					
12.0	7392	28.6	70.4	154.0	255	20	24.0	14496					

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Figure 3.--Winds aloft evaluated at Coyote Fire, Santa Barbara, Calif., September 28, 1964.

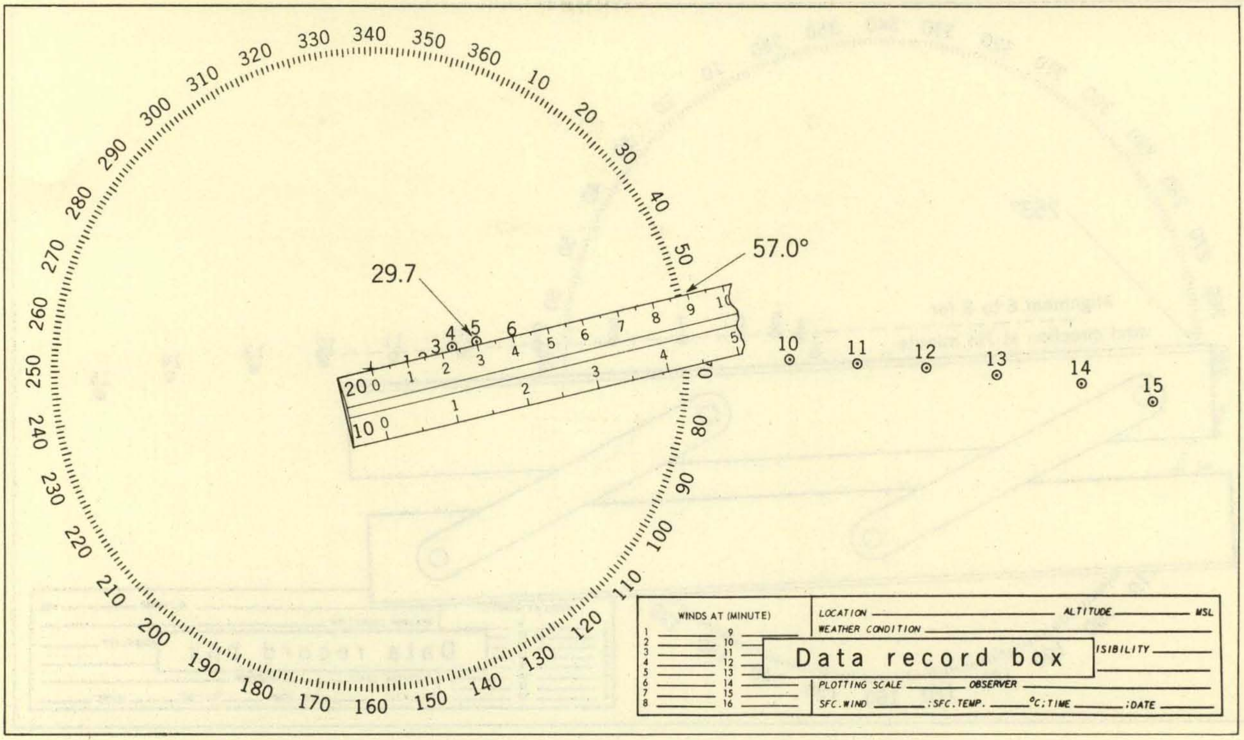

Figure 4.--Example of measuring and plotting balloon position points.

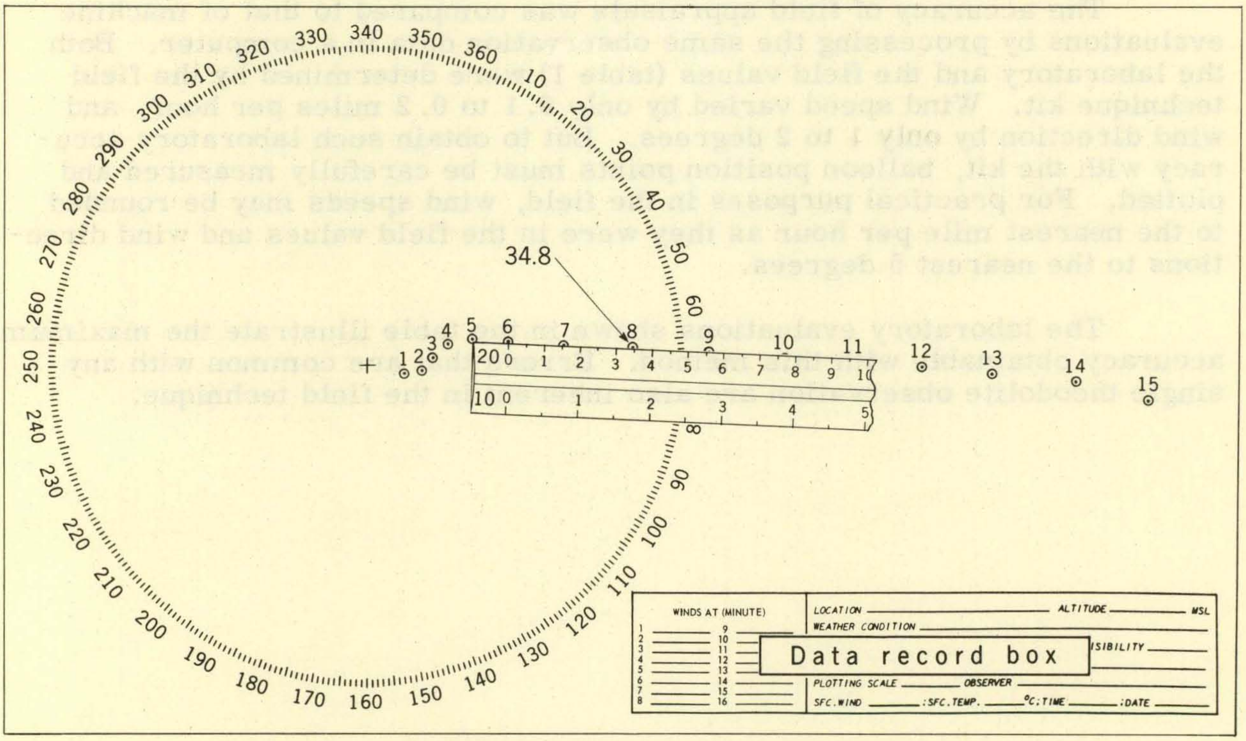

Figure 5.--Example of evaluating wind speed.

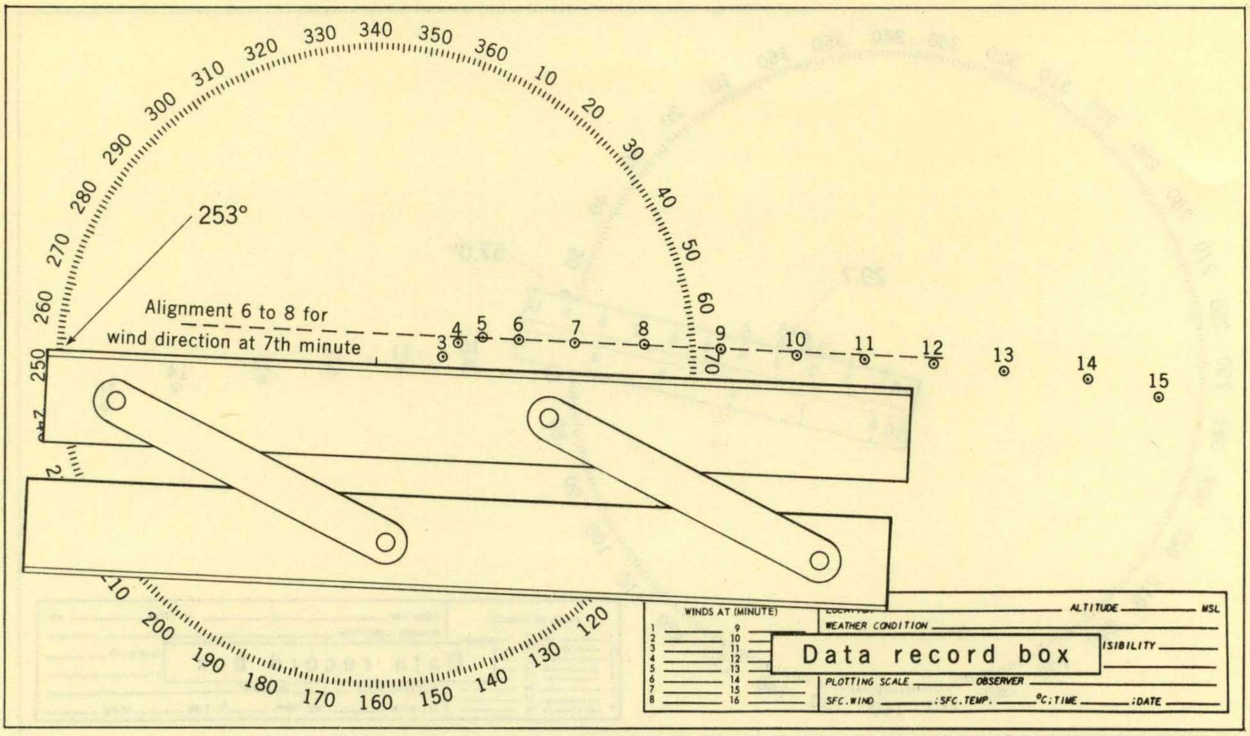

Figure 6.--Example of evaluating wind direction.

Comparative Accuracy

The accuracy of field appraisals was compared to that of machine evaluations by processing the same observation data in a computer. Both the laboratory and the field values (table 1) were determined by the field technique kit. Wind speed varied by only 0.1 to 0.2 miles per hour, and wind direction by only 1 to 2 degrees. But to obtain such laboratory accuracy with the kit, balloon position points must be carefully measured and plotted. For practical purposes in the field, wind speeds may be rounded to the nearest mile per hour as they were in the field values and wind directions to the nearest 5 degrees.

The laboratory evaluations shown in the table illustrate the maximum accuracy obtainable with this method. Errors that are common with any single theodolite observation are also inherent in the field technique.

Table 1.--*Comparison of computer, laboratory, and field techniques for evaluating winds aloft*[1]

Height of wind (feet)	Wind direction evaluated by...			Wind speed evaluated by...		
	Computer	Lab. kit	Field kit	Computer	Lab. kit	Field kit
	Degrees			*Miles per hour*		
4,692	215	SW	SW	6.0	6.0	6
5,400	258	258	258	7.5	7.5	8
6,050	218	218	218	4.8	4.8	5
6,699	204	204	204	5.4	5.5	6
7,319	226	226	226	5.9	5.9	6
7,940	248	248	249	8.1	8.2	8
8,530	253	253	253	12.8	12.8	13
9,121	253	253	253	17.4	17.4	18
9,711	253	253	253	20.0	20.0	20
10,302	254	254	254	21.1	21.0	21
10,892	254	254	253	20.2	20.3	20
11,483	254	254	254	19.3	19.3	20
12,073	255	255	255	19.3	19.4	20
12,664	257	257	256	21.6	21.6	22
13,254	260	260	259	22.1	22.1	23

[1]Using observation data from Coyote Fire, Santa Barbara, Calif., September 28, 1964.

The Author

MELVIN K. HULL was assigned to the Station's fire meteorology research staff from 1962 until 1966, when he became supervising fire-weather meteorologist at the U.S. Weather Bureau office in Eureka, Calif. From 1955 to 1962, he operated his own meteorological consulting service in the San Francisco Bay Area. A 1942 graduate (B.S. in agriculture) of the University of California, Davis, he received his meteorology training at the U.S. Naval Academy's Post-Graduate School at Annapolis, Md.