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DEPARTMENT OF INDUSTRY AND COMMERCE
METEOROLOGICAL SERVICE

INTERNAL MEMORANDUM

I.M.27/55 - PILOT BALLOON ASCENT LASTING 160 MINUTES

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Summary

On 12th July 1955 a standard 90-inch balloon was observed for 160 minutes. The winds at the time were light and there were many alterations of speed and direction. There is evidence that the balloon may have ascended more rapidly than the conventional 500 feet per minute, and may have attained as much as 100,000 feet before bursting. The fluctuations of winds observed suggest a perturbation of the cellular type.

Introduction

At 0830 GMT on 12th July 1955 a scheduled Pilot Balloon Ascent was commenced at the Dublin Airport meteorological station. The duty observer discontinued measurements after half-an-hour in order to attend to his other duties, but a second theodolite had been set up by staff undergoing training and with it Mr. Liam Ellis kept the balloon in view until it burst after 160 minutes. Four readings were missed at the end of the second hour as the balloon was crossing the zenith so that difficulty was experienced in manipulating the controls. The duration is believed to be a record for the Irish Meteorological Service.

The balloon was a 30-gram (90-inch) white rubber balloon, inflated with hydrogen to a free lift of 71.5 gm, using M.O. balloon fillers Mark III. This should give a velocity of ascent of 500 feet per minute, according to the accepted formula (See Appendix, p.5). An Askania theodolite was used. Time-keeping was by a stop-watch held by Mr. Michael Connaughton, who also took the readings, and who found the balloon after it had been lost at the zenith. The computations were by Slide-rule.

Synoptic Situation

The surface charts for 12th July show Dublin to have been near the axis of a weak ridge of high pressure, and the upper-air charts indicate the presence of a col. Radio-sonde data from Irish and British stations report stable conditions up to the tropopause at 38,000 feet. The airmass was of maritime origin and very clean, so that visibility was 25 miles. The only cloud present at the start of the ascent was a trace of Altocumulus: later there was also a trace of Cumulus humilis.

Rate of Ascent

It is customary to assume that a pilot balloon rises at a constant rate, and the weights used in determining the free lift are adjusted to make that rate 500 feet per minute. If there is no gas leakage, however, the balloon should accelerate and it seems possible that such was the case with the ascent under discussion.

The most striking change of wind observed was the marked increase in windspeed as the balloon approached the zenith. When readings were resumed at the 70th minute it was already slowing down and there was a complete reversal of direction by the 77th minute. If the balloon had been rising at 500 f.p.m. these changes would have all been within the troposphere. If one assumes that the speed was 500 f.p.m. at the surface but increased as (air density)$^{-1/6}$, then the tropopause at 38,000 feet would have been reached in 69 minutes instead of 76 minutes. Then the strongest wind would have been just at the tropopause, in accordance with what is frequently experienced. With the same assumption the maximum height reached at the end of 160 minutes would have been 113,000 feet. It is probable, however, that gas leakage had become appreciable at this stage and that the height reached is unlikely to have been much over 100,000 feet(See Appendix).

Owing to the uncertainty regarding the actual rate of ascent all the figures used in the following analysis have been derived using the assumed 500 f.p.m. The heights and wind speeds are therefore probably underestimated.

The Trajectory

Figure 1 represents the horizontal projection of the path of the balloon. A few of the smaller departures from the general trends may be due to the defects in the observing technique, notably the measuring of angles only to the nearest tenth of a degree, or to the balloon not being exactly centred in the field of view at the instant of reading. Most of the fluctuations, however, continued for several minutes and are undoubtedly real.

The most remarkable feature is the smallness of the area covered: at three stages the balloon reached about two miles from the station, but each time it returned after passing through a layer of little or no wind. The figure strongly suggests an oscillatory process, as if there were no mean wind at the time, only a perturbation from a state of rest.

The Winds

Some of the computed wind speeds are given in Tables I and II. Table I comprises values computed from every second minute, yielding vector mean winds for layers 1000 feet deep, centred at each multiple of 1000 feet. They have been rounded off to the nearest 5 degrees for direction and to the nearest knot for speed. For Table II the computations of successive 500-foot layers were consulted, and the vector mean of either three or four such layers was extracted so that they were centred near to the precise kilometric height.

The Perturbation

Figures 2 and 3 analyse the balloon motion in greater detail, and it is of particular interest to compare the observed fluctuations of wind speed and direction with those discussed by Doporto*.

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* e.g. The Cellular Solution of the Dynamical Equations and the Actual Perturbation of the Westerlies up to 16 km at Valentia. Tellus Vol. 6, 1954. pp. 32-43.

Doporto, analysing interdiurnal changes, classified by the signs of the pressure changes, found evidence of several nodal surfaces in the atmosphere, consistent with his cellular solutions of the Equations of Motion. According to those solutions the perturbations of horizontal motion should disappear at 4, 12, 20, 28 .... km. and have maxima at the intervening levels 8, 16, 24, 32 ... km. Further, the values of the West-East and South-North perturbations should be opposite in sign.

Although there are several nodes and antinodes in the case under discussion, there is little resemblance to the theoretical picture. The first maximum is at 4 km and the first node a little below 8 km, just the reverse of theory. From 8 km to the next node near 12 km u and v move oppositely and the correlation between them is quite good, $r(u,v)$ for the 19000 to 39000 foot levels being as large as -0.63 ± 0.13. In the next higher layers the behaviour is again different, u and v changing together but with v lagging behind u. Thus $r(u_l, v_{l-1})$ for l in thousands of feet from 40 to 57 is $+0.61 \pm 0.14$. Yet higher the u and v changes again seem to be in opposition, but there are many irregularities and $r(u,v)$ from 58000 to 79000 feet is -0.01 ± 0.22.

It thus appears that although there are prominent levels of minimum or zero motion, there is no linkage between the motions above and below them, each inter-nodal layer developing an independent oscillation.

TABLE I. Wind Direction and Velocity for Heights in Thousands of Feet above Mean Sea Level

Height (thousands of feet)	Direction (Degrees from true North)	Speed (knots)	Height (thousands of feet)	Direction (Degrees from true North)	Speed (knots)
Surface	50	1	40	185	8
1	65	4	41	210	9
2	45	4	42	205	5
3	90	4	43	260	3
4	135	2	44	305	2
5	60	3	45	275	1
6	15	4	46	125	1
7	85	2	47	185	4
8	90	4	48	195	6
9	150	2	49	205	6
10	160	6	50	235	4
11	175	7	51	265	7
12	190	9	52	115	2
13	210	7	53	175	8
14	210	9	54	220	9
15	210	7	55	220	5
16	230	6	56	255	7
17	210	4	57	225	1
18	215	4	58	345	4
19	250	2	59	315	1
20	120	1	60	150	3
21	75	3	61	355	6
22	15	2	62	50	8
23	95	2	63	85	7
24	120	3	64	255	2
25	115	2	65	90	2
26	155	2	66	90	6
27	285	3	67	110	6
28	335	5	68	110	8
29	350	12	69	105	4
30	340	7	70	310	1
31	340	10	71	85	3
32	350	12	72	50	8
33	(355)	(16)	73	10	7
34	(355)	(16)	74	150	4
35	(355)	(16)	75	100	3
36	15	6	76	5	5
37	20	5	77	350	2
38	120	4	78	270	9
39	160	3	79	255	9

TABLE II. Wind Direction and Velocity for Heights in Kilometres above Mean Sea Level

Height (kilo-metres)	Direction (Degrees from true North)	Speed (knots)	Height (kilo-metres)	Direction (Degrees from true North)	Speed (knots)
Surface	50	1	13	225	4
1	100	3	14	185	1
2	35	3	15	215	6
3	160	5	16	165	4
4	205	8	17	240	5
5	220	5	18	180	< 1
6	170	< 1	19	60	6
7	85	2	20	90	4
8	205	1	21	100	5
9	345	9	22	35	8
10	355	16	23	25	5
11	10	6	24	240	10
12	170	5			

APPENDIX

Rate of Ascent of Pilot Balloons

Many different expressions have been derived for the rate of ascent of pilot balloons, that adopted by the Irish Meteorological Service being $V_Z = q\,L^{\frac{1}{2}}(L+W)^{-\frac{1}{3}}$, where q is a constant, L is the free lift, and W is the weight of the balloon and attachments. The derivation is well presented in Spilhaus and Miller's "Workbook in Meteorology" (New York 1942, pp. 49-50). The factor q incorporates $\left(\frac{\rho_0}{\rho}\right)^{\frac{1}{6}}$ where ρ_0 and ρ are the values of air density at the surface and in the upper air, respectively. It is generally accepted that the tendency of this density term to accelerate the balloon's motion is counteracted by leakage of gas, and that q, L, and W can all be regarded as constant during an ascent. Unfortunately, this treatment ignores the excess of pressure inside the balloon, which must increase with height, and which causes L to increase. It is hoped to publish a comprehensive discussion of the problem in due course.

If one assumes that there is no appreciable gas leakage and that V_Z varies as $\left(\frac{\rho_0}{\rho}\right)^{\frac{1}{6}}$ it is possible to calculate the rate of ascent and the height reached in a given time in a Standard Atmosphere. Using the data for the Standard Atmosphere given in ICAO Doc. 7488, and assuming that the isothermal stratosphere extends at least as far as 114,000 feet (35 km) we can proceed as follows:

Troposphere. $$\frac{\rho}{\rho_0} = \left(\frac{T}{T_0}\right)^{4.2561}$$

Hence, if H is the height of the balloon, and a is the constant lapse rate of temperature

$$\frac{dH}{dt} = \left(\frac{dH}{dt}\right)_0 \left(\frac{T_0 - aH}{T_0}\right)^{-0.70935}$$

Integrating from H = 0 at t = 0 to H = H at t = t leads to

$$H = \frac{T_0}{a}\left[1 - \left\{1 - \frac{1.70935a}{T_0}\left(\frac{dH}{dt}\right)_0 t\right\}^{0.585018}\right]$$

or, substituting the appropriate numerical values,

$$H = 1.45447 \times 10^5\left[1 - \left\{1 - 1.17524 \times 10^{-5}\left(\frac{dH}{dt}\right)_0 t\right\}^{0.585018}\right]$$

Stratosphere. Using suffix $_h$ to denote tropopause values,

$$\frac{\rho}{\rho_h} = 10^{-2.0874 \times 10^{-5}(H - H_h)}$$

and hence $$\frac{dH}{dt} = \left(\frac{dH}{dt}\right)_h 10^{3.4790 \times 10^{-6}(H - H_h)}$$

Integrating from $H = H_h$ at $t = t_h$ to H = H at t = t leads to

$$H = H_h - 2.8742 \times 10^5 \log_{10}\left\{1 - 8.0107 \times 10^{-6}\left(\frac{dH}{dt}\right)_h (t - t_h)\right\}$$

If the Mean Sea Level value of $V_z = \left(\frac{dH}{dt}\right)$ be taken as 500 feet per minute the above formulae lead to the following table:

Time from start (minutes)	Height above MSL in geopotential ft.	Vz (f.p.m.)
0	0	500
10	5063	513
20	10260	527
30	15600	542
40	21100	559
50	26780	578
60	32660	599
65.83	36089	613
70	38660	626
80	45070	659
90	51280	695
100	58950	736
110	66520	782
120	74580	834
130	83190	894
140	92450	963
150	102440	1047
160	113300	1137

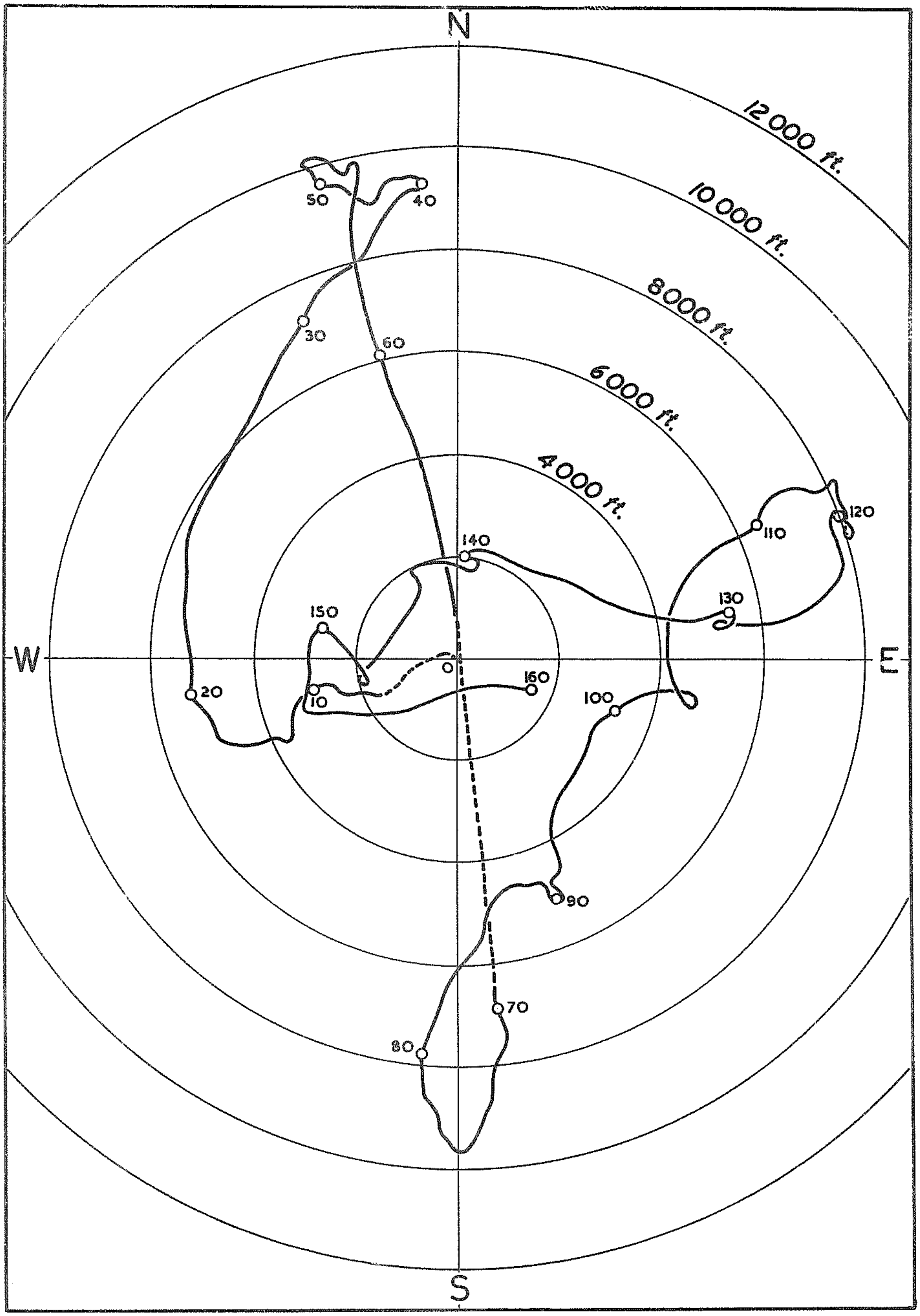

Fig. 1. Horizontal Trajectory of Pilot Balloon. Dublin Airport, 12th July, 1955 0830 GMT. Numbers indicate time from start in minutes.

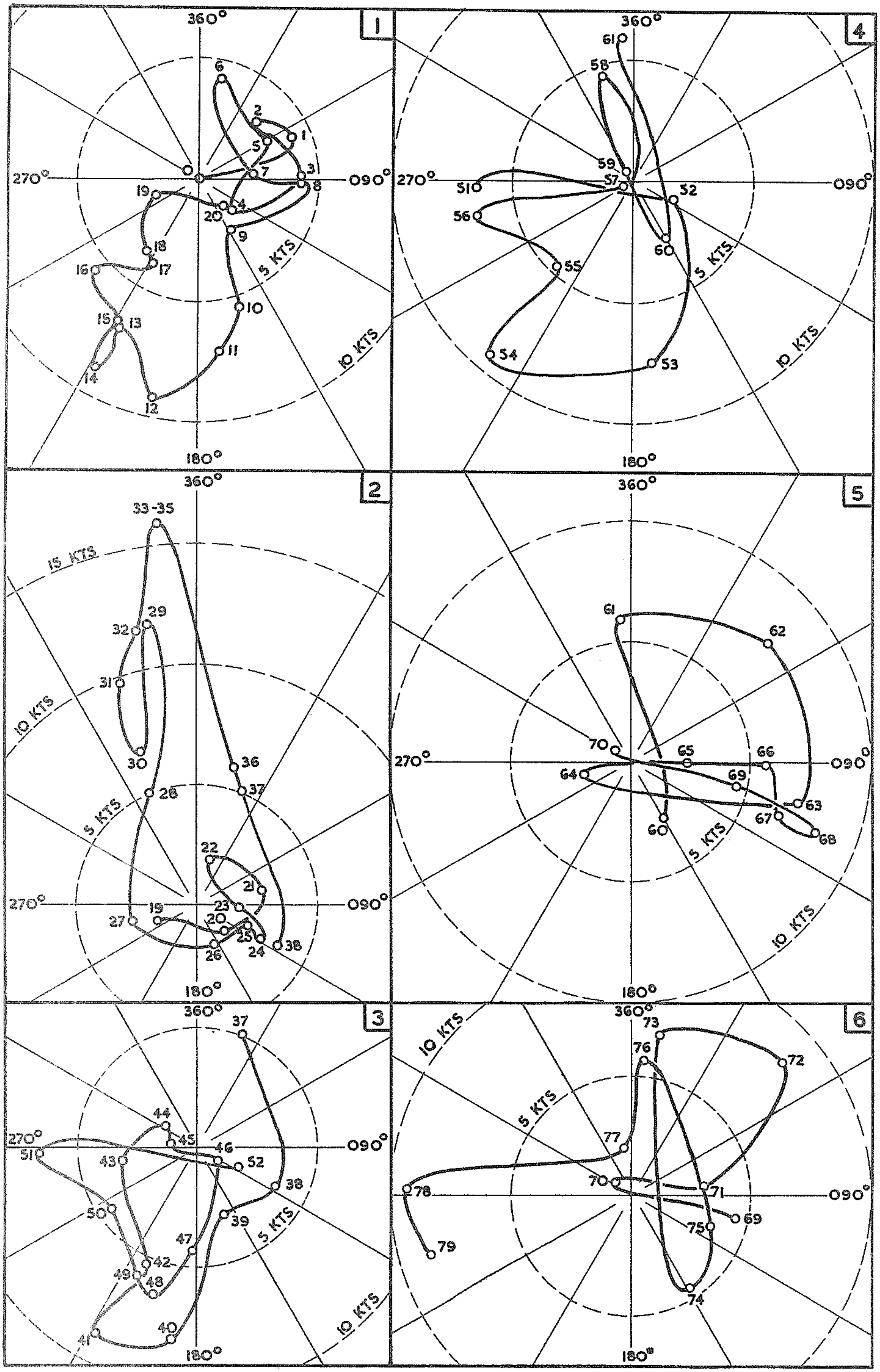

Fig. 2. Hodograph. Figures represent heights in thousands of feet above M.S.L.

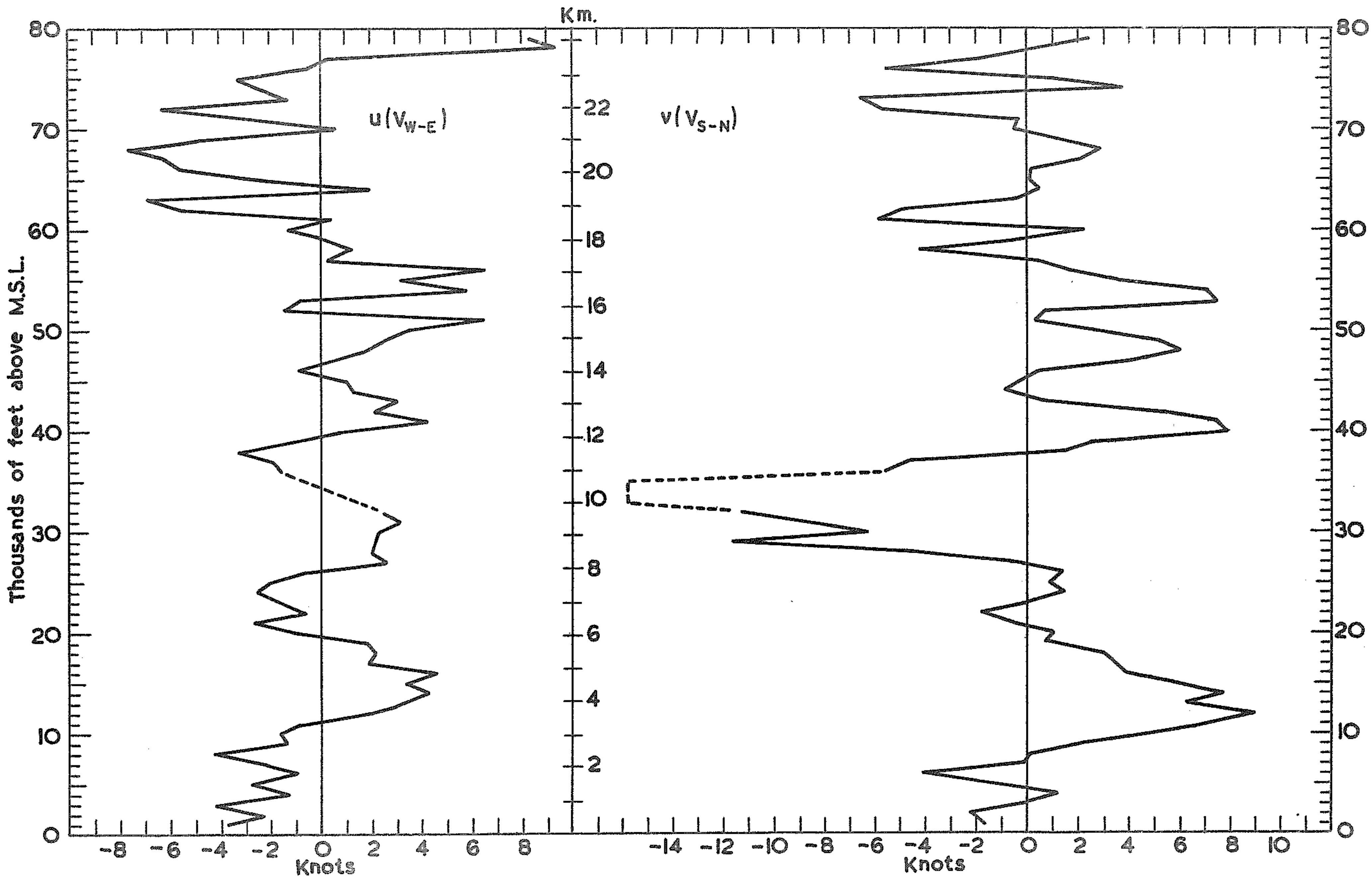

Fig. 3 Wind Components. Dublin Airport, 12th July, 1955, 0830 GMT.