A PRELIMINARY STUDY OF AIR TRAJECTORIES IN THE LOS ANGELES BASIN AS DERIVED FROM TETROON FLIGHTS[1]

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ABSTRACT

During May and early June of 1963, 88 tetroon-transponder flights were made at relatively low level in the Los Angeles Basin. Five different tetroon release sites were utilized, extending from Point Dume northwest of Los Angeles to Sunset Beach southeast of Los Angeles. The tetroons, and attached transponders, were positioned at 3-min. intervals by means of the newly installed Weather Bureau WSR–57 radar on Blackjack Mountain, Catalina. Through the use of transponders the problem of ground clutter was eliminated, and tetroon positions were obtained at ranges exceeding 50 mi. even when the tetroon was only a few feet above the ground. More than 400 hr. of tetroon-tracking time were obtained, with the longest single track of 21 hr. duration.

In general, the wind speeds derived from successive tetroon positions were small, averaging 4.4 kt. for all flights and only 2.4 kt. for flights released from Corral Beach. Aircraft tracking on more than 20 of the flights confirmed that the mean tetroon floating altitude was between 1000 and 1500 ft. However, while the tetroon height over the ocean varied little, over the land in the unstable marine layer repetitive height variations of as much as 2000 ft. were noted. There was a marked tendency for tetroon heights to vary in accordance with terrain height, and, particularly in the case of the Palos Verdes Hills, a systematic vertical motion pattern was delineated.

On the basis of 7 pairs of simultaneous tetroon releases, it was found that for the first 100 min. the square of the horizontal separation distance tends to be proportional to time to the third power. However, at times greater than 100 min., the tetroons occasionally draw closer together. In the case of tetroons released from the same site, but at different times, the distance between tetroon positions tends to increase nearly linearly with time after release, attaining an average value of 15 mi. 4 hr. after release. Surprisingly, the time interval between tetroon release does not appreciably affect this latter statistic. Analysis of the spreading or diffusion of serial trajectories in a spatial frame of reference shows that the lateral standard deviation is proportional to downstream distance to the 0.8 to 0.9 power, values comparable to those derived by quite different methods.

Considered is a series of trajectories from Long Beach which indicates land and sea breeze effects, and a series of trajectories from Venice which shows a veering of the sea breeze flow with time. A few flights from Sunset Beach suggest that at times, near the base of the inversion, there may exist a large anticyclonic cell (reverse of the usual Catalina eddy) over the Los Angeles Basin.

1. INTRODUCTION

The possibility of using 3-dimensional tetroon trajectories as approximations to 3-dimensional air parcel trajectories has been under investigation for several years. In general the tetroon positions have been obtained by radar, but with the tetroon acting as only a passive reflector of the radar pulse [1] [2] [3] [4]. More recent experiments at Cincinnati [5] have shown the advantages which accrue from the use of transponders. Thereby, ground clutter can be completely removed from the radar scopes, with a consequent great increase in tracking range, and, by using different transponder frequencies, two or more balloons may be tracked simultaneously without ambiguity.

The objectives of the experiment described here were several. First, it was desired to carry out a full-scale demonstration and test of the radar-transponder-tetroon technique of obtaining air trajectories. Second, we wished to test the technique in a location where the radar would usually be "looking down" at its target, hence where ground clutter would always be present. Thirdly, it was desired to look at an area where the airflow is complex and additional information is needed in order to delineate meso-scale circulation patterns. Inasmuch as the airflow in the Los Angeles Basin is known to be the complex result of a variety of pressure gradient, thermal, and topographic influences well worth study, and yet the winds are sufficiently light to permit acquisition of data over extended time periods, the Basin appeared a logical location at which to initiate a large-scale experiment with the tetroon-transponder system.

The newly installed Weather Bureau WSR–57 radar on Blackjack Mountain, Catalina Island, was used for tracking. This radar, at an elevation exceeding 2,000 ft.,

[1] Research performed as a portion of research activities sponsored by the Atomic Energy Commission and the Public Health Service.

has a commanding view of most of the Los Angeles Basin. Although the radar position, 20 mi. offshore, added some difficulties to tracking tetroons as they reached the northern and eastern portions of the Basin, trajectories 20 to 50 mi. in length and 12 to 21 hr. in duration were readily obtained. In such a congested area, at such ranges, and under the radar propagation conditions associated with inversions, "skin" tracking would be quite impossible with any conventional radar. This was convincingly demonstrated during these experiments by the complete failure to obtain a radar return from aluminized tetroons at ranges where the transponder signal was easily detectable. The desirability of obtaining air trajectories in the Los Angeles Basin cannot be denied, especially from the air pollution standpoint. Heretofore, trajectories of pollutants have been estimated from an extensive network of surface-based anemometers. Over and above the problem of estimating trajectories from such "Eulerian" data, there is the question of the degree to which surface trajectories are representative of mean air trajectories in the marine layer. It is believed that the tetroon-transponder system is the answer to the obtaining of such representative trajectories. While the month of May is hardly a "smog" month, and May of 1963 was no exception, the ease with which tetroon trajectories were obtained throughout the Los Angeles Basin during this month indicates the potential of the tetroon-transponder system for the subsequent investigation of smog situations and of other meterological problems involving airflow and transport (e.g., sea breeze, moisture advection, etc.).

FIGURE 1.—Tetroon and Mark II transponder.

2. OBSERVING SYSTEM

The methods and basic equipment used to obtain tetroon positions were generally similar to those used in the first test of this technique. However, since improvements were made, and since the conditions of the experiment were markedly different, the observing system and techniques will be described briefly.

Radar.—The radar used was the WSR–57 (10-cm. wavelength) installed at 2,121 ft. mean sea level on Blackjack Mountain, Catalina Island. The radar signal is carried by cable to the control console at the Catalina Airport, more than 1 mi. distant and at an elevation of 1,528 ft. m.s.l. The radar was operated in short pulse (½ microsecond) throughout the experiment since the long pulse mode (4 microsecond) was inoperative. This resulted in a loss of power output but improved the positional accuracy. The radar was manually directed toward the transponder targets. Numerical values of azimuth and elevation angles (to the nearest 0.01°) and range (to the nearest 0.01 n. mi.) were read off at 3-min. intervals from the appropriate counters. No significant difficulties were experienced in the use of the radar over the 27-day observational period even though the radar was not officially commissioned and, in fact, had been hastily returned to service especially for this project after an extended outage.

Transponder.—The Mark II transponder, built by the Cordin Co., is a more sensitive and higher powered version of the previous series. It was especially optimized for long distance detection. The transponder is 1.3 in. wide, 1 in. deep, and 10 in. long (plus a 13-in. antenna rod). Its weight, minus batteries, ranged from 112 gm. (4 oz.) to 156 gm. (5½ oz.) depending on the density of the styrofoam weatherproofing. Including batteries, identification tags, parachute, etc., the total payload weight averaged about 265 gm. (9½ oz.). Figure 1 shows a photograph of the transponder attached to a tetroon.

The transponder is powered by a pair of batteries: the "A" battery, a 1½-volt flashlight type; and the "B" battery, a 22½-volt transistor radio type. In all except a few of the last flights high energy alkaline-type batteries were used. With this battery combination the transponder power output is approximately 1 watt. No transponder failure occurred in flight, nor was there an identifiable signal decrease due to power drain, although on several flights the transponders were triggered continuously for more than 12 hr. While no specific attempt was made to determine either maximum lifetime or maxium range, one flight was continuously tracked for 21 hr. and one flight (a different one) was tracked to a range of 89 n. mi.

The transponder is activated (triggered) by a nominal

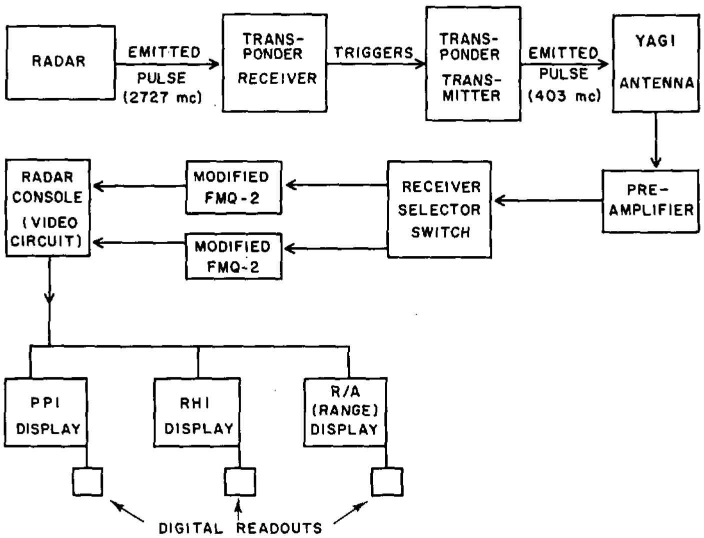

FIGURE 2.—Schematic diagram of transponder positioning system.

2800-mc./sec. signal (the Catalina WSR–57 emits at 2727 to 2729 mc./sec.) which is detected by the receiving portion of the device. This causes the transmission of a nominal 403-mc./sec. signal. The transponder is tunable over about a 10-mc./sec. band.

These devices are the heart of this system. Their performance was nearly perfect, a remarkable achievement for an instrument still in the evolving stage.

Receiving system.—The signal history for detecting and positioning the transponders is shown schematically in figure 2. The returning 403 mc./sec. signal is first detected by a rotatable V-type yagi antenna, fed into a high gain (approximately 30 db.) amplifier especially built for this purpose by the Cordin Co., thence via coaxial cable through a receiver selector switch to one of a pair of FMQ–2 receivers, modified for AM reception. This signal is then fed into the radar video circuit where the range was determined by time comparison of the radar and transponder pulses and the results displayed on the three scopes (PPI, RHI, and R/A) at the radar console. Signal strength was not particularly sensitive to the yagi direction. A position within $\pm 20°$ of the transponder azimuth was satisfactory, which made multiple transponder tracking much easier.

Tetroon.—The balloons used to carry the transponders were again the reliable tetrahedral, constant-volume tetroons, constructed of Mylar, with a skin thickness of 2 mils and a nominal volume of 1 cubic meter. Of the 90-odd balloons used, only three were defective. Two had pin-hole leaks, and on one the loop used to attach the payload pulled loose during a high-wind launch attempt.

Communications.—The first four flights of this series were launched from the Catalina Airport to check out equipment and procedures. The remainder of the 84 flights were launched from the California mainland at ranges of 22 to 42 mi. from the radar. Obviously, a primary necessity was the ability to communicate between personnel at the radar console and those on the mainland. Later, when the tetroons were being tracked by the project aircraft, a three-way exchange of information was necessary. This was accomplished by using four transceivers. One transceiver was installed at the radar console and from this point all operations were controlled. One transceiver was installed in the WBAS, Los Angeles (later moved to the quarters of the launching crews to improve coordination). The third transceiver was mobile, having been installed in a pickup truck which was kept at the launch site. Since this set could be operated off the automobile electrical power, complete mobility was possible. The fourth set was an aircraft radio which was installed in the project aircraft. All transceivers operated on a combination of 163 and 174 mc./sec. Although the communications equipment was not particularly powerful, signal exchange at any point in the Los Angeles Basin was made possible by the installation of a repeater station on the radar tower on Blackjack Mountain. This communications net was essential for the efficient conduct of these remote releases and permitted very great flexibility in adapting the flights to changing conditions.

Aircraft.—During the planning phase of this experiment it was considered desirable to obtain environmental data on temperature and humidity, both in the vertical and in the horizontal, in the vicinity of the tetroon flights. Furthermore, in anticipation of difficulties in precisely determining the tetroon heights from the elevated radar in the complicated air mass structure of the Los Angeles Basin, we thought it desirable to obtain confirmatory height data from aircraft. Contract arrangements were made with the Department of Meteorology at the University of California at Los Angeles to provide such information. Dr. James G. Edinger was in charge of this portion of the work and in fact piloted the aircraft on all flights. The aircraft used was a Beachcraft Bonanza, modified to accommodate the special UCLA high-speed meteorological data system. Data on temperature, humidity, and turbulence were automatically recorded at high speed on magnetic tape for later analysis. Tetroon heights were visually determined by the meteorological observer (in most cases, Mr. Derek Reid of UCLA) from altimeter readings during close (50–100 ft.) fly-bys. By flying a series of circles they obtained continuous height determinations to within ± 10 ft. m.s.l. at intervals of 40 to 90 sec. over periods up to several hours.

A discussion of the large volume of meteorological data obtained from the aircraft is beyond the scope of this paper and will be presented separately. Suffice it to say that the aircraft-determined tetroon heights proved to be essential and these will be considered in a later section.

3. LAUNCH AND TRACKING TECHNIQUES

A number of groups have expressed interest in using the super-pressured, constant-volume balloon concept. For this reason, and since the methods are constantly being improved (this is only the second tetroon-transponder experiment), the techniques as evolved at the end of this series will be described.

Inflation.—We desired to make tetroon releases from a number of locations in the Los Angeles area, with the tetroons designed to fly at relatively low altitudes. This required mobility between sites and an enclosed space to inflate and determine free lifts of 5 gm. or less, an impossible task in the open air. The solution was a moving van with rear doors large enough to permit passage of the inflated tetroon. Sufficient van space was available for helium and other necessary supplies. This made the launch facilities self-contained and completely mobile. The truck could be driven to a new site and tetroons launched within a few minutes of arrival. The launch truck was, in our case, accompanied by the vehicle with the radio installation, but this was for convenience only; the radio could just as well have been in the launch truck.

Launch sites and times were chosen on the basis of existing and expected weather, behavior of current trajectories, and the type of airflow desired for study. The free lift was specified as was the desirability of making multiple launches. For dual flights two balloons were inflated to about 30 mb. of super-pressure and the free lifts matched with great care. To minimize the weight attached to the tetroon, and to conserve helium, a mixture of helium and air was used to inflate the tetroons. This procedure eliminated the 150 gm. or more of sand ballast previously necessary.

Transponder activation.—While the tetroons were being inflated, the transponders were checked out and tuned by training the radar on them while they were held a few feet off the ground. When it was desired to launch two tetroons simultaneously, or to initiate a new flight while continuing to track an airborne tetroon, the tunable characteristic of the transponders was used to avoid any ambiguity in tetroon identification. One transponder was tuned and the frequency set on one of the FMQ-2 receivers. The receiver selector switch was then used to put the second receiver in the circuit and the (different) frequency of the second transponder tuned for maximum signal. After launch, switching from transponder to transponder merely required flicking a switch, a very great improvement in speed and accuracy over retuning a single receiver However, at the end of the series sufficient skill had been acquired that simultaneous tracking of three and, once, of four transponders by a combination of switching and re-tuning proved possible. It appears that the number of transponders that can be simultaneously airborne and subsequently tracked is limited only by the number of receivers, the sharpness of the transponder transmission, and the band width available for the transponder transmissions. There is, of course, a rapidly growing complexity (not to say confusion) at the tracking end but this could be eliminated with adequate staff or eventually with automation.

Tracking techniques.—As previously mentioned, this series of transponders was designed to produce signals to a range of about 100 mi. and/or to be usable when unfavorable propagation conditions (e.g., inversion base between radar and transponder) existed. This was accomplished by making the receiver portion as sensitive as possible and increasing the output of the transmitted signal. This change required rather different tracking techniques than had been used in the Cincinnati experiments [5] with the Mark I transponders. At Cincinnati the transponders were activated by only a very narrow portion of the radar beam, very near the peak power level. This made for high precision in positioning but also meant that recovery of the target after switching to another signal was both difficult and time consuming. The return signal was also weaker, which, while it also enabled precision location, severely limited the range.

In contrast the Mark II transponders were triggered by much less than the peak power of the radar beam and this feature, combined with the stronger returning signal, resulted in a broad pip which "painted" across the PPI and RHI (but not the range) scopes. This situation, which is certainly not a defect since it made detection very much easier, was corrected by using a back and forth (or up and down) sweeping technique which permitted the determination of the total signal width from which the center of the signal could be determined. Figure 12 indicates that this technique was quite accurate.

Radar data (azimuth and elevation angles, and range) were read at 3-min. intervals on most flights although on single tetroon tracks with concurrent aircraft positioning readings were obtained at minute intervals. There were a number of flights, primarily those which moved behind the Palos Verdes Hills at low elevations, where there were gaps in the detailed positioning data.

4. THE WEATHER SITUATION

May 1963 was a fairly typical May month in southern California with a high inversion and very persistent stratus. A few cold Lows moved over southern California during the month, further deepening the marine layer and in two cases nearly eradicating the inversion. The surface geostrophic flow was from the northwest, a result of a pronounced northward extension of the subtropical Pacific anticyclone. The usual thermal trough generally was in evidence in the interior valleys of California.

Figure 3 shows, for the period under investigation, the succession of radiosonde traces obtained from Clover Field, Santa Monica, just inland from the ocean. It is seen that while there was some tendency for a low inversion during the middle of May, this soon gave way to an inversion base located at a height exceeding 3,000 ft. Additional radiosonde data from San Nicolas Island, while they occasionally showed considerable difference in thermal structure near the surface, confirmed the general character and height of the major inversion structure. Figure 4 shows the succession of rawins obtained from Clover Field. Frequently the wind was westerly in the marine layer beneath the inversion, easterly for some

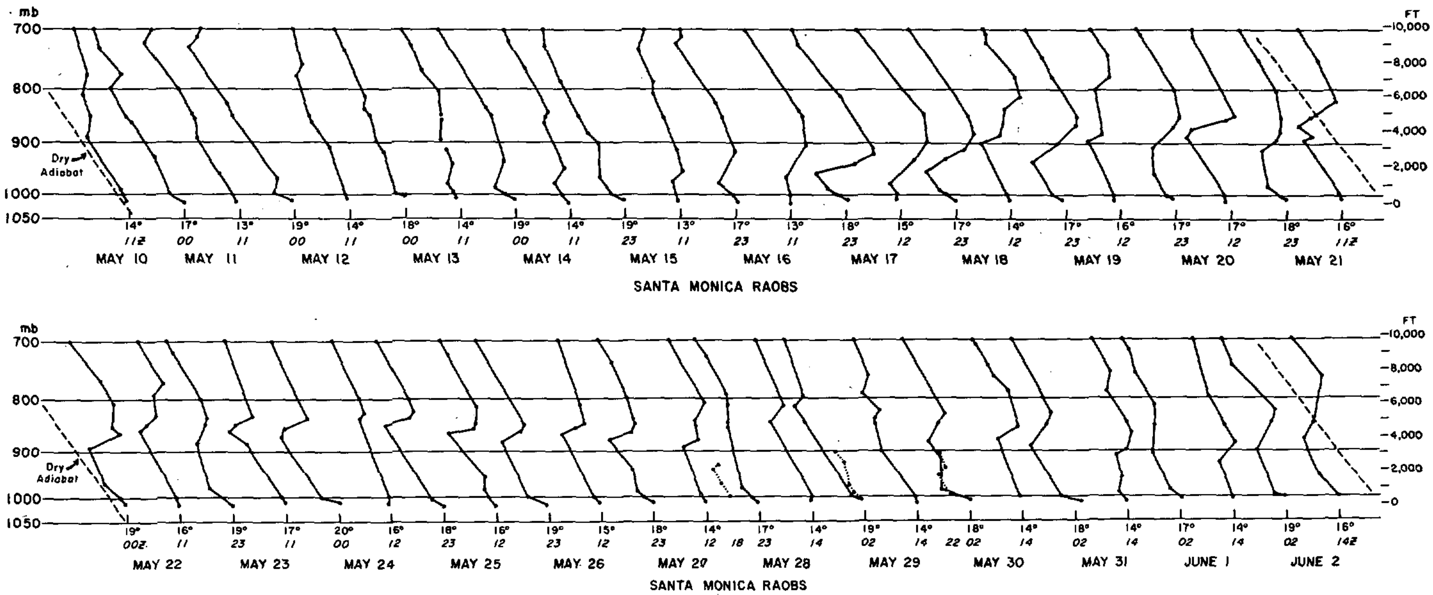

Figure 3.—Temperature variation with height at Clover Field, Santa Monica, during the period of tetroon flights. The dotted soundings were obtained from an aircraft in the vicinity of tetroon release sites.

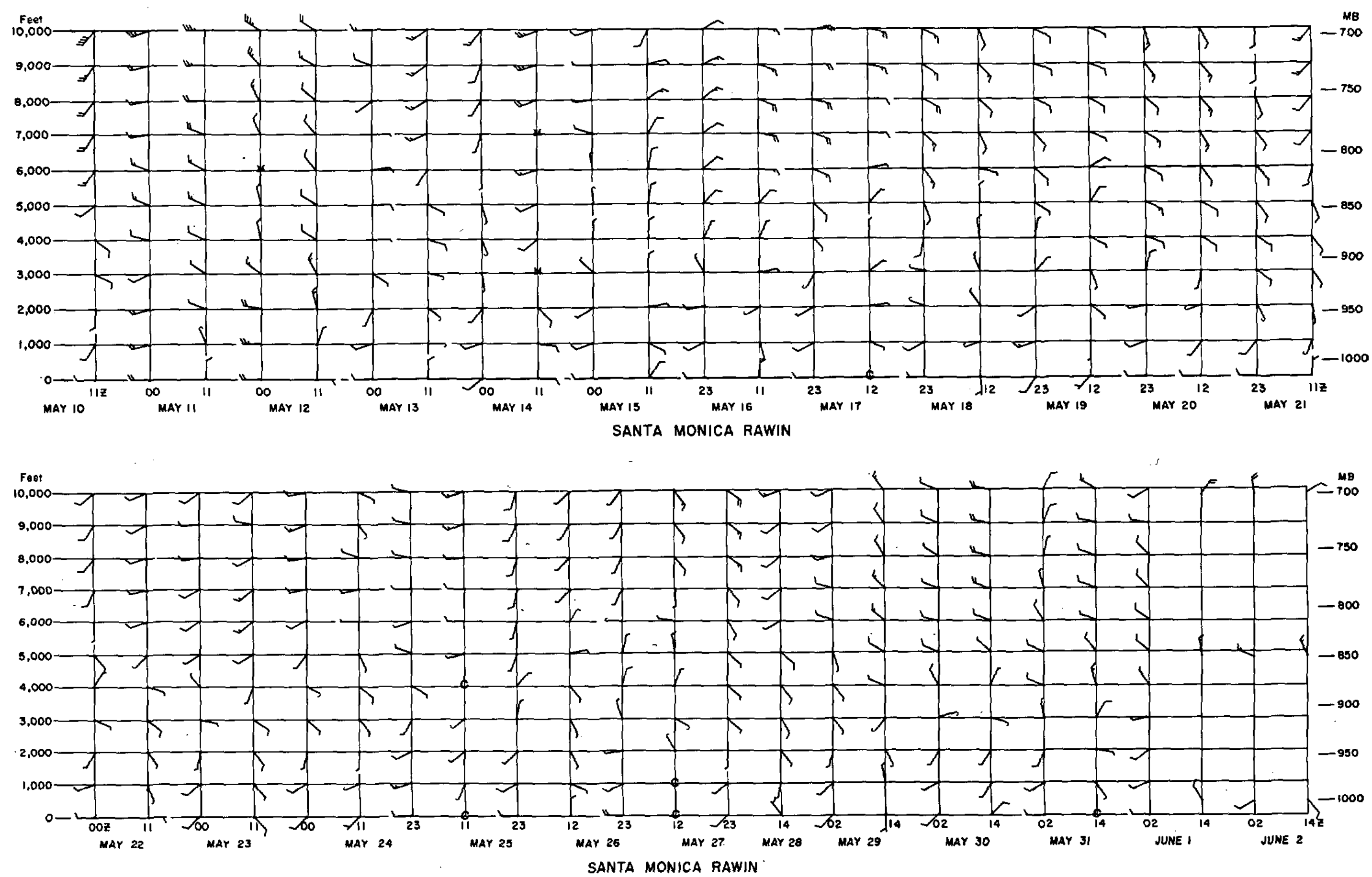

Figure 4.—Wind variation with height at Clover Field during the period of tetroon flights. Hooked barb, 2–3-kt. wind; half barb 4–7-kt. wind (except at surface where it indicates 1–10-kt. wind); full barb, 8–12-kt. wind, etc.

distance above the top of the inversion, and of mixed direction, and very light, within the inversion. Relating the direction of tetroon travel with the wind direction at Clover Field is often difficult owing to uncertainty regarding the horizontal area for which the Clover Field winds could be considered representative. This is em-

TABLE 1.—*Transponder-equipped tetroon flights within the Los Angeles Basin*

Flight No.	Date (1963)	Release time (GMT)	Launch site	Tracking duration (hours)	Average speed (knots)	Remarks
1	May 9	2103	Catalina Airport	0		Incorrect radar hookup.
2	May 10	1827	Catalina Airport	5.3	10.0	
3	May 11	0300	Catalina Airport	1.0	15.8	Transponder battered upon release.
4	May 11	2123	Catalina Airport	5.3	11.7	
5	May 12	0342	Palos Verdes (Nike Site).	4.6	10.7	Excess free lift
6	May 12	1759	Palos Verdes (Nike Site).	17.7	4.4	
7	May 14	0351	Corral Beach	0	--------	Into water
8	May 14	0429	Corral Beach	0.1	--------	Into water
9	May 14	0511	Corral Beach	0.1	--------	Into water
10	May 14	0536	Corral Beach	3.7	2.1	
11	May 14	1711	Venice Marina	0.8	8.1	Behind Palos Verdes.
12	May 14	1748	Venice Marina	5.3	4.5	
13	May 15	1940	Venice Marina	0.5	9.6	Behind Palos Verdes.
14	May 15	2036	Venice Marina	0.4	12.0	Behind Palos Verdes.
15	May 15	2201	Venice Marina	0.2	--------	Behind Palos Verdes.
16	May 15	2242	Venice Marina	0.3	13.0	Behind Palos Verdes.
17	May 15	2339	Venice Marina	9.8	2.7	
18	May 16	2325	Corral Beach	3.6	4.1	
19	May 17	0845	Corral Beach	0	--------	Into hillside
20	May 17	1140	Corral Beach	5.7	2.3	
21	May 17	1925	Sunset Beach	21.0	3.4	
22	May 17	2125	Sunset Beach	4.9	5.2	
23	May 18	1801	Sunset Beach	0.2	--------	Into fence
24	May 18	1837	Sunset Beach	14.9	4.7	
25	May 18	2202	Long Beach (Pier F)	11.2	4.6	
26	May 20	0511	Long Beach (Pier F)	4.2	2.9	
27	May 20	0656	Long Beach (Pier F)	14.1	2.9	
28	May 20	1039	Long Beach (Pier F)	8.9	1.8	
29	May 20	2100	Long Beach (Pier F)	4.8	3.8	
30	May 21	0620	Long Beach (Pier F)	18.4	2.7	
31	May 21	0815	Long Beach (Pier F)	18.7	4.0	
32	May 22	0338	Long Beach (Pier F)	1.1	5.5	Into water
33	May 22	0502	Long Beach (Pier F)	13.0	3.2	
34	May 22	0619	Long Beach (Pier F)	0.1	--------	Into water
35	May 22	0659	Long Beach (Pier F)	0	------	Into water
36	May 22	0751	Long Beach (Pier F)	8.0	5.5	
37	May 22	1805	Long Beach (Pier F)	7.3	5.1	
38	May 22	1843	Long Beach (Pier F)	4.6	7.2	
39	May 23	0300	Long Beach (Pier F)	5.3	5.3	
40	May 23	0415	Long Beach (Pier F)	3.8	8.0	
41	May 23	1656	Long Beach (Peir F)	8.2	4.5	
42	May 23	1734	Long Beach (Pier F)	9.8	4.8	
43	May 24	1501	Venice Marina	7.4	3.8	
44	May 24	1547	Venice Marina	6.3	4.1	
45	May 24	2225	Venice Marina	11.0	3.8	
46	May 24	2335	Venice Marina	3.5	7.4	
47	May 25	0403	Venice Marina	0	--------	Into wires
48	May 25	0524	Venice Marina	10.2	3.4	
49	May 25	1413	Venice Marina	7.4	7.0	
50	May 25	1733	Venice Marina	0.7	3.0	Cut down by helicopter.
51	May 25	1844	Venice Marina	4.9	7.0	
52	May 25	2140	Venice Marina	6.5	5.4	
53	May 26	0341	Corral Beach	3.5	2.7	
54	May 26	0458	Corral Beach	0.3	4.0	Into water
55	May 26	0548	Corral Beach	1.6	2.6	Into water
56	May 26	0744	Corral Beach	0.9	0.5	Into hillside
57	May 26	0810	Corral Beach	9.6	2.3	
58	May 26	0929	Corral Beach	5.3	1.5	
59	May 26	1739	Corral Beach	0.9	2.4	Into hillside
60	May 26	1856	Corral Beach	3.2	1.9	
61	May 26	2357	Corral Beach	1.6	4.5	Into hillside
62	May 27	1803	Pt. Dume	3.8	1.7	
63	May 27	1917	Pt. Dume	1.7	2.9	Behind hills
64	May 27	2321	Pt. Dume	1.0	3.9	Into hillside
65	May 28	0045	Pt. Dume	0.7	1.6	Into hillside
66	May 28	1725	Pt. Dume	1.2	3.3	Into hillside
67	May 28	1852	Pt. Dume	0.1	--------	Into water
68	May 28	1928	Pt. Dume	0.1	--------	Into water
69	May 28	1953	Pt. Dume	3.7	2.5	
70	May 28	2340	Pt. Dume	2.5	4.7	Leaky tetroon
71	May 29	1800	Marineland	2.0	6.3	
72	May 29	2142	Marineland	3.6	9.0	
73	May 29	2358	Marineland	2.3	2.8	
74	May 30	1449	Marineland	3.3	3.4	
75	May 30	1827	Marineland	5.8	4.8	
76	May 30	1827	Marineland	5.0	5.1	Cut down by helicopter.
77	May 31	1900	Marineland	0.8	2.8	Behind Palos Verdes.
78	May 31	1900	Marineland	0.7	2.8	Behind Palos Verdes.
79	May 31	2138	Marineland	2 2	4.7	
80	May 31	2138	Marineland	4.2	6.5	
81	June 1	1750	Marineland	2.5	2.3	
82	June 1	1750	Marineland	4.1	2.9	
83	June 1	2037	Marineland	4.7	6.2	
84	June 1	2037	Marineland	4.1	6.0	
85	June 2	1827	Marineland	4.4	4.9	
86	June 2	1827	Marineland	4.1	4.5	
87	June 2	2230	Marineland	0.9	7.8	Behind Palos Verdes.
88	June 2	2230	Marineland	3.6	5.3	

phasized by a comparison of the Clover Field and San Nicolas rawins which often showed directions 180° apart, as well as significant speed differences.

5. TETROON TRAJECTORIES

Table 1 indicates the date, time, and duration of individual tetroon flights, the release site utilized, the average wind speed along the flight, and appropriate remarks. It may be noted that mean flight altitude has not been entered. Because of the increased sensitivity of the transponders and the inadequacy of this particular radar for height determinations, plus the refraction of the radar beam under inversion conditions, it has so far proved impossible in many cases to derive reasonable tetroon heights from the radar elevation angles. From the free lift of the tetroons at release, plus the heights obtained by the tracking aircraft, one would judge that in most cases the float altitude was between 1,000 and 1,500 ft. In any event, it seems quite certain that all flights were within the marine layer, i.e., the free lift was never sufficient to permit the tetroon to break through the inversion "lid."

Figures 5–9 indicate the trajectories of two or more hours' duration obtained from the various tetroon release sites. For simplicity, tetroon positions are given only at hourly intervals, even though the trajectories themselves are based on positions at 9-min. intervals. We shall reserve a study of some particularly interesting trajectories for a later section. When viewed from the overall point of view the entire set of trajectories, covering a period of 26 days, provides an illuminating picture of the complexity of the flow in the Los Angeles Basin, with numerous trajectory reversals, loops, and directional shifts. This is in marked contrast to the previous five series of tetroon experiments. From these Los Angeles data, we note the general "milling around" of the tetroons released from Corral Beach and Point Dume (fig. 5), and the tendency for the tetroons released from Venice (fig. 6) and Marineland (fig. 7) to drift toward the northeast, whereas the tetroons released from Long Beach (fig. 8) tend to move toward the northwest. This change in flow direction is not merely temporal, but typifies the tendency for the airflow to be from the south or southeast at Long Beach at the same time it is from the west or southwest at Venice, with a consequent line of convergence (very evident in cloudiness) appearing to the northeast of the Palos Verde Hills. Because of slight movements of this line of con-

TABLE 2.—*Mean speed derived from successive tetroon positions for flights released from given site*

Release site	Mean speed (knots)
Catalina Airport	11.3
Point Dume	2.8
Corral Beach	2.4
Venice Marina	4.7
Marineland, Palos Verdes	5.2
Long Beach Harbor	4.0
Sunset Beach	4.0
Average	4.4

Figure 5.—Tetroon trajectories of two or more hours' duration for releases from Corral Beach and Point Dume. Hours after tetroon release indicated next to small circles; tetroon flight number at end of trajectory. Topography shading (progressively darker) for heights exceeding 500, 1000, and 2000 ft.

FIGURE 6.—Tetroon trajectories for releases from Venice Marina.

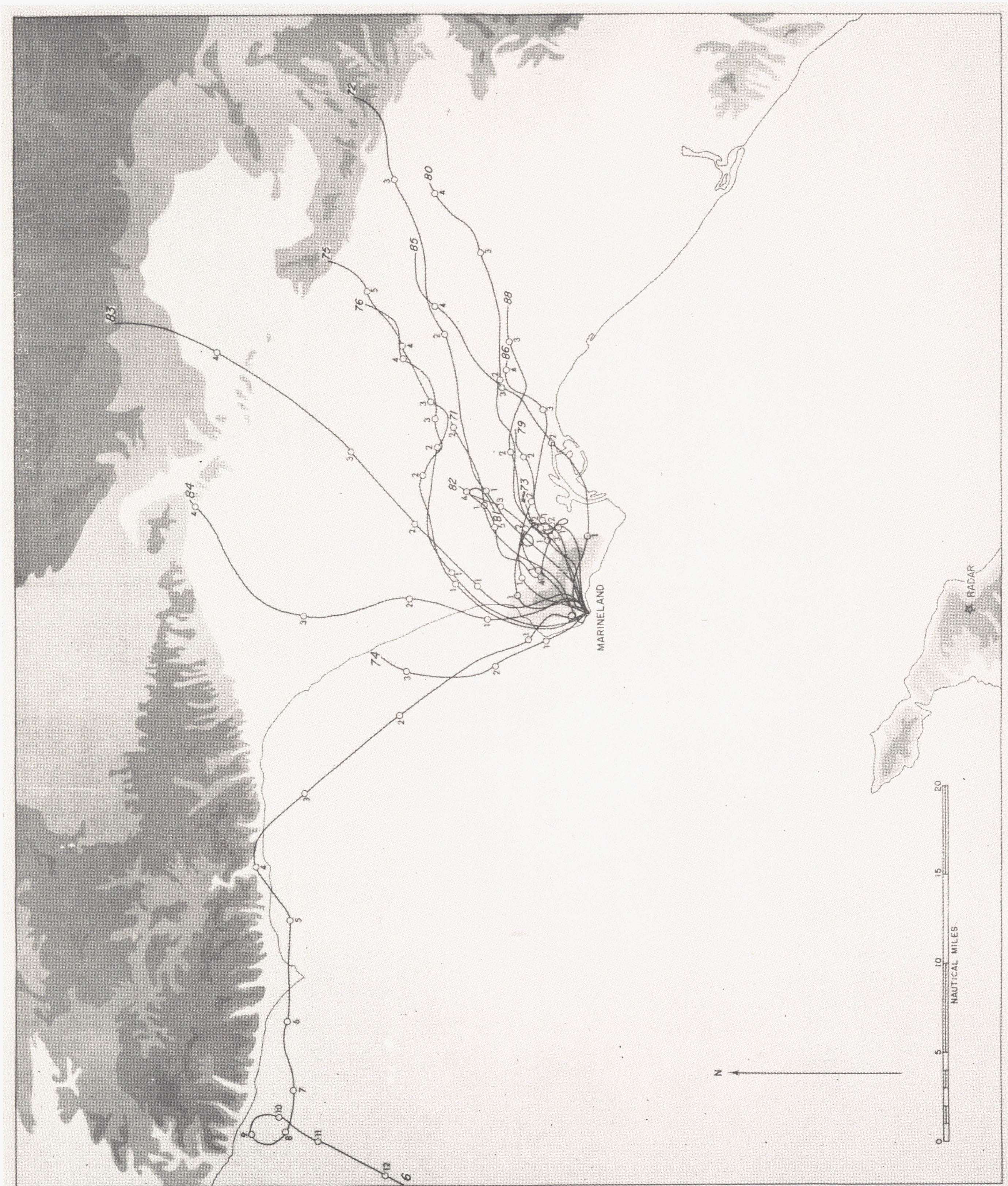

FIGURE 7.—Tetroon trajectories for releases from Marineland, Palos Verdes.

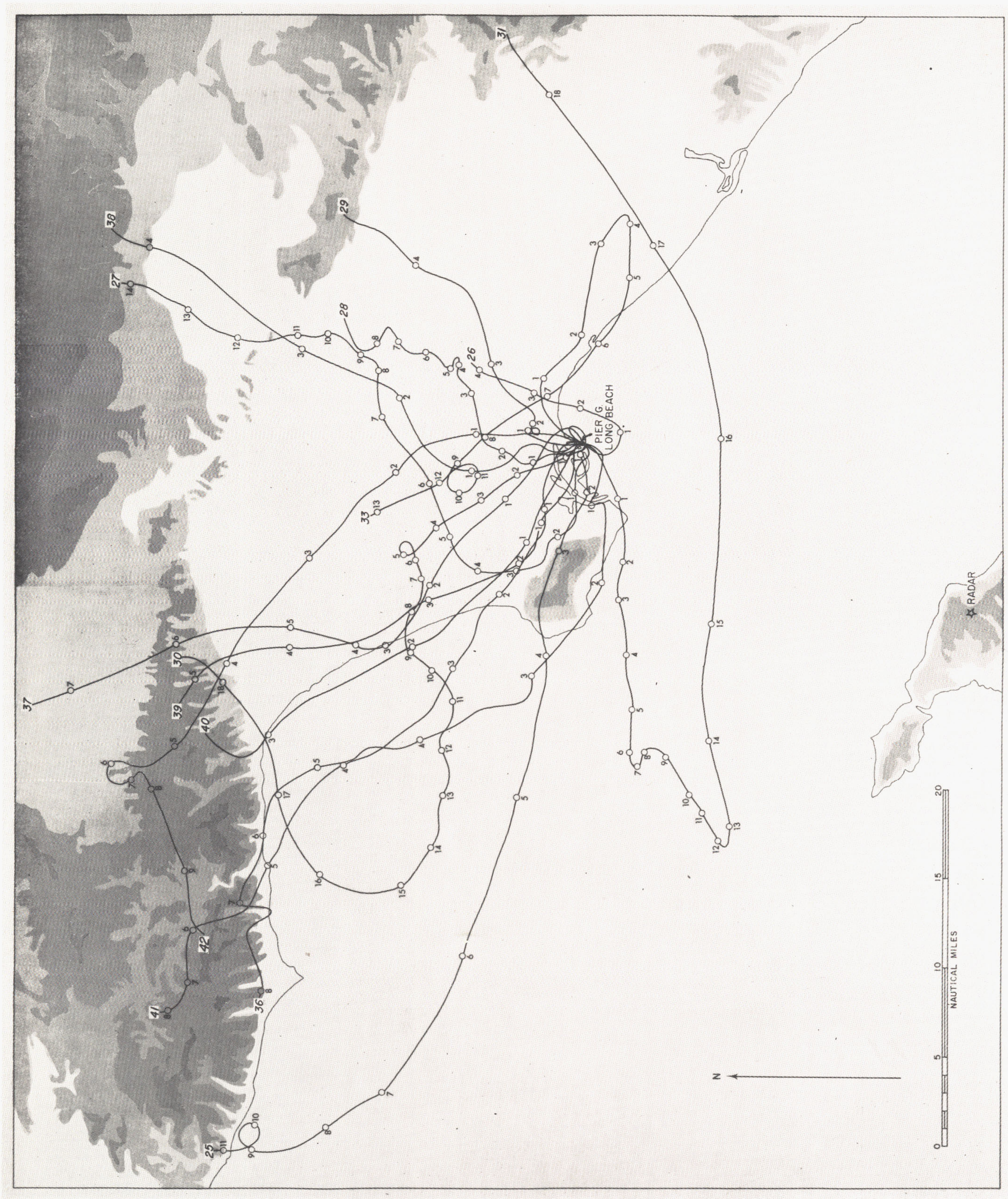

FIGURE 8.—Tetroon trajectories for releases from Long Beach Harbor.

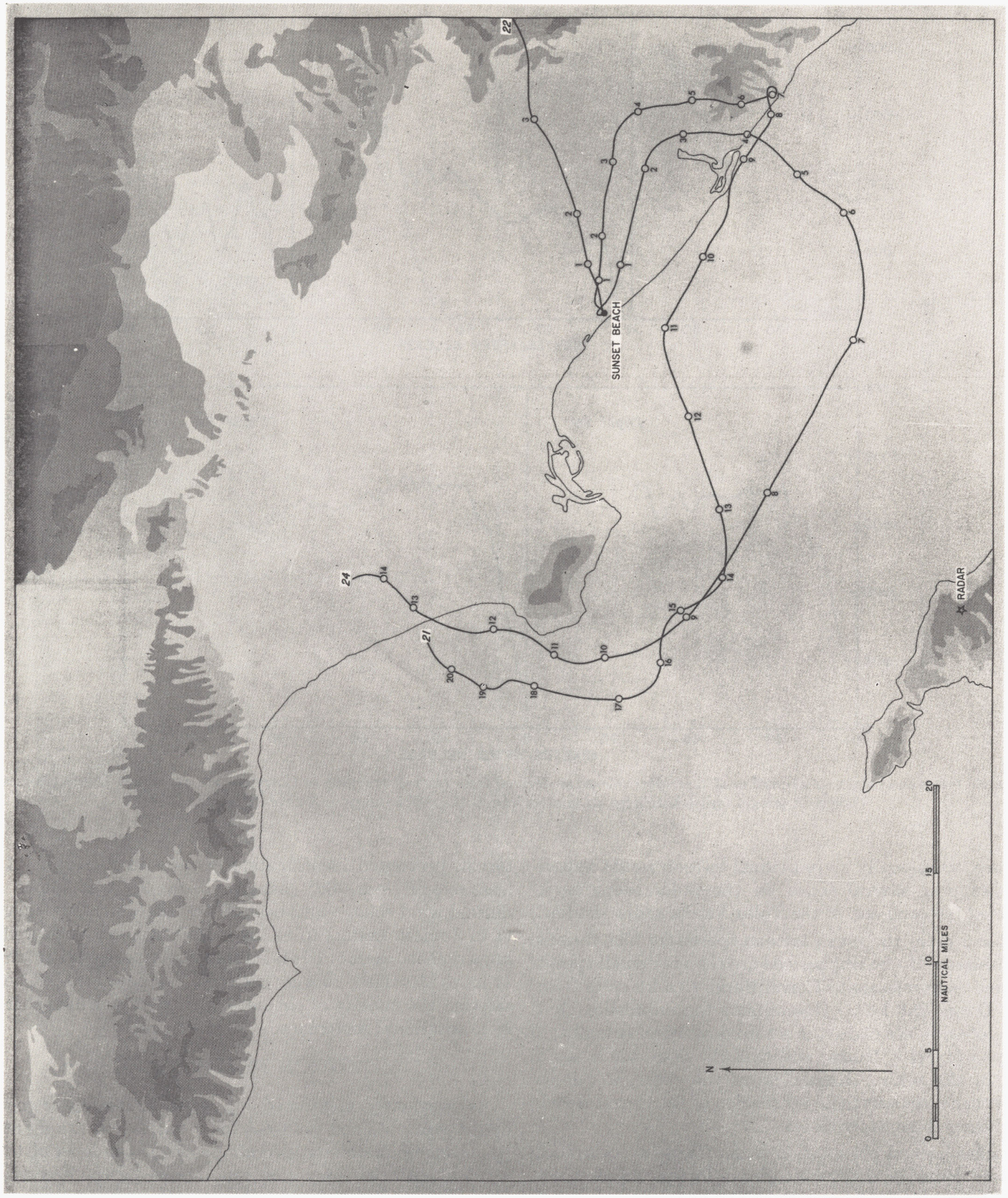

Figure 9.—Tetroon trajectories for releases from Sunset Beach.

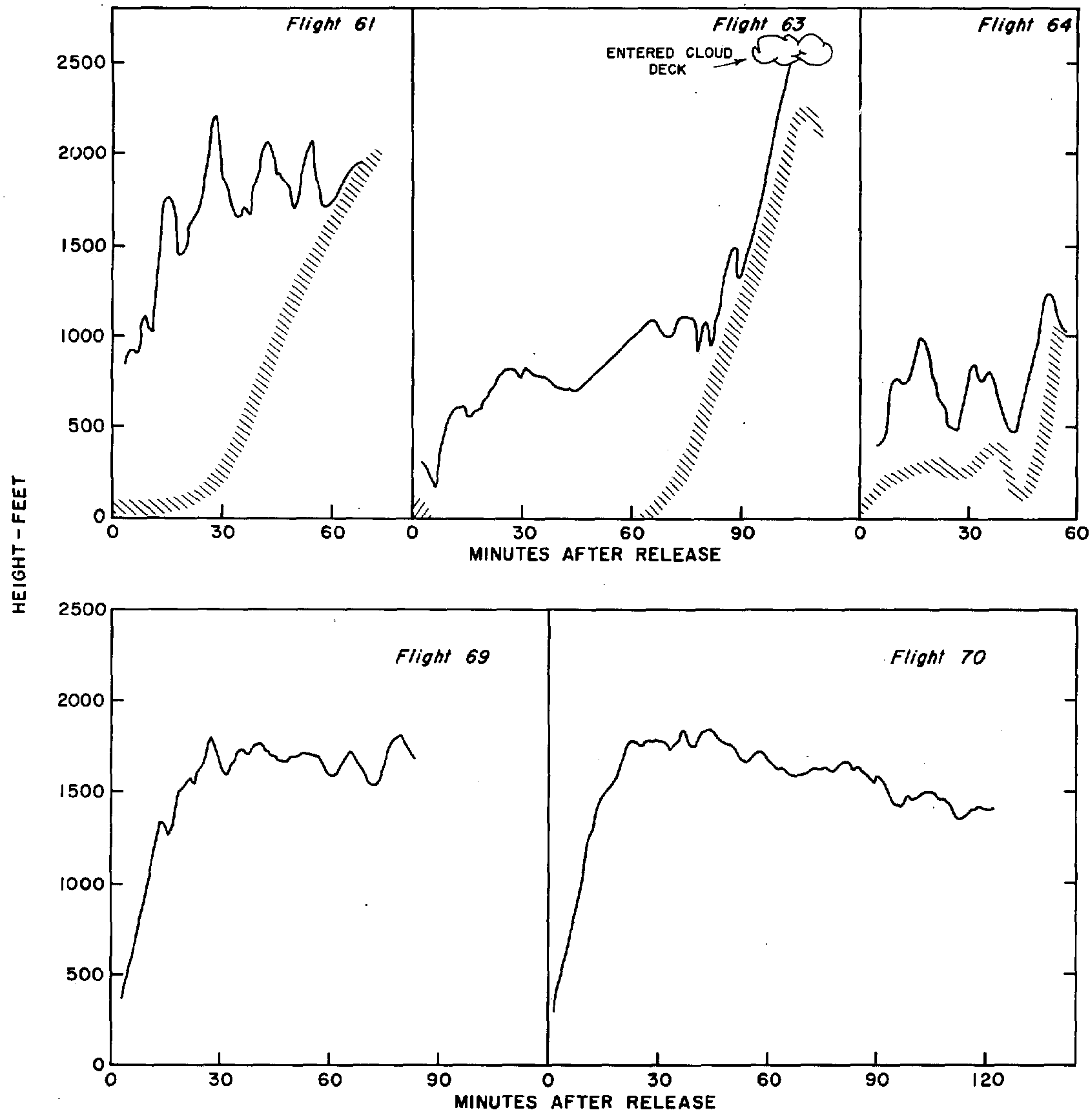

FIGURE 10.—Tetroon height as a function of time after release as derived from aircraft tracking of Corral Beach and Point Dume releases. Height of terrain (cross-hatching) estimated from topographic maps and aircraft reports.

vergence, occasionally an individual tetroon would appear and disappear several times on the radar scope as it oscillated into and out of the Palos Verdes radar shadow.

Table 2 gives the mean tetroon speeds for the various launch sites. To be emphasized are the very small speeds resulting from releases at Corral Beach (2.4 kt.) and from Point Dume (2.8 kt.). One obtains the impression that a type of eddy circulation is set up downwind (usually to the east) of Point Dume, and that the light winds are a result of this eddy. Regardless of the cause, it can be stated that there was little ventilation of the Corral Beach area during these experiments.

Another general observation is the frequent occurrence of closed loops in the trajectories. Twelve flights show this phenomenon and four flights had two or more such loops. It is probable these are minimum numbers since the distance from the radar, and the observational interval, prevented identification of very small loops. At least one of these 360° changes (Flight 33) was due to a diurnal wind change but most of the others were too small (1 to 2 mi. in radius) to be associated with any such well-known phenomenon. It is interesting to note that of the 17 loops identified, 10 were cyclonic, 7 anticyclonic. Considering the paucity of the data, one must conclude there is no rotational preference.

6. TETROON HEIGHT TRACES

As previously mentioned, on some 20 flights tetroon height was obtained (at least for a portion of the flight) by means of successive aircraft passes at the level of the tetroon. Aircraft operation was limited by the necessity to maintain visual flight rules, by the various control zones around Los Angeles and Long Beach Airports, and by the restriction against flying low over densely popu-

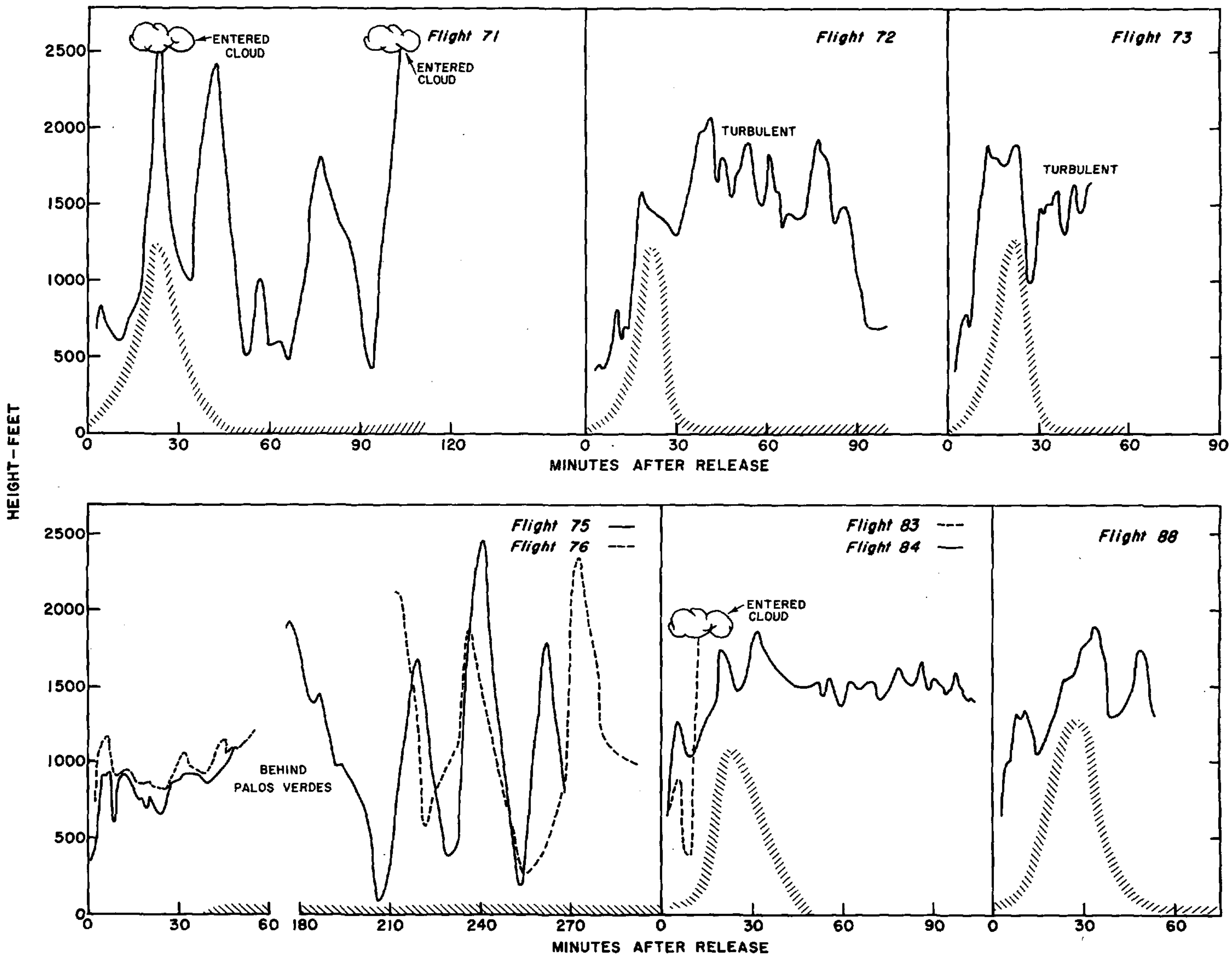

FIGURE 11.—Same as figure 10, but for tetroon releases from Marineland, Palos Verdes.

lated regions. Figures 10 and 11 show the height traces for most of the tetroon flights tracked by the aircraft. A few aircraft-tracked flights from Corral Beach and Point Dume that went straight northward up the mountain slope have not been included since, essentially, there was no flight at constant level. The topography indicated in these figures is derived from tetroon-trajectory plots on a topographic map as well as from estimated heights above terrain as given by the aircraft. Of necessity the topography has been smoothed and no attempt has been made to indicate individual valleys or ridges.

Interesting points in figure 10, which involve tetroon releases from Corral Beach and Point Dume, include the approximately 14-min. height periodicity on flight 61, the ascent over the mountain ridge on flight 63 (note also the downward motion of the tetroon in the lee of Point Dume), and the tendency on flight 64 for the tetroon to follow the topography with, perhaps, the tetroon oscillation in the vertical displaced slightly upstream from the ground undulations. Flights 69 and 70 were over the water and exhibit relatively little height fluctuations (the slow descent of flight 70 was due to a pinhole leak in the tetroon). However, on flight 69 there is a tendency for vertical oscillations of 14-min. period, as also noted on flight 61.

The height traces depicted in figure 11 are associated with tetroon flights from Marineland, most of which passed over the Palos Verdes Hills. The two flights which did not pass over these hills, the paired flights 75 and 76, indicate the great difference between vertical tetroon oscillations (and presumably vertical air motions) over the water and over the land, with height variations in the former case of order 200 ft. and in the latter case of order 2,000 ft. Over the land, particularly on flight 75, there is a pronounced vertical-motion periodicity of about 20 min.

All the tetroon flights that went over Palos Verdes Hills give evidence, to a greater or lesser degree, of a slight

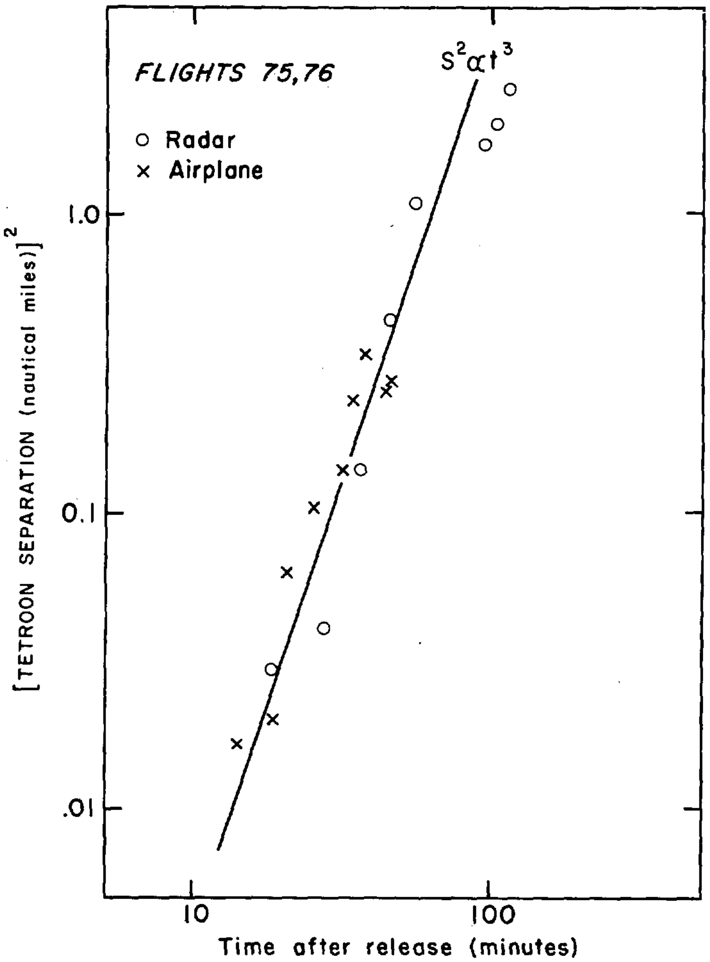

FIGURE 12.—Initial variation of the square of the separation distance as a function of time after release for simultaneously-released tetroon flights 75 and 76. Circles indicate separations obtained from radar positions, crosses separations obtained from aircraft passes.

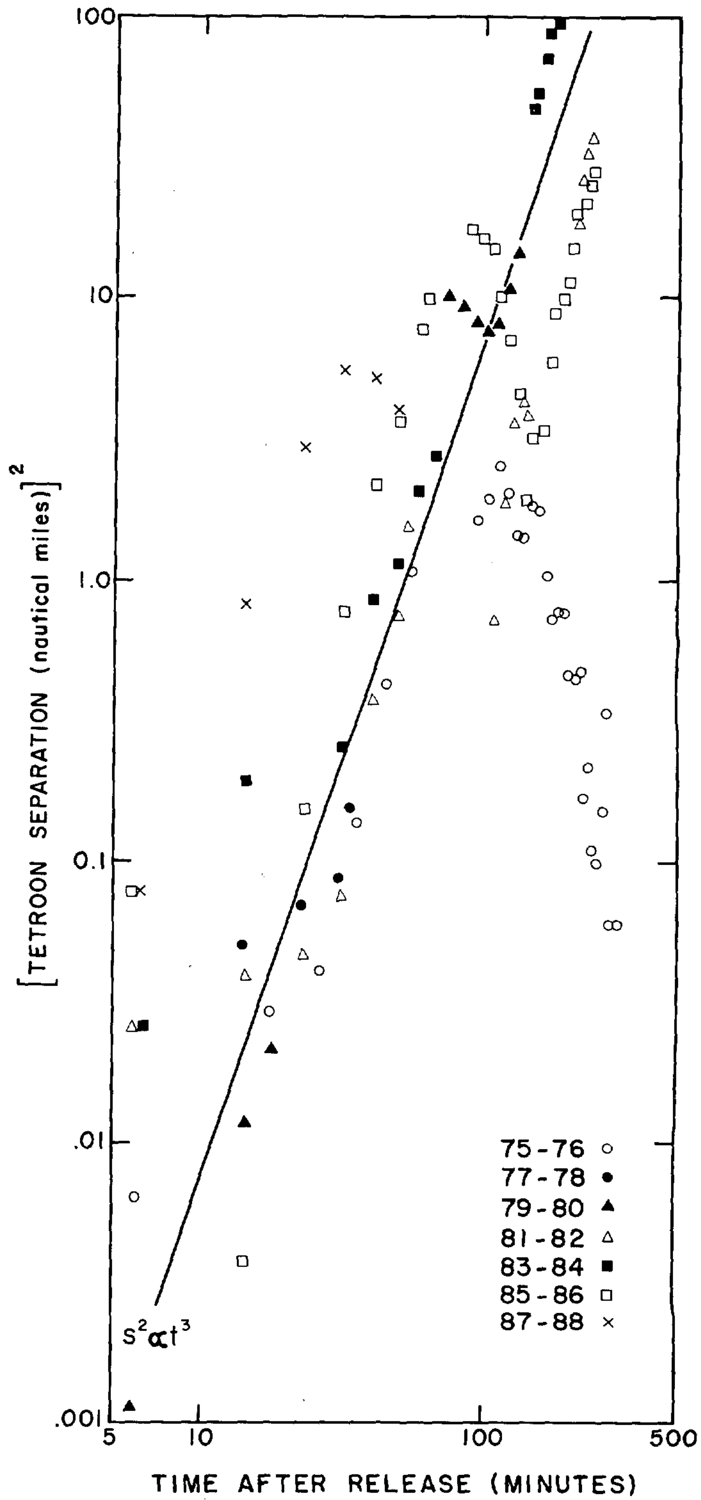

FIGURE 13.—Square of the radar-determined separation distance as a function of time after release for seven pairs of simultaneously-released tetroons. Release site, Marineland, Palos Verdes.

downward motion a mile or so upwind from the crest of the Hills followed by a rapid ascent up the side of the Hills with the highest point of the tetroon trajectory nearly coinciding with the high point of the terrain. There then follows a quite rapid descent just on the lee side of the Hills, followed by another rapid ascent a mile or so downwind. On flights 72 and 73 the aircraft reported considerable turbulence. It is of interest that this turbulence was not associated with the larger-scale vertical oscillations noted along tetroon flights 71, 75, and 76 (about a 20-min. period), but rather with the oscillations of about 10-min. period noted along flights 72 and 73. The aircraft made a vertical sounding between flights 72 and 73 and this sounding indicated a 2.5°C. temperature increase between 1,500 and 2,000 ft. Thus, the turbulence was occurring very near the base of this rather weak inversion. In comparing the magnitude of the vertical tetroon oscillations along flight 71 (released at 1800 GMT on May 29) and flights 72 and 73 (released at 2142 and 2358 GMT on May 29), it is appropriate to note the great increase in stability of the Clover Field sounding between 1100 GMT on May 29 and 0000 GMT on May 30 (fig. 3). Similarly, the large vertical oscillations along flights 75 and 76 were associated with steep lapse rates (see sounding for 0000 GMT on May 31), whereas at the time of flight 84 the lapse rate was again more stable (see sound-

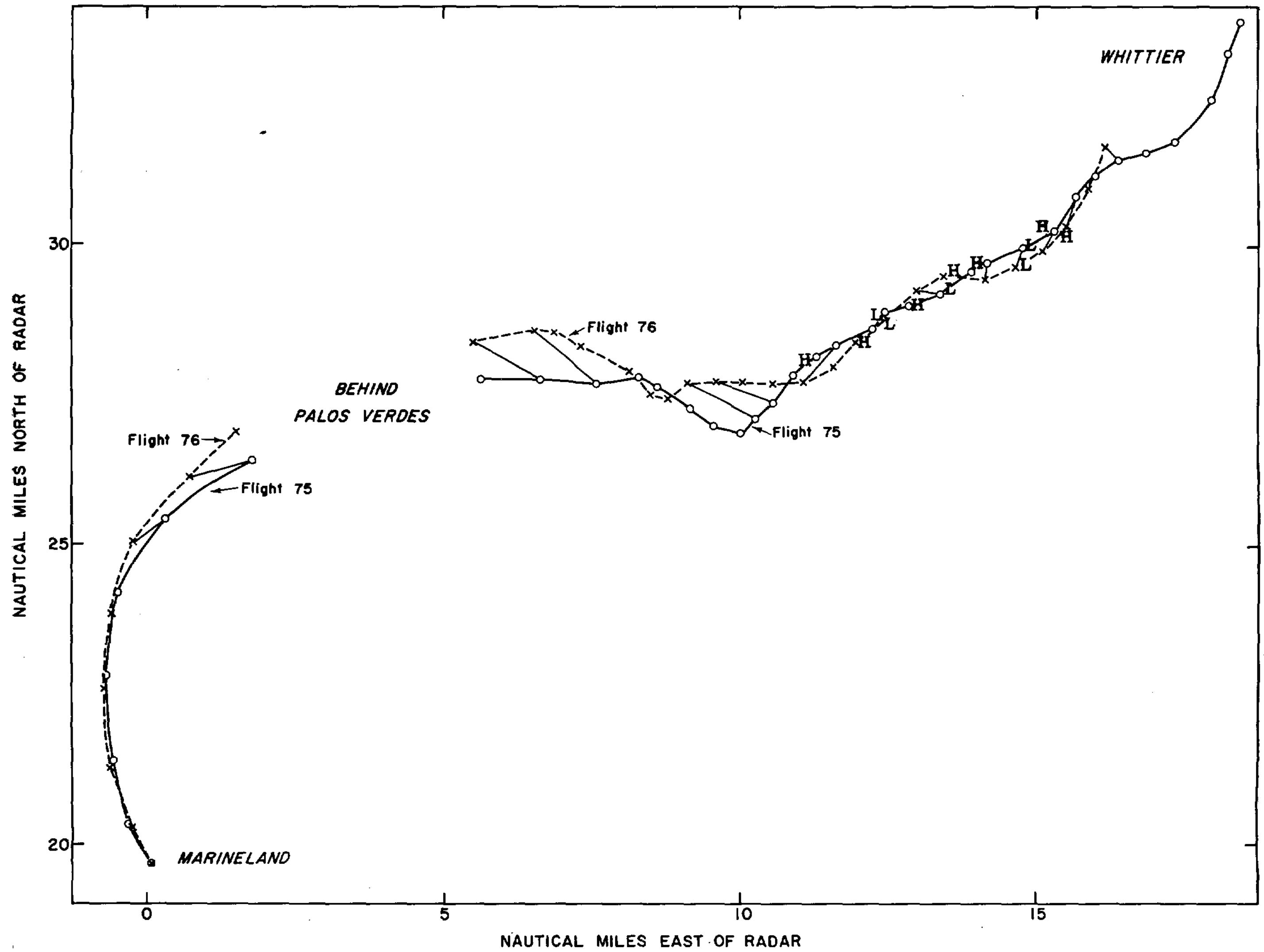

Figure 14.—Smoothed trajectory plot for simultaneously-released tetroon flights 75 and 76. Tetroon positions shown at 9-min. intervals; *thin solid lines (isochrones) connect positions at the same time.* Letters H and L *indicate high and low points in tetroon height traces* as obtained from figure 11.

ing for 0000 GMT on June 2). As in previous tetroon experiments, there appears to be a correlation between the period and amplitude of tetroon oscillations in the vertical and the lapse rate.

7. DUAL TETROON RELEASE

In order to obtain mesoscale estimates of relative dispersion (smoke-puff type dispersion), in seven instances two tetroons were released simultaneously from the same site. Comparison of the height traces for flights 75 and 76 (fig. 11) shows that through a precise weigh-off technique tetroons can be placed very nearly at the same level. Thus, dispersion statistics derived in this manner should have considerable reliability if the distance between tetroon pairs can be determined accurately. In order to test the accuracy of the radar in estimating rather small separation distances at ranges exceeding 20 mi., on flights 75 and 76 the aircraft was periodically requested to estimate the distance between the tetroons. This was accomplished by finding the time it took to pass from one tetroon to the other at a given speed. Assuming this time is accurate to within 1 sec., the resulting estimate of tetroon separation should be accurate to within 200 ft. Figure 12 shows a comparison between separations estimated by the aircraft (crosses) and separations estimated from radar positions smoothed over 9 min. (circles) during the early portions of flights 75 and 76. The evidence that the separation distances determined from the radar are quite accurate is gratifying indeed and indicates that worthwhile dispersion statistics may be obtained in this way. The straight line in figure 12 shows that during the first 100 min. the square of the horizontal separation distance was very nearly proportional to the third power of the time (t^3), as had been found from smoke-puff experiments on a considerably smaller scale [6].

Smoothing the other paired trajectories, one obtains the results presented in figure 13. Also when all the pairs are considered, there is evidence that for the first 100 min. or so after release the square of the horizontal separation distance is proportional to the third power of the time. At greater times, however, some of the separation distances actually become less and the picture is quite confused. The most striking example of a decrease in separation distance with time is to be found from flights 75 and 76, which were only ¼ mi. apart 5 hr. after release, after having been over a mile apart 1½ hr. after release. This decrease in separation distance took place in spite of the large tetroon oscillations in the vertical (see fig. 11). These examples of decreasing separation with time of paired tetroons emphasize the theoretical injunction that only ensemble statistics can be used for analysis of this kind.

Figure 14 shows a detailed plot of the trajectories of flights 75 and 76. Tetroon positions are indicated at 9-min. intervals, and where undue confusion does not result, thin solid lines join tetroon positions at the same time. It is seen that a decrease in separation distance occurred in both the along-stream and cross-stream directions. So close did the trajectories become that they crossed each other 6 times in the course of a few miles. To the east of the Palos Verdes radar shadow the two trajectories traced out a ridge and trough pattern at exactly the same time even though the tetroons were in different locations. Consequently the tetroons cannot have been passing through a mesoscale circulation system, but instead, at a given time, there must have been a change in wind direction over a considerable area (alternatively, a similar wind shift in a random wind field, which seems unlikely).

The letters H and L along the trajectories indicate the high and low points in the tetroon height traces as taken from figure 11. It is surprisingly difficult to line up these high and low positions in a coherent manner. Thus, moving backwards along the trajectories, it is reasonable to associate the first pair of H's and L's with vertical motion patterns through which the tetroons were moving at nearly the same place and time. However, moving westward, the H's and L's occur at nearly the same time (see fig. 11) but at quite different locations and in the unexpected sense, that is, the high and low points of the lagging tetroon (flight 76) occur *upstream* from the high and low points of the leading tetroon. This signifies either an upwind extension of the vertical motion pattern with time or a random nature to the vertical motions. It might be noted that also on the paired Cincinnati tetroon flights, there was difficulty in relating vertical motions in either temporal or spatial frames of reference.

8. SUCCESSIVE TETROON RELEASES

A series of tetroon releases at intervals of time should yield an estimate of the dispersion to be expected from a continuous point source (smoke-plume-type dispersion).

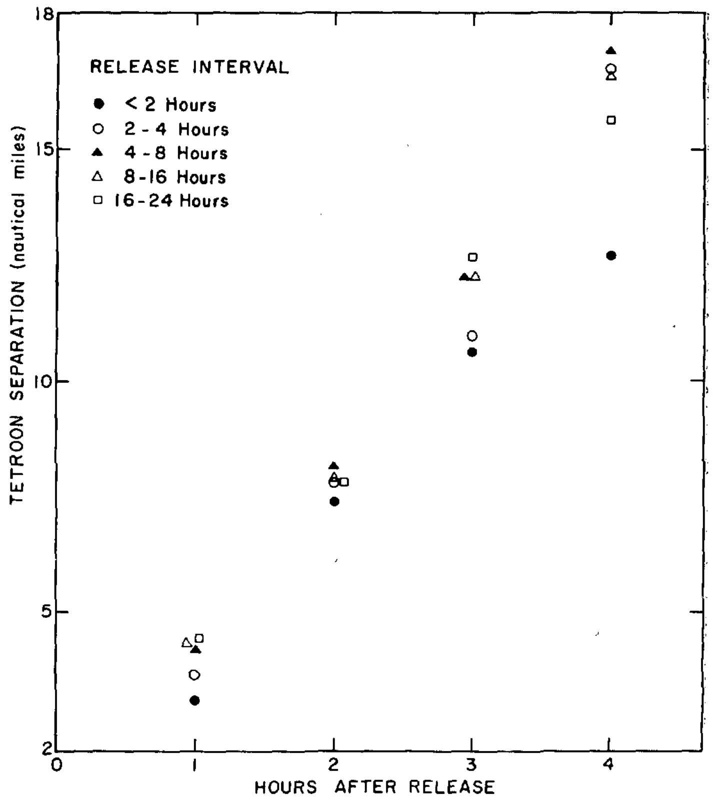

FIGURE 15.—Distance between pairs of non-simultaneously released tetroon flights as a function of time interval between release and hours after release.

However, such a calculation tacitly assumes the existence of a well-defined mean flow, and in many cases such a mean flow can hardly be said to exist in the Los Angeles Basin. For example, tetroons released only a few hours apart can go off in directions 180° apart, making the estimate of cross-stream standard deviation of position almost meaningless. In order to emphasize the oftentimes chaotic nature of trajectories in the Basin, we first of all determined, as a function of time after release, the average distance between pairs of trajectories originating at different times. This was done for various time intervals between release up to 24 hr. The rather unexpected result, shown in figure 15, is that the distance between non-simultaneously released tetroon pairs is much more a function of the time since release than of the time interval between respective releases. Thus, for tetroons released within 2 hours of each other, comparison of the separation distance after each has traveled one hour shows their average separation to be 3 n. mi. whereas after each has traveled four hours their average separation is nearly 13 n. mi. On the other hand, for tetroons released 8–16 hr. apart the corresponding numbers are 4.5 and 16.5 n. mi. This result was unexpected because one would anticipate slow turnings of the wind such that tetroons released at less frequent time intervals would be found at greater separation distances.

TABLE 3.—*Sets of serial flights*

Flight Nos.	Launch site	Time of first launch in series (GMT)	Time interval between first and last launch (hours)
26–30	Long Beach	0511	25.2
30–36	Long Beach	0620	25.5
36–40	Long Beach	0751	20.4
37–42	Long Beach	1805	23.5
43–46	Venice	1501	8.6
73–80	Marineland	2358	45.7
79–88	Marineland	2138	48.9

Careful examination of individual trajectory pairs indicates that the time dependent separation usually increased to a maximum then decreased, but that this reversal took place over a wide variation of times after release of the first flight. The averaging process masks this phenomenon, which could be due to a cyclic wind variation, perhaps of the land-sea breeze type. The existence, for most of the observational period, of a heavy stratus deck over the Los Angeles Basin, together with the passage of the cold Lows previously mentioned, both reduced the intensity of the sea breeze and altered its timing from day to day, at least at tetroon altitude. Thus, study of the effect of repetitive circulation patterns on long term trajectory dispersion must be done under other circumstances.

However, another, and less restrictive approach produced results which would be more nearly expected but which, over the times and distances involved, are of considerable interest in assessing atmospheric dispersion. This analysis of serial trajectories was done in a spatial framework. Seven sets of serially released tetroon flights from three different launch areas, encompassing 46 separate flights, were chosen where it appeared possible to define, even roughly, a mean wind. Trajectory reversals and movements in a direction opposite to the mean flow were considered quite acceptable as long as they remained within the initially defined angular sector. Table 3 shows the grouping of the flights meeting these conditions, together with the launch sites, and time interval between the first and last flights of each set.

The lateral separation of each set of trajectories was determined in 2½-n. mi. increments from the launch site and in two quite different ways. First, the arc distance between the outermost trajectories was measured at each distance. These outermost trajectories were quite independent of whether the flights were launched first and last, first and second, or even simultaneously. To convert these data into a form similar to that used in conventional diffusion analyses the arbitrary assumption was made that the separation distance at each arc contained 95 percent of all the possible trajectories that might have occurred in this period, or in other words, that they represented $\pm 2\sigma$ about the (undefined) mean. There is no justification for this assumption (although we have a "feeling" it is reasonable) and it renders the absolute values of the "plume" spread suspect. However, we wished to look at the rate of spreading and this is unaffected by the particular choice of numerical σ value. In addition, and as a check on this approach, a second procedure was used. Here we defined, by eye, an azimuth which appeared to best represent the "mean wind" of a particular set of trajectories and at each arc distance the standard deviation of the set of trajectories was calculated. Inherent in both these methods is the assumption that the lateral spreading of the tetroons is taking place in a random turbulent field and that there is no (or at best very little) serial correlation between tetroon paths. In other words, it is as likely for the first and second tetroons of a series to end up farthest apart as for the first and last of the series. This is the main thesis of the statistical theory of diffusion, and in spite of an intuitive reluctance to make this assumption, the data appear to bear it out in many cases, as shown below.

Figure 16 shows the results obtained from the "4σ envelope" assumption. In this figure the slope of the straight line (an eye-estimate of the best fit to the points) yields an approximation to the lateral cloud spread (σ_y) with downstream distance x. We thereby find that σ_y is proportional to $x^{0.9}$. By the second method we estimate that σ_y is proportional to $x^{0.8}$. Thus, the two methods give quite similar results on the *rate* of lateral spread with downstream distance and, what is perhaps more surprising, give actual lateral standard deviations differing by no more than a factor of two (table 4). For comparison, Prairie Grass diffusion experiments [7] carried out with a tracer gas (SO_2) from a surface source over a maximum range of 800 m. showed that cloud spread varied with distance as $x^{0.8}$ to $x^{0.9}$ for unstable conditions and as $x^{0.8}$ for near neutral conditions. On an entirely different

TABLE 4.—*Standard deviation of lateral tetroon displacement (n. mi.) as a function of downstream distance for sets of serial flights. Numbers without parentheses indicate results obtained from 4σ assumption; numbers within parentheses, results obtained by computing σ (see text)*

Flight nos.	Downstream distance (n. mi.)										
	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5
26–30	1.2 (2.1)	2.2 (3.7)	3.2 (5.9)	3.4 (6.2)	4.6 (8.2)	5.5 (11.0)	---	---	---	---	---
30–36	1.2 (2.2)	2.2 (4.3)	2.7 (5.1)	3.4 (6.2)	---	---	---	---	---	---	---
36–40	1.1 (1.7)	1.7 (2.3)	2.6 (3.8)	4.0 (7.1)	4.7 (7.7)	5.3 (8.0)	6.0 (8.6)	6.5 (9.3)	---	---	---
37–42	0.9 (1.3)	1.5 (2.6)	2.0 (3.9)	3.0 (5.0)	4.0 (6.2)	4.8 (7.3)	5.7 (8.0)	6.4 (8.6)	7.1 (9.6)	8.0 (10.8)	8.7 (13.4)
43–46	0.9 (1.6)	1.8 (3.9)	2.8 (5.2)	3.4 (7.1)	4.2 (8.3)	5.2 (9.7)	6.5 (11.3)	6.1 (11.1)	---	---	---
73–80	1.1 (2.2)	1.9 (3.3)	2.8 (4.5)	3.3 (5.8)	3.8 (7.0)	---	---	---	---	---	---
79–88	0.8 (1.4)	1.8 (2.4)	2.5 (2.9)	2.9 (4.8)	3.7 (6.2)	4.6 (7.1)	5.3 (8.1)	5.4 (8.1)	---	---	---
Average	1.0 (1.8)	1.9 (3.3)	2.7 (4.6)	3.4 (6.1)	4.2 (7.3)	5.1 (8.8)	5.9 (9.1)	6.1 (9.4)	7.1 (9.6)	8.0 (10.8)	8.7 (13.4)

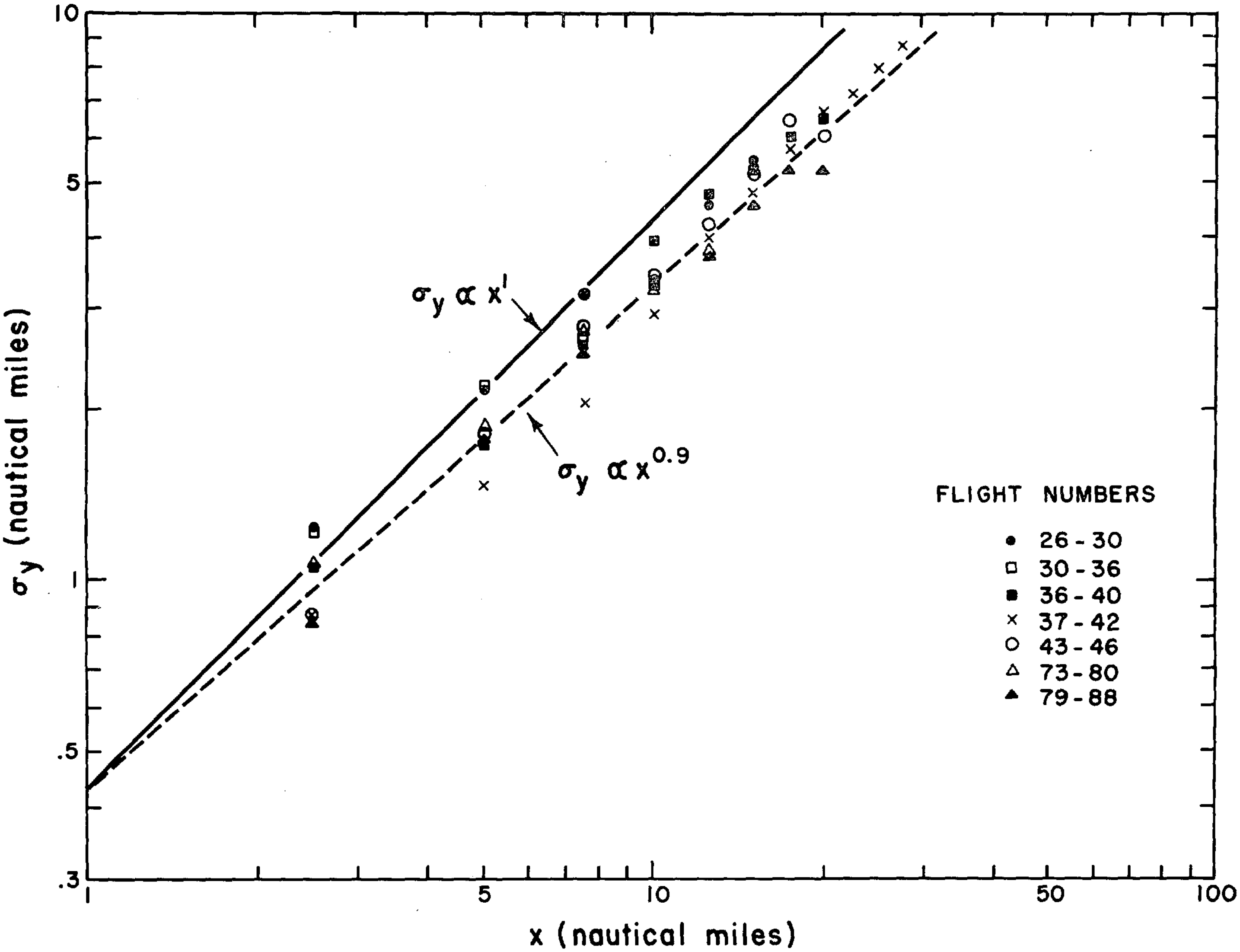

FIGURE 16.—Standard deviation of lateral tetroon displacement (σ_y) as a function of downstream distance (x) for sets of serial releases Data obtained from "4σ" assumption (see text).

scale Sutton's [8] reanalysis of Richardson's and Procter's data from manned balloon competitions over distances of 50 to 500 km. showed the spreading of the balloons to be nearly as $x^{0.875}$. Since the tetroon data cover distances from 4.5 to 50 km. and time spans of 8 to 48 hr. they are intermediate in scale to the Prairie Grass and balloon data, yet the results are quite similar. As an additional comparison, it is interesting to recall that Sutton [9] suggests that the variance (σ^2) in cloud spread will be a variable power of the distance depending upon stability, and indicates that it will be as x^{2-n} where $n=0.25$ for an adiabatic lapse rate and $n=0.33$ for a weak inversion. The tetroon data would yield values of n varying from 0.22 to 0.37, and the Clover Field raobs confirm that within the layer through which the tetroons were spreading, the lapse rate varied from adiabatic to approximately isothermal.

From the point of view of operational usefulness, note that there is no real difference in the spreading of the trajectories for the series of tetroon flights 43–46, released over an 8½-hr. period, and the series of flights 79–88, released over a 49-hr. period. If one interprets this in terms of a continuously emitting source, then the concentrations during the period May 31 through June 1 would have been six times greater than on May 24. It thus appears that this technique has a potential in diffusion research, particularly at locations where there are appropriate radars. Conducting continuous gaseous aerosol tracer experiments over ranges in excess of a few miles or times of more than a few hours is a very expensive and complicated undertaking, perhaps costing hundreds of thousands of dollars. In contrast, the work described here was carried out by four men with a total cost, in expendables, of less than $5,000. There are, of course, obvious limitations to this approach, but it must be remembered that in addition to providing statistical data on the spreading of "particles," information is obtained on how each "particle" arrived at a particular point.

9. TETROON TRIADS AND THE ESTIMATION OF FIELD PROPERTIES OF THE FLOW

Without great difficulty it has been found possible to track three transponder-equipped tetroons with one WSR–57 radar. This makes it possible to estimate, from temporal changes in area of the resulting triangles, field properties of the flow such as horizontal divergence, vorticity, and deformation. As an example, figure 17 shows the triangle (solid line) formed by flights 81, 83, and 84 at 2308 GMT on June 1 and the triangle (dashed line) delineated by these same flights 22 min. later. The triangular area changes from 22 to 26.5 n. mi.^{2} which, over the 22-min. time interval, yields a horizontal divergence of 1.55×10^{-4} sec.$^{-1}$. With the assumption that this value can be applied to the mid-level of the tetroon oscillations in the vertical (about 400 m.), and assuming zero vertical motion at the ground, this yields an overall downward vertical velocity of about 12 cm. sec.$^{-1}$ at a height of 800 m. In addition, of course, vorticity and deformation can be estimated by rotating the tetroon displacements 90° and determining different triangular areas [10]. It seems unlikely that any other measurement technique would permit, at these heights, evaluation of the field properties of the flow on such a small horizontal scale. While these data may be questionable until further information on the character of divergence, vorticity, and deformation on this scale is obtained, the ability to compute values from more than three trajectories plus the ability to evaluate the changes with time of these parameters should provide information of interest. The simultaneous release of three or more tetroons would be the most logical way of obtaining the necessary data.

Here again the tetroon-transponder system appears to offer unique possibilities. The relation, on the mesoscale, among divergence, vorticity, and deformation, and pressure changes, cloud cover formation (or dissipation), and development of convection, etc., provides opportunities for investigations of a new and basic nature.

10. LAND AND SEA BREEZE TRAJECTORIES

From this multitude of trajectories many interesting case studies can be made. It obviously is possible to deal with only a few of them here, and we have chosen to present examples of three phenomena of interest, namely, the sea breeze-land breeze reversal at heights near 1,000 ft., the veering with time of trajectories in the sea breeze at a still lower level, and a "reverse" Catalina eddy near the inversion base.

In order to delineate the sea breeze-land breeze reversal, consider tetroon flights 29, 30, 31, 33 and 36, released from Long Beach Harbor between 2100 GMT May 20 and 0800 GMT May 22 (fig. 18). A glance at figure 4 shows that at 1,000 ft. from May 21 through May 23, the Clover

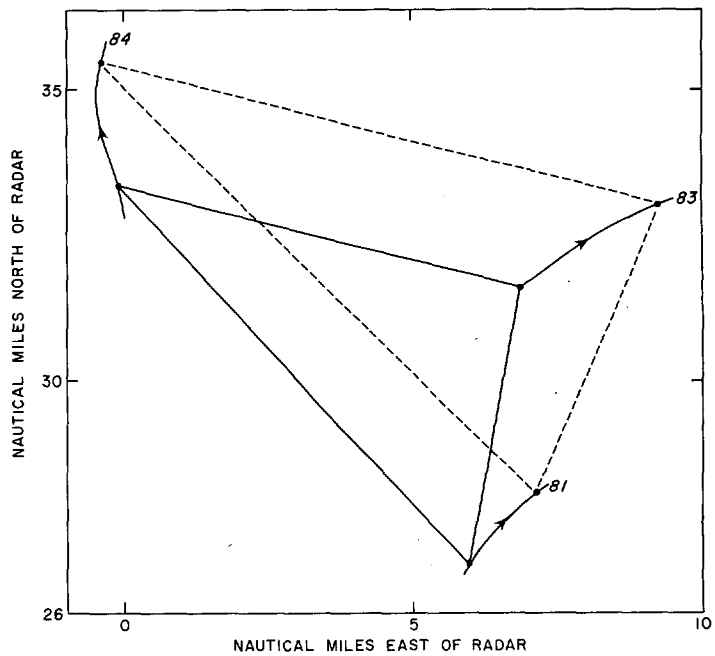

FIGURE 17.—Change with time of the triangular area delineated by a triad of tetroons.

Field winds tended to be westerly at 0000 GMT (1600 PST) and easterly at 1200 GMT (0400 PST), so there is evidence for a sea breeze-land breeze reversal during this period.

Flight 29, released at 1300 PST, moved in general to the northeast and either grounded upon, or was lost behind, the Puente Hills. It would appear that flight 29 was initially embedded in the Long Beach sea breeze from the south, and that this sea breeze then mingled with the Venice sea breeze from the west (note the small anticyclonic loop) and thereupon took on a more eastward movement.

Flight 30 was released at 2220 PST on the same day. This flight first moved to the north-northwest, performed a small anticyclonic loop and turned westward at 0340 PST, after which time it was obviously embedded in the land breeze. At 1340 PST, flight 30 turned toward the shore, arrived over the beach at 1530 PST, passed over the northern outskirts of Santa Monica, and then moved into the San Fernando Valley over a low portion of the Santa Monica Mountains. Certainly the turn at 1340 PST appears to have been associated with the inception of the sea breeze. Less certain is whether the initial movement of the tetroon to the north-northwest from Long Beach should be considered the dying remnant of the sea breeze or a land breeze forced, for some reason, to go north of the Palos Verdes Hills. On the other hand, flight 31, released only about two hours later (at 0015 PST), appears to have been embedded in a true land breeze from the very start, moving straight west, and therefore south of Palos Verdes Hills, making a cyclonic turn (in the opposite sense to that of flight 30) at 1230 PST, and coming on shore in

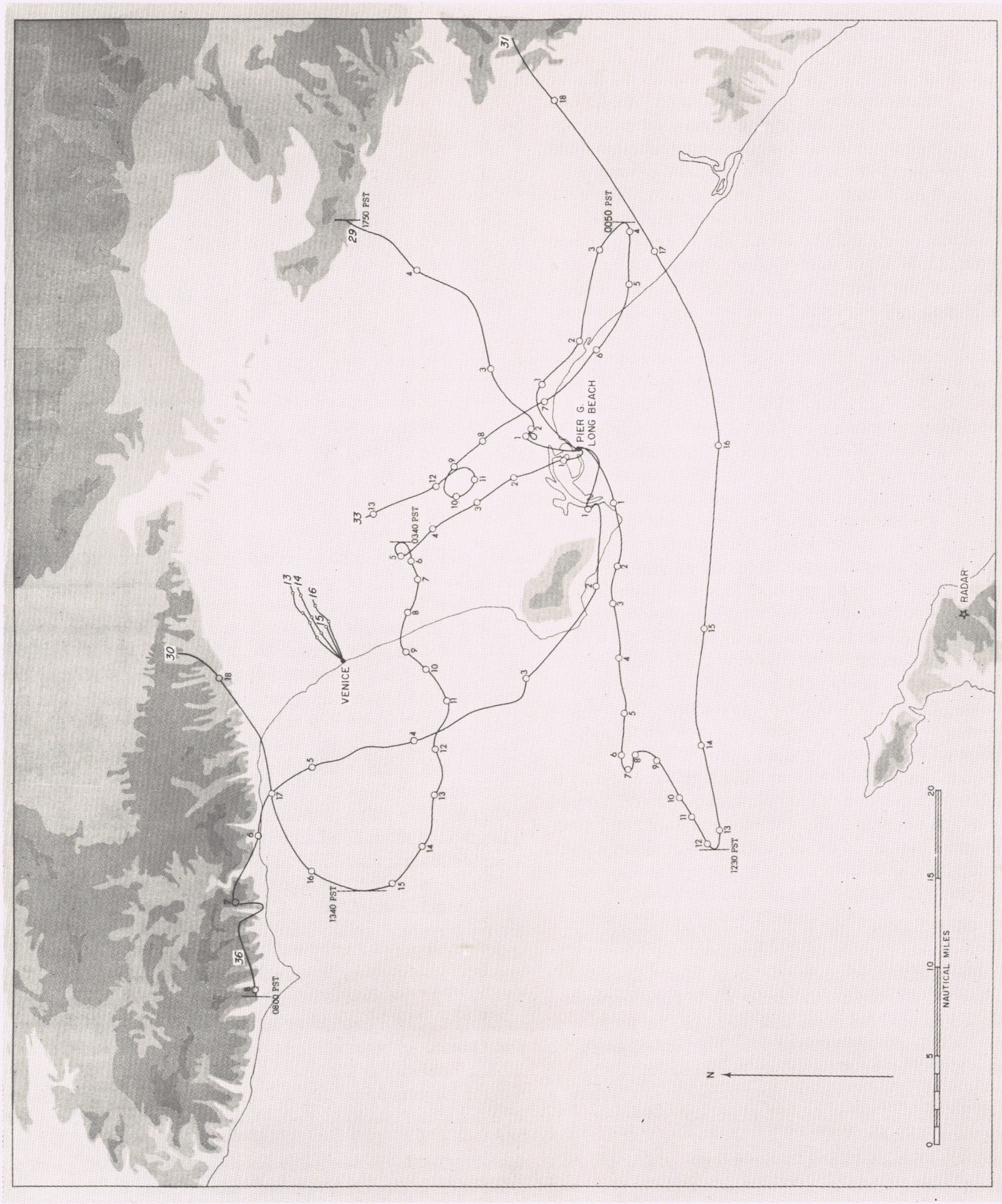

FIGURE 18.—Series of tetroon trajectories originating at Long Beach showing land and sea breeze effects, and a series originating at Venice Marina (positions at 6-min. intervals) showing veering of sea-breeze flow with time. Labeling as in figure 5.

the sea breeze at 1650 PST at Huntington Beach. Especially to be noted from flights 30 and 31 is the great difference in trajectory which may result, at certain critical times, from tetroon releases only two hours apart (see also section 8), and the tendency for the sea breeze to start more than an hour earlier to the south-southwest of Palos Verdes Hills (flight 31) than to the west of Venice (flight 30).

As a check on the above results we have flights released approximately 24 hr. later. Most interesting is flight 33, released at 2102 PST, 1¼ hr. earlier than flight 30 was released on the previous day. Flight 33 started off to the northeast as though still embedded in the typical Long Beach sea breeze regime. However, within one hour it turned and moved to the southeast. It is not certain, but this movement may have been associated with the Venice sea breeze which had come around the Palos Verdes Hills from the northwest and had overpowered the dying Long Beach sea breeze. In any event, at 0050 PST (almost exactly 12 hr. after the time of reversal from land breeze to sea breeze on flights 30 and 31) the trajectory turned by nearly 180° and moved back toward the northwest almost paralleling the initial movement of flight 30. Flight 33 was lost in the Palos Verdes radar shadow and therefore presumably turned to the west just as did flight 30. In agreement with flight 31, flight 36, launched nearly 24 hr. later (at 2351 PST), moved south of the Palos Verdes Hills, but then adopted a more northwesterly course. This flight was still moving westward just south of the Santa Monica Mountains (and very close to the Point Dume launch site) when it was lost at 0800 PST.

In retrospect, the unresolved question is whether to associate the north-northwestward movement of the tetroons in the Long Beach area during the hours near midnight with a dying Long Beach sea breeze or with a true land breeze induced to go north of the Palos Verdes Hills. The authors tend to the latter view, feeling the offshore flow is stronger, and probably starts earlier, in the Venice area (partially due to the proximity of the Santa Monica Mountains) and, through some eddy-friction effect, may actually induce the nearly stagnant air in the Long Beach area to move with it for a short time, and hence to move north of the Palos Verdes Hills.

With regard to the veering of tetroon trajectories in the sea breeze, a glance at table 1 shows that on May 15, because of the continual loss of tetroons in the Palos Verdes radar shadow, a series of tetroon releases at frequent time intervals was made from the Venice Marina during the period of the afternoon sea breeze. These flights, apparently prevented from rising to their normal floating level by a weak low-level inversion, almost certainly were floating at heights of less than 1000 ft. (otherwise they could have been "seen" by the radar over the Palos Verdes Hills) at the times represented by the trajectory segments in figure 18. Of significance is the continuous veering of the trajectories with time, suggesting that the Coriolis force was having some influence on the direction of the sea-breeze flow. The difference in the release time of flights 13 and 16 was three hours and during this time the tetroon trajectory changed direction by about 10°. This yields an angular velocity of 0.17×10^{-4} sec.$^{-1}$, in comparison with the earth's angular velocity about the local vertical at this latitude of 0.39×10^{-4} sec.$^{-1}$. Thus, while the trajectory veering with time was of the correct order of magnitude, undoubtedly influences other than that of the Coriolis force were effective.

Figure 9 illustrates two rather striking tetroon trajectories (flights 21 and 24) which originated (on different days) from Sunset Beach to the southeast of Los Angeles. These trajectories each made a large anticyclonic loop, entered upon the coast to the south of Venice, and apparently disappeared in the Palos Verdes radar shadow. While the direction changes along flight 21 could have been associated with an early sea breeze-land breeze reversal, the direction changes along flight 24 could not. Further, during this period the Clover Field winds showed no pronounced tendency for such a sea breeze-land breeze reversal. It thus seems likely that the tetroon trajectories were delineating a pattern of anticyclonic circulation which, at this time, existed near the inversion base. Such a circulation would be the antithesis of the usual Catalina eddy. Whatever the cause of such a "reverse" Catalina eddy, it would certainly serve to keep pollutants within the Los Angeles Basin even without the presence of the customary land and sea breeze regime.

11. CONCLUSION

This preliminary, albeit large-scale, experiment with a tetroon-transponder system in the Los Angeles Basin has proven the potential of this system for investigations of various kinds. With specific reference to Los Angeles, there appears no reason why trajectories of great value could not be obtained in true smog situations, and the obtaining of such trajectories will be attempted within the year. The greatest drawback to the system, as now constituted, involves the inability accurately to determine height from the WSR–57 radar at such great ranges. The development of a temperature-measuring device to be associated with the transponder is now well under way, and this will indirectly yield the tetroon height in regions where radiosonde data are available. The obtaining of pressure directly appears much more difficult. With the inclusion of a temperature-measuring device, the tetroon-transponder horizon appears almost limitless.

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