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REPORT ON TESTS OF THE WATER-DROPPING CHARACTERISTICS OF THE MARTIN MARS AIR TANKER

NANAIMO, B.C. -- SEPTEMBER 1960

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D.E. Williams

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Introduction

A Martin Mars, a large four-engined military flying boat, was converted to a water bomber early in 1960 and put into operation during the following fire season by Forest Industries Flying Tankers of Vancouver, owned jointly by six of the larger West Coast forest operators. (It is interesting to note that, of the six aircraft of this model built, four are in existence today and all four are owned by this Company.) Based at Sproat Lake on Vancouver Island, the converted Mars is used to drop large quantities of water on incipient forest fires mainly in the coast forests.[2/]

The water tank in the Mars has four separate compartments, each with a capacity of 1,500 gallons (Fig. 1). The water is picked up by two retractable probes while the aircraft is accelerating on the water prior to taking off. It enters the two rear compartments and then, through one-way gates, into the foreward compartments. Vents are provided to allow the replaced air to escape from the tanks, and spring-loaded doors dispose of the over-flow. Air scoops are also provided so that, when the aircraft is in flight, a slight air pressure is maintained in the air space of the tanks to allow for quick ejection of the water when the drop gates are opened.

The water drop can be made using water from one, two, three, or four compartments — quantities of from 1,500 to 6,000 gallons can be dropped in one pass. The controls are designed so that the compartments to be emptied can be pre-selected on the way to the target; over the fire a single switch then controls the operation of the drop gates on those compartments.

[1/] Research Officer, Forest Research Branch, B.C. District Office, Victoria, B.C.

[2/] On June 23, 1961, the aircraft described here crashed while on a water-dropping mission near Parksville, B.C. All members of the crew were killed and the aircraft was a total loss. In October, 1961, it was announced by the operating company that a second Mars will be fitted as an air tanker and is expected to be ready for use at the start of the 1962 fire season.

Further information on the aircraft itself may be found in "The Timberman" magazine for June, 1960, and in the Appendix of this report.

On September 22, 1960, representatives from Forest Industries Flying Tankers; MacMillan, Bloedel and Powell River Ltd.; B. C. Forest Service; and the Forest Research Branch of the Department of Forestry met at Sproat Lake to plan a series of water drop tests for the Mars. These tests were carried out at Cassidy Airport, Nanaimo, B. C., on September 26, 1960.

Object of Tests

The object of the tests, as set down at the Sproat Lake meeting, was to determine the ground pattern produced when various quantities of water are dropped, the water concentration within this pattern, and the relationship of these to the volume released and to the altitude of release. It was also agreed that an attempt should be made to assess the extent of water loss resulting from evaporation of the falling water, a matter of considerable interest to anyone concerned with water bombing. When water is released from an air tanker its forward motion is resisted by the air and the turbulence thus created breaks the water up into a wide range of droplet sizes. In theory, the volume of water evaporated is a function of the amount and duration of turbulence, droplet size, and the evaporating capacity of the air.

Test Methods

(a) Field Measurements

The test area was an 800 by 400-foot section of the rough lying between the runway and main taxi strip of the Cassidy Airport. On this area, tin cans having a diameter of 3.95 inches (28 oz. size) were placed at 50-foot intervals to form a squared grid. A central square of this grid, 400 feet by 400 feet, contained an additional row of cans between each longitudinal row, giving a spacing in this square of 25 feet across the line of flight (Fig. 2). Each can was held in place by an eight-inch stake and a wire loop (Fig. 3). Two men were stationed at the end of each transverse row and, after each test, the depth of water in each can was measured either by a dip-stick or a graduated shell vial (30 ml. capacity) depending on the amount of water in the can (Fig. 4).

Relative humidity, temperature, and wind readings were taken after each test by a British Columbia Forest Service meteorologist. The release of water was timed with stop-watches and a photographic record of each test was taken using a movie camera.

Eight separate test drops were made at an air speed of 120 knots during the period 1300 hours to 1430 hours. During this period the air temperature averaged 66° F. and the relative humidity varied from 59 to 54 per cent. Six of the tests produced ground patterns that fell completely within the target area and were suitable for analysis. They were as follows:

Test Number	Altitude (ft.) Above Ground[3]	Number of Tank Compartments Released
1	120	3
2	120	2
3	120	1
4	120	4
5	250	4
6	750	4

(b) Analyses

For each test the depth of water measured in each can was plotted on a plan of the test grid using a scale of 1" = 50' and isograms (lines connecting points of equal value) were drawn for depths of 0.02, 0.04, 0.06, 0.08, 0.10, 0.20 and 0.30 inches. These gave ground patterns and water concentrations obtainable under each altitude and volume combination tested.

For an analysis of the amount of water reaching the target area it was necessary to multiply the same taken by the area represented by this sample. This was done in two different ways to determine if there were any significant difference in the results obtained by each. First, each catch was multiplied by the area represented by that particular can (1,250 feet in the centre of the target area) and the result converted to gallons. The total quantity thus computed for all cans was assumed to be the gallonage reaching the target area. Secondly, the area between each isogram was determined using a planimeter. This figure was multiplied by the mean of the values represented by the isograms bounding each side of the area and the result converted to gallons. A separate field test in which a known amount of water was sprayed over a test area containing a grid of sample vials was analyzed using the same two methods. Results indicated that either method gave an equally accurate answer.

It was noticed, during the Mars tests, that a considerable quantity of water tended to adhere to the inside of the sample cans as the catch was measured. Later tests with the cans showed that this retention varied from a minimum of 0.002 inch to 0.011 inch depending on how much effort was made to remove all the water from the can where the measurements were made. Under what might be called normal measuring practices, this retained water was found to represent between 0.004 and 0.007 inch. In estimating the quantity of water reaching the target, these values were added to each measured catch and were also applied to those sampled recorded as traces. The differences between the total amount dropped and the totals of the two re-computed amounts reaching the ground should bracket the loss by evaporation. It was felt that this method would be preferable to that using a mean value of water retention in that it indicates the variation to be expected with the data used.

[3] The best measure of altitude is shown. For tests 1 to 4, altitude was measured on photographs taken of the aircraft over the test-drop area. For tests 5 and 6 the altitudes shown are those at which the pilot was directed to maintain the aircraft.

(c) Results

(i) Pattern and Water Concentration

The ground pattern and water concentration for each of the six tests are given in Figures 5 to 10. The dashed line represents the outermost limit of noticeable wetting. In all instances the wind was NNE at 4 to 6 miles per hour while the flight direction was south to north.

When one tank compartment or two compartments on the same side of the aircraft were emptied at an altitude of 120 feet, an elongated pattern having one or two heavy concentrations along the centre line was obtained. When all four tank compartments were emptied at the same altitude, two similar overlapping patterns obtained, the centres of high concentration being roughly 75 feet apart. A strip directly beneath the travel of the aircraft hull received a relatively light concentration (Fig. 8). When all four compartments were emptied from 250 feet, two relatively high-concentration areas approximately 110 feet apart were obtained, but the over-all pattern was broader and less concentrated. The same quantity dropped from 750 feet produced a much broader pattern but with a considerable reduction in quantity reaching the target. The dual pattern was still in evidence but was much less pronounced than from tests made at lower altitudes.

As might be expected, the highest concentration of water (0.31 inches) was obtained from a full load being dropped at the lowest altitude tested. However, a heavy central concentration is not necessarily the best pattern for water dropping and, although there appears to be little agreement on what amount of water constitutes an effective wetting for the average fire[4], it would seem that a broadened, more uniform distribution such as that obtained from the 250-foot altitude test might be more effective.

An analysis of the estimates of water reaching the ground indicated that the greater the altitude from which the water is dropped the more evenly it will be distributed. However, the proportion reaching the ground in what might be termed effective quantities and, consequently, the area covered by such quantities, lessens with increasing altitude.

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[4] Values equivalent to 0.03 to 0.06 inch have been suggested as effective against fires burning in light fuels. See 1, 2, 3, and 5 in list of references.

This is shown in Table 1 where, for the full 6,000-gallon load, (a) indicates how much of the water reaching the ground did so in concentrations equal to or greater than those shown, and (b) indicates how much of the pattern ('pattern' refers to the areas denoted on Figs. 5 to 10 within the dash-line boundaries) was covered by such concentrations.

TABLE 1. WATER DISTRIBUTION

(a) Per cent of water reaching ground in concentrations equal to or greater than:

Alt.	0.20"	0.15"	0.10"	0.06"	0.04"	0.02"
120'	6	11	21	49	65	82
250'	2	7	13	35	59	85
750'	0	0	1	13	42	74

(b) Percentage of pattern covered by concentrations equal to or greater than:

Alt.	0.20"	0.15"	0.10"	0.06"	0.04"	0.02"
120'	1	2	5	16	25	40
250'	0	1	3	12	26	50
750'	0	0	1	4	16	48

For example, if 0.06 inch were assumed to be effective on a fire, Table 1 shows that 49 per cent of the water reaching the ground from an altitude of 120 feet will be effective and will cover some 16 per cent of the pattern area. When dropped from an altitude of 250 feet, the comparable percentages will be 35 and 12 respectively.

Probably the most significant point shown here is the similarity of values from drops made from altitudes of 120 and 250 feet. It would appear that the benefit gained from dropping from altitudes below 250 feet is not worth the additional risk. It is unfortunate that data from the 500-foot drop test cannot be included here; this was one of two tests that did not yield results suitable for analysis.

(ii) Losses

When the water is dropped, the bulk of the load is released in the first three to four seconds after the gates are tripped. The remainder, or "tail", streams out for a further half-minute, a quantity that has been estimated by those familiar with the aircraft to be up to 20 per cent of the load. This volume, of course, was lost to the target area. Evaporation and drift of the smaller droplets would account for a further loss.

Table 2 gives an estimate of the losses encountered as percentages of the total load.

TABLE 2. AMOUNT OF WATER REACHING TARGET AREA

Altitude	120'				250'	750'
Load (gals.)	1500	3000	4500	6000	6000	6000
Volume Measured (gals.)	960	1540	2610	3690	3350	2850
Correct'n.(0.004") Retention	160	230	320	380	480	540
Traces	130	130	150	180	130	220
Total	1250	1900	3080	4250	3960	3610
Similarly using a value of 0.007" for corrections						
Total	1370	2060	3290	4490	4260	3920
Estimated Range of Loss, Percentage of Load	9-17	31-37	27-32	25-29	29-34	35-40

If the value of 10 to 20 per cent is accepted as a reasonable quantity making up the tail of the drop, then the remaining percentages can be attributed to evaporation and drift. This is shown in Table 3.

TABLE 3. ESTIMATED EVAPORATION LOSS

Altitude (feet)	Volume of Water Released Over Target if Loss in Tail is - 20% (gallons)	10%	Estimated Evaporation Loss as Proportion of Vol. Released Over Target (per cent)
120	1200	1350	0 to 4
"	2400	2700	17 to 27
"	3600	4050	12 to 22
"	4800	5400	9 to 19
250	4800	5400	14 to 24
750	4800	5400	22 to 30

If, as is suggested by some, the tail constitutes less than ten per cent of the load, then the volume lost to evaporation must be correspondingly higher. Also, it is to be noted that the tests took place under weather conditions (temperature 66°F., relative humidity 56%, light winds) that did not favor as high as evaporation rate as might be expected during the more hazardous periods of the fire season. There is no explanation for the high recovery obtained from the single tank drop at 120'.

(iii) Length of Time for Water to Reach Ground

As noted earlier, the bulk of the water load carried by the Mars is released in the first three to four seconds after the gates are tripped. The length of time for the water to first reach the ground and the time required for this portion of the load to complete the drop from the various altitudes are given in Table 4.

TABLE 4. TIME FROM GATE RELEASE IN SECONDS

Altitude	Water First Reaches Ground	Bulk of Water on Ground
120'	3	5
250'	6	10
500'	15	26
750'	29	45

A diminishing stream of water continued to fall from the tanks for some 30 seconds after the bulk of the load had been dropped.

Observations and Recommendations

(a) Field Measurements

These tests, although adequate to provide information on pattern sizes and shapes for the various altitudes and loads tested, did not provide sufficiently detailed data from which to obtain accurate measures of evaporation loss. To do so, it would be necessary to measure the amounts of water in the cans to the nearest one-thousandth of an inch. Although this might be done with accurate rain gauges, better results would be obtained by weighing the containers after each test. As this would involve the gathering and weighing of some 200 containers after each test it would greatly increase the time and cost of the tests. Adequate results might be obtained by weighing the containers in each second or third row and measuring the depth in the others. The process could also be speeded up if the containers were capped with air-tight lids after each test for later weighing, though for this procedure a complete set of containers would be needed for each test made on any one day.

Another source of error in estimating the quantity of water reaching the ground, particularly when it is dropped from low altitudes, is the occurrence of heavy concentrations of water in narrow strips that may fall between containers. Replication of drops would largely eliminate this problem but it could also be eliminated, at less cost, by staggering the containers in alternate transverse rows so that a container in one row would be in the centre of the gap between two cans in the preceding row. A combination of both remedies would probably give best results.

(b) Martin Mars Aircraft

The Mars is unique among air tankers in that it operates as a flying boat and, for that reason, has its gates on the sides of the fuselage. The gates provide an opening of 2,300 square inches for each 1,500-gallon tank compartment. This is considerably less than the 1,000 square inches per 200 to 250 gallons recommended by the Arcadia Equipment Development Center to give the most desirable pattern. However, it is understood that the existing structure of the aircraft limits the size of the gates and any structural changes would be very expensive. Any improvements in pattern would likely be attained at less expense by accelerating the flow of the water out of the tanks. This might be attained by increasing the slope of the tank bottom, increasing the air pressure in the tanks, and possibly by coating the inside of the tank to reduce friction. The gate-opening mechanism was improved to ensure that the gates would not interfere with the water flow once released. Such interference is thought to be the cause of multiple high-concentration areas along the pattern. The appearance of similar multiple "high spots" in the pattern of drops from other aircraft, however, suggests that improvements in gate articulation may not entirely solve the problem.

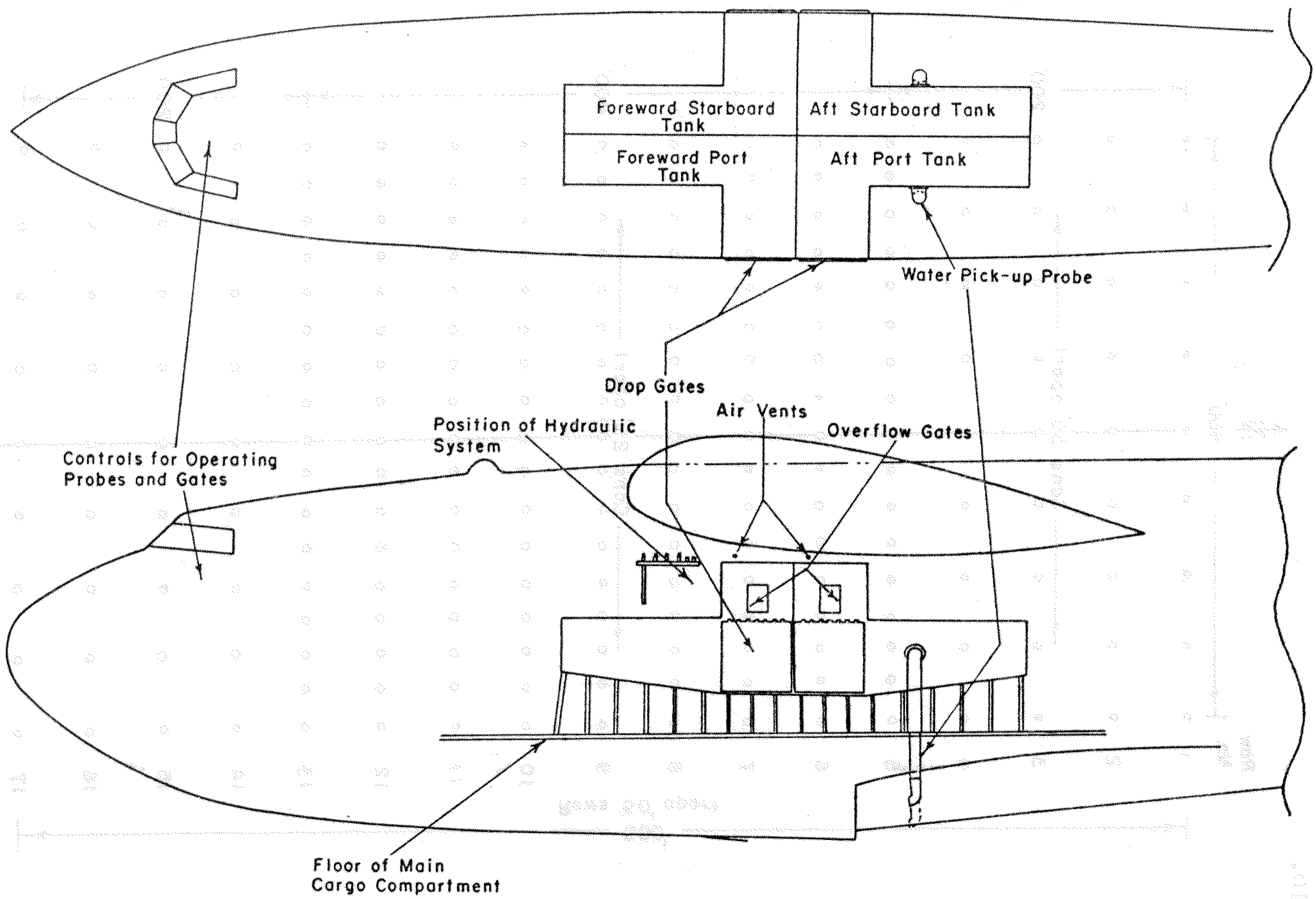

Fig. 1 – MARTIN MARS AIR TANKER
Indicating Position of Tank and Related Installations.

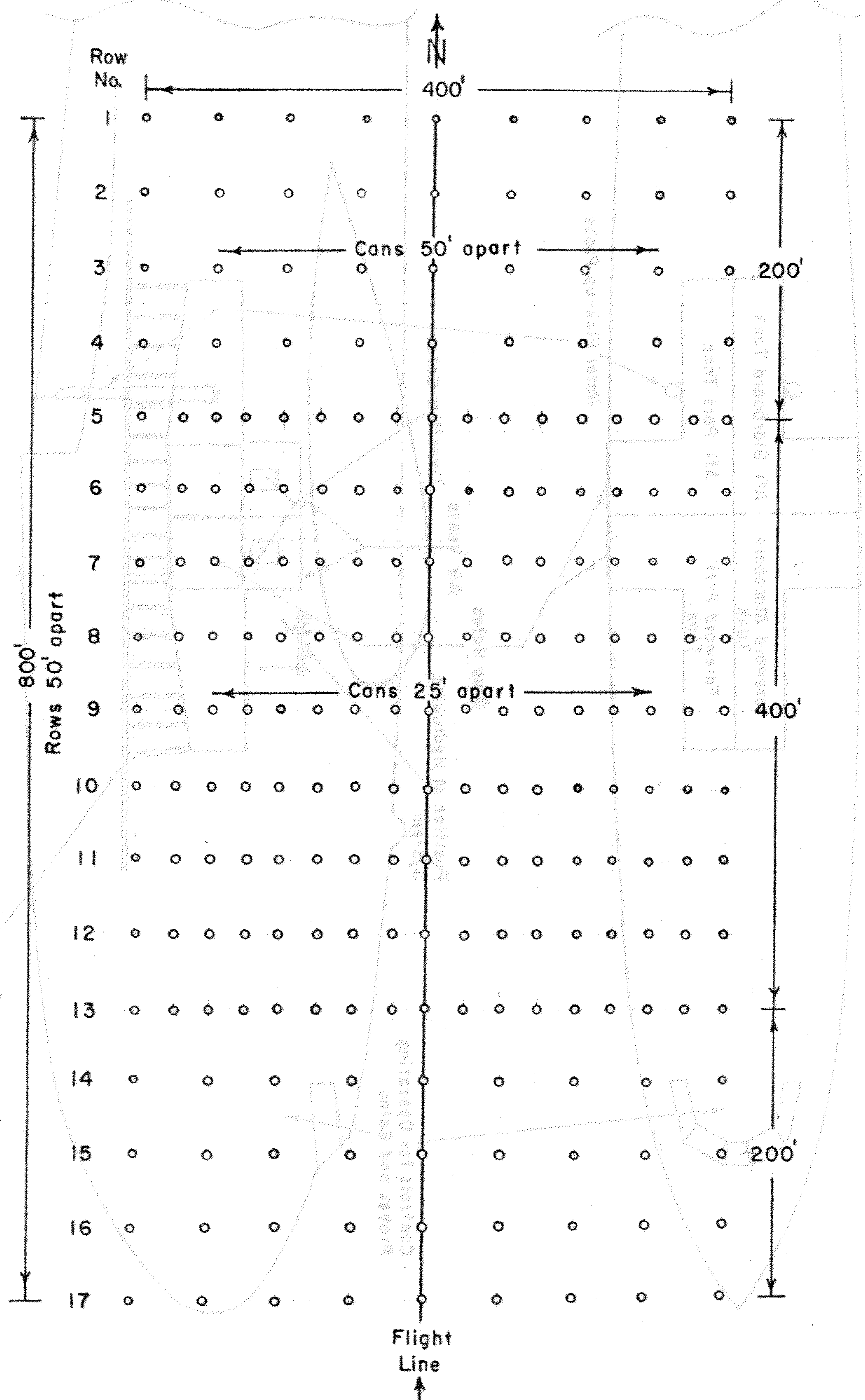

Fig. 2 — Arrangement of Cans in Test Grid.

Figure 3. Sampling can showing supporting stake and wire loop.

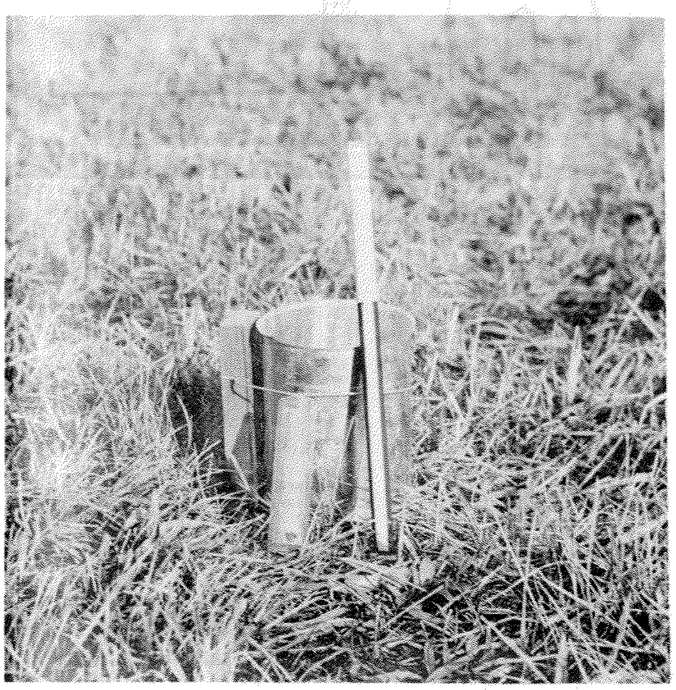

Figure 4. Sampling can and devices for measuring the catch.

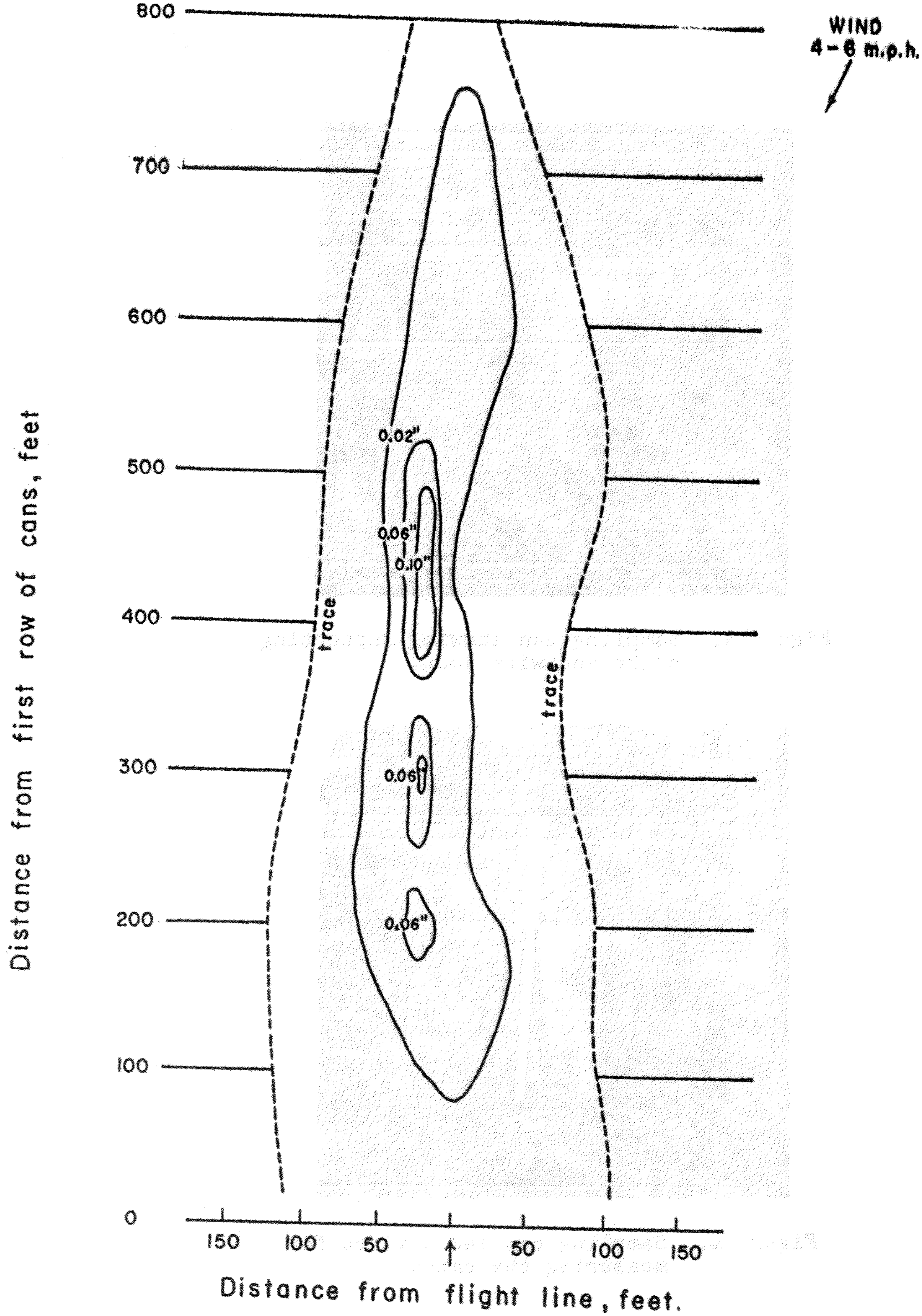

Fig. 5 — Pattern of 1,500 gals. (1 tank) dropped from 120 feet.

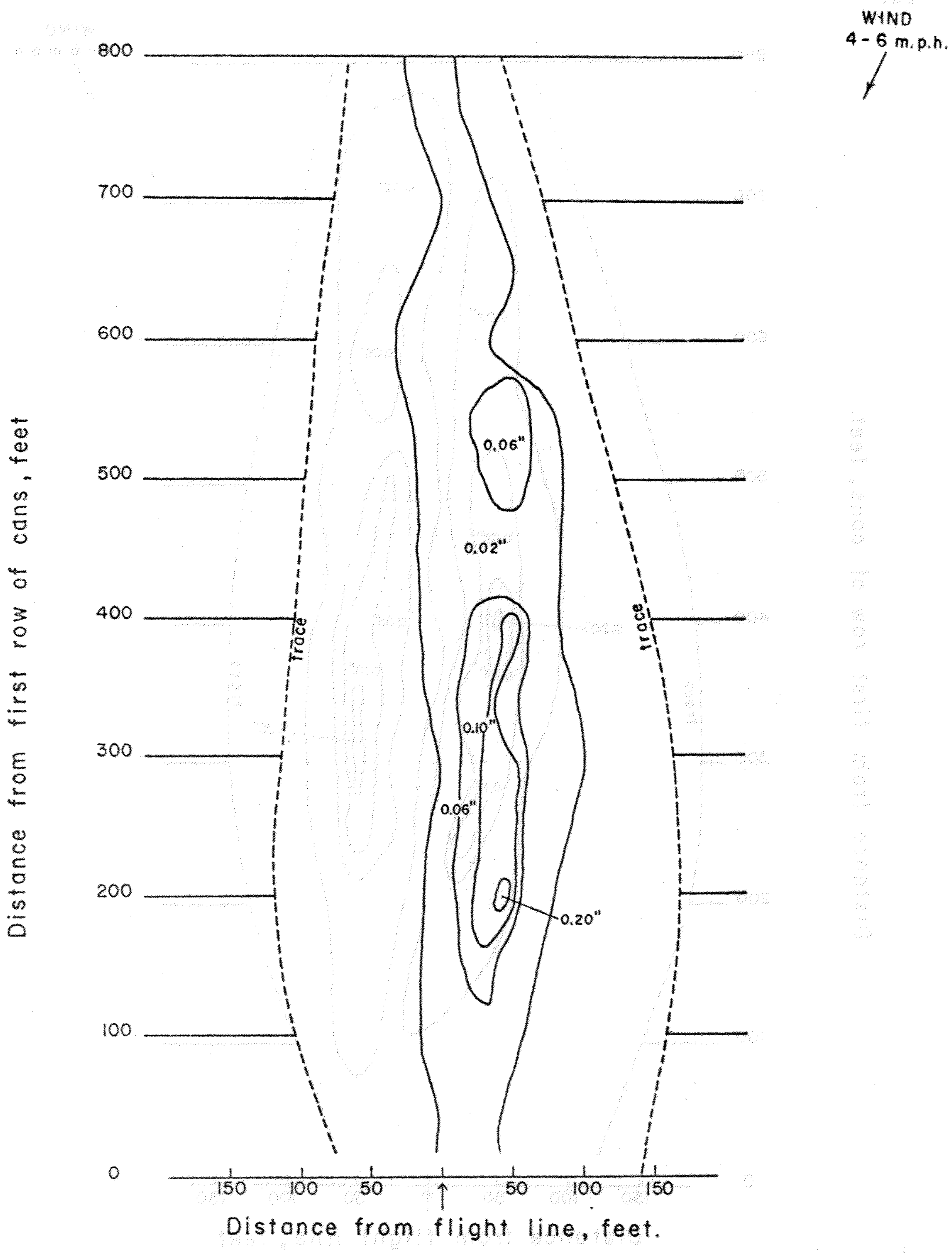

Fig. 6 — Pattern of 3,000 gals. (2 tanks) dropped from 120 feet.

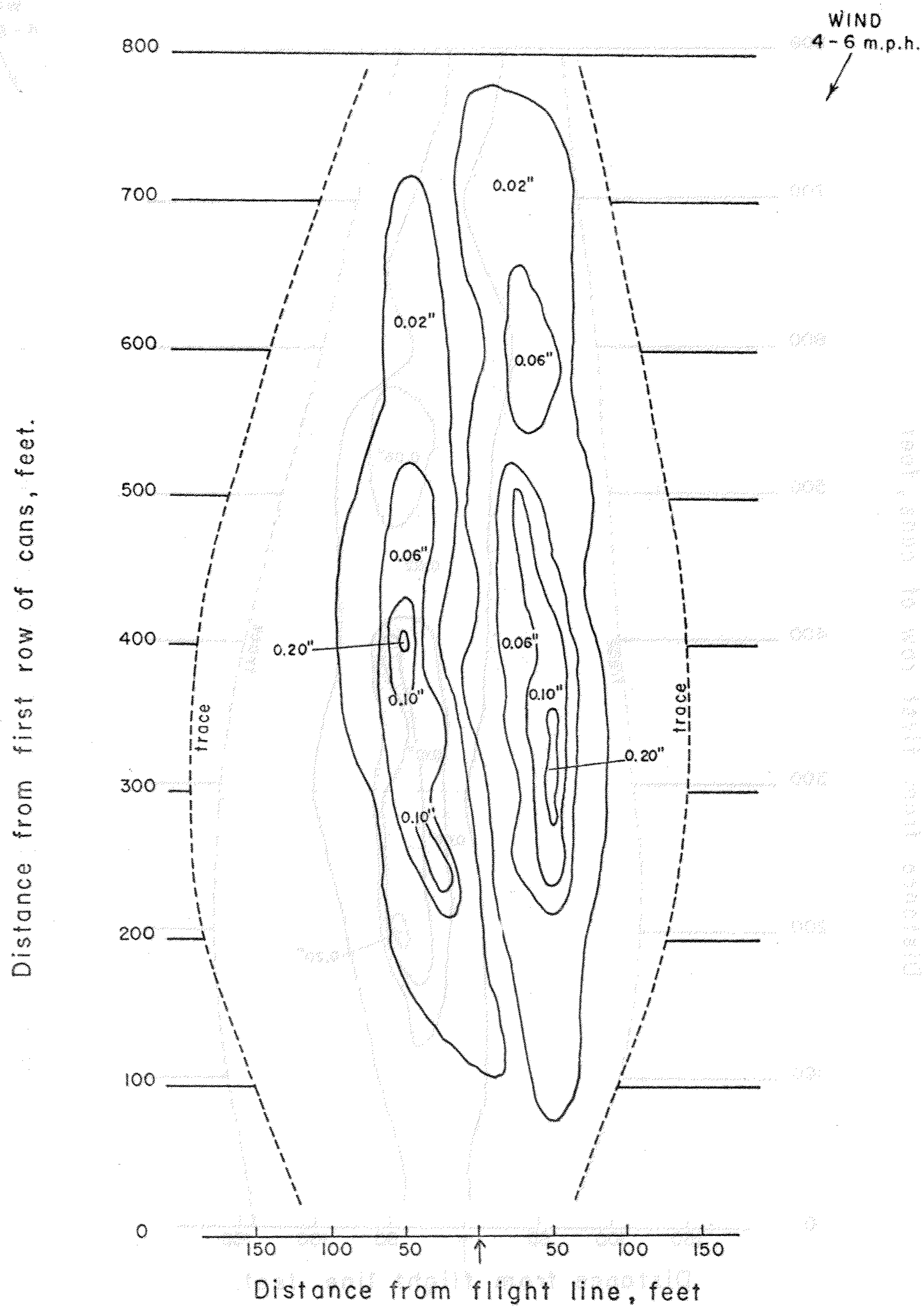

Fig. 7 — Pattern of 4,500 gals. (3 tanks) dropped from 120 feet.

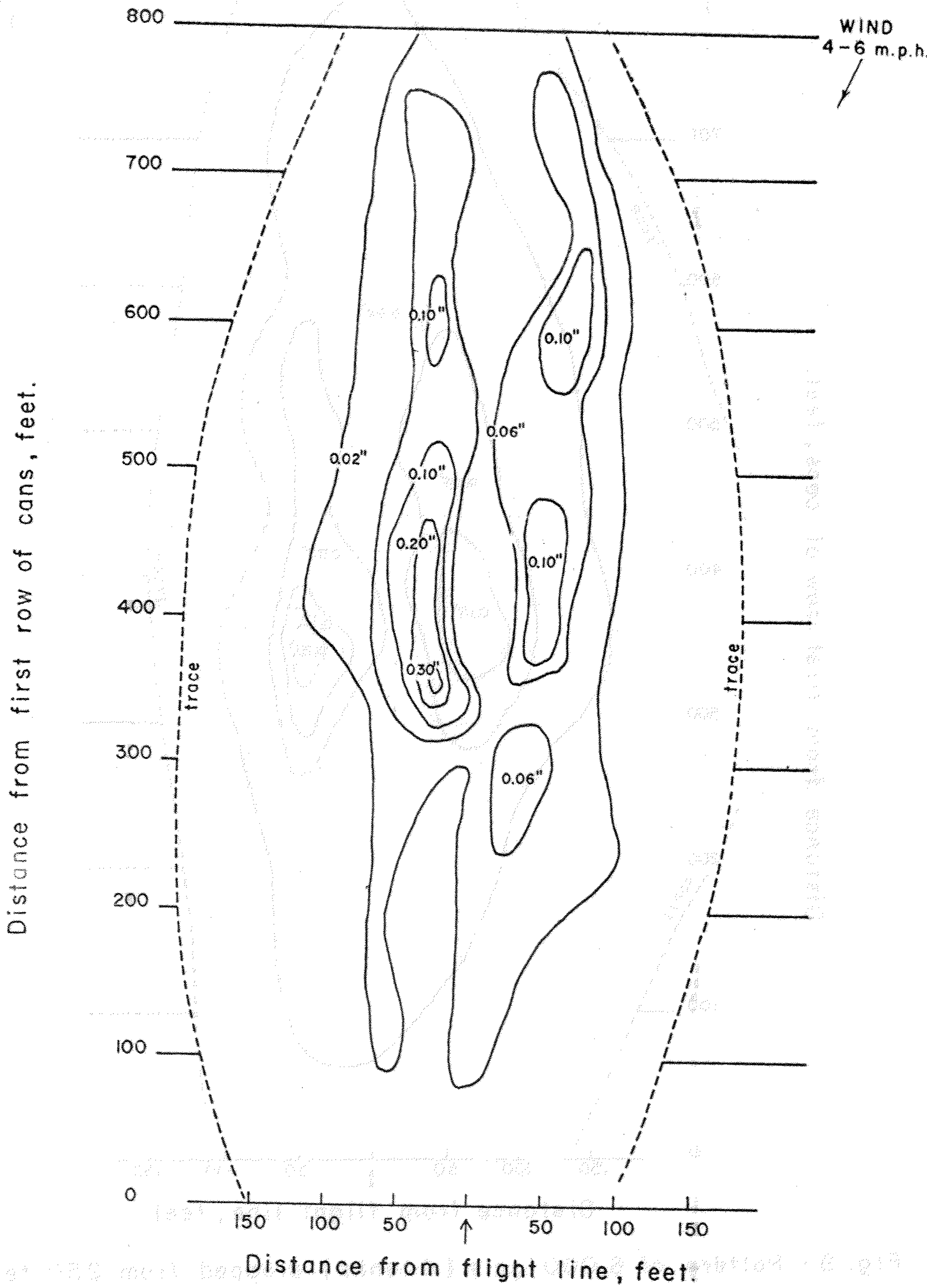

Fig. 8 – Pattern of 6,000 gals. (4 tanks) dropped from 120 feet.

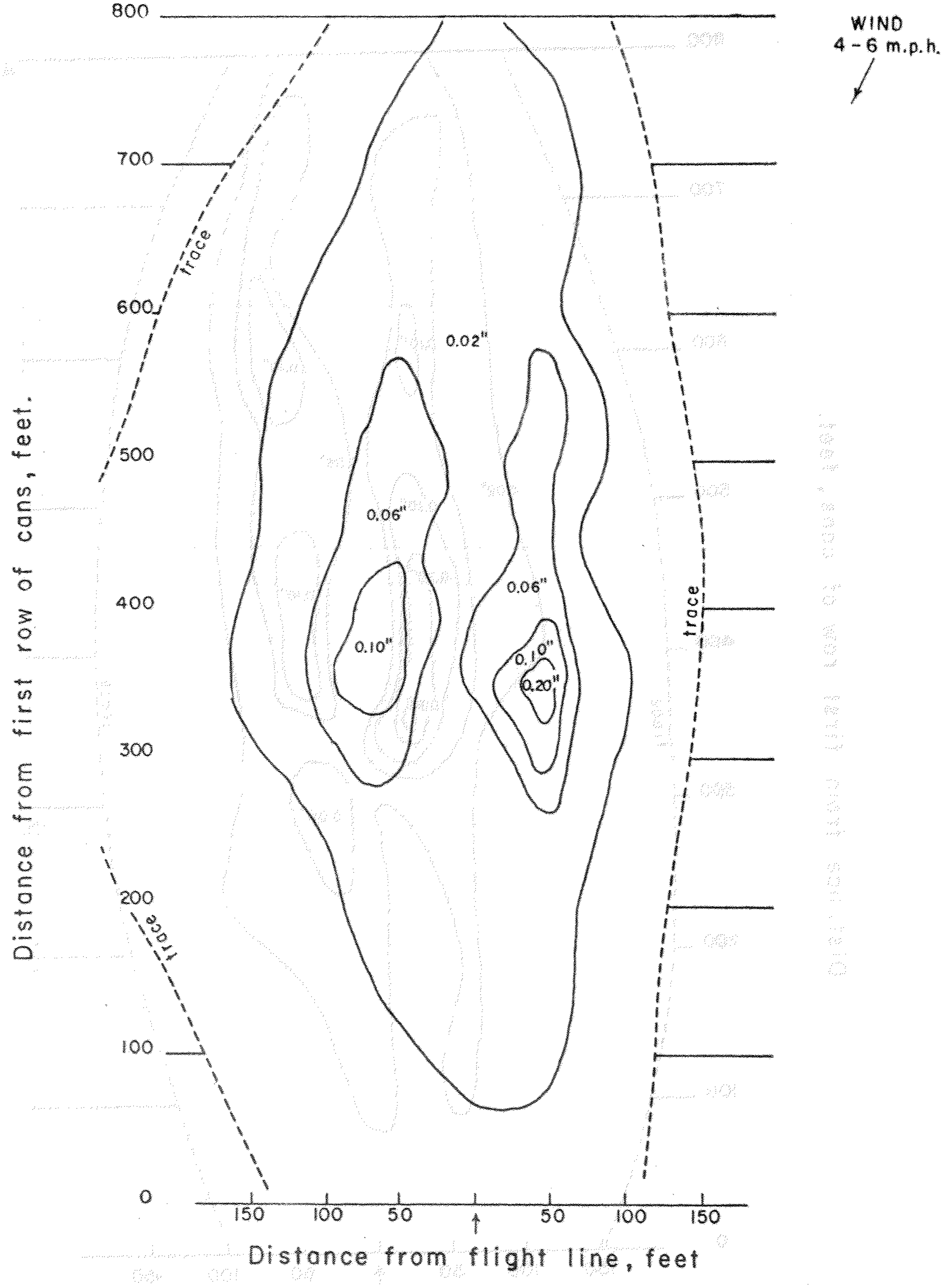

Fig. 9 – Pattern of 6,000 gals. (4 tanks) dropped from 250 feet.

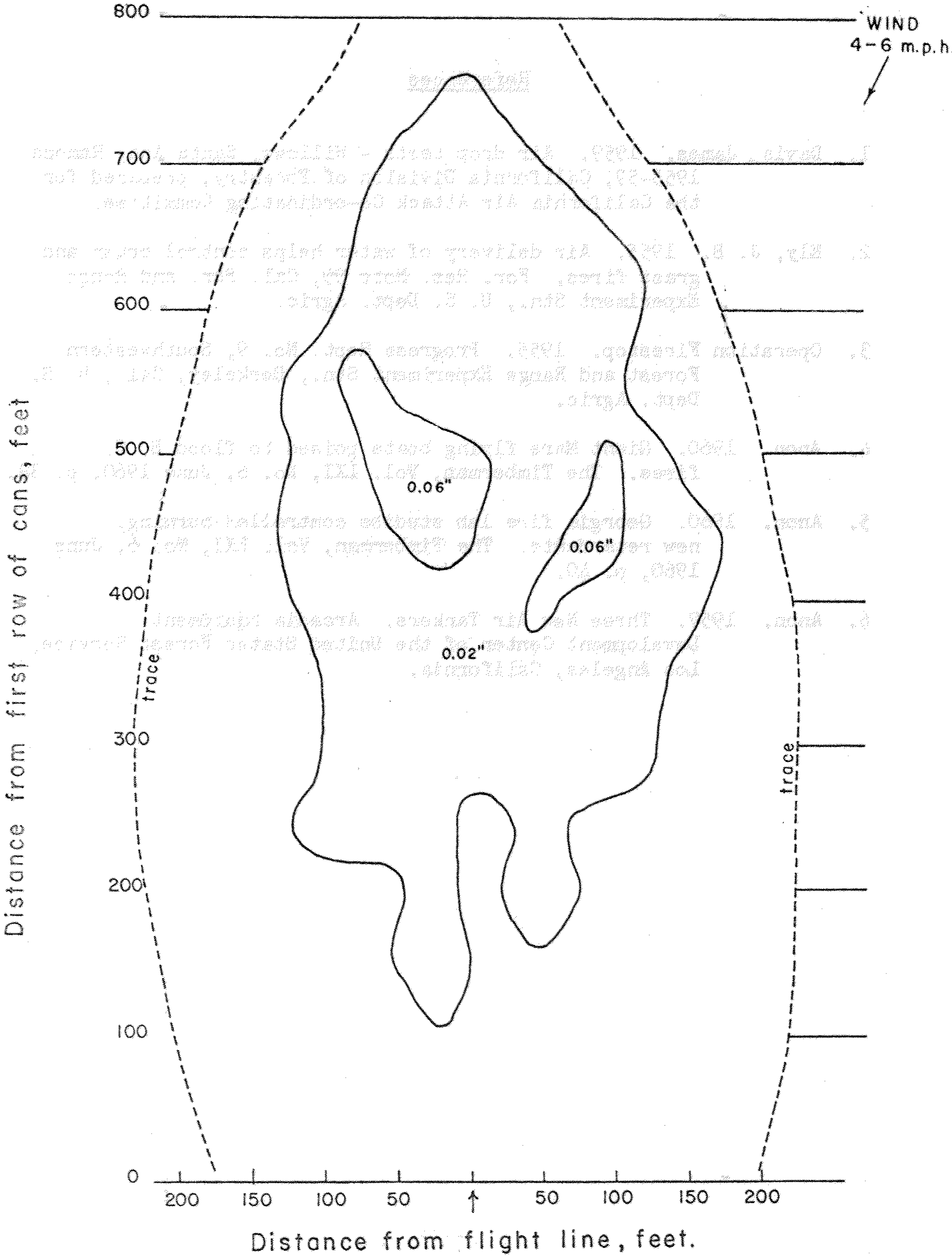

Fig. 10 — Pattern of 6,000 gals. (4 tanks) dropped from 750 feet.

References

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5. Anon. 1960. Georgia fire lab studies controlled burning, new retardants. The Timberman, Vol. LXI, No. 6, June 1960, p. 40.

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Appendix

Martin Mars Airtanker

Wingspan --- 200'	Length --- 120' 3"	Height --- 44'7"

Designed gross weight	165,000 pounds
Tanker " operating weight (mountainous country)	162,000 "
Water capacity at g.o.w.	6,000 gallons
Fuel capacity " "	2,100 gallons, 4 hours
Maximum fuel capacity	10,500 " 20 "
Operating speed	130-140 knots
Pick-up time and speed for full load	25 secs. at 60+ knots
Drop time for full load	3-4 secs.