EVALUATION OF AIRCRAFT SPRAY TECHNIQUES

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Summary

Field tests were conducted to determine the effects of micro-meteorological conditions and height of flight on deposition of sprays released from agricultural aircraft. A portable micro-weather-station was used to record wind velocity profile, temperature, temperature gradient, humidity gradient, wind direction, and turbulence. Spray deposit patterns were measured for a single line emission for a range of conditions of the above parameters. Average deposits and uniformity of deposits were calculated for typical multiple swath applications as an aid to the selection of optimum bout widths and operating conditions.

INTRODUCTION

THE safe and efficient use of pesticides is of prime concern to agriculturists, Government officials, and in recent years the general community. Some information was available on spray distributions under ideal conditions (Taylor, 1961; Yates and Akesson, 1966), but little information was published for a variety of application conditions. During the past year a research programme was initiated at the N.Z. Agricultural Engineering Institute to evaluate the performance of agricultural aircraft spray equipment and application techniques. The programme was designed to evaluate the basic physical factors related to the total recovery and uniformity of the spray deposits.

METHODS

AIRCRAFT AND SPRAY EQUIPMENT

Initial tests were made with a 235 h.p. Piper Pawnee aircraft fitted with Transland spray equipment. The boom was mounted a few inches behind the trailing edge of the wing with 64 Spraying Systems Tee Jet diaphragm check valves. Nozzle caps and tips were removed to provide a 5/32 in. jet diameter which was directed downward or at 90° to the airstream. At 100 mph the system produced a flow rate of 117 gal/min with a boom pressure of approximately 15 lb/sq. in. Thus, at a 36 ft bout width, an average application rate of 16.0 gal/acre was obtained. During each test a remote controlled camera was located on the ground and directed along the flight line to record the altitude and position of the aircraft over the sampling line (Fig. 1).

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FIG. 1

MICROMETEOROLOGICAL MEASUREMENTS

One of the objectives of the programme was to develop a portable station that would record the atmospheric conditions that affect the deposit and distribution of sprays released from agricultural aircraft. The basic factors that have a direct influence on the trajectory of solid particles are the wind velocity profile, wind direction and atmospheric turbulence. In addition, the vapour pressure deficit has a direct effect on the rate of evaporation of liquid particles.

Wind Velocity Profile. The wind velocity profile was measured with light weight, low torque, cup anemometers (Sumner, 1968) that were located at 32, 16, 8 and 4 ft elevations. The anemometers have a linearity of $\pm 1\frac{1}{2}\%$ and a starting speed of no more than 10 cm/sec.

Wind Direction. A lightweight wind vane, R. M. Young Co. Model 12301 (U.S.A.), was positioned at a 16 ft elevation. The vane is constructed of lightweight foamed polystyrene and has a delay distance (50% recovery) of 3.1 ft and a dampening ratio of 0.44.

Atmospheric Turbulence. A number of different parameters can be used to identify the turbulence or stability of the atmosphere. The stability ratio is one index that has been useful in correlating atmospheric turbulence and drift residues resulting from agricultural aircraft application (Yates *et al.*, 1966). The stability ratio was calculated as follows:

$$\text{S.R.} = 10^5 (T_{32} - T_8) / \bar{U}^2$$

where T_{32} and T_8 are the temperature in °C at 32 and 8 ft, respectively, and $\bar{U}$ is the average wind velocity in cm/sec at 16 ft. Platinum resistance thermometers were connected in a wheatstone bridge arrangement to measure accurately the temperature difference between the two dry bulb sensors. The sensors were matched for similar changes in resistance with temperature and calibrated to the nearest 0.01°C with mercury bomb calorimeter thermometers.

A large positive value for the stability ratio, obtained with a strong temperature inversion and a low wind velocity, represents a very stable

atmospheric condition, while negative values are associated with unstable or turbulent conditions. Values near zero are considered nearly neutral. For accurate stability calculations with moist air, it is necessary to correct the temperature to the *virtual* temperature (Sutton, 1955) or the temperature at which dry air would have the same density as the moist air.

Also, the intensity of turbulence in the horizontal plane can be calculated from the fluctuations of the low inertia wind vane. If the angular fluctuations are small, the standard deviation of the angular variations can be used as a measure of the turbulence (U.S. Atomic Energy Commission, 1968).

Humidity. The moisture content or water vapour pressure was calculated from the wet and dry bulb temperatures. To provide accurate measurements, the platinum resistance probes were connected in a bridge, first to measure the temperature difference between the wet and dry probes, then secondly to measure the absolute dry bulb temperature.

The rate of evaporation of water drops is directly proportional to the difference in the saturated vapour pressure and the ambient vapour pressure (Marshall, 1954) which is commonly referred to as the vapour pressure deficit. However, it should be noted that the evaporation of a large mass of spray would increase the ambient vapour pressure and would consequently reduce the vapour pressure deficit from the initial condition.

Temperature Shields and Towers. Two aspirated radiation shields were constructed for use at 8 ft and 32 ft, respectively. The shields were constructed with foamed polystyrene, aluminium foil, and PVC pipe. Each contained a dry temperature sensor mounted parallel to the axis. A second sensor was covered with a wet wick and located near the rear. A vane-axial blower driven with a 6 watt electric motor was adjusted to provide an air velocity of 5.1 m/sec past the sensors. The temperature sensors had a time constant of approximately 40 sec under this aspiration. A 32 ft aluminium mast was designed and constructed to support the temperature probes and anemometers (Fig. 2). The 32 ft temperature measuring unit was designed to enable it to be lowered for servicing and "zero" calibration adjustments.

A 16 ft mast was used for the sensitive wind vane. Both masts were constructed in 8 ft sections and can be readily erected by a three-man crew.

Data Acquisition System. The data acquisition system was portable and self-contained such that it could be operated in remote areas from an a.c. generator.

Multi-channel Millivolt Recorder. This recorder, Philips Model PR3500, was used to record sequentially five temperature measurements and one wind velocity. Three different millivolt ranges were available and used to maintain high sensitivity for different ranges of output. Channel 1 measured the difference in temperature between 32 ft and 8 ft, with a full scale (100 div.) sensitivity of -2.5°C to $+2.5^{\circ}\text{C}$. Channels 2 and 3 measured the wet bulb depression at 32 ft and 8 ft, respectively, with a full scale sensitivity of 10°C . Channels 4 and 5 measured the absolute temperature at 32 ft and 8 ft, respectively, with a full scale sensitivity of 25°C . Channel 6 measured the wind velocity at 16 ft with a full scale sensitivity of 20 mph. The pulse from the cups was converted to a d.c. signal with a Philips PW4242 ratemeter. Alternatively, during a given test the output

FIG. 2

from all the cups could be measured simultaneously by four electric counters. The velocity profiles for the following tests were obtained by starting the counters at the beginning of the spray application and stopping them at the end of 1 minute. The multichannel recorder was operated at a print speed of 5 sec, thus for 6 channels the cycle time was 30 sec.

Single-channel Millivolt Recorder. This recorder, Heath EV 20V with multi-speed chart drive, was used to measure continuously the fluctuations of the wind vane. The sensitivity was adjusted to provide an output of 9 in. for a movement of 360° and a planimeter was used to measure the area under the curve to determine the average wind direction. The wind direction was used to calculate the respective cross-wind components for each elevation. Simpson's rule was used to calculate the average cross-

wind velocity for the entire profile and provide a single number to correlate with spray deposits.

SPRAY SAMPLING AND ANALYSIS

A stable water-soluble tracer, manganese sulphate, was used in all the tests. For some tests a red dye, Kiton Rhodamine B, was also added to provide rapid identification for drop size analysis. The lateral distribution was initially assessed for uniformity with low crop cover, 2 to 3 in. grass turf. Spray samples were collected on 3 × 6 in. stainless steel plates. The plates were placed at 2 ft intervals transverse to the flight line from 20 ft upwind to a distance of 140 ft downwind and then at a 10 ft spacing to a total of 480 ft downwind.

The residue on the plates was dissolved into 40 ml of a solution containing water plus 0.2% liquid detergent. A Philips automatic vaccinator gun calibrated at 4 ml, was used to meter the solution and wash the

FIG. 3

TABLE 1: CONDITIONS FOR TESTS A-D

Test No.	Ht. of Boom (ft)	Wind Vel. at 16 ft (mph)	Wind Dir. Rel. to Flight (°)	Avg. Cross-wind Comp. (mph)	Temp. at 8 ft (°C)	$T_{32}-T_8$ (°C)	Rel. Humid 8 ft (%)	Vap. Press. Deficit 8 ft (mm Hg.)	Stab. Ratio	Recovery (%)	CV at 36 ft Spacing (%)
A	36	4.6	33	2.7	21.4	-0.41	38.5	11.8	-1.14	98.1	21.7
B	28	7.1	100	6.5	17.5	-0.35	62.2	5.7	-0.37	91.5	17.4
C	29	11.0	73	9.8	22.2	-0.10	38.5	12.3	-0.08	84.0	8.4
D	4	12.5	59	10.0	21.2	+0.12	38.5	11.6	+0.03	97.3	20.5

plates (Fig. 3). An atomic absorption spectrophotometer was used to determine the concentration of manganese in the samples. Tank samples from the aircraft were analysed for each test and used to calculate the sample recoveries in terms of gallons per acre.

SPRAY TESTS

A series of four spray tests are reported in this paper to illustrate examples of the procedure that can be used to assess the performance of aircraft spray applications. The tests were selected to show a variety of conditions ranging from a low release height to relatively high release heights. Also the wind varied from low to marginal conditions. Table 1 lists the specific conditions for each test.

SPRAY FORMULATIONS

Spray mixture for test A contained 15 lb of 87% manganese sulphate, 1 gal "IWD 1734" (nonactive aero scrub desiccant, 1.21 S.G.), ½ lb Kiton Rhodamine B dye, plus water to make 29 gal of spray solution.

Spray mixture for tests B, C and D contained 15 lb of 87% manganese sulphate, 1 gal "IWD 1737" (nonactive aero scrub desiccant, 0.96 S.G.), plus water to make 29 gal of spray solution.

DISCUSSION AND RESULTS

Table 1 contains the percentage recovery for each test. This value was arrived at by calculating the equivalent weight of manganese recovered per foot of travel from the sum of the deposits and dividing by the weight of manganese emitted per foot of travel. The recovery follows the expected trend for releases at a high elevation if the average cross-wind component is noted for tests A, B and C. Test D illustrates the higher recovery obtained at a low release height even under marginal wind conditions. A

FIG. 4

computer program was utilized to calculate the total concentration for overlapped patterns at various bout widths and further compute the coefficient of variation for each spacing. The following assumptions must be recognized in interpreting the values of the maximum departures and coefficient of variation: (1) Spacing of the flight line was exactly at selected value, and (2) the single distribution pattern was repeated identically for each of the overlapping patterns. Although in practice it is unlikely that the above conditions can be attained, the above technique does permit the quality of a given pattern to be determined and also aids in selecting a satisfactory bout width. By repeating the experiment several times, a bout width suitable for a variety of conditions could be selected.

FIG. 5 (Test A — height 36 ft, cross-wind component 2.7 mph).

FIG. 6 (Test B — height 28 ft, cross-wind component 6.5 mph).

FIG. 7 (Test C — height 29 ft, cross-wind component 9.8 mph).

FIG. 8 (Test D — height 4 ft, cross-wind component 10.0 mph).

Figure 4 illustrates the effect of bout width on the coefficient of variation for each of the test patterns. It is obvious that the overall uniformity is generally improved by using very narrow swath spacings — *i.e.*, for all patterns the maximum coefficient of variation was less than 13% for any bout width less than 19 ft. Tests A and D with a low cross-wind component or at low elevations, produced a narrow pattern and consequently required narrow bout widths to obtain a low coefficient of variation. The selection of the bout width depends on the tolerance level for the chemical, crop, pest combination and the possible variations of flight height and wind.

Figures 5, 6, 7 and 8 illustrate the single deposit pattern for each test. A bout width of 36 ft was selected to illustrate the combination effect of

FIG. 9

the percentage recovery and variation in total deposit. It should be noted that all of the patterns would be substantially improved by using a 24 ft bout width.

Figure 9 shows the sensitivity of the different patterns to a variation from the intended swath spacing. The average calibrated rate (100%) is shown as well as the minimum deposit that occurred. For instance, if the aircraft deviated 5 ft from an intended spacing of 36 ft and an average of 16.0 gal/acre, the minimum deposit for a low cross-wind, test A at 41 ft, was 8.6 gal/acre whereas tests with higher cross-winds gave minimum values of 11.5 gal/acre or higher.

This paper describes the principles involved in evaluating the efficiency of aerial spray applications. The data indicate typical results for a few specific conditions. However, it should be emphasized that several replicate tests would be required for each application condition before general conclusions can be drawn. Future tests are planned to determine variability between tests under constant conditions as well as to examine the effects of atomization, micrometeorology and spray formulation.

ACKNOWLEDGEMENTS

The assistance of Aerial Sowing Ltd. is gratefully acknowledged.

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