EVALUATION OF A MODIFIED DOUGLAS DC-7B AIRCRAFT AND SPRAY SYSTEM FOR FOREST INSECT CONTROL

Project No. CC-001-2

By

A. P. Randall and B. Zylstra

Chemical Control Research Institute

Ottawa, Ontario

Information Report CC-X-23

October, 1972

E r r a t a

Page 6, Paragraph 2, line 3

90^{o} to the north/south flight track and parallel to the east boundary

Page 14, Table I

The last column should read as follows:

Meteorological Conditions			
Temperature			Wind
Dry	Wet	RH	(mph)

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Abstract

The performance of a modified DC-7 aircraft equipped with spray apparatus was assessed in field trials in the Mojave Desert, Barstow, California, during the spring, 1972. The basic spray equipment consisted of cabin-mounted tanks, electrically driven pumps, spray booms and nozzles mounted above the wing. Spray simulants of dyed diesel oil and dyed water were used to ascertain rate of flow, spray cloud, and spray droplet characteristics. Results of the trials showed that the aircraft was sufficiently maneuverable to operate at spray heights as low as 100 feet above ground level. Spray droplet spectrum analysis of straight pipe nozzle emission of diesel oil at 30 psi fluid pressure, and air speeds of 200 kts showed a maximum drop size of 200-300 microns (µ) with a mass median diameter (MMD) of 68-92 µ and a number median diameter (NMD) of 50-70 µ respectively. Upwind swath deposit values of 10 drops/cm^2 at 1,200 yards and crosswind deposits in excess of 5 drops/cm^2 at 1.4 miles downwind were possible using diesel oil as the spray simulant. Swath flight intervals of 1,000 yards could be expected on operational spray programs provided crosswind spray emission techniques utilizing the Porton height/wind product (HU) method of application are used. Dyed water used as the spray simulant failed to reach the ground under similar experimental conditions.

A study of the spray cloud indicated the presence of six wake turbulence tubes within the post spray cloud. Presumably these are formed by the slip stream effect of each motor and the wing tip vortices. The overall effect is the formation of a single large funnel or tube of spray from each wing within which the three smaller tubes occur. The apparent effect of these tubes on the spray cloud is to maintain the original emitted swath width.

Introduction

In the fall of 1971, a proposal was submitted to the Quebec Department of Lands and Forests by Midair (Can.) Ltd., of the availability of a modified Douglas DC-7B spray aircraft for possible operational use against the spruce budworm, Choristoneura fumiferana (Clem.), on the 1972 budworm control program. The salient features of the proposal were as follows:

1. High volume capacity with high speed performance, hence a reduction in time and cost to spray a given area.

2. Use of an accurate electronic guidance system to place the aircraft on the target site and thereafter provide parallel swath tracks over the spray block.

3. VFR and IFR flight capabilities with the possibility of operational night spraying.

4. Application of other effective insecticide at a cost per acre basis equivalent to that of fenitrothion at 5 ounces actual per acre.

5. A spray droplet spectrum in the medium fine drop size category comparable to or better than the present aircraft used for forest insect control.

The proposal was based on past performance data of other four engine spray aircraft (Lockheed Constellation, Boeing B-17) (Spears, J. F., 1971) and a knowledge of the effectiveness of present day electronic guidance systems. No actual data was available on the spray or guidance system or on the spray droplet spectrum produced by a DC-7B aircraft.

Early in 1972 (February) at the request of the Quebec Department of Lands and Forests and Midair (Can.) Ltd., followed by consultation with the Director of the Chemical Control Research Institute, it was agreed to undertake a series of calibration trials on a prototype DC-7 sprayer aircraft. Since the installation of an Inertial Guidance System would be a costly venture, it was considered advisable to first determine if the DC-7 was a suitable sprayer aircraft before proceeding to the next phase of development. The purpose of the trials was to provide the Quebec Department of Lands and Forests, Midair (Can.) Ltd., and CCRI, with pertinent information on the performance of the DC-7 for forest spraying, and to determine the characteristics of the spray droplet spectrum, spray deposition, and swath widths obtained.

Data on the Litton Systems proposal for precision guidance for spraying aircraft is presented in Appendix A. In addition, a letter report on a meeting of CCRI, Midair, and Litton Systems personnel held in Toronto, Ontario is included as appendix.

This report contains the findings on the calibration trials undertaken at Barstow, California, U.S.A.

Experimental Site

To meet the requirements of the Quebec request, the calibration trials would have to be undertaken in the immediate future in order to place the aircraft (if successful) in position for operational spray use in 1972. Since the aircraft was currently being modified and serviced at Los Angeles, California, and due to the extremities of our Canadian winters in February and March, the logical site for the trials would be the desert terrain of California.

The airport and experimental site was selected after careful consideration of the following requirements:

1. Low flight density airfield with a hard surface runway of adequate length (5,000 feet +) to accommodate and service DC-7 type aircraft.

2. Up-to-date meteorological station and equipment suitable for weather forecasting and data recording.

3. Service facilities and accommodation for a field laboratory.

4. Open terrain within travelling distance from the airport for the establishment of an experimental field site.

Of the three potential areas, Mojave, Needles, and Barstow, the latter site was selected because of its suitability in meeting the above requirements. The test site was selected within a four-square-mile area of open desert northeast of the Barstow-Daggett Airport. Meteorological data provided by the local weather office of the Barstow-Daggett Airport established the prevailing sunrise and sunset breezes to be predominantly in an east/west direction. This simplified the placement of aircraft flight lines and ground sampling station as the airport boundaries were established on a longitude/latitude bearings as shown in Fig. 1. Long-term forecast of local weather conditions (February-March) for the Mojave Desert area indicated a progressive deterioration of stable air conditions with the approaching spring. Expected high winds and rising temperatures indicated that the experiments had to be conducted in a 10-14 day period. A sample of a typical daily weather report for the Barstow-Daggett area is shown in Appendix B, Fig. 1.

Experimental Design

An aerial survey of the test site indicated that definite boundaries of readily identifiable flight lines would be required to lay a swath track across the sample card layout. At expected speeds of 230 mph and elevations of 100 to 150 feet above the desert terrain, narrow desert roads and ground markers would be indistinguishable from the background under twilight conditions. The most prominent feature within the test site area was a seven-foot high boundary fence which fortuitously was laid out parallel to the main runway and in line with the prevailing winds. Permission was granted by the Airport Officials to use the east and south boundaries as flight lines for the calibration trials as shown in Fig. 2. Two sets of sampling lines were laid out for both the

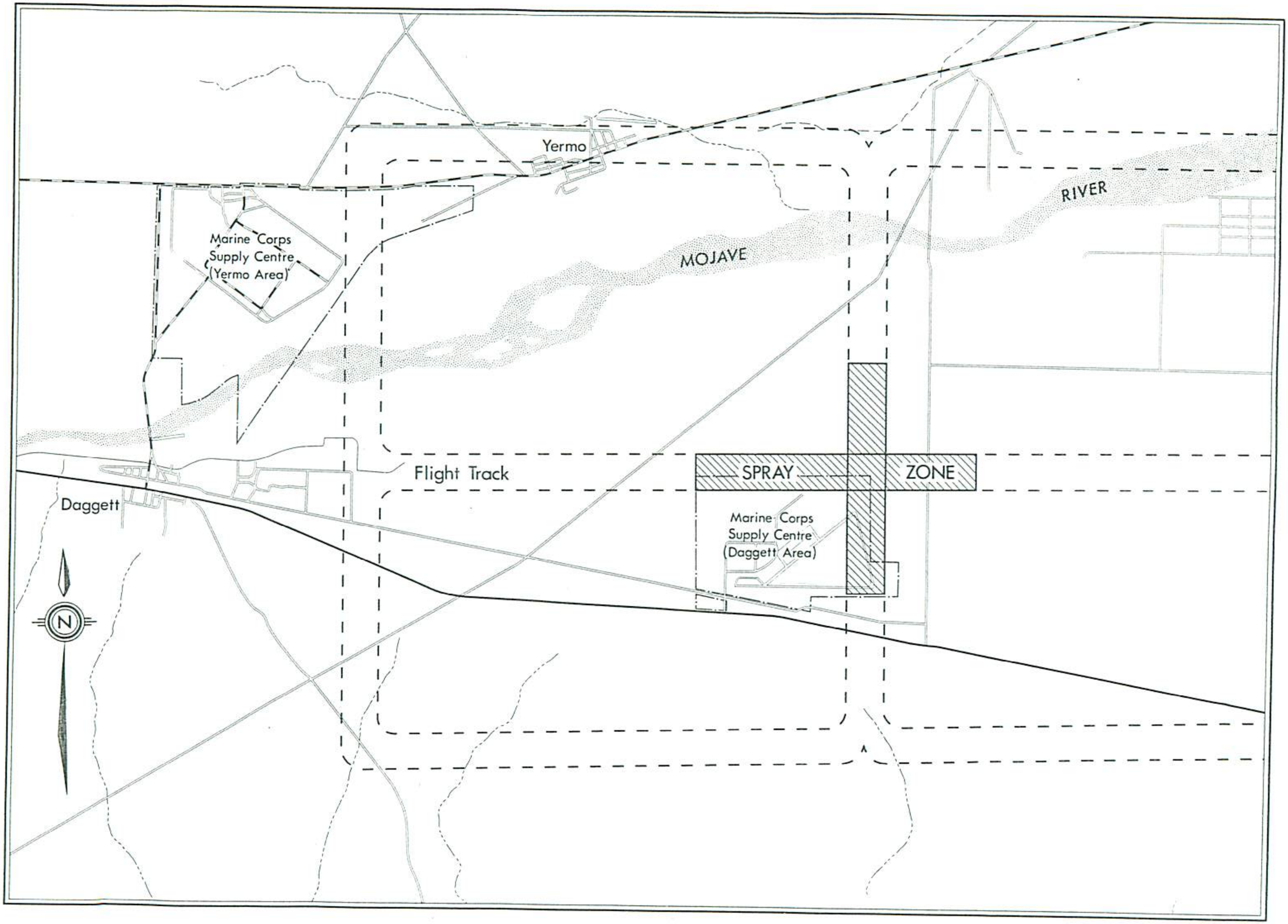

FIG. 1. MAP OF EXPERIMENTAL SITE

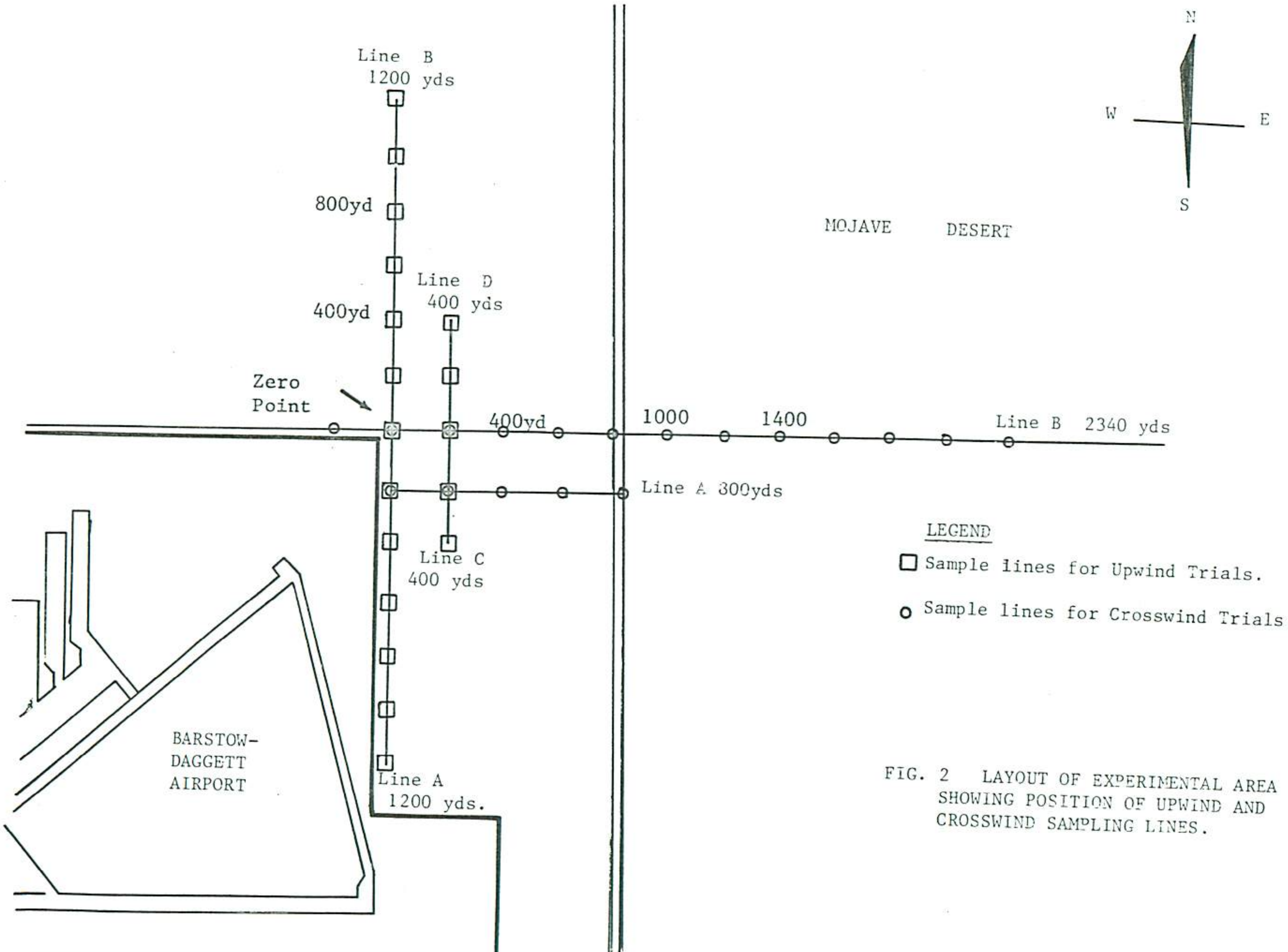

FIG. 2 LAYOUT OF EXPERIMENTAL AREA SHOWING POSITION OF UPWIND AND CROSSWIND SAMPLING LINES.

upwind and crosswind trials using the northeast corner as the zero position for both layouts. Five-foot flag markers were positioned at 200 yard intervals from the zero position on all lines for ease of position identification. All lines were measured and staked from the zero position as follows: 10 yard intervals for the first 200 yards, 20 yard intervals for the next 400 yards, and 40 yard intervals for the remainder of the lines.

The crosswind layout consisted of two lines, A and B, with the latter commencing at the zero position and surveyed at track and parallel to the east boundary of the airport. The lines were 200 yards apart and 800 and 2,300 yards long, respectively. Upwind markers to the -200 yard position were established as a safety zone for spray drift errors.

The upwind layout consisted of two parallel lines, AB and CD, at 200 yard intervals, with the zero position midpoint on line AB which extended 1,200 yards on either side of the zero point. Line CD transected the zero center line 200 yards east of the zero position and extended 400 yards north and south of the center line. All station positions were selected in open areas of the desert for ease of identification and relocation.

Materials and Methods

Description of Aircraft

The Douglas DC-7B aircraft is a low wing monoplane with full cantilever wing and empennage, semi-monocoque fuselage, utilizing fully retractable tricycle-type landing gear, Fig. 3.

The aircraft is powered by four Wright Turbo Compound, 18-cylinder, 3,350 cubic inch displacement, radial, air-cooled engines. The engines are equipped with Hamilton Standard Hydromatic, reversible, auto-feathering, constant speed, four-bladed propellors. At sea level, the engines are rated at 3,250 BHP at 2,900 RPM. Each engine has an independent fuel system consisting of an engine-driven fuel pump, electrically driven booster pumps, fuel strainers, instruments, selector valves, crossfeed valves, dump valves and chutes. Fuel consumption at cruise configuration is approximately 450 gallons per hour (gph Imp.).

The original configuration of the aircraft served as a commercial airliner with a carrying capacity of 77 passengers, a crew of 5, and a baggage compartment with a weight capacity of 13,840 pounds.

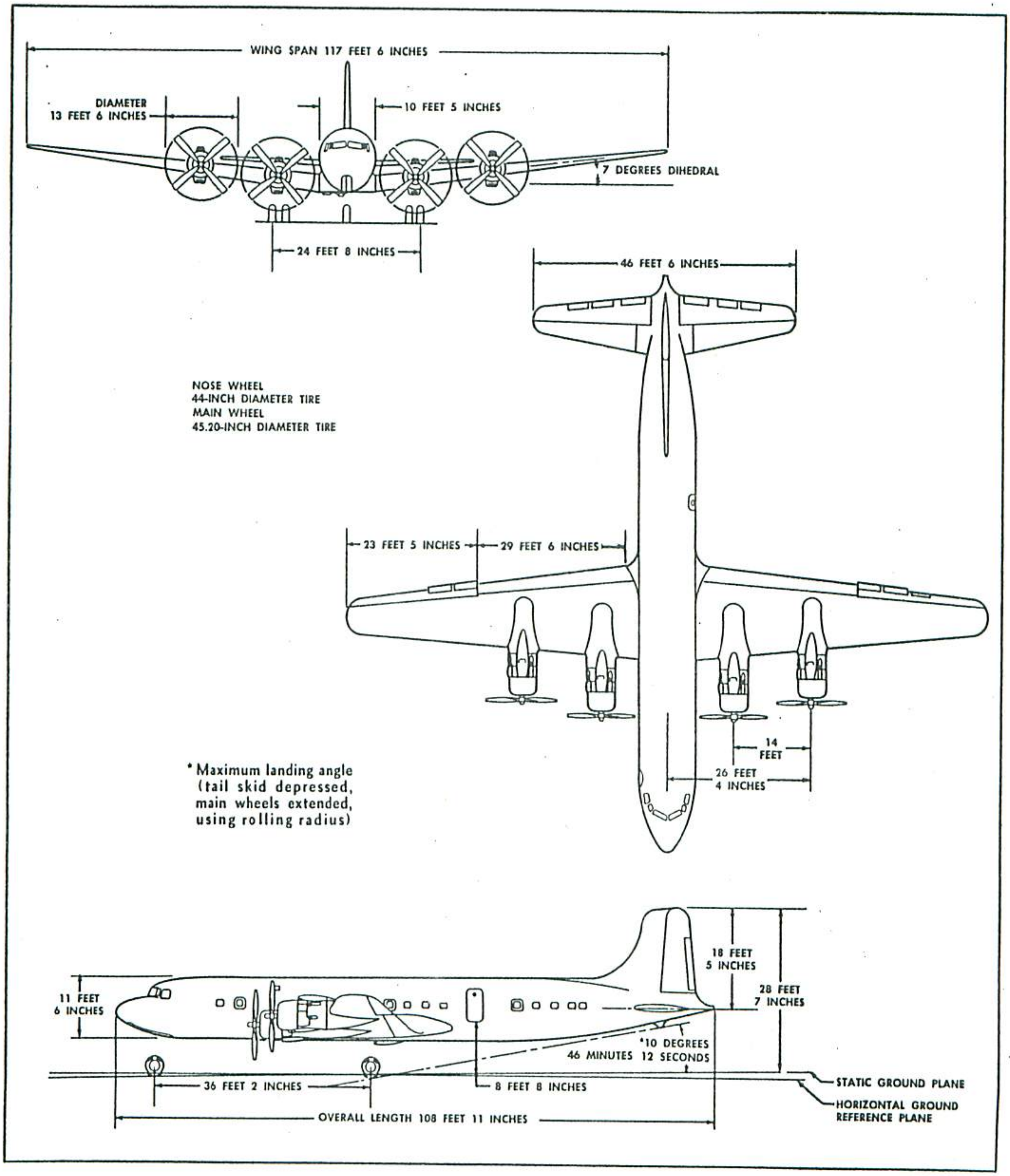

Fig. 3. Three-Way View of Aircraft - Dimensions

The structural limits for the DC-7 series 705 to 720 are as follows:

Maximum take-off gross weight	124,272 lbs
Maximum landing gross weight	102,000 lbs
Zero fuel weight	96,000 lbs
Empty weight (stripped)	66,000 lbs
Useful load (approx.)	30,000 lbs

All weights in excess of 96,000 lbs, must be fuel and oil up to the gross weight of 124,272 lbs.

Design limit level flight speed	265 knots

Description of Spray Equipment

The conversion of the DC-7 for aerial spraying included the removal of seats and all equipment nonessential to flight and safety requirements. The main cabin area aft of the cockpit was converted to hold six, 800 gallon (U.S.) tanks arranged in two banks of three tanks on either side of the fuselage. The tanks were interconnected to a common collector unit from which the spray fluid was pumped to the two wing booms by means of an electrically driven centrifugal pump. A schematic diagram of the system is presented in Fig. 4. A general description of the component parts of the spray apparatus are as follows:--

The holding tanks were heavy walled regulation aircraft fuel tanks of the KC-97 type with 3 inch diameter outlets located at the top and bottom ends of each tank. Each tank was mounted on a cradle with metal straps and the whole assembly secured to the floor via the standard seat track fittings thus eliminating modifications to the airframe. The cradle and tanks were cross-braced with aircraft cable fittings for maximum rigidity and strength as shown in Appendix B, Fig. 2(a). Loading of each tank was accomplished via an external loading quick-fit coupling and shut-off valves on the main collector sump. Each tank was vented to a common duct which terminated on the upper wall of the fuselage to provide air displacement for gravity flow of the spray liquid. The original flush skin 3-inch diameter opening was subsequently modified with a small air scoop to pressurize the tanks.

The pumping system consisted of a 24 volt 9 hp DC aircraft-type electric motor, a high capacity "Transland" centrifugal pump, a 50 mesh filter, 3-inch aluminium alloy tubing and a central fluid collector chamber as shown in Appendix B, Fig. 2(b). The

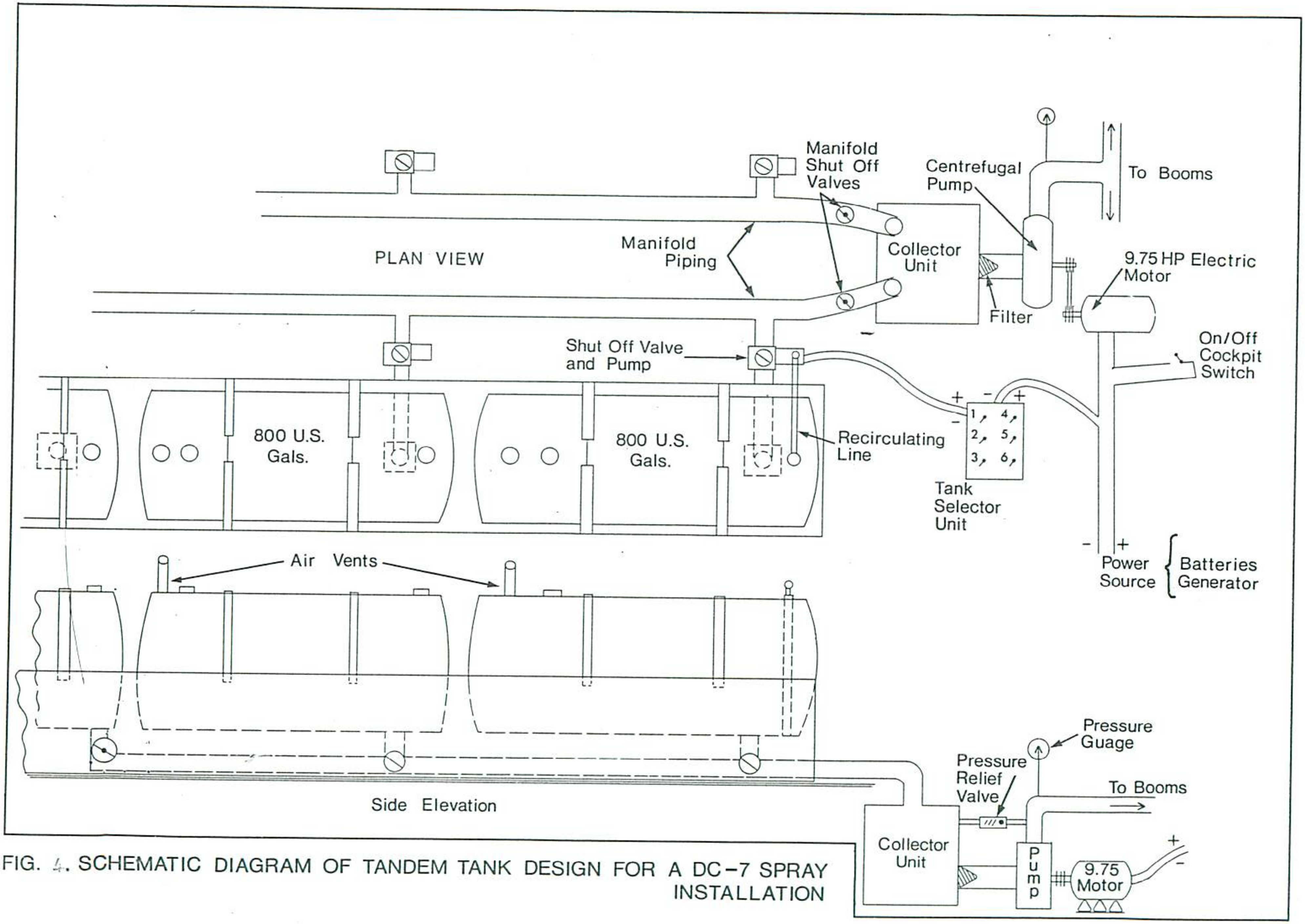

FIG. 4. SCHEMATIC DIAGRAM OF TANDEM TANK DESIGN FOR A DC-7 SPRAY INSTALLATION

centrifugal pump was connected to the motor via a belt and pulley system to provide a 1:1 drive ratio with a fluid output of approximately 200 gallons per minute at 30 psi. The electric motor required a maximum of 450 amperes at full load. A toggle switch located in the engineer's compartment in the aft section of the fuselage controlled the electrical circuits to the pumping unit. The complete unit was mounted on an aluminium base and secured to the stressed skin airframe under the floor of the aircraft in the aft luggage compartment area as shown in Appendix B, Fig. 2(b).

The boom was tapered in design, approximately 50 feet in length on each wing and constructed in three sections. The base of the boom (inboard section) was 15 feet in length and constructed of 3-inch heavy wall tubing. The middle section 20 feet in length of 2-inch tubing and the remaining 15 feet of 1 1/2-inch tubing. The total span including the fuselage would be approximately 110 feet. All sections were constructed of heavy walled (1/4-inch) aluminium alloy tubing. Each boom was mounted on vertical supports, 18 inches above the upper surface of the wing as shown in Appendix B, Fig. 2(c). Bracket supports for the boom were constructed of 1/4-inch sheet aluminium alloy and attached at main rib sections to provide maximum horizontal and vertical stability. Nozzle outlets on the boom were spaced at 8-inch intervals along the upper surface of each boom to provide a total of 72 positions for nozzle attachment. Each nozzle opening consisted of a 3/8-inch coupling welded onto the boom. Spraying Systems Nozzles of 3/16-inch diameter throat opening with diaphram check valve assembly were used throughout the system. All nozzles were set at 90° to the line of flight. For the calibration trials a total of 76 nozzles were operative. The remaining ports or nozzle openings were sealed as shown in Appendix B, Fig. 2(d).

Spray Solution

The spray solutions used for the calibration trials were not formulated to simulate a specific type of insecticide formulation but rather to represent the two types of basic solvents used for aerial sprays for forest insect control, i.e., petroleum solvent and water.

Of the petroleum solvents, fuel oil and diesel oil are by far the most economical and thus more widely used. The formulations used for the Barstow trials were as follows:

Petroleum type		Water	
Diesel Chief	450 gals.	Tap water	500 gals.
Ashland Hi-Solv	15 50 gals.	Rhodamine "B" dye	5 lbs.
	500		
Dupont oil Red dye	10 lbs.		

The properties of Diesel Chief and Ashland Hi-Solv 15 are presented in Appendix B, Tables I and II. The droplet spread factor for the diesel oil formulation on Kromekote® cards are given in Appendix B, Fig. 3(a). Relationship of stain class - drop diameter and volume for diesel oil - are presented in Appendix B, Table III.

Sampling Units

Ground deposits of spray were recovered on sampling units consisting of dyed and undyed 2-inch by 3-inch Kromekote® cards mounted on a 6-inch by 6-inch Beaver board. Droplet size assessment of the spray was determined from stain deposits on each card. The relationship between stain diameter and drop diameter was determined by calibration of the spread factor for the spray formulation on the paper surface over the range of drop sizes encountered. The deposit data were then calculated in terms of drop numbers per square centimeter and percent cumulative frequency by number and mass. The droplet size spectrum of the various spray deposits are compared on the basis of their maximum drop size (D_2max), mass median diameters (MMD)[1], and number median diameters (NMD)[2].

Calibration Trials

Rate of Flow Calibration

The spray system in the DC-7 aircraft for these trials was a prototype installation in which only two of the six spray tanks were operative and connected to the central fluid collecting unit. In addition, the individual tank selector units, shut-off valves, and fluid recirculating pumps were nonoperative. Liquid flow through the manifold from either tank to the collector unit was controlled by the manifold shut-off valves. The rate of flow was dependent on the head of liquid within the spray tank and the output capacity of the centrifugal pump which, being electrically driven, was in turn dependent on the power supplied to the electric motor and its capacity. Fluid pressure to the nozzles could be varied by altering the pressure relief valve.

Prior to the main calibration trials, a series of preliminary upwind trials (TUR) were undertaken to establish the operating efficiency of the spray apparatus and determine the droplet spectrum characteristics of the test nozzles at speeds of 200 kts. For comparative purposes with operational spray aircraft

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[1] (MMD) - The droplet diameter at which half the mass is made up of droplets larger than the stated diameter.

[2] (NMD) or frequency median diameter - the droplet diameter at which half of the total number of droplets are smaller than the stated diameter.

(TBM) the boom was fitted with Spraying Systems Nozzles. The nozzles in the slip stream area of each propellor were equipped with no. 8015 flat fan tips with the remaining nozzle units fitted with no. 8010. A total of 76 nozzles were used for spray emission. The first trial (TUR-0) developed mechanical problems in the electrical drive of the spray pump and had to be aborted. The second trial (TUR-1) was flight tested for mechanical operation prior to the calibration run and then operated over the test layout at 100 foot elevation and 200 kts with a spray pressure of 28.5 psi indicated. Deposit data from this trial indicated an extremely fine droplet spectrum in the maximum drop size (D_{max}) of 150 μ and a very light deposit due to the preponderance of extremely fine droplets. Results obtained in the TBM (Grumman Avenger) trials (Randall, 1957) indicated that 3/16-inch open nozzles may be acceptable. Thus the (TUR-1 and -2) trials using the 8015 and 8020 flat fan tips were omitted in favor of the full flow configuration.

Initial rate of flow calibration of the DC-7 spray apparatus was undertaken at the Barstow-Daggett Airport under static conditions with 76 nozzles operative. The aircraft was loaded with 500 U.S. gallons of water and spray emission time for complete release of solution (i.e., maximum pressure (30 psi) to initial drop in pressure) was determined by stop watch during ground testing as shown in Appendix B, Fig. 4(a). A rate of flow of 201 gallons per minute (gpm) was recorded for 76 nozzles or a flow rate of 2.8 gpm per nozzle at 28.6 psi fluid pressure. These figures agree quite favorably with the TBM calibration trials using diesel oil/DD1 formulation of 4.1 gpm per nozzle at 40 psi (Randall, 1956).

Experimental data obtained at Defence Research Board, Suffield (Hurtig, H., 1951), however, indicated no appreciable difference in rate of flow for water and fuel oil. Final rate of flow figures for full load emission would be obtained under operational spraying conditions at a later date.

Field Trials

In the crosswind trials the eastern fence boundary of the airport was used as the visual flight marker for aircraft positioning. Prior to each trial a flight briefing on meteorological conditions was carried out to establish the correct flight line position according to wind velocity; thus the lower the wind speed the closer the flight tract to the zero position. In all crosswind trials the ground sampling units were placed downwind from the proposed flight tract of the aircraft. Spray emission and shut-off occurred one-half mile on either side of position zero. Spray emission duration for each flight was approximately 20 seconds with a volume delivery of approximately 70 gallons.

In the upwind calibration trials the northern fence boundary was used as the visual flight marker. Flight briefing to establish duration and aircraft location was carried out to ensure spray deposition on the target site. Ground sampling units were placed 1,200 yards on either side of the proposed flight line which crossed the zero position or marker on crosswind layout, line B. With increasing wind velocities, the upwing spray emission lines were increased to ensure total recovery of all droplet size categories of the spray cloud.

Upon completion of each spray run, the sampling units were collected one-half hour after spraying and returned to the airport laboratory. The units were dismantled on location and the Kromekote® cards, filter paper, and a sample of the dyed spray solution forwarded to CCRI laboratory in Ottawa for analysis of spray deposition by volume and droplet size.

Results and Data

To assist in the classification of data from the various calibration trials, a brief outline of events are presented in Table I. The complete flight and summary data from each trial are shown in Table II.

Since the TUR series of trials were basically equipment orientation tests, no attempt was made to accumulate scientific data other than to establish the working parameters of the subsequent upwind and crosswind trials. A brief summary of events for the TUR series are outlined below.

<u>TUR series of trials</u>.--The aircraft was to track upwind over center line (zero position) at 200 kts at 100 feet above ground elevation.

TUR-0 - This trial was aborted due to mechanical difficulties in the spray pump and electrical drive motor.

TUR-1 - This trial was designed to check the droplet spectrum obtained from spraying systems nozzle orifices of 8010 and 8015 located at boom positions outside and inside propellor slip stream areas respectively. All nozzles were placed at right angles to the airstream. Results of this trial indicated that the nozzle size and configuration at 30 psi produced an extremely fine droplet spectrum that probably would be undesirable for a large aircraft on operational spraying. Experimental data (Randall, 1957) obtained from 3/16-inch open nozzles operating at 150 mph indicated a MMD within the ranged 200 → 225 μ. Thus, to save time, the TUR-2 and -3 trials using 8015 and 8020 Tee jet tips in the above configuration were omitted to proceed directly to the open 3/16-inch nozzle orifice which would provide maximum rate of flow output at operating pressure.

Table I

Outline Summary of Calibration Trials

Test No	Code	Date	Time	Type of Trial	Aircraft Speed	Solvent	Meteorological Conditions			
							Temperature of wind			
							dry	wet	RH	mph
0	TUR-0	1/3/72	6:25 pm	Upwind emission	200 kts	Diesel oil	64	44	11%	0-1
1	TUR-1	2/3/72	6:30 am	Upwind emission	200 kts	Diesel oil	45	39	57%	8-12
2	TX-1	3/3/72	5:34 pm 5:40 pm	Crosswind	200 kts	Dyed Diesel oil	77	59	32%	10-15
3	TX-2	4/3/72	6:15 am	Crosswind	200 kts	Dyed Diesel oil	52	49	81%	15-22
4	TX-3	4/3/72	7:25 am	Crosswind	200 kts	Dyed Diesel oil	59	55	78%	10-15
5	TU-0	4/3/72	5:35 pm	Upwind	200 kts	Dyed Diesel oil	78	57	24%	4-6
6	TU-1	5/3/72	6:05 am	Upwind	200 kts	Dyed Diesel oil	51	45	62%	6-8
7	TU-2	5/3/72	6:55 am	Upwind	170 kts	Dyed Diesel oil	55	47	54%	0-1
8	TU-3	5/3/72	5:33 pm	Upwind	200 kts	Dyed Diesel oil	78	57	26%	0-1
9	TX-4	6/3/72	5:48 pm	Crosswind	200 kts	Dyed H_2O	80	59	26%	8-10

TABLE II

Summary Data of the DC-7 Calibration Trials

Trial No.	TUR-0	TUR-1	TX-1	TX-2	TX-3	TU-0	TU-1	TU-2	TU-3	TX-4
Place	Barstow	Barstow	Barstow	Barstow	Barstow	Barstow	Barstow	Barstow	Barstow	Barstow
Date	1/3/72	2/3/72	3/3/72	4/3/72	4/3/72	4/3/72	5/3/72	5/3/72	5/3/72	6/3/72
Time	6:25 pm	6:30 am	5:34 pm	6:15 am	7:25 am	5:35 pm	6:05 am	6:55 am	5:33 pm	5:48 pm
<u>Aircraft Data</u>										
Speed (mph)	230	230	230	230	230	230	230	192	230	230
A/C Height (ft.)	100	75-100	100	100	100	100	100	100	100	100
<u>Spray Equipment</u>										
Length of Boom	70 ft.	70 ft.	70 ft.	70 ft.	70 ft.	70 ft.	70 ft.	70 ft.	70 ft.	70 ft.
No. of Nozzles	76	76	76	76	76	76	76	76	76	76
Diam. of nozzle jets	(8010, 8015)	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16
Emission Rate (approx.)	200	200	200	200	200	200	200	200	200	200
Fluid Pressure (psi)	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5
<u>Weather Conditions</u>										
Wind Speed (mph)	0-1	8-12	10-15	15-22	10-15	4-6	6-7	0-1	0-1	8-10
Wind Direction	280		230	200	210	60	270	270	90	300
Temperature F	64	45	77	52	59	78	51	55	78	80
R.H. %	51	57	32	81	78	57	62	54	26	26
Atomospheric Stability	stable	stable	stable	stable	stable	stable	stable	stable	stable	stable
Cloud Cover	0/8	0/8	0/8	0/8	0/8	0/8	0/8	0/8	0/8	0/8
<u>Spray Liquid</u>										
Formulation	Fuel Oil	Fuel Oil	Dyed Fuel Oil	Dyed Fuel Oil	Dyed Fuel Oil	Dyed Fuel Oil	Dyed Fuel Oil	Dyed Fuel Oil	Dyed Fuel Oil	Dyed Water
Density (gms/cc)	0.796	0.796	0.806	0.806	0.806	0.806	0.806	0.806	0.806	1.000
Viscosity (centipoise)	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	-
<u>Spray Characteristics</u>										
M.M.D. (u)	Insufficient Data to do an accurate assessment			90	124	Insufficient Data to do accurate assessment		92	68	Nil
N.M.D. (u)				62	65			68	50	Nil
Max. Drop Size				212	196			166	50	Nil
Effective Drop Coverage (yds.)				1240	1520			100	1200	Nil

The spray system was then calibrated for rate of flow using a total of 76 open 3/16-inch nozzles. Results using tap water as the test liquid indicated an initial rate of flow of 203 gallons (U.S.) per minute at 28.5 psi indicated. This would provide an approximate flow rate of 2.7 gal/min per nozzle which would probably be lower for the diesel oil formulation.

TX series of crosswind trials.--These trials were designed to provide data on drop size distribution and drift characteristics of drop size classes for diesel oil under various wind speeds and spray heights. The data serves as a base line for the establishment of the effective parameters for operational swath widths for the particular aircraft, formulation, and spray equipment. All pertinent data on the TX series of trials are shown in Table 2. A résumé of each trial is presented below.

TX-0 - This trial consisted of preliminary flight testing of spray equipment to check for leaks, overheating of electric drive roter, power settings, and spray emission. No attempt was undertaken to determine droplet patterns and spray distribution of the open nozzle configuration. The test was successful.

TX-1 - This trial was a single spray pass complicated by the pilot's choice of flight track. The first spray run was 200 yards downwind of proposed flight track; the pilot decided to make a second pass over target area to correct for wind drift of first swath. Both spray runs were off target and short of the proposed mile emission run. Results of double swath application showed maximum deposit densities at 360 and 880 yards downwind, which correspond to the two swath runs, Appendix B, Table IV. Because of the duplication of spray runs and the relatively short duration of emission the data does not lend itself to proper analysis.

TX-2 - This trial was a repeat of TX-1. The sample line was extended to 1,600 yards downwind to allow for the excessive high wind gusts, i.e., 15-22 mph. The aircraft tracked 100 yards upwind of zero position. Ground recovery of the largest droplets occurred at 10 yards downwind of zero position on lines A and B and extended to the end of both lines, i.e., 800 yards for line A, and 1,600 yards for line B. Droplet data in terms of drops/cm^2 and oz./acre are presented for all stations in Appendix B, Table IV. On the basis of frequency of 6 drops/cm^2 at the 1,200-1,600 yards zone, one could expect a downwind deposit of up to 4 drops/cm^2 for another 1,000 yards.

TX-3 - This trial was a repeat of TX-2 to delineate the drift potentialities of the DC-7 spray cloud since the size of the deposited droplets at position B-1600 fell in the 125 to 141 μ drop sizes. This would indicate that a sizable portion of the spray drops were deposited beyond this station since the NMD of the spray cloud occurred at approximately 60 microns (μ) as shown in Appendix B, Fig. 5. To record the spray droplet spectrum beyond this point, line B was extended to 2,400 yards downwind of the zero position and upwind to -200 yards. With the exception of a change in wind velocity (10-15 mph), experimental conditions of the trial were similar to TX-2. Results of the trial showed an initial deposit at position B-minus-180 and extended the full length of line B. Deposit density in terms of drops/cm^2 and oz/acre are shown in Appendix B, Fig. 6, and Table IV. Deposit varied according to wind velocity and droplet size with the D_{max} of 205 μ at 120 yards upwind of B-0 and a D_{max} of 116 μ at position B-2360. A deposit of 3 drops/cm^2 at B-2360 indicated that a considerable portion of the fine droplets of the spray cloud would have settled beyond this point.

TX-4 - This trial was a repeat of TX-3 using dyed water as the spray formulation. Line B was extended to 2.4 miles downwind of zero position. Meteorological conditions were decidedly unfavorable for water emission since the temperature was 80°F with a RH of 46%. All other meteorological conditions were ideal, <u>i.e.</u>, wind velocity 8-10 with inversion conditions.

No spray deposit was recorded on any of the spray cards although meteorological conditions were similar to trial TU-3 in which diesel oil was used as the spray simulant (Table I). Under the conditions of the trial, one would expect the larger droplets to descend against the RH gradient. These results show the sensitivity of a water formulation to evaporation which would become even more pronounced with increase in aircraft spray height. The use of an evaporation retardant or co-solvent would partially decrease this effect.

<u>TU series of upwind trials.</u>--These trials were designed to provide data on the total droplet spectrum of sprays deposited at airspeeds of 150, 170, and 200 kts using dyed diesel oil as the spray simulants. In addition, drop distribution patterns of the spray cloud would provide information on the effectiveness of nozzle position, slipstream and wing tip vortices effects for speeds comparable to those of the TBM (Grumman Avenger) and up to 200 kts. At the request of the pilot for safety reasons, the 150 kt trial was cancelled. All trials called for the aircraft to track along the center line (<u>i.e.</u>, line B of crosswind trials) at 100 feet above ground level. All pertinent flight data is shown in Table II for each trial.

TU-0 - Sample cards were laid out 600 yards on either side of zero position. The aircraft tracked over target layout at 200 kts. A slight crosswind condition drifted the spray onto line B such that spray deposition commenced 90 yards from the center line and extended to the end of line B-600. Drop deposits of 24/cm^2 indicated that lines A and B would have to be extended an additional 200 yards from the center line in order to record the full spectrum of spray droplets.

TU-1 - This trial was a repeat of TU-0 with the proposed aircraft speed at 170 kts with lines A and B extended to 800 yards on either side of center line. This test was aborted due to a wind shift during the final run and because the aircraft was out of position. In addition, spray emission time was cut to 5 seconds when the pilot recognized his error; thus only three cards on D line showed evidence of spray deposits which would represent the D_{max} of the spray spectrum.

TU-2 - This trial was a repeat of TU-1. To compensate for a change in wind drift, the aircraft was requested to track 200 yards upwind of center line. At the commencement of spray emission, a 90° shift in the wind occurred which resulted in an aborted spray run. Results showed a coarse deposit on cards 280 to 540 yards downwind of zero position which was representative of the D_{max} of the spray cloud at 170 kts.

TU-3 - Because of the lack of time and predicted deterioration in weather conditions, the proposed TU series of trials were cut short and all efforts were concentrated on obtaining data on the droplet spectrum of the spray cloud produced at airspeed of 200 kts. To ensure maximum spray deposit recovery, lines A and B were extended to 1,200 yards. During the final spray run, a slight crosswind component of 0.5 mph was observed at spray emission height, although meteorological conditions at ground level indicated zero wind conditions. Spray deposits commenced at 20 yards downwind of zero position and extended beyond the 1,200 yard marker on line B which indicated 15 drops/cm^2. Had the layout been extended to 2,400 yards, it is quite conceivable that the complete visual droplet spectrum would have been captured. Photographic samples of spray deposits recovered at 10, 300, 600, and 1000 yards downwind are presented in Appendix B, Fig. 3(b).

Of the series of calibration trials, only trials nos. TX-2, TX-3, and TU-3 contained sufficient deposit data for an in-depth analysis of the spray. All trials, unfortunately, did not record the lower range of visible drop sizes although sampling stations were established a mile beyond the point of spray emission. It was unfortunate that a deposit swath of the magnitude that occurred in both the upwind and crosswind trials was not anticipated since a large fraction of the spray cloud below 30 μ drifted beyond our experimental layout. For future calibration trials, it would be advisable to have the sample lines extended 3 to 5 miles beyond the layout with air sampling devices placed at strategic intervals to record the airborne particles.

Deposit assessment of the recorded deposits for the crosswind trials (TX-2 and TX-3) are presented graphically in Appendix B, Fig. 6, and Table IV. Both trials show the positive effect of a strong crosswind component on the spread of spray drops to achieve uniform deposits over a large area downwind of the emission point. Similar deposit data from the two upwind trials (TU-0 and TU-3) are presented in Appendix B, Fig. 7, and in Table V. In the absence of a crosswind component most of the spray droplets fall in a very narrow band in a relatively uniform deposit. The spray pattern is quite unlike that which occurs in upwind trials of single engine aircraft. The latter usually produces a bimodal deposit. In both of the upwind trials a slight crosswind component shifted the deposit pattern to the right. This effect is much more pronounced in TU-0 as shown by the uniformity of droplet numbers over the 600 yards of deposit.

An analysis of cumulative drop numbers (NMD) and mass (MMD) for all four trials are shown in Appendix B, Fig. 5. Of the four trials, TU-3 and TX-3 would provide the closest approximation of a total spray, thus a diesel oil formulation emitted from a DC-7 at 100 feet above ground level, operating at 200 kts would have a D_{max} of approximately 200-220 μ, a NMD of 50-60 μ and a MMD of 80-90 μ. The time required for droplets in the 50-60 μ class to fall 100 feet is approximately 6-7 minutes. The loss due to volatilization for a diesel oil formulation would be approximately 70% to 80% of the original, thus the drop spectrum at point of emission would be greater than that calculated from the deposited spray as shown by Hopewell, 1957. When a highly volatile solvent such as water is used as in trial no. TX-4, zero deposit can be anticipated due to the complete evaporation of the solvent.

Discussion

Principles of Aerial Spraying

When a solution is dispersed through atomizing nozzles from an aircraft during flight, the following events occur to the spray droplets. The velocity of the spray droplets following emission from the nozzle is rapidly dissipated in the air and thereafter, is subject to the slip stream and wake turbulence of the aircraft's passage through the air. The largest and heaviest drops separate from the spray cloud first, and settle to the ground. This sequence is repeated until only the extremely fine droplets of particle size approaching that of fog or less remain in the air.

All droplets follow Stokes Law ($V = \frac{2 \times 980 \times R^2(d_1-d_2)}{2n}$) for speed of fall thus the smaller the drop size the longer they remain airborne. Concurrently, the spray cloud is subject to meteorological conditions prevalent during the time the cloud remains airborne.

The distance and rate of travel of the various drop sizes will, to a large extent, depend on wind velocity and direction in relation to the flight track of the aircraft and the height of spray emission. Assuming a fixed spray emission height of 100 feet and an increase of wind velocity from 1 mph to 10 mph one would expect the total swath to be displaced further downwind at 10 mph with the least amount of displacement to occur in the largest droplet size categories. Data plotted from two trials TU-3 for 0-1 mph and TX-3 for winds of 8-10 mph show this drift effect. In an upwind trial, or in the absence of a crosswind component, the spray droplets from an aircraft will descend to the ground in a pattern of mixed drop sizes according to the distribution of mass of spray drops in the spray cloud. In most single engine aircraft a biomodal deposit occurs. The introduction of a crosswind component produces a winnowing effect of droplets according to size and weight. By utilizing the factor of aircraft height and wind velocity, i.e., a height wind products (HU), the degree of spread of the drop classes can be controlled. The principle, known as the Porton method (Gunn, D. L., 1948) enables the doubling or even tripling of effective swath widths for aerial emission of sprays. This principle can be used with either fixed height and increasing wind speed or fixed wind speed and increasing height to achieve the same effect as shown in Appendix B, Fig. 8.

Data collected from Trial TU-3 was obtained under very low wind conditions, as evidenced by the extremely heavy drop deposits at all sampling stations from B-0 to B-1250. The same spray cloud if subjected to a 10 mph crosswind would have the various sized droplet class spread over a much larger area as shown in Trial TX-3. The time interval that each drop class remains airborne would be the same, the difference occurs in lateral displacement. Further evidence of lateral displacement is shown in the deposit results of TX-2 under inversion conditions and high wind velocities of 15-22 mph. By utilizing this principle in conjunction with information on aircraft height and meteorological conditions a swath width can be determined in which cumulative deposits provide the bases for the determination of the swath width or flight lines. For example, under wind conditions of 0-1 mph, a drop deposit density occurs over an area of up to 1,200 yards as in Trial TU-3. If the spray height were increased by an appropriate factor, a deposit density comparable to that shown in TX-3 could be achieved provided that no change in drop size or meteorological conditions occurred.

On the basis of 10 to 15 drops/cm^2 for effective control of a forest pest such as the spruce budworm, a swath interval of 1,000 yards would allow the equivalent of a triple deposit over a target site to occur during the course of three spray runs. Should a shift in wind direction of 90° occur, as in an upwind emission, sufficient deposit would reach the ground to provide the necessary coverage from one of the three spray runs. The same effect can be achieved by maintaining a fixed spray height and operation under higher wind velocities as in TX-3.

Spray Cloud Characteristics

When an object is held in a stream of moving air or is forcibly moved through a mass of air the latter is displaced and tends to flow around the object. The resulting flow pattern will depend on the shape of the object and the relative velocity of the object through the air. The more streamlined the object the smoother the flow pattern and vice versa. Since an aircraft utilizes wings to provide the necessary lift, the resulting airflow pattern will be influenced by the aerodynamic shape of the airfoil. To produce lift, a large amount of air must be displaced downward. This displaced air tends to flow spanwise toward the area of lowest pressure, hence, on the top surface of the wing the air tends to flow toward the fuselage whereas on the lower surface the flow tendency is toward the wing tip. When these two airflows unite at the trailing edge of the wing they are flowing contrawise and therefore tend to create vortices. At each wing tip these vortices are of much greater magnitude. For a given wing area the magnitude of these wing tip vortices will increase with an increase in aircraft weight since more air will have to be displaced downward to create the required lift. Similarly, their magnitude will change inversely as a function of the aircraft forward speed.

The addition of propellor slipstream into the airflow patterns created by the aerodynamic shape of the aircraft fuselage and wing causes the overall flow pattern to change somewhat since the air pushed back by a revolving propellor has a corkscrew motion which tends to expand outward in a circular pattern. Since the two wing tip vortices rotate in opposite directions it necessarily follows that any propellor slipstream must rotate in the same direction as one wing tip vortice and opposite to the other. In a single engine aircraft the combined effect of these three vortices produces two rather distinctive expanding cones trailing behind the aircraft as shown in Appendix B, Fig. 9(a).

In a multi-engined aircraft, particularly when the engines are mounted on the wing chord line, the propellor slipstream action, together with the two wing tip vortices create an airflow pattern comprised of six vortices as shown in Appendix B, Fig. 9(b). On the port side, the direction of rotation of the tip vortice and the propellor slipstream are the same. As a result the three cone-shaped patterns tend to persist far behind the aircraft. On the starboard side the tip vortice and propellor slipstream rotate in opposite directions. Thus, the slipstream from the outboard engine and the wing tip vortice tend to interfere with each other, eventually resulting in their intermixing to form a single but much larger cone-shaped helix, as shown in Fig. 5(a). Meanwhile the pattern of the starboard inboard engine remains similar to those on the opposite wing. As a result of these vortices generally maintaining their own conical shape, the total spray swath tends to maintain the original spray emission width of the installed boom. This effect appears to be further enhanced by placing the boom and nozzles above the trailing edge of the wing and hence above the vortices created at the trailing edge as shown in Fig. 5(b).

The resulting airflow around an aircraft determines the initial shape and characteristics of the spray cloud and the presence of very fine spray droplets in the air mass make the resulting pattern visible to the observer.

The finer the spray droplets within the cloud the longer the cloud remains airborne and thus subject to the vagaries of air currents. Under ideal meteorological conditions and assuming no loss of spray through volatilization, most of the droplets will settle to the ground. The deposit pattern and density of drop coverage are dependent upon total volume of liquid and the effectiveness in the conversion of volume into drop numbers.

The spray output of the DC-7 aircraft was approximately 200 U.S. gallons per minute, and at an airspeed of 230 mph, the aircraft will cover approximately 3.8 miles in one minute. To achieve a deposit of 20 ozs/acre, an effective swath coverage of approximately 900 yards would be necessary. Experimental evidence (Fettes, 1952) has shown that drop numbers/cm^2 and not oz/acre is the criteria for effective budworm control. Therefore, the drop density on an upwind spray run must fall within this category. From the drop number data from trial TU-3 it was evident that the spray cloud contained a high percentage of small droplets in order to obtain a coverage in excess of 1,000 yards. Under normal operational conditions, it would be quite unlikely that a spray height of 100 feet above ground level would be used, thus a lower drop/cm^2 count could be expected over a wider area with a greater degree of uniformity.

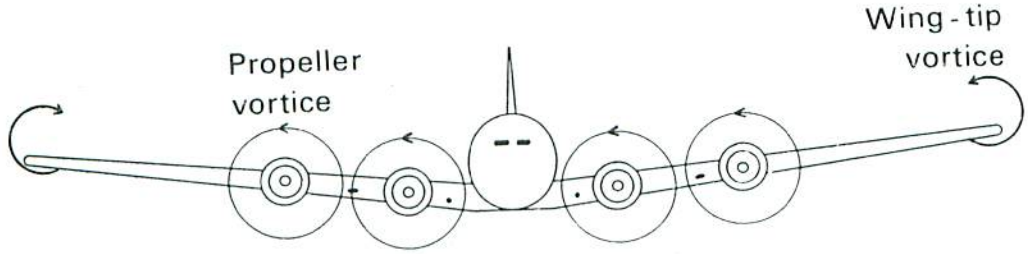

Fig. 5(a). Showing air flow patterns around the wings of a four-engined aircraft.

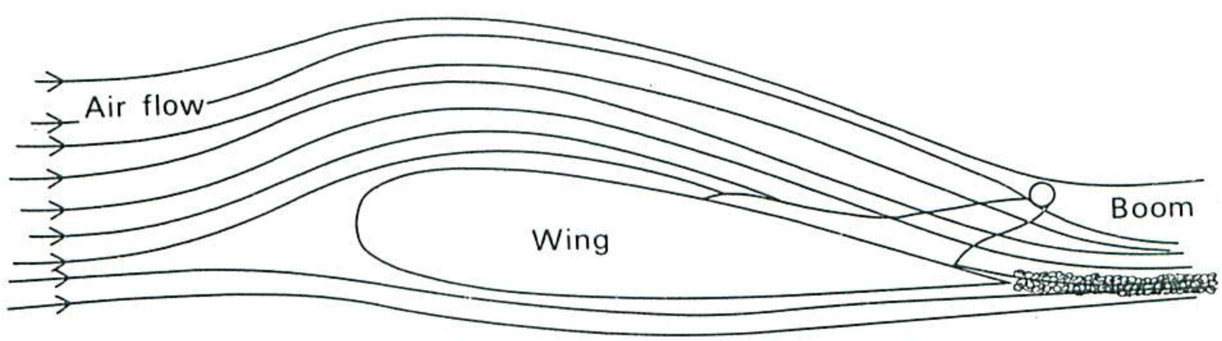

Fig. 5(b). Diagram showing air-flow pattern around the boom when it is mounted above the wing, away from the trailing edge.

The absence of the typical bimodal spray deposits commonly formed by agricultural spray aircraft appears to be due to the length and positioning of the boom above the wing and the interference patterns created by the four engines. Since the flow of air on the underside of a wing is outwards to the wing tip, it follows that sprays emitted from booms and nozzles mounted under a wing will eventually move outward to join the wing tip vortex. This creates a low density area of spray droplets in the fuselage slipstream. By positioning the spray boom above the wing and away from the trialing edge, the effect of the overall wing tip vortex appears to be minimized. Thus the full span of the spray swath is maintained as shown in Appendix B, Fig. 9(b). The overall effect of a span of spray emission of 110 feet is to create a pattern of droplet size classes whose 76 points of emission is a band 110 feet long. This becomes apparent in a study of drop size classes over the range of spray deposits as found in TX-3 and illustrated in Appendix B, Fig. 8.

Conclusions

A summation of data obtained from the calibration trials to date leads to the following conclusions:

1. The prototype spray equipment appears to be well engineered particularly the spray tanks, booms and fluid delivery lines. It would appear, however, that a potential problem area exists in the capability of the electric motor to drive the centrifugal pump continuously as would occur under operational conditions.

2. Rate of flow calibration using water at 30 psi through 76 open nozzles of 3/10-inch diameter orifice indicated a fluid output of 205 gpm (U.S.) or approximately 3 gpm per nozzle.

3. Open nozzle emission of a diesel oil formulation at airspeeds of 200 kts at 100-150 feet above ground level produced a droplet spectrum with the following characteristics. D_{max} 220 μ, MMD 80-90 μ, and a NMD of 60-70 μ.

4. Ground deposits based on drops/cm^2 show an effective swath width of 900 to 1,000 yards from point of spray emission.

5. Utilizing six cabin mounted tanks, the DC-7 aircraft has a carrying capacity of 4,000 gallons. At a delivery rate of 200 gpm, an emission coverage of 20 ozs/acre, and a swath width of 1,000 yards, the projected coverage would be 25,000 acres in 20 minutes of continuous spraying.

6. Insect control capabilities of a guidance equipped DC-7 spray aircraft would be superior to equipment currently available.

Recommendations

On the basis of the calibration data obtained from the Barstow trials the following recommendations can be made:--

1. Further research and development should be undertaken on the spray delivery system to minimize failures under operational conditions.

2. An immediate assessment of the proposed Litton Inertial Guidance System should be undertaken to determine the feasibility of adapting it for sprayer aircraft use. The theoretical capabilities of the guidance system should be confirmed by field evaluation prior to operation spraying.

3. In view of the poor performance of the aqueous formulation and the droplet spectrum characteristics of the spray, it is recommended that only a non-aqueous formulation be used in the DC-7.

4. To maintain maximum uniformity of spray deposition under operational spraying, all flight lines should be established at right angles to the prevailing breezes at 1,000 yard intervals to achieve optimum crosswind components. This should provide (under inversion conditions and crosswind emission) an acceptable droplet density pattern in the range of 5-15 drops/cm^2.

5. Further research and development should be undertaken on spray boom and nozzle positioning to further elucidate spray cloud characteristics and effects of wing tip vortices on drop distribution.

6. In view of the extensive swath deposits obtained with the DC-7 aircraft, a study of airborne spray droplets and air masses over forested areas should be undertaken in order to predict deposit densities over rough terrain.

Acknowledgments

The calibration trials reported herein required widespread cooperation with many agencies in the planning and completion of the trials. It is impossible to acknowledge all the assistance offered by the many individuals who contributed to the success of this report. The Quebec Department of Lands and Forests and various members of this organization, particularly Mr. Gérard Paquet, were most helpful in supporting this project. To Midair (Can.) Ltd. who initiated the original concept, the authors wish to express their appreciation for the many courtesies, cooperation and support throughout the project. Particular appreciation is due to members of the Chemagro Corporation, Kansas City, and especially to Jerry Phillips, for the liberal use of aircraft, time, and effort, during the calibration trials. Credit is due to Dr. Don Schmiege, Head U.S.D.A. Forest Service, Berkeley, California, and C. L. Edgar, Flight Service Station, Daggett Airport, for their interest, advice, and help in obtaining meteorological services. To Mr. Goodwin of the Department of Airports, County of San-Bernardino, a special note of thanks is due for arrangement of airport facilities and experimental site. A very special note of thanks is due to Mary and Ben McCarty without whose assistance it would have been impossible to complete all of the trials. Lastly, the authors wish to express their appreciation to Dr. James J. Fettes, Director, Chemical Control Research Institute, for his full support and interest in this project, and to Messrs. Hopewell and Haliburton for spray deposit analysis.

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APPENDIX "A"

DC-7 Calibration Trials

A-1 Documentation on Proposed Inertial Navigation System for DC-7 Aircraft (2 pages)

A-3 Documentation on Meeting on Proposed Inertial Navigation System (3 pages)

PRECISION GUIDANCE FOR SPRAYING AIRCRAFT

GENERAL

This document provides a brief technical description of a precision navigator for applications which include spraying aircraft. This system is currently under development for Midair (Canada) Limited.

SYSTEM DESCRIPTION

The problem is to provide continuous navigation accuracy in the order of 200 feet for low flying aircraft. The guidance system must allow the aircraft to be flown on successive parallel lines to the accuracy of the system.

The LTN-51 provides excellent short term navigation but its error characteristics are cumulative with time. The time factor in system errors can be eliminated with Distance Measuring Equipment (DME) and the intent is to utilize available precision DME which has the added advantage of including highly portable ground stations.

The solution can therefore be carried with the vehicle. This fact permits a high resolution approach to the problem within the LTN-51. This approach is to create a flat earth approximation over a limited area. Specifically the system can provide a resolution of four feet over an area approximately 88 x 88 nautical miles. The limiting factor on an area for spraying is therefore the altitude at which the vehicle is flying and the coverage provided by the ground transponders. An example is that for an aircraft at 400 feet and a DME transponder at ground level the maximum line-of-sight range is approximately 28 miles. This can be enhanced by elevating the transponder antenna.

The overall system will combine the instantaneous precision position of the DME and the dead-reckoning ability of the INS such that continuous correction factors are available and applied to the INS. This will use the same principles as are in use today for DME augmentation of the LTN-51 but with higher resolution and better DME's.

Establishing parallel grid lines is no problem for the system and their accuracy is only dependent on the overall system knowledge of position. The system will be coupled to the aircraft autopilot thus eliminating the pilot error and providing high resolution steering.

. . /2

To establish a particular grid the operator will only need to know certain points in the vicinity which are visible from the air. The transponders may be randomly dispersed with some consideration for geometry of the DME signals relative to the aircraft. The computer will determine the transponder positions as follows: the pilot will fly over each of three identification points and depress a button which will tell the system to make simultaneous range measurements to as many as three ground transponders. From this information the LTN-51 computer can determine the precise location of each ground station. The limiting factor in accuracy is the point at which the pilot made the measurements but inaccuracies will only move the overall grid and will have no effect on the ability of the system to navigate along parallel lines within the grid.

The dimensions of the grid will be inserted into the INS computer through the Control Display Unit and will be relative to some reference point as determined from existing maps. Grid line separation and grid line lengths will also be inserted via the Control Display Unit. Heading of the original grid line will be computed from available information in the computer and subsequent grid lines will be precisely parallel. The computer will also determine the point at which the spraying valves should be opened or closed. This may be indicated to the pilot using an annunciator or may be used to automatically open and close the valves.

In summary, the system will consist of an existing LTN-51 with software changes only, a precision DME receiver which provides three channel reception, and any number of portable ground transponders. It will provide highly accurate navigation along lines within a limited area. The specified area has a size limitation but may be moved anywhere on the earth simply by establishing a known reference point and positioning the ground stations to provide range information within that area. Grid sizes, shapes and orientations as well as line separations and lengths are variable and can be hand programmed by the operator.

MEMORANDUM — NOTE DE SERVICE

GOVERNMENT OF CANADA — GOUVERNEMENT DU CANADA

C O P Y

(A3)

FROM / DE: A.P. Randall
L.B. Pollock

TO / À: Dr. J.J. Fettes

SECURITY CLASSIFICATION - DE SÉCURITÉ

OUR FILE - N/RÉFÉRENCE

YOUR FILE - V/RÉFÉRENCE

DATE: March 30, 1972

SUBJECT / SUJET: The proposed Inertial Navigation System installation for DC-7 spray aircraft and its suitability for navigational guidance of aerial applicators for the control of forest insects.

A meeting was held on March 27, 1972, at Litton Systems (Canada) Limited, Toronto, to discuss the proposed DME/Inertial Navigation system installation in a DC-7 aircraft and to assess the suitability of such a system with reference to the proposed aerial spraying of spruce budworm infested softwood forests in Quebec. The meeting was chaired by Mr. E.J. Bush, Sales Manager, Litton Systems (Canada) Limited with the following representatives present:

Litton Systems (Canada) Ltd. 25 Rexdale, Toronto	N. Emmott, Senior Applications Engineer D. Hensley, Systems Engineer, Los Angeles, Calif.
Midair (Canada) Ltd. Norwich, Ontario	E. Schwendau, President P. Cheeseman, Exec. Vice-President General Manager K.J. Johnson, Vice-President A. Foster, International Sales
Chemical Control Research Institute 25 Pickering Place, Ottawa, Ontario	A.P. Randall, Research Scientist L.B. Pollock, Research Pilot

After brief introductions, Mr. Bush presented a concise outline on the Litton Systems organization and world wide application of inertial navigation systems. An introduction to the fundamental principles of inertial navigation, using slides and film, was given by Mr. Emmott. The remainder of the Litton Systems presentation was given by Mr. Dave Hensley on the role of the proposed system installation in the DC-7 aircraft and the navigational capability to locate the area to be sprayed and the guidance that would facilitate flying parallel swaths with acceptable swath width accuracies.

Following the Litton presentation, Mr. Randall outlined the spruce budworm problem in Canada, the role played by aircraft in the application of pesticides and the difficulties encountered with current navigational methods of parallel swath tracking on operational control projects.

A-4

Memorandum to Dr. James J. Fettes March 30, 1972.

For the benefit of those not familiar with inertial guidance systems a brief description is presented below. The LTN-51 inertial navigation system operates by sensing aircraft accelerations from a gyro-stabilized, 4-gimbol, all-attitude platform. Navigation and guidance computations are performed by a microelectronic, general-purpose digital computer. Current manufacturing techniques and component design have greatly reduced drift error associated with a gyro-operated system. This inherent error can be further reduced by utilizing a DME update principle to provide, as stated in the attached Litton Systems letter to Mr. Randall, on accuracy of ± 200 feet random error for any swath track. Accurate determination of the ground position of the two DME stations would result in little, if any, shift in the grid system established for the particular spray area. A more detailed explanation of the system as proposed by Mr. Hensley (Litton Systems) is covered in the attached Telex letter.

The dual DME updated inertial system has several features which would be particularly suited to aerial spraying of vast areas of inaccessible forests. These are:

(a) the selected starting point for a particular operation could be located with considerable accuracy. This accuracy would be repeatable so that a return to the same point at any future date is possible

(b) the guidance capability would allow parallel swath tracking to within ± 200 feet after a continuous run of at least 20 miles

(c) because the inertial system is continuously updated the guidance accuracy achieved on any parallel swath will be the same

(d) the system has the capability to locate the exact point on a swath track where spray emission ceases so that a return to this same location is possible upon return from the fixed base where the spray tanks were refilled

(e) a capability exists to permit an aircraft shift in swath tracking to correct for extreme wind direction shifts that could occur during the spray operation thus minimizing the risk of excessive overlapping or gapping due to spray drifting during application

(f) the system is completely independent of any existing electronic position fixing devices other than the two self-contained portable DME stations which would be pre-positioned prior to commencement of spraying. Furthermore, because of this independence the guidance system can be utilized anywhere in the world.

Following a general question and answer period on the capabilities and limitations of the proposed installation, the field operations envisaged and spray area proposals, it was rather evident that even with immediate acceptance of the spray aircraft and guidance system proposal time was of the utmost importance to allow proper coordination by all parties concerned

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Memorandum to Dr. James J. Fettes March 30, 1972.

to achieve a successful operation.

The limitation stated in the CCRI note regarding the requirement for a demonstration of the guidance capability prior to acceptance of the total concept severely reduces the possibility of utilizing the DC-7 aircraft for the 1972 aerial spray program in Quebec because of the lead time necessary to equip the aircraft, program the computers and arrange logistic support.

On a theoretical basis, therefore, it is our considered opinion that the proposed dual DME/inertial navigation system when programmed to the appropriate coordinates will have the capability to locate the target area accurately and ensure parallel swath lines over the proposed spray area. The degree of accuracy and precision will be dependent on the time available for calibration of the equipment and training of the flight crew.

(Sgd. A.P. Randall)

A.P. Randall
Research Scientist

(Sgd. L.B. Pollock)

L.B. Pollock
Research Pilot

Attach.

APPENDIX "B"

DC-7 Calibration Trials 1972, Barstow, California

APPENDIX "B"

Fig. 1. Daily weather report from airport Weather Office

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

SURFACE WEATHER OBSERVATIONS

(Abridged for use at designated Civil Stations)

STATION: Daggett, Calif. - FAA

DATE: 1 MAR 1972

To convert LST to GMT ADD 8 hrs. SUBTRACT ______ hrs.

TYPE (1)	TIME (L.S.T.) (2)	SKY AND CEILING (Hundreds of feet) (3)	VISIBILITY (Statute miles) SURFACE (4)	TOWER (4a)	WEATHER AND OBSTRUCTIONS TO VISION (5)	SEA LEVEL PRESS (mb.) (6)	TEMP (°F) (7)	DEW PT. (°F) (8)	WIND DIREC-TION (00–36) (9)	WIND SPEED (Kts.) (10)	WIND CHAR-ACTER (11)	ALTIM. SETTING (Ins.) (12)	REMARKS AND SUPPLEMENTAL CODED DATA (13)	STATION PRESSURE (Ins.) (17)	DRY BULB (°F) (18)	WET BULB (°F) (19)	TOTAL SKY COVER (21)	TOTAL OPAQUE SKY COVER (36)	OBSERVER'S INITIALS (15)
R	0058	0	15			150	52	23	24	12		002	115	27.985			0	0	PB
R	0158	0	15			150	52	24	30	13		002		27.985			0	0	PB
R	0258	0	15			159	51	26	30	12		004		28.005			0	0	PB
R	0358	0	15			166	47	25	30	10		006	314 47	28.025			0	0	PB
R	0458	0	15			173	46	25	31	10		007		28.035			0	0	PB
R	0558	0	25			183	44	25	27	10		010		28.060			0	0	PB
R	0658	0	20			195	44	25	26	10		013	223	28.090			0	0	PB
R	0758	0	20			202	47	27	29	10		015	CIE	28.110			0	0	WF
R	0858	0	20			204	52	30	29	10		016	CIE	28.120			0	0	WF
R	0958	0	20			207	56	30	27	13		017	114 44	28.130			0	0	WF
R	1058	250 - Ⓘ	20			202	61	26	29	08		016		28.120			5	1	WF
R	1158	250 - Ⓘ	30			190	65	18	32	07		013		28.090			2	0	WF
R	1258	250 - Ⓘ	30			183	67	17	01	06		011	717	28.070	64.2	44.8	2	0	FV
R	1358	250 - Ⓘ	30			175	69	13	03	08		009		28.050	66.4	45.2	1	0	FV
R	1458	250 - Ⓘ	30			165	70	12	02	07		006		28.020	67.1	45.4	3	0	FV
R	1558	250 - Ⓘ	30			169	70	10	01	05		007	514 70	28.030	67.4	45.2	2	0	FV
R	1658	250 - Ⓘ	30			170	70	12	00	00		007		28.030	66.7	45.2	4	1	CA
R	1758	250 - Ⓘ	30			168	67	12	00	00		006		28.025	64.0	43.8	8	2	CA
R	1858	250 - Ⓘ	15			172	63	18	26	05		007	500	28.030			8	3	DM
R	1958	250 - Ⓘ	15			178	59	14	26	05		008		28.040			7	3	DM
R	2058	250 - Ⓘ	15			181	59	28	31	10		010		28.060			3	1	DM
R	2158	250 - Ⓘ	15			185	57	29	24	12		011	214 71	28.070			2	0	DM
R	2258	250 - Ⓘ	15			191	56	29	30	11		013		28.090			2	1	DM
R	2358	250 - Ⓘ	15			190	55	28	29	11		013		28.090			4	3	DM

TIME (L.S.T.) (42)	NO. (43)	PRECIP. (Ins.) (44)	SNOW FALL (Ins.) (45)	SNOW DEPTH (Ins.) (46)	MAX. TEMP. (°F) (47)	MIN. TEMP. (°F) (48)
MID. TO	X	0	0	0	54	47
0356		0	0	0	57	47
0956		0	0	0	56	44
1556		0	0	0	70	56
2156		0	0	0	71	57
		0	0	0	57	55

STATION PRESSURE COMPUTATIONS

TIME (L.S.T.) (59)	0359	0459	1559	2159
ATT. THERM. (60)				
OBSRVD. BAR. (61)				
TOTAL CORR. (62)				
STA. PRESS. (63)	28.025	28.130	28.030	28.070
BAROGRAPH (64)	28.020	28.130	28.035	28.080
BAR. CORR. (65)	+.005	+.000	-.005	-.010

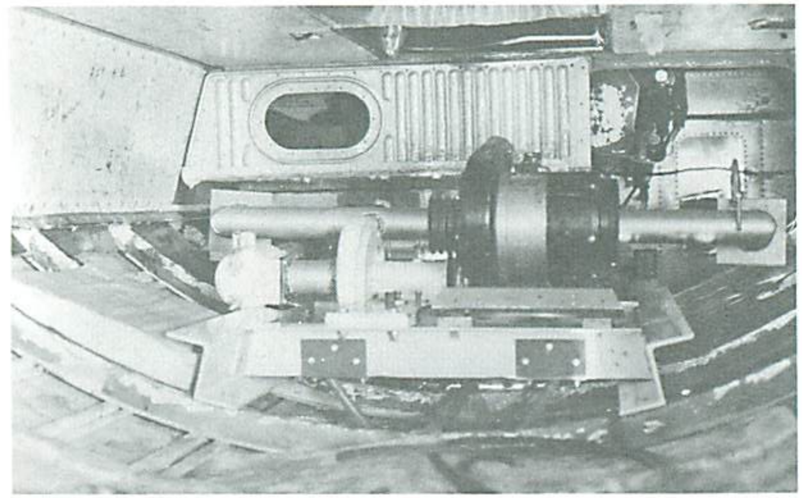
SUMMARY OF DAY
(Midnight to Midnight)

24-HR. MAX. TEMP. (°F) (66)	24-HR. MIN. TEMP. (°F) (67)	24-HR. PRECIP. WATER EQUIV. (Ins.) (68)	24-HR. SNOW FALL UNMLTD. (Ins.) (69)	1200 GMT SNOW (Ins.) (70)
71	44	0	0	0

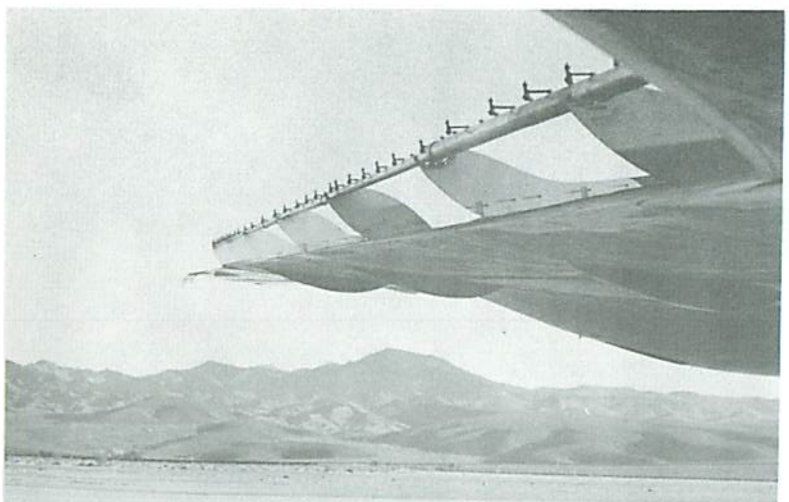
REMARKS, NOTES

Fig. 2(a,b,c,d). Details of prototype spray system in DC-7

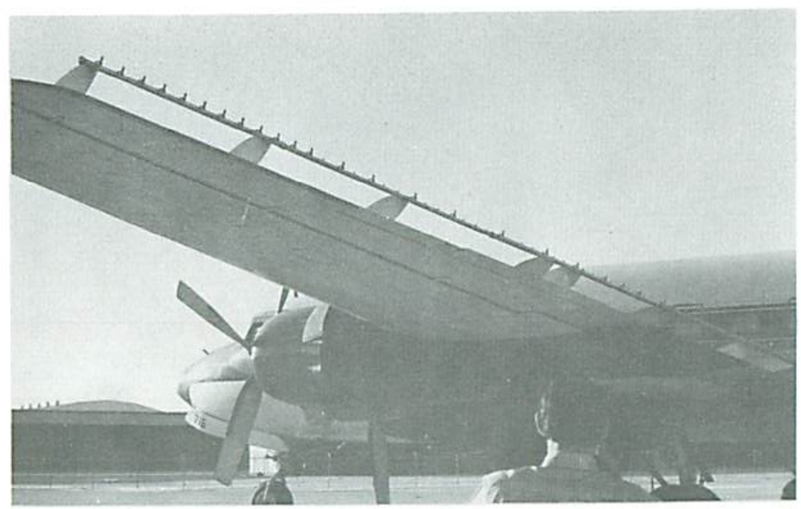
Fig. 2 (a) Interior view of DC-7 showing tank mount bracket (left) and mounted tank (right)



(b) Close-up view of electrically driven pump and shut-off valve



(c) Rear view of wing showing above wing mounted , telescopic boom with open nozzles facing upwards.



(d) Close-up of port wing showing boom and spacing of nozzles.

TABLE I

CHEMICAL AND PHYSICAL PROPERTIES OF DIESEL CHIEF L.

Appearance	Clear and Bright
Gravity, °API	41.8
Flash, PM °F	142
Copper Strip Corrosion	1 a
Visc. SUS at 100°F	
Water & Sediment	Nil
Sulphur, % Wt.	0.17
Cloud Point	-45
Pour Point	-45
Cetane Index	48.5
Distillation, °F	
10% Recovered	389
50% Recovered	428
End Point	519
Heat of Combustion, BTU/Gal 10^3	162.9

TABLE II

CHEMICAL PROPERTIES OF ASHLAND HI-SOLV 15

Typical Properties

Gravity, °API	26.5
Specific Gravity @ 60°F	.8956
Pounds per gallon	7.46
Mixed Aniline point, °F	63.2
Kauri-Butanol value	91
Flash Point, °F TOC	160
Distillation, °F	
IBP	366
5%	372
10	374
20	376
30	378
40	380
50	381
60	382
70	385
80	388
90	394
95	402
DP	436

Aeromatic Content 98%+

Fig. 3(a). Spread factor graph for Diesel Chief oil or Kromekote^R paper

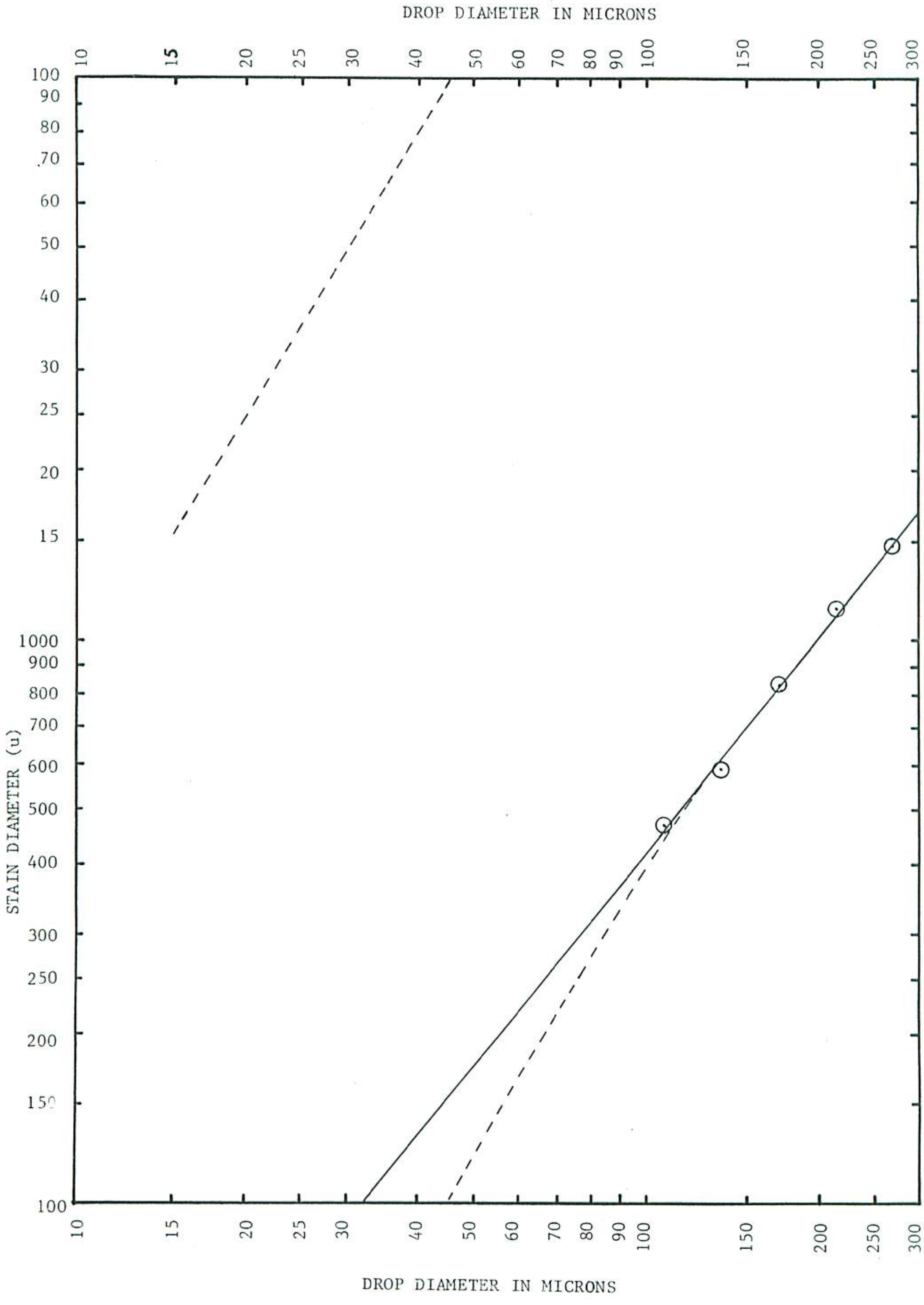
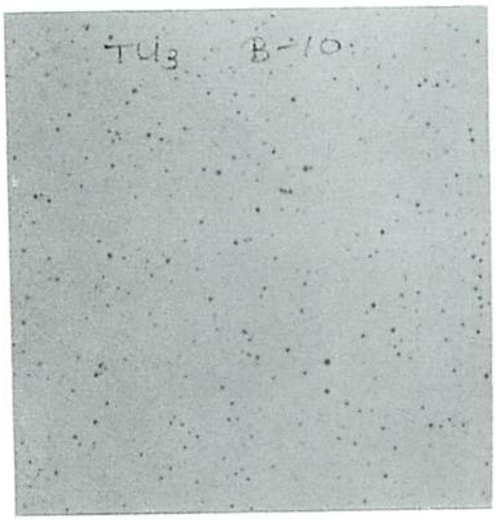
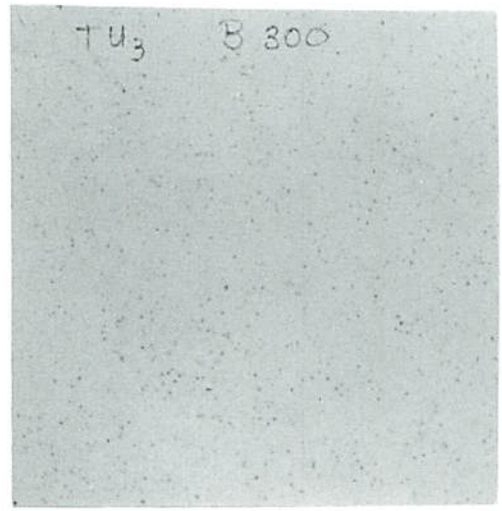
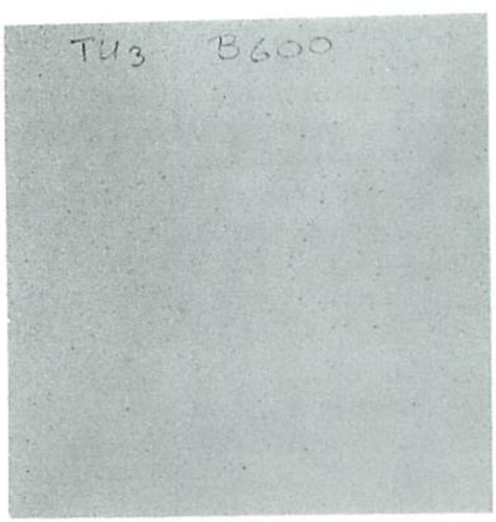

DROP DIAMETER IN MICRONS
STAIN DIAMETER (u)
DROP DIAMETER IN MICRONS

Fig. 3(b). Photographic samples of spray recovery at 10, 300, 600 and 1000 yards downwind (magnification 1.075x)


TU3 B-10


TU3 B 300


TU3 B600

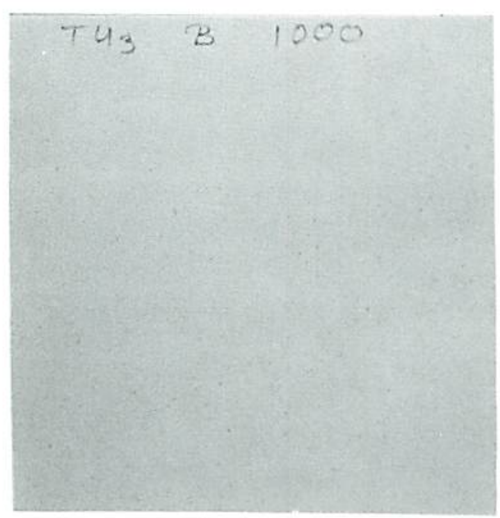

TU3 B 1000

TABLE III

RELATIONSHIP OF STAIN CLASS-DROP DIAMETER AND VOLUME FOR DIESEL* OIL

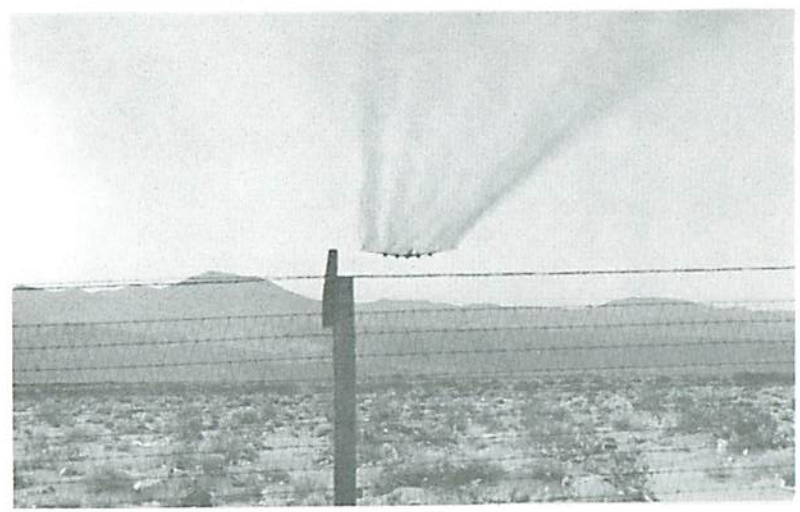
Class	Stain Class Limits	Ave. Stain Size (μ)	Drop Diameter (μ) Class Limit	Class mean	Drop Vol. (μl)	oz/ac per drop/cm^2
0	1 - 75	70	1 - 37	37	$.265 \times 10^{-4}$	.0375
1	75 - 150	115	38 - 56	49	$.612 \times 10^{-4}$	.089
2	150 - 250	200	57 - 76	67	1.57×10^{-4}	.224
3	250 - 350	300	77 - 93	84	3.10×10^{-4}	.440
4	350 - 450	400	94 - 109	101	5.4×10^{-4}	.760
5	450 - 550	500	110 - 124	116	8.2×10^{-4}	1.15
6	550 - 650	600	125 - 141	133	1.23×10^{-3}	1.75
7	650 - 750	700	142 - 158	149	1.89×10^{-3}	2.45
8	750 - 850	800	159 - 175	166	2.40×10^{-3}	3.40
9	850 - 950	900	176 - 190	183	3.22×10^{-3}	4.50
10	950 - 1,050	1,000	191 - 205	198	4.08×10^{-3}	5.7
11	1,050 - 1,100	1,100	206 - 222	213	5.05×10^{-3}	7.15
12	1,150 - 1,250	1,200	223 - 236	228	6.25×10^{-3}	8.8
13	1,250 - 1,350	1,300	237 - 250	243	7.55×10^{-3}	10.7
14	1,350 - 1,450	1,400	251 - 266	259	9.15×10^{-3}	12.8
15	1,450 - 1,550	1,500	267 - 282	275	1.09×10^{-2}	15.4

Fig. 4(a,b,c,d). Details of spray emission from the DC-7 aircraft

Fig. 4 (a) Side view of the DC-7 during stationary spray emission at airport.

(b) Cone shaped spray cloud resulting from mixing of the wing- tip vortice and propeller slipstream

(c) Front view of the DC -7 showing spray emission and spray cloud formation.



(d) Calibration run over airport boundary line at Barstow, California.

TABLE IV

SPRAY DEPOSIT DATA (DC-7 CROSSWIND CALIBRATION TRIALS 1972)

Yards Down-Wind	TX-1								TX-2								TX-3							
	L - A		L - B		L - C		L - D		L - A		L - B		L - C		L - D		L - A		L - B		L - C		L - D	
	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC	Drop/ cm^2	oz/AC
-180	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3.6	-	-	-	-
-170	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	6.6	-	-	-	-
-160	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	5.8	-	-	-	-
-150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	6.9	-	-	-	-
-140	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	6.9	-	-	-	-
-130	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	5.2	-	-	-	-
-120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	6.9	-	-	-	-
-110	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	6.9	-	-	-	-
-100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	6.5	-	-	-	-
- 90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	11.0	-	-	-	-
- 80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	6.9	-	-	-	-
- 70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	8.7	-	-	-	-
- 60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	6.2	-	-	-	-
- 50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	3.9	10	6.9	-	-	-	-
- 40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	5.4	16	10.1	-	-	-	-
- 30	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	18	14.4	16	10.1	-	-	-	-
- 20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	10.5	17	10.7	-	-	-	-
- 10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	14.0	15	9.6	-	-	-	-
0	-	-	-	-		4.6	-	-	3	0.4	0	0.0	10	22.5	1	4.6	12	14.0	14	16.9	-	-	-	-
10	-	-	-	-	-	-	-	-	5	0.4	0	0.0	-	-	-	-	43	19.1	24	18.7	-	-	-	-
20	-	-	-	-	1	5.1	0.04	4.1	10	0.4	0	0.0	10	15.1	1	5.0	34	13.2	34	24.0	11	11.5	6	6.0
30	-	-	-	-	-	-	-	-	8	0.4	0	0.0	-	-	-	-	25	16.7	21	16.9	-	-	-	-
40	-	-	-	-	1	3.7	-	-	2	0.4	0	0.0	11	24.4	5	5.5	32	15.6	21	16.5	10	10.1	20	19.6
50	-	-	-	-	-	-	-	-	2	0.4	0.2	0.4	-	-	-	-	21	12.4	21	10.8	-	-	-	-
60	-	-	-	-	1	3.2	-	-	3	0.4	0.2	0.8	9	11.0	1	6.4	27	17.9	20	9.0	14	11.9	11	10.0
70	-	-	-	-	-	-	-	-	3	1.2	0	0.0	-	-	-	-	20	12.4	20	19.0	-	-	-	-
80	-	-	-	-	1	4.1	0.2	3.2	4	0.4	1	1.9	9	10.6	1	6.0	29	12.0	19	9.7	8	7.8	8	11.0
90	-	-	-	-	-	-	-	-	2	0.4	1	0.8	-	-	-	-	26	15.1	18	11.5	-	-	-	-
100	-	-	-	-	1	2.3	-	-	2	0.4	1	0.4	11	11.9	5	4.1	19	13.2	20	10.0	7	5.5	9	9.0
110	-	-	-	-	-	-	-	-	4	0.8	1	0.9	-	-	-	-	25	12.0	18	9.7	-	-	-	-
120	-	-	-	-	1	3.2	-	-	3	1.2	2	0.8	1	7.8	1	6.0	13	6.6	22	11.8	6	6.9	14	12.0
130	-	-	-	-	-	-	-	-	3	1.2	2	2.3	-	-	-	-	11	4.7	10	3.2	-	-	-	-
140	-	-	-	-	1	3.7	0.5	4.6	3	0.8	2	1.5	5	10.1	6	7.4	12	6.6	14	8.9	7	9.2	8	9.0
150	-	-	-	-	-	-	-	-	2	0.8	2	1.5	-	-	-	-	7	6.6	17	11.1	-	-	-	-
160	-	-		0.4	1	3.7	0.6	6.0	3	6.2	3	1.9	10	7.8	5	6.9	6	4.3	11	8.2	8	8.3	5	8.0
170	-	-	-	-	-	-	-	-	2	2.7	1	1.5			-	-	5	3.1	14	8.2	-	-	-	-
180	-	-	-	-	1	2.3	5.0	9.2	3	3.1	2	1.9			5	7.8	6	3.1	17	9.3	5	6.9	8	7.0
190	0.02	0.4	1	1.5	-	-	-	-	6	3.9	3	3.5			-	-	4	4.0	18	10.0	-	-	-	-
200	0.02	0.4	0.1	0.4	1	5.1	-	-	8	-	3	4.7			6	8.7	2	3.5	19	9.3	1	4.6	7	8.3
220	0.05	0.4	0.8	1.2	4	6.0			6	3.9	4	4.3					2	3.0	14	5.7				
240	0.08	0.8	1	2.3	1	5.1			7	4.7	3	3.1					4	4.0	17	7.9				
260	12	7.0	4	1.2	1	4.1			10	5.0	4	2.3					7	5.5	25	8.9				
280	7	1.9	4	6.6	1	6.0			4	2.3	3	1.9					1	1.5	13	7.2				
300	14	6.6	2	3.5	1	4.6			9	4.7	4	2.3					9	7.0	19	9.7				
320	10	8.2	12	5.4					4	5.4	7	4.3					8	7.5	23	11.1				
340	17	6.6	13	8.5					6	4.3	5	2.7					9	6.6	17	10.0				
360	20	7.0	29	7.0					11	7.4	4	2.7					17	7.8	11	7.5				
380	14	7.8	17	7.6					13	5.8	4	3.9					12	5.0	10	4.7				
400	12	5.8	13	6.8					9	5.8	6	2.7					8	2.7	11	5.7				
420	13	7.0	12	5.8					5	2.7	3	2.7					9	3.1	11	6.5				
440	9	3.5	11	3.9					3	4.3	9	3.5					6	3.1	12	7.9				
460	7	3.5	13	4.5					4	3.5	5	3.9					5	4.7	21	12.6				
480	11	4.7	15	4.7					4	4.3	13	4.7					2	-	16	8.6				
500	10	4.3	15	4.9					7	4.3	3	3.1					6	3.1	14	5.7				
520	13	4.7	15	5.4					8	3.9	6	6.6					4	3.1	3	2.9				
540	14	5.4	10	5.1					10	4.3	6	4.7					5	3.2	5	1.8				
560	19	6.6	13	6.8					10	3.9	5	3.9					5	2.9	2	2.1				
580	8	5.4	12	6.2					4	2.7	3	3.1					6	2.5	8	2.9				
600	10	5.4	18	6.4					8	2.3	6	8.2					6	2.3	5	1.4				
640	7	5.0	14	5.0					11	3.1	5	7.9					5	3.5	8	3.2				
680	8	2.3	12	4.8					9	5.0	7	3.1					2	2.3	5	2.5				
720	5	2.7	18	4.9					24	1.9	5	5.4					1	2.7	9	2.5				
760	8	3.9	25	7.8					4	4.7	11	3.9					1	2.3	9	2.5				
800	13	10.9	21	6.3					8	3.9	13	5.0					1	4.3	11	6.1				
840			19	5.8							11	5.8							11	5.4				
880			23	9.3							3	3.1							13	4.7				
920			17	8.9							16	5.0							8	5.0				
960			10	5.4							1	4.7							11	3.6				
1000			9	5.8							7	5.0							12	5.4				
1040			10	5.0							14	6.2							10	4.3				
1080			14	4.9							7	4.3							11	5.7				
1120			9	4.0							5	4.7							14	5.0				
1160			10	6.0							9	6.2							7	5.4				
1200			6	3.0							8	6.6							13	4.7				
1240																			14	7.0				
1280																			14	3.5				
1320																			14	7.0				
1360																			6	3.9				
1400																			11	4.3				
1440																			9	4.3				
1480																			4	2.3				
1520																			3	2.3				
1560																			4	1.5				
1600																			10	5.4				
1640																			5	2.7				
1680																			5	1.9				
1720																			8	3.1				
1760																			5	4.7				
1800																			7	3.5				
1840																			8	3.5				
1880																			7	8.5				
1920																			7	3.5				
1960																			8	4.3				
2000																			8	4.7				
2040																			7	3.9				
2080																			8	4.7				
2120																			8	5.0				
2160																			7	4.3				
2200																			8	3.9				
2240																			6	3.9				
2280																			7	4.7				
2320																			6	5.4				
2360																			3	7.4				

Fig. 5. Graphs showing mass median and number median diameter for four of the calibration trials

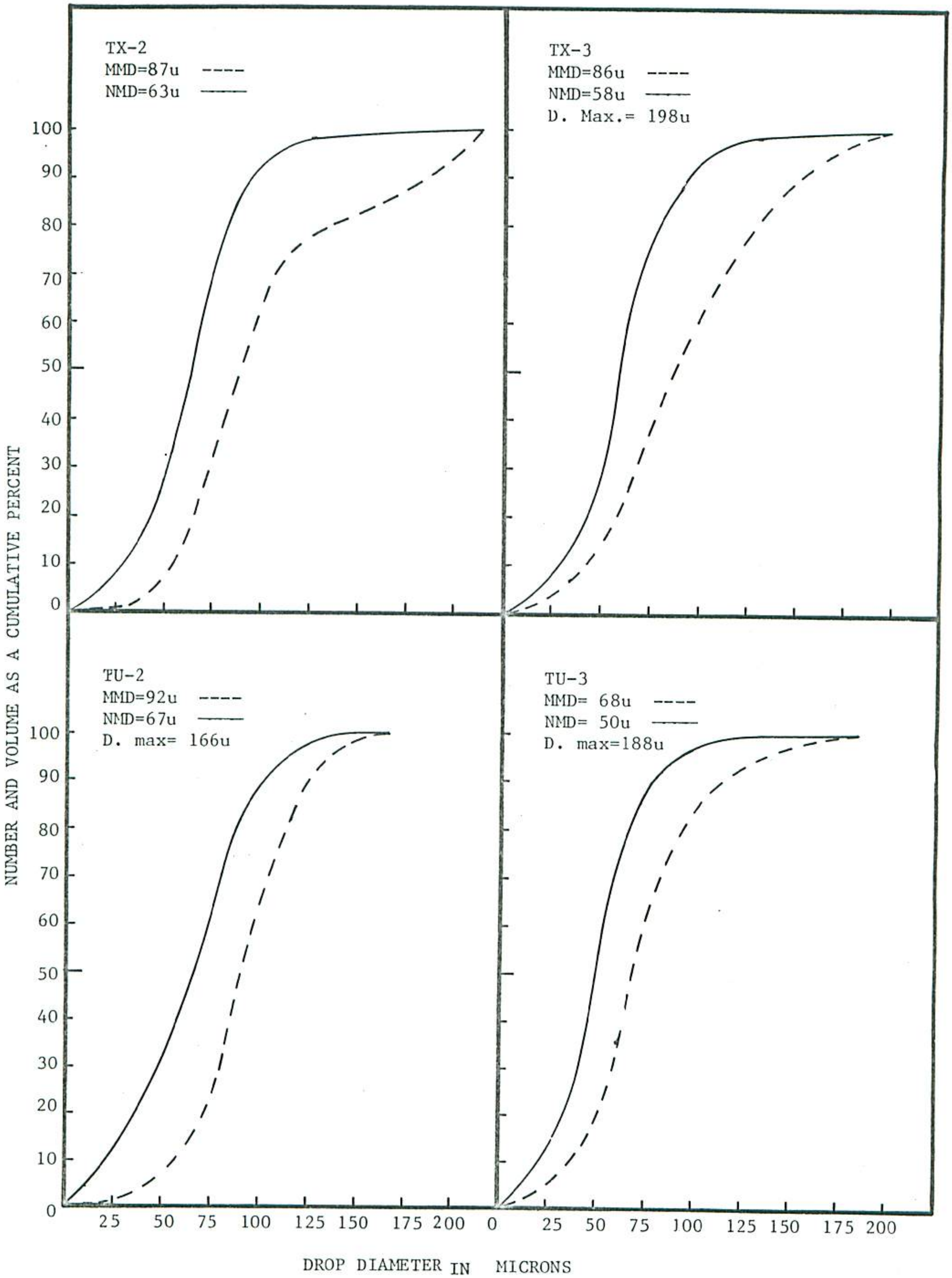

TX-2
MMD=87u ----
NMD=63u ——
TX-3
MMD=86u ----
NMD=58u ——
D. Max.= 198u
TU-2
MMD=92u ----
NMD=67u ——
D. max= 166u
TU-3
MMD= 68u ----
NMD= 50u ——
D. max=188u
100
90
80
70
60
50
40
30
20
10
0
NUMBER AND VOLUME AS A CUMULATIVE PERCENT
25 50 75 100 125 150 175 200 0 25 50 75 100 125 150 175 200
DROP DIAMETER IN MICRONS

Fig. 6. Graph showing deposit in drops/cm^2 and fluid oz/acre for crosswind trials TX-2, TX-3

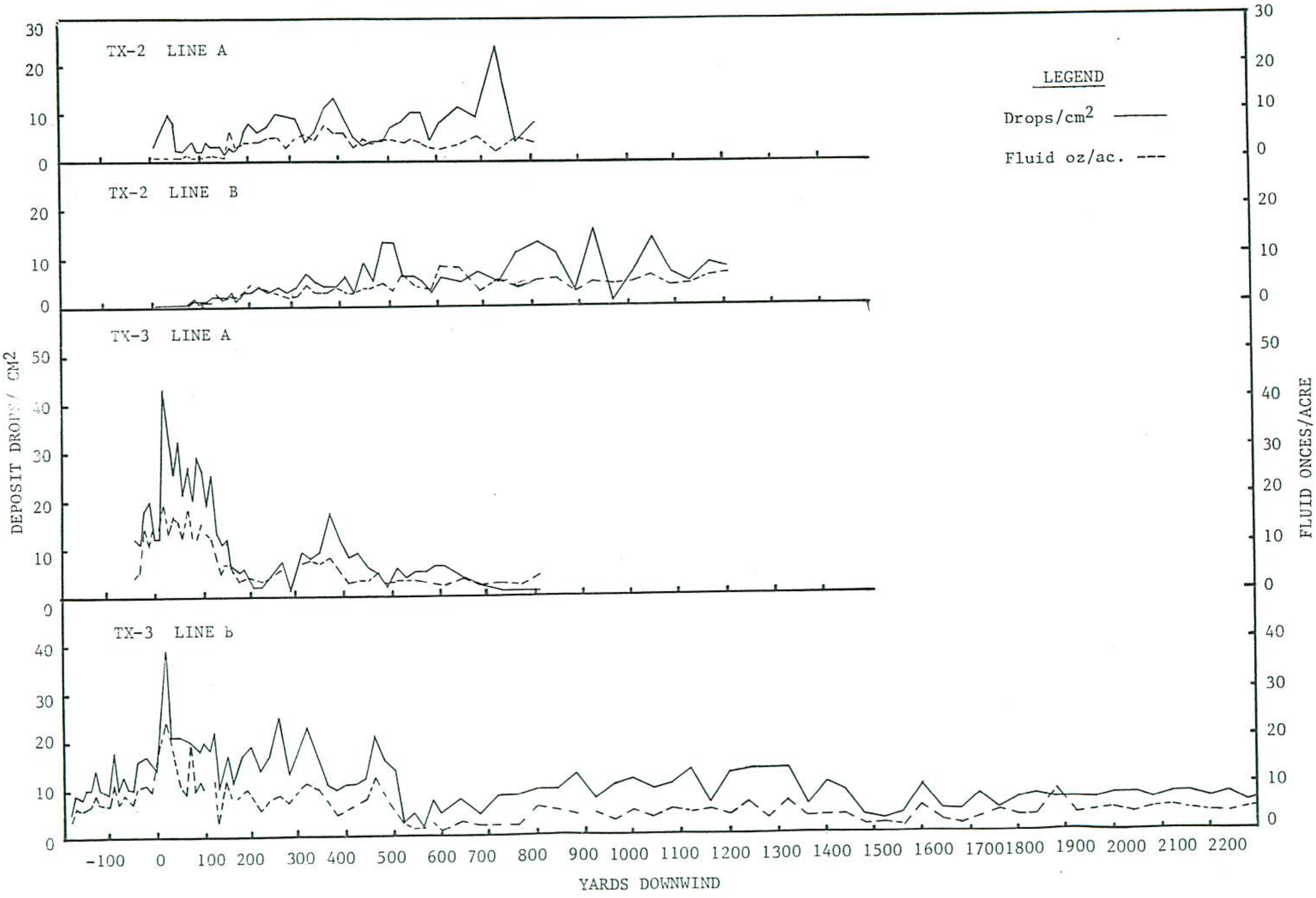
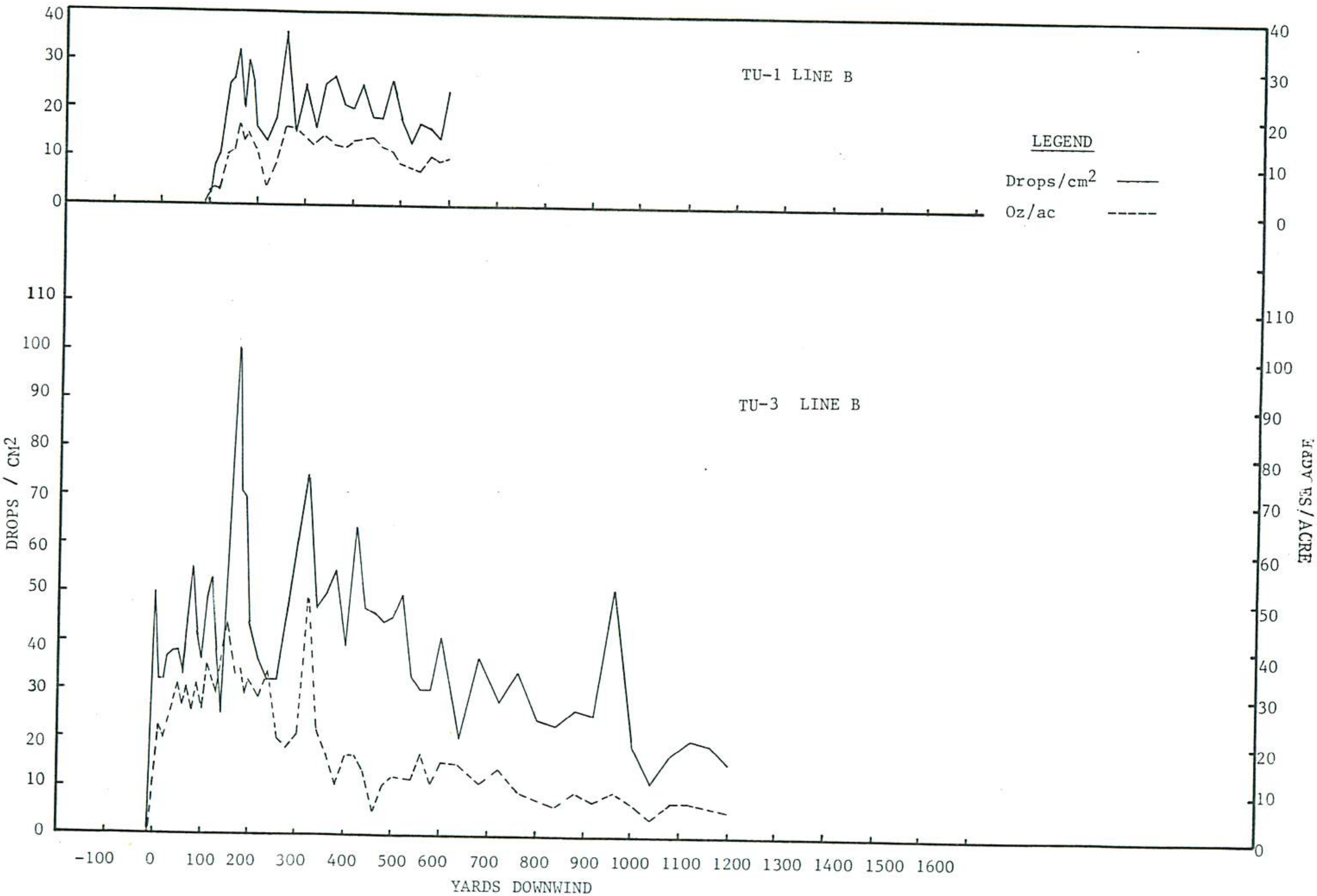

TX-2 LINE A
TX-2 LINE B
TX-3 LINE A
TX-3 LINE b
LEGEND
Drops/cm2
Fluid oz/ac.
DEPOSIT DROPS/ CM2
FLUID ONCES/ACRE
YARDS DOWNWIND
-100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200

Fig. 7. Graph showing deposit in drops/cm^2 and fluid oz/acre for upwind trials TU-1 and TU-3



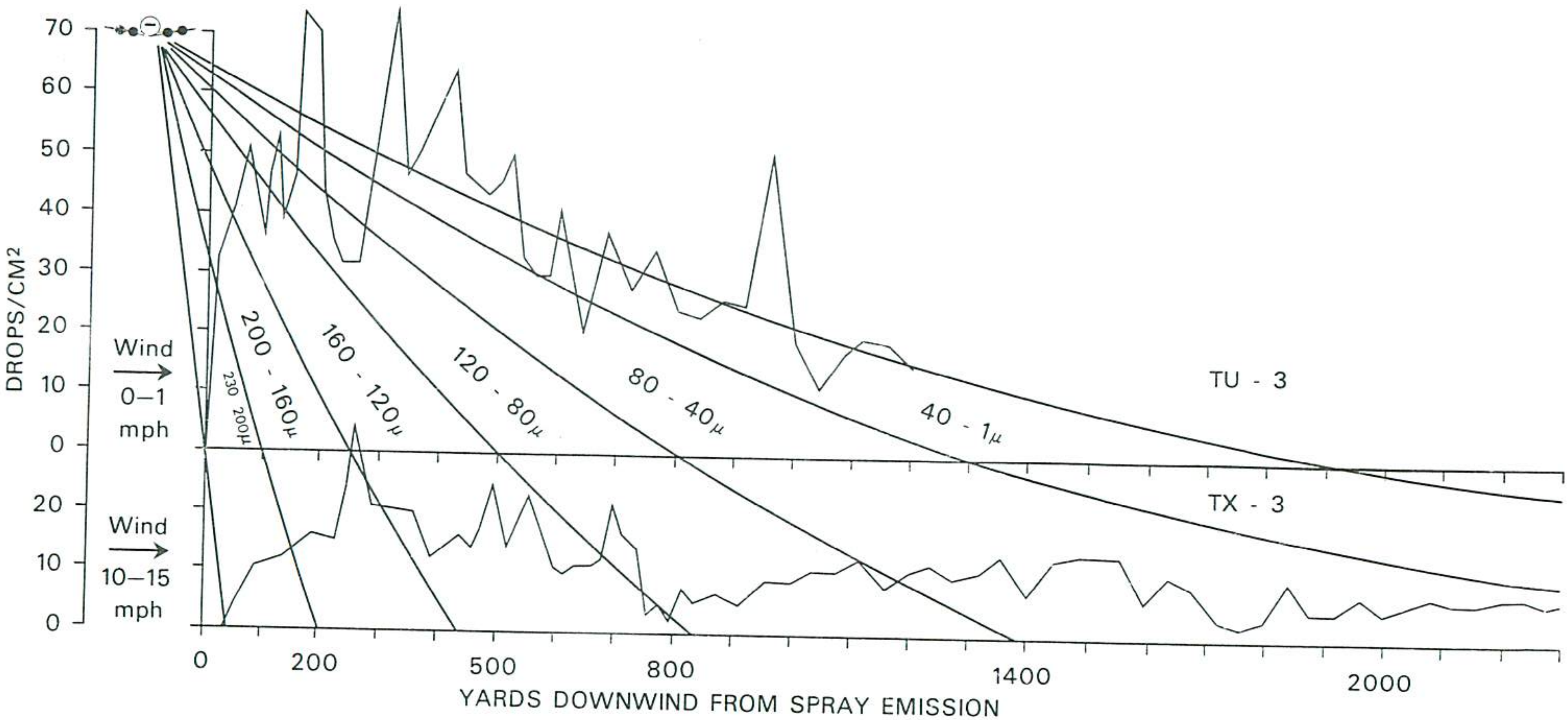
TU-1 LINE B
LEGEND
Drops/cm2
Oz/ac
TU-3 LINE B
DROPS / CM2
YARDS DOWNWIND
-100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600

TABLE V

SPRAY DEPOSIT DATA DC-7 UPWIND CALIBRATION TRIALS 1972

Yards Down-Wind	TU-0								TU-2								TU-3							
	L - A		L - B		L - C		L - D		L - A		L - B		L - C		L - D		L - A		L - B		L - C		L - D	
	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC	Drop/ cm²	oz/AC
0	-	-	-	-	-	-	0	0.0	-	-	-	-	-	-	-	-	-	-	50	15.6	-	-	25	11.7
10	-	-	0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	1	1.2	32	22.5	-	-	-	-
20	-	-	0	0.0	-	-	0	0.0	-	-	-	-	-	-	-	-	-	-	32	19.8	-	-	21	12.4
30	-	-	0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37	24.4	-	-	-	-
40	-	-	0	0.0	-	-	0	0.0	-	-	-	-	-	-	-	-	-	-	38	26.7	-	-	29	11.7
50	-	-	0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38	31.3	-	-	-	-
60	-	-	0	0.0	-	-	0	0.0	-	-	-	-	-	-	-	-	-	-	33	26.7	-	-	30	11.7
70	-	-	0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	46	30.4	-	-	-	-
80	-	-	0	0.0	-	-	1	0.4	-	-	-	-	-	-	-	-	-	-	55	25.8	-	-	31	14.4
90	-	-	<1	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	42	31.3	-	-	-	-
100	-	-	2	2.7	-	-	2	1.9	-	-	-	-	-	-	-	-	-	-	36	25.8	-	-	28	15.6
110	-	-	8	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48	34.9	-	-	-	-
120	-	-	10	3.1	-	-	26	12.4	-	-	-	-	-	-	-	-	-	-	53	33.1	-	-	26	17.1
130	-	-	18	7.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38	29.4	-	-	-	-
140	-	-	25	10.5	-	-	23	10.9	-	-	-	-	-	-	-	-	-	-	25	29.9	-	-	25	16.3
150	-	-	26	11.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	46	43.2	-	-	-	-
160	-	-	32	17.1	-	-	13	11.8	-	-	-	-	-	-	-	-	-	-	74	37.7	-	-	38	21.4
170	-	-	21	13.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	101	33.1	-	-	-	-
180	-	-	30	14.7	-	-	27	9.7	-	-	-	-	-	-	-	-	-	-	71	34.0	-	-	38	24.1
190	-	-	26	12.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70	29.0	-	-	-	-
200	-	-	16	10.9	-	-	46	16.7	-	-	-	-	-	-	-	-	-	-	44	32.2	-	-	39	24.5
220	-	-	13	3.9					-	-	-	-	-	-	-	-	-	-	36	28.5	-	-	43	23.3
240	-	-	18	9.3					-	-	-	-	-	-	-	-	-	-	32	33.6	-	-	46	24.1
260	-	-	36	15.9					-	-	-	-	-	-	-	-	-	-	32	20.2	-	-	39	18.7
280	-	-	15	15.6					-	-	-	-	-	-	-	-	-	-	47	18.4	-	-	35	17.1
300	-	-	25	14.0									0.2						61	20.7	-	-	27	12.4
320	-	-	16	12.8					-	-	-	-	5	-	-	-	-	-	74	49.2	-	-	23	12.0
340	-	-	25	14.4					-	-	-	-	5	-	-	-	-	-	47	22.1	-	-	31	9.7
360	-	-	27	12.8					-	-	-	-	5	-	-	-	-	-	50	17.0	-	-	[illegible]	9.7
380	-	-	21	12.4					-	-	-	-	7	-	-	-	-	-	55	10.6	-	-	25	10.5
400	-	-	20	13.2					-	-	-	-	28	-	-	-	-	-	39	16.6	-	-	25	8.9
420	-	-	25	20.6					-	-	-	-					-	-	64	16.6			22	8.2
440	-	-	18	13.6					-	-	-	-					-	-	47	13.3			17	7.8
460	-	-	18	12.0					-	-	-	-					-	-	46	5.1			21	7.4
480	-	-	26	11.3					-	-	-	-					-	-	44	10.6			17	7.4
500	-	-	18	8.5					-	-	-	-					-	-	45	12.0				
520	-	-	13	7.8					-	-	-	-					-	-	50	63.0				
540	-	-	17	7.4					-	-	-	-					-	-	33	11.5				
560	-	-	16	10.1					-	-	-	-					-	-	30	17.0				
580	-	-	14	8.9					-	-	-	-					-	-	30	11.0				
600	-	-	24	9.7					-	-	-	-					-	-	41	15.2				
640																	-	-	20	14.7				
680																	-	-	37	11.0				
720																	-	-	28	13.8				
760																	-	-	34	9.2				
800																	-	-	24	7.8				
840																	-	-	23	6.4				
880																	-	-	26	9.2				
920																	-	-	25	7.4				
960																	-	-	51	9.2				
1000																	-	-	19	6.9				
1040																	-	-	11	3.7				
1080																	-	-	17	6.9				
1120																	-	-	20	6.9				
1160																	-	-	19	6.4				
1200																	-	-	15	5.1				

Fig. 8. Graph showing effect of HU factor on spray cloud drift and deposit


DROPS/CM²
70
60
50
40
30
20
10
0
20
10
0
Wind
0–1
mph
Wind
10–15
mph
230 200µ
200 - 160µ
160 - 120µ
120 - 80µ
80 - 40µ
40 - 1µ
TU - 3
TX - 3
0
200
500
800
1400
2000
YARDS DOWNWIND FROM SPRAY EMISSION

Fig, 9(a,b). Spray cloud characteristics produced by vortice effect from single- and multi-engine aircraft

Fig. 9(a). Picture of spray cloud characteristics produced by vortice effect from single engine aircraft.

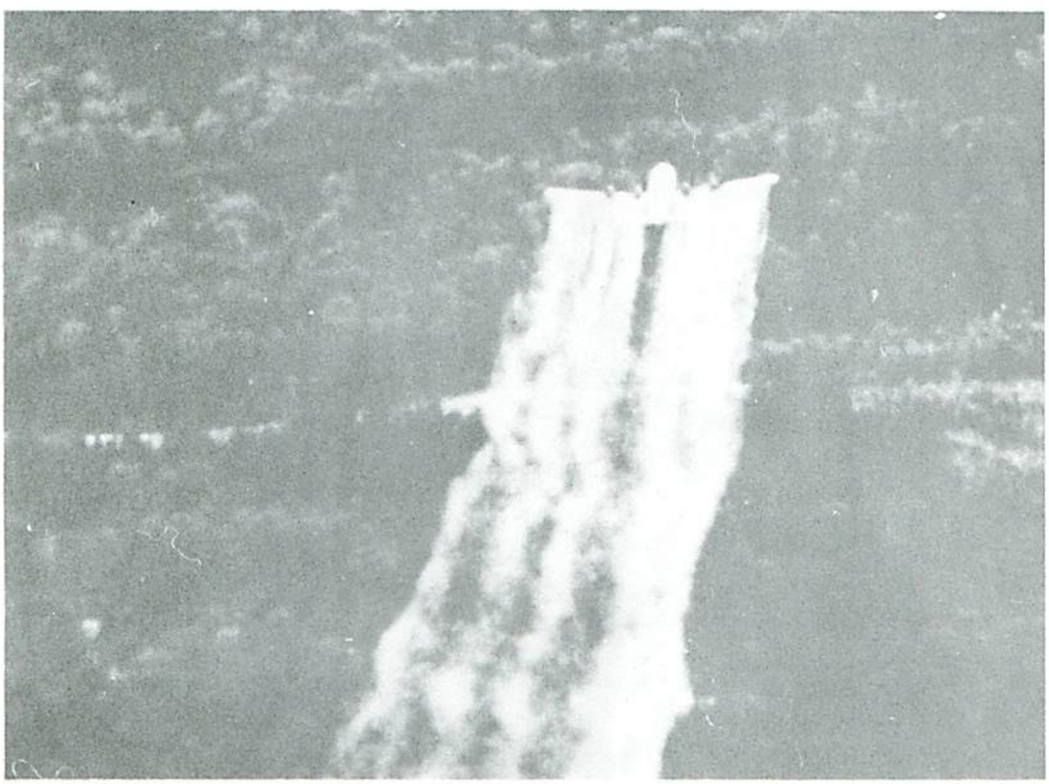


Fig. 9(b). Picture of spray cloud characteristics produced by vortice effect from multi-engine aircraft.