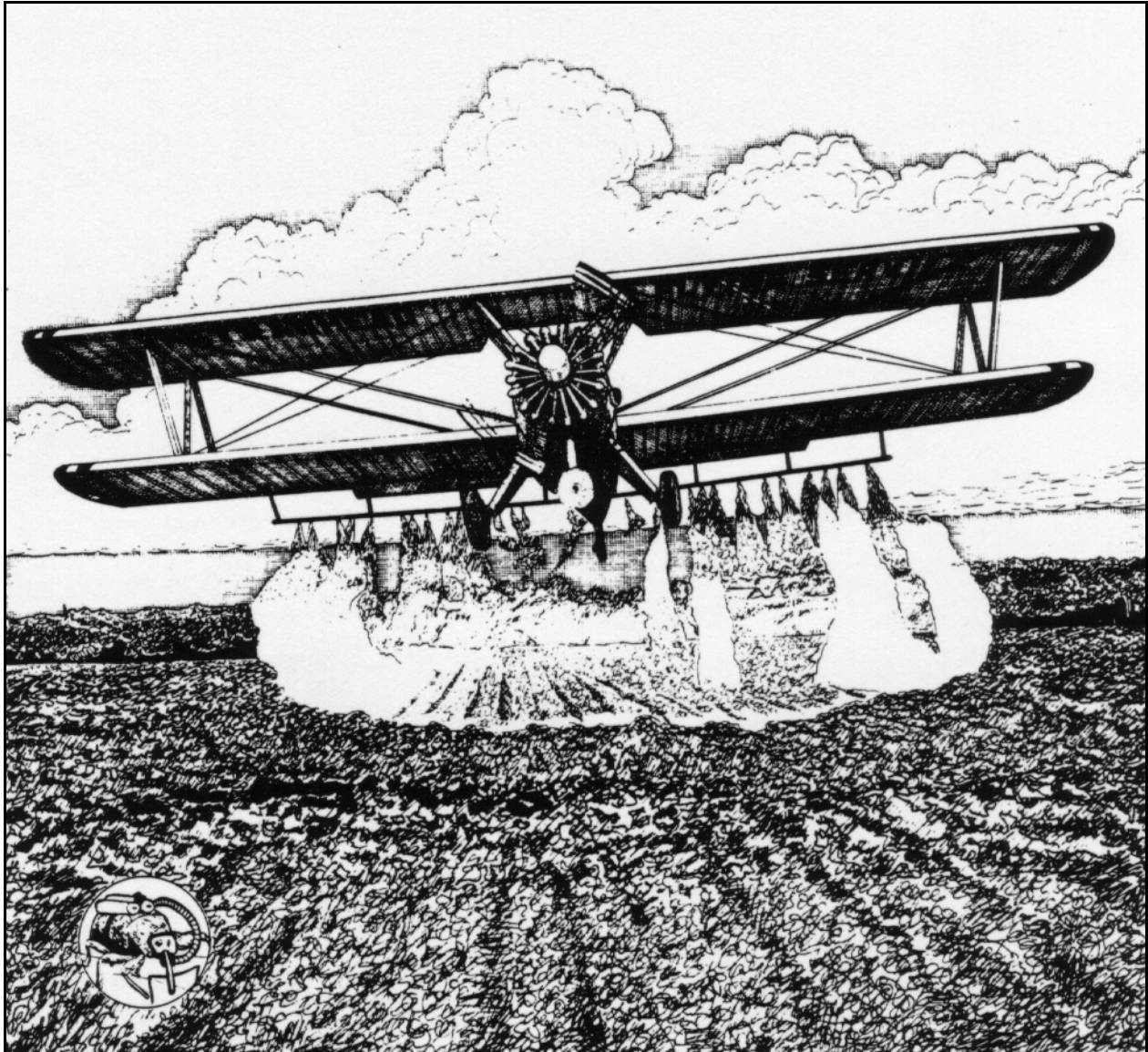


Agricultural Aircraft Calibration and Setup for Spraying



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By Dennis R. Gardisser and Dennis K. Kulhman¹

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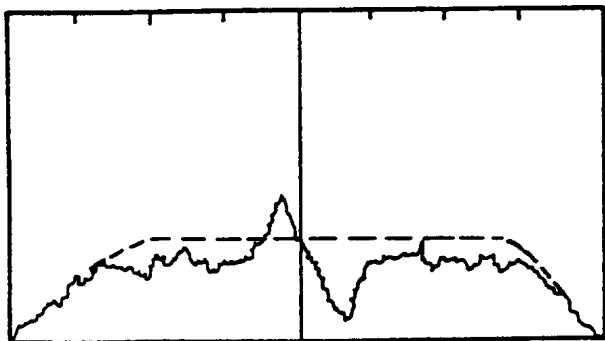
By Dennis R. Gardisser and Dennis K. Kulhman

Effective pest control is critical in a business that is as competitive as aerial application. The successful aerial applicator recognizes the importance of uniform distribution, proper aircraft setup, spray droplet size, drift control, and weather conditions. Each of these has a big effect on the degree of efficacy with most pesticides. These topics are introduced to assist persons who are evaluating and modifying spray system performance. Pattern testing gives a measurement of spray swath uniformity, droplet size, and effective swath width.

Uniform Distribution

A symmetrical nozzle arrangement (same number of nozzles on both wings with symmetrical spacing) seldom gives uniform deposition. Spray distribution is disrupted by turbulence due to the wake of an aircraft in flight such as air rotating from the propeller (propeller or rotor wash - see Figure 1) and by air being forced outward from beneath the wing tips (wing tip vortices). Small droplets are often carried further off target by this turbulence than larger droplets.

Figure 1. Single swath distribution with prop wash pattern distortion.



Prop wash turbulence, which is the result of the clockwise propeller air helix spiraling into the fuselage, carries droplets from nozzles to the right of the fuselage and deposits them on the target located beneath or to the left of the fuselage. Counter clockwise rotation propellers (counter clockwise rotating engines such as the PZL) will have similar but reversed prop wash problems with the excess deposit on the opposite side of the aircraft.

The result of prop wash is a lack of spray deposit reaching targets from the center to approximately 6 feet right (or left in the case of the PZL engines) of the fuselage. Historically, aerial application workshops have resulted in a high percentage of the aircraft requiring compensation for this problem. The seriousness of prop

wash spray shift depends on several factors including aircraft fuselage and aerodynamics, propeller length and rotation speed, special cowlings -- like speed rings, spray droplet size, and spraying height.

Helicopters exhibit similar **rotor wash** characteristics. The rotation of the rotor creates a swirling, cone-shaped helix that descends downward and trails the direction of flight. This rotating air mass traps small spray droplets and transports them resulting in a distortion of the spray deposit away from the leading rotor and in the direction of the trailing rotor. This shift can be influenced by many factors including the aircraft aerodynamics, location of boom mounting, spray droplet size, forward flight speed, and weight of the aircraft.

Prop wash is anticipated with propeller aircraft, especially those with larger radial engines. Some compensation is possible with proper nozzle location. Extra nozzles should be installed to the right of the fuselage usually in line with or just inboard of a point directly behind the propeller tip. To determine this point, align the propeller horizontally and visualize a line parallel to the line of flight rearward to the spray boom. Radial powered Ag Cats typically require more nozzles on the right than other types of aircraft. Engine **speed rings** alter the airflow around the engine and result in differing distortions to the deposition patterns than the same aircraft without a speed ring. The deposition pattern of the large Melex Dromader aircraft is particularly sensitive to the addition of third party manufactured speed rings. Following the addition or relocation of any nozzle position, the aircraft should be pattern tested to verify the change in deposition uniformity.

Wing tip vortex originates in the turbulence behind the wing, as a result of the air stream moving quickly from the high pressure area under the wing meeting the low pressure air from the top of the wing surface. The air mass travels the shortest route which causes part of the air to **slip** outward from under the wing introducing a large amount of turbulence and rotation. This rotation can be visualized as a spinning cone of air with the highest velocities toward the center of the cone. The highest velocity (strongest) vortex action is produced by heavy, slow-moving aircraft. Bi-wing aircraft produce vortices at each of the wing tips that quickly combine into a single vortex behind the aircraft. The combined vortex is approximately the same strength as that produced by a monowing aircraft of the same weight and air speed.

Larger droplets released inboard and well below the wing are least influenced by the wing tip vortex. Wing down wash airflow causes the pattern spray to spread. Wing tip vortices are also partially responsible for a swath wider than the aircraft wingspan. However, it is essential that spray enters only the outer, gently swirling air during its second or third rotation rather than the eye of the vortex. The outer portion of the vortex has a downward and outward motion that carries primarily the smaller droplets down to the crop outside the wingspan. The eye of the vortex traps all but the largest droplets, rotating them above the aircraft wing level. These droplets may be suspended long enough that the pesticide carrier (water) may evaporate or move off target (Figure 2).

Helicopters produce rotor vortices in much the same way as fixed wing aircraft except that the rotor blade changes the angle of attack as it travels around in a circular path. The rotor vortices form just below and behind the blade tip with the maximum strength existing at the point where the rotor blade is at the highest angle of attack. Nozzles should be placed inboard of the rotor blade tips to help prevent entrainment of the spray in the vortex. Toe mount booms produce less rotor distortion than do skid or heel mounted booms.

Placing nozzles inboard and/or below the trailing edge of the wing reduces the amount of spray trapped in the vortex circulation. Recent NASA research on fixed wing aircraft indicates that removing nozzles inboard from the wing tips until a 10 percent reduction in effective swath width was noted will reduce (by up to 90 percent) potential driftable fines. Fly-in pattern testing has verified that the drift hazard reduction is maximized by not placing a nozzle within 6 to 10 feet of the wing tip. Normally, the swath width of conventional aircraft is not reduced by reducing the boom length to 70 or 75 percent of the wingspan. The effect of reducing boom length more than 70 percent depends on the aircraft, nozzle pressure, and spray droplet size.

Applicator tests using rotary nozzles (i.e., Micronair) have indicated that the outermost nozzle position may be positioned inboard as much as 55 percent of the wingspan to ensure that material is not entrained in the wing tip

vortex circulation.

Nozzle stoppage, improper swath width, and other factors can cause poor distribution. Strips of poor weed control, streaking, indicate poor distribution. However, identifying the cause and remedying this problem from field results is strictly chance. If one waits for problems to show up in a field situation, the damage has already been done and is hard to remedy. Pattern testing should be completed and calibration adjustments made to the aircraft to obtain uniform deposition prior to making annual applications. Some useful patterning techniques are described later in this publication.

Basic Formulas for Aircraft Calibration

Calibration is a process to determine how much liquid solution must be delivered from the nozzles to deposit the required amount of product active ingredient (AI) per acre. The amount of material applied by an aircraft can be changed only by a change in ground speed or a change in flow rate. Swath width should never be used as a method of changing the application rate without physically changing the nozzle configuration. The basic steps of aircraft calibration are:

Case 1

1. Determine the acres your aircraft system treats per minute at the speed and estimated swath width you plan to fly. The effective swath width should match that determined by pattern testing.

Equation 1

$$\text{Acres per Minute} = (0.00202)(\text{Swath Width})(\text{Speed})$$

Example using: 60 ft swath and 120 MPH
 $\text{Acres/Minute} = (0.00202)(60 \text{ ft})(120 \text{ MPH}) = 14.4$

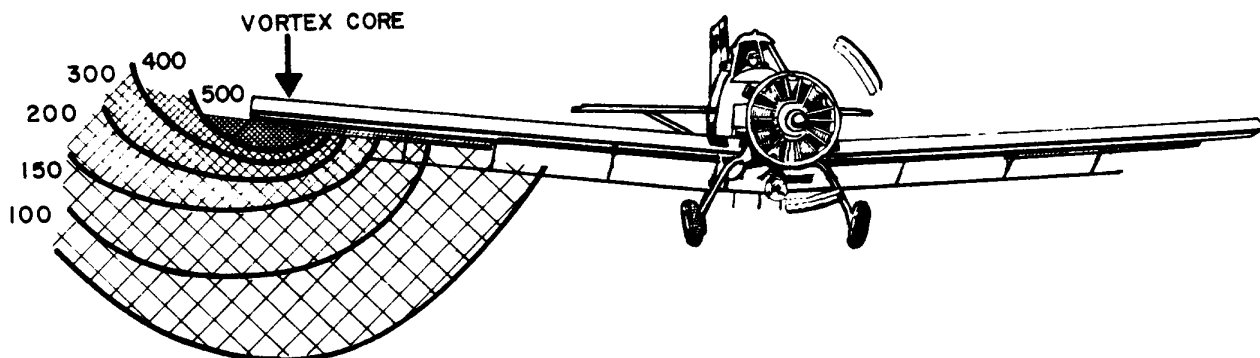
2. Determine the gallons you must spray per minute to apply the recommended gallonage rate.

Equation 2

$$\text{GPM} = (\text{Acres per Minute})(\text{Application Rate})$$

Example using: 10 gallons per acre
 $\text{GPM} = (14.4 \text{ A/min})(10 \text{ GPA}) = 144 \text{ GPM}$

Figure 2. Wing tip vortex zones where smaller droplets can become trapped (droplet diameters shown in microns, μ).



- Once the flow rate has been determined, select the nozzle orifice size and number of nozzles needed to deliver the correct number of gallons per minute within the allowable operating pressure range of your system. It is generally recommended that spray pressures remain greater than 18 psi and less than 40 psi (preferably 18-30 psi to minimize drift).

Case 2

Determine the number of nozzles to use. Assume you are using a nozzle with a flow rate of 3 GPM at 25 psi.

Equation 3

$$\text{Number of Nozzles} = \frac{\text{Total Flow}}{\text{GPM per Nozzle}}$$

$$\frac{144 \text{ GPM}}{3 \text{ GPM/Nozzle}} = 48 \text{ Nozzles Needed}$$

A total of 48 nozzles would need to be operational to obtain the desired application rate. The positioning of each nozzle should be selected and the system pattern tested to verify distribution pattern uniformity and nozzle pattern changes required.

Case 3

Determine what nozzle tip size to use. For this calculation, the total number of nozzle outlet positions on the boom or the total number of positions one plans to use must be selected before calculations begin. Assume that 66 nozzles are needed.

Equation 4

$$\text{GPM per Nozzle} = \frac{\text{Total Flow}}{\text{Number of Nozzles}}$$

$$\frac{144 \text{ GPM}}{66 \text{ Nozzles}} = 2.18 \text{ GPM}$$

Based on this calculation, one would select a nozzle that has a flow rate close to 2.18 GPM in the desired pressure range of 18-30 psi.

Calculating flow rates from individual nozzles once they are mounted on a boom system is difficult, especially when equipping an aircraft for high application rates. Individual nozzle flow rates vary depending on location, turbulence in the boom, and the number of boom restrictions. After placing nozzles on the boom, make a trial run to ensure the proper application rate is being

applied and that the spray results in a uniform deposition. A high number of larger nozzles (larger orifices) results in high fluid velocities inside the boom and a large pressure drop from the center of the boom to the end of the boom where the last nozzle is located. This pressure differential may result in narrower effective swath widths. Full three inch liquid systems (no restrictions smaller than three inches from the pump outlet on) are recommended for field applications greater than 9 GPA.

The exact flow rate (GPM) or pressure (psi) needed for a particular nozzle may not be listed in the available tables. If the flow rate is known at one pressure, the pressure or flow rate can be calculated for other pressures or flow rates by using the following equation:

Equation 5

$$\frac{GPM_1}{GPM_2} = \frac{\sqrt{PSI_1}}{\sqrt{PSI_2}}$$

If the desired pressure is known, the unknown nozzle flow rate may be calculated by rearranging the above equation:

Equation 6

$$GPM_{Unknown} = \frac{(GPM_{Known})(\sqrt{PSI_{Desired}})}{\sqrt{PSI_{Known}}}$$

Or if a desired flow rate is known, the needed pressure may be calculated by rearranging Equation 6:

$$PSI_{Unknown} = \left(\frac{(GPM_{Desired})(\sqrt{PSI_{Known}})}{GPM_{Known}} \right)^2$$

Equation 7

This relationship is accurate for most hydraulic nozzles.

As an example, suppose we would like to use 6530 flat fan tips at a flow rate for Case 3 scenario above. From the nozzle catalog, determine that the flow rate of this nozzle at 40 psi is 3.0 GPM.

$$PSI_{Unknown} = \left(\frac{(2.18 \text{ GPM})(\sqrt{40 \text{ PSI}})}{3.0 \text{ GPM}} \right)^2 = 21 \text{ PSI}$$

From Equation 7 the unknown pressure needed to provide a flow rate of 2.18 GPM with this nozzle is calculated to be 21 psi. This is within the acceptable range for this nozzle.

The above calculation assumes that all nozzles receive the same pressure. This is usually not the case, especially on higher volume applications. Pressures will usually have to be increased approximately 10 percent to compensate for flow restrictions and pressure loss along the boom.

Inboard and outboard pressure gauges should be installed to check for significant (1-2 psi or more) pressure drops along the boom at high flow rates. Switch gauge positions to check for gauge error. Make a trial run to ensure the aircraft is dispersing the desired application rate.

Pattern Testing

There are several pattern testing methods for isolating specific aerial spray problems. A simple method utilizes water sensitive papers or spot cards that do not require dye to obtain a visual image of the droplet impact locations, size, and density. These water sensitive cards are manufactured by Ciba Geigy and marketed through Spraying Systems Company, Wheaton, Illinois. Techniques used with water sensitive cards may also be used with water, dye, and clean paper.

This visual analysis allows the pilot to check his pattern frequently and to adjust his equipment quickly for particular applications. Taking 30 minutes to evaluate spray patterns with string kits, water sensitive papers, or paper and dye replaces years of trial-and-error adjustments using field results. Operators may also verify their patterns by observing spray deposition that is apparent on irrigation pipe or a similar collection surface across the flight path or swath following a single pass.

When pattern testing, swath pattern testing should duplicate field situations. Boom height, aircraft trim and power, spray pressure, and nozzle arrangement should be typical of daily operations. Experience indicates that the best pattern testing results are when aircraft are lightly loaded as light loads produce the most nonuniform field deposition patterns.

The best time for testing is early morning before the sun heats the ground and causes thermal turbulence. It is desirable to choose a time when the wind is blowing steadily and from one direction **at less than 10 miles per hour** so that pattern non uniformities can be identified and corrected with minimal effects from crosswind. Choose an

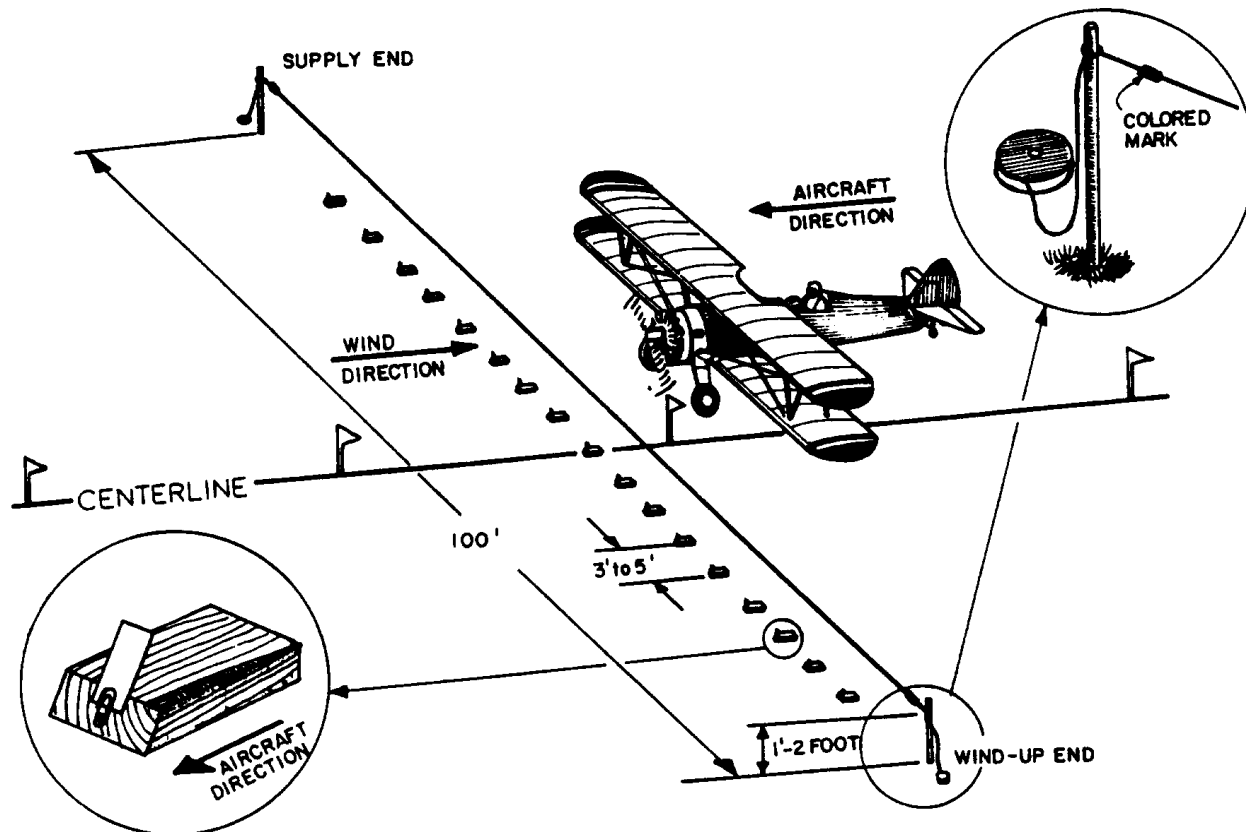
open, unrestricted area where the lane can be flown directly into the wind without danger of flight obstructions for some distance prior to and beyond the sample line. All pattern testing should be done with the aircraft making a good level approach and exit over the sample station. Three to four hundred feet of level flight on both sides of the sample line is desirable.

Prepare for Pattern Test

(The following steps are basically the same whether using spot card or paper image analysis or a type of string collection system.)

1. **Obtain material to conduct the pattern tests**, such as string kits, water sensitive papers, or spot cards and dye. Material sources are shown in the Appendix.
2. **Clean tank, filter, nozzles, screens, and boom.** Ensure that all nozzle bodies and tips are of the proper size. Pressurize the system and check nozzle flows to ensure uniform flow across the boom length and check the system for leaks.
3. **Put about 100 gallons of clean water in the tank and fly a short pass** to verify that the aircraft is ready and that the pump will develop the desired pressure. This is a good time to check the calibration of your flow meter to ensure that the proper flow rate is being obtained.
4. If using a commercial string kit, **mix the dye as Indicated on the kit Instructions.** If using a dye and paper technique - follow the mixing procedures on the dye bottle or those suggested in the Appendix. If using water sensitive papers, no dye mixing is necessary.
5. **Determine wind direction and align flight path flags** into the wind about 100 yards either side of the deposition line along the centerline of the sampling site. The pilot should be able to see the flags readily and center the aircraft directly over them when making a pass directly into the wind over the system (Figure 3).
6. **Lay out 25 spot cards perpendicular to the wind** starting with the far left (from pilot's viewpoint) as number one. Space cards on 4-foot intervals (3 to 5 feet acceptable) up to 50 feet on both sides of the center. This may be done by laying a 100-foot tape (or a 100-foot string or small cable with knots or markers at desired spacing) down on the ground as an alignment guide. The 100-foot width is adequate for most aircraft but can be adjusted if necessary with the addition of more cards or a wider space between cards for large aircraft or special situations.

Figure 3. Suggested field layout for string kits and/or card analysis. When using the card technique, there may be more cards, but they will be laid out in the same fashion. Cards may be supported by a wooden block to keep them off the grass -- see inset.



String Kit Layout and Procedure

Follow the directions included in the string kit for this procedure. All the supplies needed to do a complete pattern test will be included in the kit. The string should be suspended 12 to 24 inches above the plant canopy to prevent contamination of the string with dye deposited on the target surface from the previous pass. Research has verified that the deposition uniformity measured will be essentially the same when sampled at 12 inches as when sampled on the ground surface. String kits for pattern analysis usually consist of four sections of string premarked to identify the ends and center. The string should be laid out as shown in Figure 3. Pay particular attention to where the supply and wind up ends are located in relation to the aircraft's right and left side (as viewed from the pilot's perspective).

Depositions should be made on all four sections of the string with only one pass made over each section. The string should be wound off the supply spool onto the storage spool after each pass. A disposable winder comes with the string kits; however, a more convenient method of winding treated string is to use a battery powered drill. The spool may be attached to the drill using a headless bolt, flat washers, and a wing nut (Figure 4). Place the cover over each spool while other passes are being made to avoid contamination of the string on each spool from

succeeding spray passes.

Pattern Test

1. After aircraft takeoff, if dye is being used, purge the spray lines until dye is observed at both end nozzles of the boom. Make sure spray pressure is properly

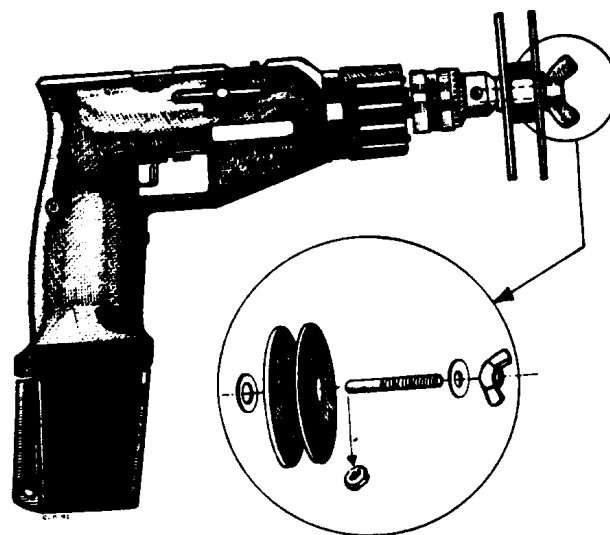


Figure 4. Suggested method of attaching windup spools to a battery-powered drill.

adjusted to achieve the desired flow rate.

2. Align aircraft with flags into the wind using the aircraft and power configurations to duplicate those used in field application while making approach for pattern testing.
3. Turn spray system on at least 100 yards ahead of the sample collection site on the approach side and keep the spray on for at least 100 yards on the departure side of the test site. Maintain level flight for at least 400 yards beyond the collection line if possible. Sudden control surface movements immediately after passing the collection line may produce distortions in the collected pattern.
4. Replace cards and repeat as needed to ensure that a representative sample has been obtained with minimal crosswind interference. If string kits are being used, wind up the exposed string, seal it to prevent contamination, and signal the aircraft to make additional passes as needed. It takes about 60 to 90 seconds to wind up the string, so the aircraft can circle until you are ready for the next pass. Water sensitive cards are also supplied with string kits but should be used on only one of the four passes to identify leaks, relative droplet size, and other potential problems.

Spot Card Evaluation

Visual evaluation requires some experience, but common problems with spray uniformity, droplet size, and swath width can be identified. Best results are obtained by quickly scanning all cards (in place) looking for the card with the most spray deposit. This card then becomes the **basis card** for further comparison on either side.

Swath Width

While spot cards are still on the ground, walk along the entire set scanning them for uniformity. With a very uniform deposition pattern, little variation should be evident in the amount of dye (color) present on the cards across the center of the pattern when compared with the basis card determined earlier. If nonuniformity is noted in the deposition, refer to the Pattern section below for possible causes and suggested solutions.

To estimate effective swath, begin at one end of the cards and compare the amount of deposit with the basis card. Continue to move toward the centerline until a card is found that has about one-half the amount of deposit (half the number of equal sized droplets) as the basis card. Mark that card. Repeat the process beginning at the opposite end. The effective swath width (the swath width that the aircraft should work) will be the distance between the two marked one-half deposition cards. The cards may also be placed side by side on a cardboard strip to make comparison easier, and the effective swath width calculated by knowing the spacing used between the cards during the test. Droplet

density on the spot cards should be uniform, or nearly so, across the wingspan width, then gradually taper off to the half-deposit marked cards. The effective swath will be considerably narrower than the distance between the outside samples where dye is evident. Gradual dye level reduction at the edge of the pattern is ideal. The overlap from an adjacent pass which has one-half of the deposit density is allowed to combine with the present pass without voids or double rates where the patterns overlap.

Under typical circumstances, agricultural aircraft **effective swath widths** usually range from 40 to 70 feet wide, while **total swath widths** may range from 60 to 120 feet. Those spray droplets that impact beyond the effective swath width are fewer, subject to prevailing weather conditions, and are needed to provide overlap feathering for the next swath. Under normal flying conditions, the overlap will be sufficient for good coverage.

Complete additional pattern tests to verify the effective swath width for this aircraft, spray boom, and height. Use dependable flagmen, permanent markers, or some type of electronic precision control system to maintain accurate swath widths while working.

String Kit Evaluation

Specialized equipment is used to analyze commercial string kits. Many states or aerial application associations have equipment and trained analysts to perform this task. Private firms also offer this service for a fee (see Appendix). The analysis will be performed and sent back to the operator with an explanation. The results may look like the illustrations in Figures 5 and 6.

Figure 5. Single swath pattern developed from analysis of string.

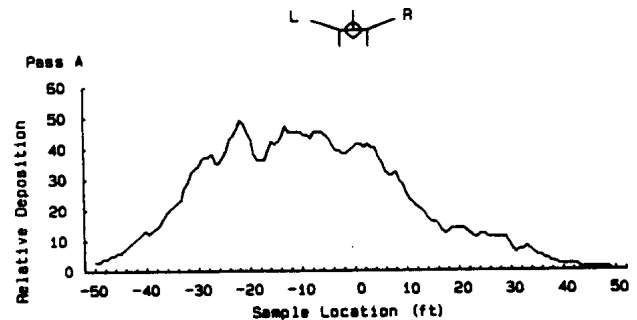
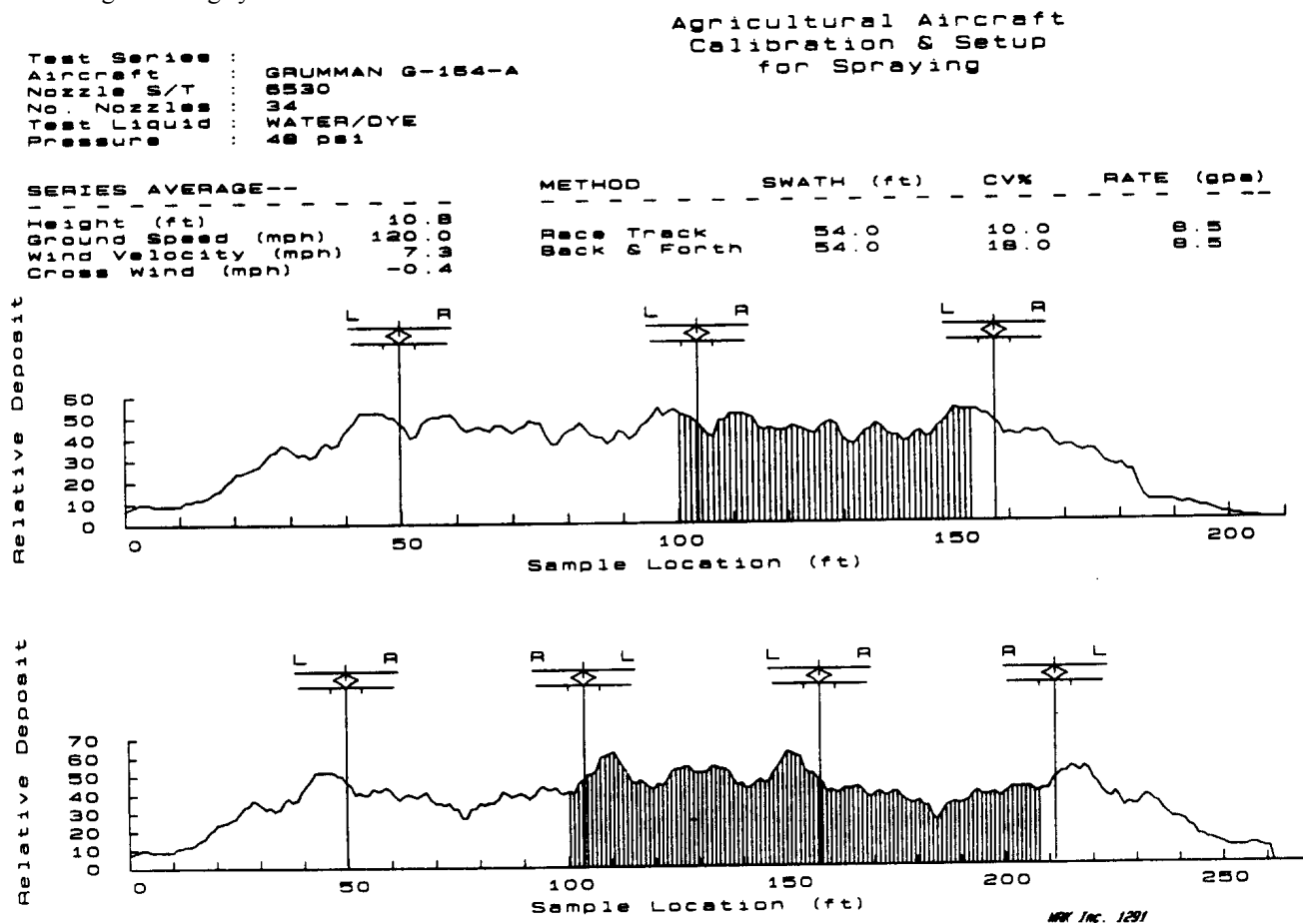


Figure 6. Aircraft overlap patterns showing the deposition uniformity one would expect during a field application with the setup tested using the string system.



Pattern

There are no cookbook solutions to distribution problems. Every aircraft and pilot combination will produce its own unique characteristic distribution, because:

- No two aircraft are exactly alike. Wing mountings, riggings, power and propeller efficiencies vary. Experienced ag pilots agree that each agricultural aircraft flies differently.
- Each pilot has his own flying techniques. On a spray run, sounds and vibrations associated with the correct setting feel different to each pilot.
- Even though booms appear to be mounted the same, there may be significant differences between aircraft.
- Differences in booms and hanger styles, boom hanger position and angles, bleed lines, nozzle plumbing designs, nozzle angles, nozzle orifices, and pressure gauges are a few of the liquid system items that may affect the uniformity of the distribution pattern.

To evaluate the distribution pattern with spot cards, examine each sample and note any irregular deposition. A graph of the amount of material present on the cards can be prepared which may help in the visualization of the deposition pattern. If using commercial string kits, refer to the deposition graphs and suggested solutions in the analysis report.

Determine if there is:

1. **Light deposition on right side of the fuselage** - This pattern distortion is often due to the influence of the propeller moving spray material from the right side of the aircraft to the left, creating a light coverage area on the right side of the swath centerline and may produce a heavier deposit on the left side. To compensate for prop wash, add one or two nozzles on the right, directly behind the outer area of the propeller rotation arc. Remove nozzles under the belly or on the left only if it is apparent that the vortex has shifted too much spray to the left. If there is a heavy buildup to the left of center as in Figure 1, it may be necessary to remove nozzles under the belly or on the first 2 to 3 feet just left of the fuselage.

A common problem is the overcompensation for prop wash with too many nozzles placed to the right or under the belly of the aircraft. Pattern testing has indicated that most aircraft need few if any belly nozzles with application rates of 3 GPA or less. Higher application rates may require the addition of some belly nozzles.

Turbine powered aircraft which have the propeller located forward as compared to radial powered aircraft exhibit much less distortion due to prop wash. The prop wash characteristics will be reversed in the case of reverse rotation PZL engines.

2. **Light deposition on the left of fuselage** - With radial powered aircraft, a light deposit left of centerline generally is the result of plugged or inoperative nozzles. First check that the nozzles immediately to the left of the fuselage and belly nozzles aren't partially plugged. Belly drop nozzles with very flexible hose connections will often swing back in flight thereby kinking the hose connection and effectively turning the nozzle off. Only after verifying that there are no plugged nozzles and after confirming the pattern with several passes to eliminate wind effects should additional nozzles be added under the belly or just left of the fuselage.
3. **Light deposition at other points within the wingspan** - Areas of light deposit are often caused by a blocked nozzle, poor nozzle locations near wheel struts or wing supports, bent or crooked boom hangers, flaggers, trim tabs, and other obstructions that cause turbulence and pattern distortion. Moving nozzle positions away from hangers, adding a tee and extra nozzle (double nozzle), or removing the obstruction causing the distortion are potential solutions to the distortions.

Operators adding automatic flagger deflectors to deflect flags away from the elevator often find a light area of deposit due to the distortion in airflow caused by the deflector. Helicopter operators may find that one or two additional nozzles are needed under the center of the aircraft to compensate for fuselage distortion and that an additional nozzle may be needed just outboard of the skid on one or both sides to compensate for the distortion caused by the counterbalance rotor.

4. **Heavy deposition within the swath** - Heavy deposits are often caused by crooked boom hangers or some other object that causes distortion in the airflow behind the wing. A crooked boom hanger can cause the output of two or more nozzles to be pushed together as though the liquid spray had been emitted from one nozzle. Eliminate or reposition nozzles only after flying several passes to confirm the heavy application is not due to unusual wind. Inspect the plumbing and fuselage for streaking stains from plumbing drips and leaks.

5. **Irregular deposition due to wing vortices and/or crosswinds** - Wing tip or rotor vortices will generally cause two high levels of deposition (peaks or humps) approximately near the ends or edge of the wingspan or mid-rotor span in calm wind or in pattern tests flown directly into the wind, or a high level deposition on the upwind side and a gradual trailing with smaller peaks on the downwind side. Indications of vortex entrainment should be vivid warnings of potential drift problems. Plug the end two or three nozzles and repeat the pattern test until outer peak spray densities decline uniformly. Full length booms do not contribute to an aircraft's effective swath width. Spray released near the end of the wing is deposited inboard of spray from nozzles at about one-half to three-fourths of the wingspan. Cut boom lengths to 75 percent of the wingspan to minimize drift from wing tip vortices.

When booms extend beyond the position where the last nozzle is located, a properly installed bleed-back line is needed. This avoids the possibility of a compressed air pocket in the end of the boom. When there is a compressed pocket of air in the system, it is compressed during spraying operations and slowly expands when the spray pressure is turned off. This extends the time it takes for the shutoff valves to completely stop flow out the nozzles. Positive shutoff is needed to lessen the drift potential.

6. **A few unusually large droplets** - Large irregular drops that often impact the water sensitive cards in differing directions are an indication of leaks or boom slobbering. Check boom and nozzles for leaks making sure there are no odd-sized or worn orifices. Boom slobbering is indicated by areas behind the nozzle on the boom surface being discolored or having spray material on it indicating that the nozzle is releasing the liquid spray into an area of high turbulence and eddy currents. Relocate those nozzles to remove them from turbulent airflow areas.
7. **Miscellaneous pattern problems** - Most pattern problems are caused by the propeller effects, wing tip vortex, or by an obstruction in the airstream. Areas of light or heavy deposit between the pattern center and the outer ends may be caused by irregular wind conditions during a pattern test and should be confirmed through repetitive sampling before taking corrective action. A pattern distortion that is confirmed or repeats itself in two out of three pattern tests warrants corrective action.

Droplet Size

Nozzles dispense a wide range of droplet sizes ranging from very small (the smallest of these may not be visible) to very large. The desired range of droplet size is generally

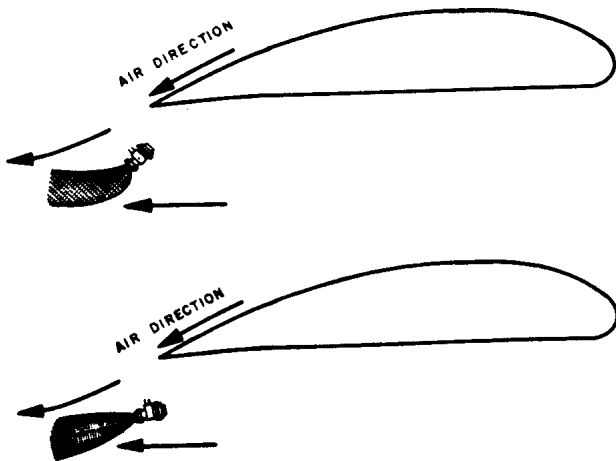
obtained by the choice of nozzle size and type. Some nozzles produce a wider spectrum than others. Unusually large droplets on one or more spot cards are often an indication of partially plugged, dirty, or worn nozzle orifices. Nozzle tips (especially brass tips) do wear out and are easily damaged by improper cleaning with a wire or knife. Nozzle tips are precision machines and cannot be returned to service once worn or damaged by drilling or other technique. Worn or damaged nozzle tips should be removed from service and discarded.

Nozzles that vary more than 10 percent from the flow of the other nozzles should be replaced. Replacement nozzle tip sets should be stainless steel, ceramic, or high-density plastic tips. Brass nozzle wear is irregular and rapid and a poor investment. Aircraft boom systems that have not been calibrated should start with a new set of nozzles. Calibration with old, worn nozzle tips wastes money. When replaced with new tips later, the pattern will be different.

Orientation of nozzles has often been used in the past to alter the droplet size of a nozzle configuration. Recent research indicates that nozzles should be oriented such that the liquid stream is released parallel to the airstream to limit the amount of driftable fines produced (Figure 7.).

Modification of the droplet size should be achieved through the selection of nozzle type and orifice size.

Figure 7. Nozzle orientation with the airstream to reduce the amount of driftable fines produced. The upper tip has an airflow which is almost parallel to the liquid flow which should result in a more uniform droplet size than the lower tips with air shear.



Sheet flow type tips such as the flat fans and CP's produce less exposed shear area and generally allow better control of droplet size. When the spray pattern from a sheet nozzle is viewed from the side, there is much less area exposed to the prevailing wind. Sheet nozzles with a narrower spray angle have reduced wind interference.

When this is compared to a conventional disc and core nozzle, you can visualize why there is less shatter and wind effect with the sheet nozzles (Figures 8 and 9), resulting in better drift control with CP and narrow spray angle flat fan nozzles.

Figure 8. The amount of spray with airstream may be better with sheet type nozzles, reducing the amount of potential shear.

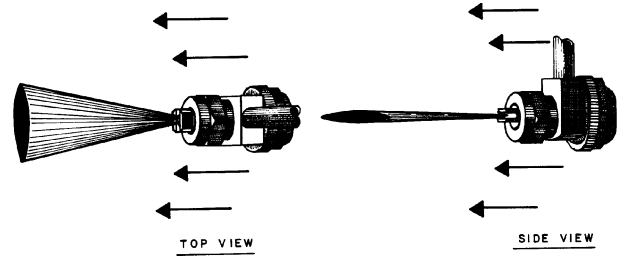
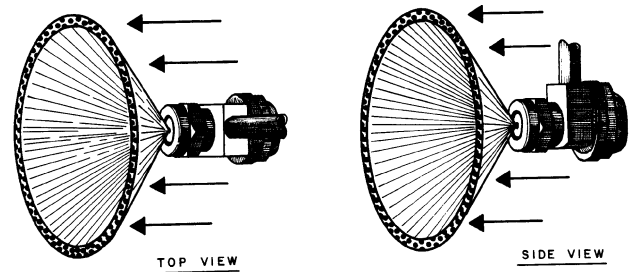


Figure 9. Cone type nozzles fan the spray out in all directions and allow the wind to catch a lot of the particles and increase the potential for particle shatter.



Spray Boom Adjustments

When pattern testing indicates that changes should be made, the following suggestions can be used as a guide.

Number of Nozzles

The primary reason for changing the number of nozzles is to obtain more uniform pattern or to change the volume of material applied. However, once you choose an orifice that gives a desirable droplet size, varying the number of nozzles will alter the volume per acre while maintaining the same droplet size characteristics. **Minor** volume adjustments can be made by adjusting boom pressure, but pressure changes should be limited to ± 5 psi.

Nozzle Angle, Type, and Orifice

On fixed-wing aircraft, especially, nozzle angle adjustment makes a dramatic droplet size change. For example, it may be possible to simply change the nozzle angle to adjust droplet size when moving from one job to another (some nozzles such as the CP have this feature built in). As the temperature increases and humidity decreases, angling the nozzle more directly parallel to the wing slipstream helps maintain better deposition

efficiencies. Adding drift control agents or other additives may change the droplet size considerably. Recent research indicates that nozzles operated such that the emitted liquid spray is released parallel to the direction of the wing slipstream (0 degrees shear) will produce the least amount of potential drift for that particular nozzle type and boom arrangement.

Impacting droplet sizes vary with boom height above the target, spray boom arrangement, material being applied, drift reduction or other adjuvants, and weather conditions.

Spray System Pressure

Pressure should be adequate to force liquid equally to all nozzles. Generally, a pressure between 20 to 30 psi is desirable. Increased pressure may be used for slight increases in volume per acre or vice versa. However, increasing pressure above the 30 psi range increases the number of small drift-prone droplets. Large pressure increases should not be used to increase the volume per acre. A correct combination of orifice size and nozzle type matched to the mixture ratio of the active ingredient gives the most application flexibility.

Flight Height and Swath Width

Increasing boom height from 8 to approximately 12 feet should not change the effective swath width significantly. Boom operation lower than the 8 feet level decreases the swath width and produces a less uniform deposition. An aircraft that has basically the same swath width throughout this flying range allows the pilot some flexibility. Repeated testing should be done under a variety of wind, relative humidity, and temperature situations to assure that uniform coverage is obtained at a particular height. Pattern testing indicates more uniform deposition patterns may be obtained with the higher application heights. However, higher discharge heights significantly increase droplet fall time; increasing evaporation of droplets and off target drift potential.

Certain weather conditions combined with small droplets warrant extra caution. Allowing droplets to fall from greater elevations drastically increases evaporation, wind effects, coverage, and possible drift. If higher altitudes are desirable, be sure to pattern the aircraft and adjust droplet size to compensate for drift and evaporation.

Droplet Size, Coverage, and Drift

Droplet size selection is a tradeoff between the desired and undesired effects. If the droplets are too large, there will not be enough of them for proper spray coverage of the target. But, if droplets are too small, they may evaporate or become airborne and never reach the target. The goal is to dispense the bulk of the pesticide in droplet sizes that both reach the target and provide effective control.

A typical aerial spray has a wide range of droplet sizes including very small drops. The larger drops are often 50 times the diameter of the small ones. Doubling the diameter increases the volume in the droplet eight times. For this reason a slight change in droplet size can have a very pronounced effect on pest control.

Even though sprays are composed of a range of droplet sizes, a mid-range droplet diameter called volume median diameter (vmd) is helpful for description. This droplet describes a spray that has 50 percent of the spray volume in droplets smaller than the median size and 50 percent of the spray volume in larger droplet sizes.

Large droplets fall rapidly and are less affected by wind and evaporation. Actual deposition size is dependent on the volatility of the droplet and weather conditions.

Phenoxy herbicides, even at low concentrations, are damaging to sensitive crops such as cotton. Specific state government application regulations (such as boom lengths not exceeding 70 percent of the wingspan and restricting nozzles to a **straight back** position) are an effort to minimize drift. (Contact your appropriate regulatory agency for specifics.) Using larger orifices and low pressures and/or angling nozzles backward to obtain 400 micron (μ) vmd droplets or larger is also very important. Drift residues from a typical 290 μ vmd spray may be twice that of a 420 μ vmd spray 200 yards downwind.

Research in Arkansas shows that both propanil and phenoxy herbicides drifted from rice fields when they were applied in less than 100 μ diameter droplets. Larger droplets were effective in controlling some grass, but a consistent kill of the smallest grass required 10 gallons per acre. The higher volume simply provides more droplets per square inch to give more thorough coverage of the grass.

Efficacy depends on coverage with the proper droplet size and an adequate volume of spray mix per acre. A specific pesticide's mode of action and the canopy density dictate the proper droplet size and what is a required volume per acre. For example, once cotton has a dense canopy 3 to 4 feet tall, most bollworm insecticide applications are more effective at 3 gallons per acre than at 1 gallon per acre. This is generally true of other canopied crops such as corn and sorghum. The larger droplets hit the top surfaces, and the medium and smaller droplets penetrate within the foliage. High volumes per acre can be used to overcome low humidities and high temperatures provided appropriate nozzles are used. Simply increasing spray pressure worsens the risk of drift and may actually decrease canopy penetration because smaller droplets are produced.

Droplets smaller than 100 μ diameter, generally referred to as driftable fines, tend to float with air movement. One-half of the volume in a 100 μ vmd spray would be

defined as driftable fines. These droplets can evaporate in less than 10 seconds in 50 percent R.H. (relative humidity) weather; under these conditions the majority of these droplets will evaporate before they reach the canopy (if largely water). Low boom height is often considered helpful for increased deposition of pesticides during hot, dry weather. Other techniques to increase deposition should be used if possible. Lowering boom height below 8 feet usually results in poor distribution uniformity and should be avoided.

In general, if drift is a critical factor, the drift hazard can be reduced by increasing the droplet size or by using techniques to prevent the formation of driftable fines. If increased coverage (droplets per square inch) is important to the mode of action of the active ingredient, select a nozzle type that produces the optimum droplet size at a pressure in the 20-30 psi range and use the number of nozzles required to provide the liquid flow rate needed to apply the highest labeled volume per acre.

Good equipment, properly adjusted and operated, makes the most effective use of a pesticide regardless of the total volume per acre. Where adverse weather or critical drift situations occur, extra volume and large droplets may be the key differences. An application is simply a compromise between small droplets for coverage and larger droplets for drift control.

Meteorological Conditions

Wind has a great effect on coverage, especially during gusty periods. A side wind causes spray to pile up on the upwind side. Additional applications with the proper swath width will overlap and smooth out the overall field application. Field applications are usually made under crosswind conditions. When wind velocities become too high, the distribution may become distorted such that additional application swaths will no longer be able to compensate for the wind turbulence effects. A uniform deposition pattern into the wind (while pattern testing) provides the most uniform crosswind field deposition pattern. Flying with crosswind will not correct the pattern aberrations of a nonuniform deposition.

Applications of drift-sensitive pesticides should be confined to times when the wind velocity is below labeled speeds or below 5 miles per hour. Wind direction should always be away from a sensitive crop. Avoid applications under conditions of no wind, dead calm, night temperature, or under stable conditions or inversions (it is better to at least know what direction driftable fines will move than to have no idea where they will go).

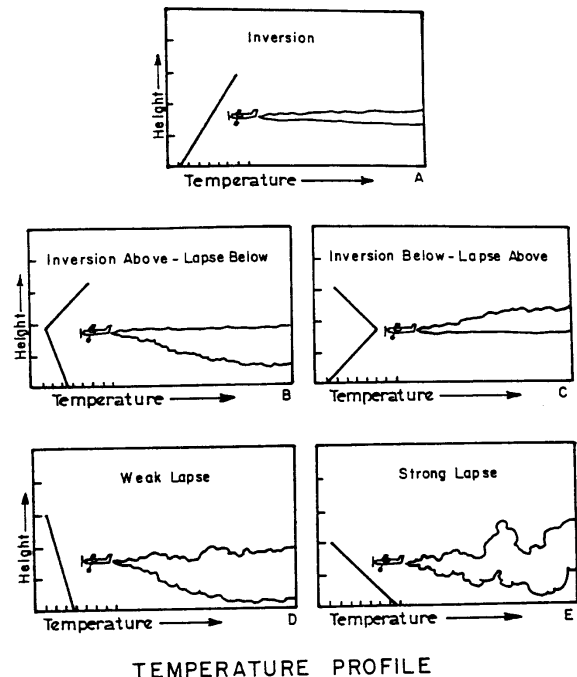
Increasing droplet size and adding a drift reduction agent that increases droplet surface tension, reducing potential evaporation, will help limit the distance at which drift damage could occur. An aircraft-mounted smoke generator is a prudent tool to use in determining the

potential for movement of driftable fines. Wind directions vary a lot on a given field or pasture, especially with hills, creeks, and trees bordering the site.

A pilot should also be watchful for signs of a temperature inversion (cool air at ground level with a warmer air layer above). They often occur when wind velocities are very low or still at ground level. High deposition percentages may occur during temperature inversions, but the direction which drifted pesticide moves is uncertain. Shifting winds may cause damage to an adjacent crop on any side of a herbicide application.

A pilot can determine the presence of a strong inversion by watching for a rise in outside air temperature as his aircraft climbs through 100 feet of altitude (Figure 10A). Failure to observe a change in outside air temperature does not ensure that an inversion does not exist, but it could be the pilot's only indicator. Observation of wind movements, dust from gravel roads, smoke or steam from power or industrial plants, for example, will provide indicators of air stability. Inversion wind shear levels can vary from 50 feet to 500-1000 feet or more above the terrain level.

Figure 10. Atmospheric stability effects on spray (A) inversion; (B) inversion above, lapse below; (C) inversion below, lapse above; (D) weak lapse; (E) strong lapse. (Blerly and Hewson, 1962).



The key threat, then, is a temperature gradient that causes air to rise and stagnate. A smoke plume that rises from a ground source and hits a **ceiling** is an ideal indication of severe air stagnation due to temperature inversion conditions (Figure 10B). Patches of ground fog suspended about windshield height, **thick haze** or fog

across a creek or depression, are also indicators of inversion conditions.

Localized inversions may form over fields that are wet or flooded, ranging from a flooded rice field to a corn field under a center pivot irrigation system as shown in Figure 10C, due to the cool temperatures that exist next to the soil or water surface. These localized conditions may be strong enough to prevent the penetration of spray into the plant canopy. Smoke from an aircraft mounted smoker should descend into the canopy in the absence of a localized inversion.

Air temperature and humidity have a pronounced effect on the evaporation rate of droplets as well as the activity of some pesticides. Evaporation of water or volatile carriers becomes critical with droplets less than 100 microns in diameter.

Relative humidity above 70 percent is ideal. A relative humidity below 50 percent is critical enough to warrant special application adjustments. Temperature, wind, and relative humidity are not independent. Aiming nozzles straight back, using larger orifices and/or reducing spray pressure are methods to increase initial droplet size. One of these simple adjustments could be a solution to preventing a **control failure**.

Morning applications combine the desirable spraying weather variables such as low temperature, low wind velocity, and high relative humidity. When an application must be made after 9 a.m. or before 7 p.m., an applicator needs a low wind, humid, cool day. When this isn't the case, increasing the droplet size and the total volume per acre is necessary to get the pesticide to the target. Cost, risk, and percent of pest control efficacy are factors that the applicator must weigh and discuss with the producer. However, applying certain pesticides around sensitive crops or locations simply should not be done under adverse weather. Leaving a wider buffer zone and ground spraying may be the wisest solution at sensitive application sites.

Summary

These spray pattern analysis techniques can help improve pesticide deposition and minimize off-target drift. Experience with droplet patterns and string system printouts builds confidence and skill in interpretation. This is a practical way to gain an understanding of where spray goes and how to compensate for weather conditions and other application needs. The final factor is applicator skill. Experience and understanding are keys to maximizing control and acquiring judgment to make acceptable compromises. The objective of any application is to properly place the material with respect to the target pest and the plant so that the pesticide can perform. The most valuable tool that the aerial applicator has is the accumulation of gray matter between the ears.

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Appendix

NOZZLE MANUFACTURERS

(contact your local dealer or the following):

The CP Products Company, Inc.
Mesa, AZ 85201
Phone: (602) 834-5593 or 969-4929

Delavan Delta, Inc.
20 Delavan Drive
Lexington, TN 38351
Phone: (901) 968-8152
FAX (901) 968-5085

Spraying Systems Company
Agricultural Division
North Avenue at Schmale Road
P. O. Box 7900
Wheaton, IL 60189-7900
Phone: (708) 665-5000

DYE SOURCES

(Marker Dyes)

Becker-Underwood
701 Dayton Road
Ames, IA 50010
Phone: (515) 232-5907

AgMark Dye
LAN Products, Inc.
P. O. Box 1514
Brownwood, TX 67801
Phone: (915) 646-0067

Precision Laboratories, Inc.
P. O. Box 127
Northbrook, IL 60065
Phone: 1-800-232-6280
In Illinois: 312-498-0800

(Fluorescent Dyes)

Keyacid Rhodamine WT Liquid
WRK, Inc. (Any quantity)
5703 Saddlerock Road
Manhattan, KS 66502
Phone: (913) 537-7516

Keystone Aniline Corporation
(Bulk or large quantities)
2501 West Fulton
P. O. Box 75871
Chicago, IL 60675-5871
Phone: (312) 666-2015

WATER AND OIL SENSITIVE PAPERS

(any Spraying Systems Company dealer or:)
Spraying Systems Company
Agricultural Division
North Avenue at Schmale Road
P. O. Box 7900
Wheaton, IL 60189-7900
Phone: (708) 665-5000

WRK, Inc.
5703 Saddlerock Road
Manhattan, KS 66502
Phone: (913) 537-7516

STRING KITS

In Arkansas contact either of the following

Mr. Wayne Rupe
Executive Director AAAA
P. O. Box 58
Lonoke, AR 72086
Phone: (501) 676-3591

WRK, Inc.
5703 Saddlerock Road
Manhattan, KS 66502
Phone: (913) 537-7516

STRING AND STRING ANALYSIS EQUIPMENT

WRK, Inc.
5703 Saddlerock Road
Manhattan, KS 66502
Phone: (913) 537-7516

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