

Reducing Driftable Fines in Aerial Application of Pesticides by Controlling Nozzle Environment

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Abstract

Spray drift is one of the most significant issues facing aerial applicators. Material not applied to the target crop or pest is a financial loss for the farmer and a potential liability for the applicator. Off-site drift also represents an environmental liability, particularly as habitat and water quality concerns demand greater attention with larger buffer and/or no-spray zones.

Current practice delivers liquid material through a nozzle, under pressure, and utilizes air shear for at least a portion of the atomization, creating a range of droplets with those less than 200 microns, known as fines, particularly susceptible to off-site drift. As airspeed increases, so does the effect of air shear on the spray leaving the nozzle, resulting in further shatter/fracture of droplets producing even more fines, leading to more off-site drift.

Control of the nozzle environment allows for control of air velocity where atomization occurs, reducing the production of driftable fines and reducing off-site movement of spray material. Control of nozzle environment is accomplished using a chamber having three sections, called a Reverse Venturi Atomization Chamber (RVA). Air enters the first section (diffuser), with a restricted opening, and flows into a larger area (settling chamber) where air velocities are reduced, the nozzle is located, and where atomization occurs. The atomized spray and air then travel through the third chamber section (constrictor) where they are accelerated to match the aircraft's air speed. By reducing the air speed where atomization occurs, the atomization profile demonstrates fewer fines, leading to less drift.

Data to date, using the prototype RVA, water as the test medium, and a selection of commercially available nozzles, we have demonstrated up to a 74% reduction in fines at 100 mph and 58% reduction in fines at 150 mph air speed.

Introduction

Spray drift is one of the most significant issues presently facing agricultural applicators. Agricultural applicators are committed to the management of chemical drift and take responsibility on a daily basis for making good decisions in the field. Material that drifts off-site is material that is not applied to the target crop or pest and represents both wasted time and wasted material. This equals increased costs for the farmer, applicator and consumer. Materials that drift off-site can be a serious financial liability, particularly if surrounding crops are negatively impacted either by actual crop damage or by unacceptable, off-label, residues present on the crop.

Environmental concerns for air and water quality protection and for habitat and endangered species protection make off-site spray drift an increasingly "hot issue". Many waterways, protected habitats and endangered species are adjacent to agricultural areas where materials are applied. Drift into/onto protected or particularly sensitive areas presents a serious liability for both the applicator and the environment.

Off-site spray drift is also an urban encroachment concern. As suburban populations increase and spread, encroaching on formerly rural and agricultural areas, buffer zones and/or no spray zones between

populated areas and agricultural areas will increase in number and in total acreage, increasing the likelihood of conflict between aerial applicators and the public. It simply will become more and more difficult to avoid them. The more complaints that are registered and the more lawsuits filed, the more likely that additional regulations and/or restrictions will be enacted.

In summary, the minimization of off-site drift is to the benefit of all concerned - aerial applicators, farmers, regulators, the public and the environment.

Background and Rationale

The majority of agricultural materials are applied as a liquid solution from a nozzle-atomizer by either aircraft or ground-based methods. In either scenario, the nozzle-atomizer unit must perform two functions: 1) It must discharge the solution at a controlled and metered rate to provide appropriate coverage and accurate dosage for the material being applied and the crop/pest being treated/targeted; and 2) The nozzle-atomizer must break the solution into appropriately sized small drops for dispersal onto the target. Most nozzle-atomizers in use on agricultural sprayers produce a range of drop sizes approximating a Gaussian or bell curve distribution range, which may be somewhat skewed towards smaller drops. It has not been determined that the production of a single-size drop would produce the most desirable for coverage of plant surfaces, but it is widely understood that a narrowed spectrum, which eliminates both the smallest and largest drops in the range, would be a desirable improvement in nozzle-atomizer design. By concentrating the drop size in a narrower range, the smallest, most drift-prone drops (fines, droplets <200 microns) and the largest drops that produce poor coverage would be reduced significantly.

Most nozzles utilize traditional designs - either hydraulic pressure, fan, cone, solid core dispersion, or rotary screen types (Akesson and Yates, 1989). These nozzles, when used on an aircraft, release the spray solution into the airstream and utilize both the nozzle and air shear for atomization.

Most aerial applicators use “off-the-shelf” nozzles, originally designed for ground applications, not aircraft. Applicators have been creative in combining nozzles and spray pressures, and diligent in their attention to environmental conditions, to obtain satisfactory application patterns. Newer, more advanced nozzles are more convenient in actual use. Angle of deflection and orifice size can be changed quickly and easily. Even with these newer nozzles, there has been minimal success in reducing driftable fines. A system is needed that is relatively easy to use that addresses fines and, hence, drift. Unfortunately, as air speed increases, so does the percentage of fines. Air shear “shatters” the large droplets, resulting in more fines and as air speed increases, so generally does turbulence, also increasing the percentage of fines.

Single-size droplets have been produced with or without an airstream under controlled laboratory conditions (Yates et al. 1983a and 1983b; Womac et al. 1992). Unfortunately, no commercially suitable atomizers producing single-sized droplets are presently on the market, especially for aerial applications. Work with magneto-strictive and piezo-electric pulsed jet nozzles (Wilce et al. 1974), and microjet airfoil systems (Yates et al. 1983a) appeared promising. Unfortunately, both systems were limited by the very small orifices required to produce a useful drop size, ~ 300 μ . The small orifices were easily blocked and clogging problems doomed them as not commercially feasible. Subsequent work utilized the wire brush theory, hoping to produce useful drop size by leading drops down a wire brush placed in an airstream to obtain a narrowed drop size range (Akesson and Gibbs 1990), but this has yet to provide a solution that is viable on a commercial scale.

Our goal was to develop a method of dispensing agricultural materials, in a dependable manner (ultimately from a fixed-wing aircraft), that would produce an appropriate size range of droplets, with a reduced percentage of driftable fines, and ultimately to reduce the potential for off-site spray drift.

Work by Akesson and Yates, 1974, determined the critical air velocity (the speed at which droplets break up/shatter) and corresponding drop sizes at which this occurs. This work explored a variety of nozzles and atomizers, using water, in the wind tunnel at the University of California, Davis. As seen in Table 1, at air speeds of over 100 mph, drops larger than ~380 μ can be broken up into smaller droplets and, subsequently there is an increased percentage (or strong likelihood) of driftable fines.

Table 1. Critical air velocity at which droplets break up

Critical Velocity, (km/h / mph)	Drop Size (microns, μ)
80.5 / ~ 50 mph	1500
105 / ~ 65 mph	900
137 / ~ 85 mph	535
161 / ~ 100 mph	385
241 / ~ 210 mph	170

Previous studies by this team investigated the performance of a number of commonly used nozzles. The results of these evaluations are included below:

Micro orifices of 125 μ produced a very narrow drop spectrum in an airstream of 60 mph, particularly when pulsation was employed. When the same orifice was placed in an airstream of 103 mph, the pulsation did not appreciably improve the results. Also, micro orifices experienced problems with clogging and using larger orifices did not yield similar results because the larger spray stream was more susceptible to break up in the airstream. Other investigators theorized that if liquid drops were emitted at air stream velocity, they would not be further broken up, although this only considered the relative velocity factor and did not account for other factors. The most notable factor of concern is the increased liquid pressure in the system required to increase the emission velocity of the fluid. Pressures \geq 100 psi act to break up the stream at emission by inducing turbulence within the stream.

Other nozzles considered included: RD series hollow cone atomizers generated larger drops than standard disc-core nozzles, but the drop size range was unacceptable. Pre-orifice fan type nozzles allowed control of pressure and flow, resulting in lower pressure at the discharge fan and generally larger drops. The spectrum range, however, was not improved with these designs when compared to standard fan nozzles. Deflector fan atomizers were evaluated. Bouse (1992), reported a reduction of small drops and reduced drift with these units, but the tests at UC Davis were inconclusive and did not confirm a significant reduction in the drop size range. Hollow cone nozzles are designed to produce large drop size sprays and utilize a tangential entry, whirl chamber design. Although drop sizes were somewhat smaller, the range remained similar to deflector fans and increased air speed again broke up the drops resulting in no overall improvement. Finally, brush atomizers were evaluated. Several wire brush designs were attempted but experienced sheeting, large fragments and turbulence behind the brush. A nylon brush design gave somewhat better results, but produced a turbulent wake due to its thickness, and denied the more uniform size drops anticipated.

Example 1 Comparison of two flat fan nozzles (8010, 8020) under the same conditions at 50 (reference), 100 and 150 mph airspeeds, performed in the UC Davis wind tunnel. Both nozzles were oriented at 0° to the air stream and operated at 40 psi using water. The key criteria predicting off-site drift is the percentage of droplets in the < 200 μ range. As air speed increased from the reference point of 50 mph, the number of droplets (% volume of particles) less than 200 μ increased 2.9-3.0% at 100 mph and 18.8-18.4% at 150 mph.

Example 2 Comparison of CP drift reduction high volume flat fan nozzle under the same conditions at two air speeds. The nozzle utilized the same orifice (15), was operated at 40 psi and oriented at 0° to the airstream. The key criteria for our evaluation was the percentage of droplets < 200 μ. At 50 mph, the percentage was 2.15% and at 100 mph, the percentage increased to 9.67%. This is a four-fold increase in driftable fines. The effect of increased airspeed, which increases air shear and results in the formation of more fines, clearly increases the potential for off-site movement or spray drift (Kirk 2000; Kirk 2001).

Droplets formed at slower air speeds (and emanating from a nozzle at 0° to the airstream) experience less wind shear and, subsequently, producing less driftable fines. When combined with appropriate orifices and fluid pressures, these slower air speeds are a primary reason why material applied by helicopter has less potential for drift. Depending on the nozzle and application scenario, sometimes a combination of higher fluid pressure and a smaller orifice will accelerate the fluid closer to actual air speed, reducing the wind shear effect on the droplets, and provide the desired size droplet. This study seeks to utilize this information and apply this concept to high-speed, fixed-wing aircraft applications.

The rationale for this research was that an atomization chamber can be utilized to control the nozzle environment to minimize the wind shear effect on the spray droplets, reducing driftable fines.

To address the problem of off-site drift of agricultural materials from fixed-wing aircraft, a prototype Reverse Venturi Atomization (RVA) chamber was constructed (Figure 1). The chamber has three sections (shown left to right, below). Air enters the first section (diffuser), with a restricted opening, and flows into a larger section (settling chamber). In the settling chamber, it decelerates to approximately one half the outside air speed as it reaches the center of the chamber (due to the proportions of the chamber). This is where the nozzle is located (at 0 degrees deflection from the airstream, minimizing air shear), and where atomization occurs. The atomized spray and air then travel through the third chamber section (constrictor) where they are accelerated (due to the constriction of the chamber) to approximately that of the aircraft. The droplets then enter the airstream as they were formed without the fracture or shattering due to abrupt air velocity normally found at the nozzle.

Air flow →

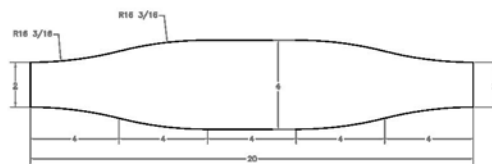


Figure 1. The prototype RVA chamber

Methods and Results

Our primary objective was to develop a unit that would produce a droplet spectrum with a reduced percentage of fines (droplets of < 200 μ) when mounted on and operated from a fixed-wing agricultural aircraft. A prototype Reverse Venturi Atomization (RVA) chamber was developed and has since been modified (see below).

The following **technical objectives** were addressed:

1. Investigate air flow behavior in the prototype RVA chamber
2. Determine optimum RVA chamber configuration(s)
3. Investigate changes in droplet behavior in several configurations of the RVA chamber.
4. Evaluate five (5) nozzles in three wind speeds (50, 100 and 150 mph)

Objectives 1, 2 and 3 - Air flow behavior, chamber configuration, droplet behavior

Three versions of the prototype RVA chamber (described below) were constructed of plexiglas, all 20 inches long, 7 inches wide and 2-4 inches high at the in-flow and out-flow points.

Chamber 1: The original chamber (see Figure 1, above).

Chamber 2: This chamber has the same entrance opening as Chamber 1, but the settling chamber is broken at the center point and the top and bottom surfaces are 1 inch higher and lower, respectively, totaling 6 inches high; the exit is 4 inches high (see Figure 2, below).

Chamber 3: This design (see Figure 2, below) was recommended by consultant aerodynamic engineer, Will Peschel, and reverses the design of Chamber 2. Known as a boundary layer ejection slot, this design effectively draws the boundary layer along the top and bottom surfaces of the chamber out of the chamber and virtually removes the boundary layer effects (drag or friction of the air against the upper and lower chamber surfaces) seen in the previous two designs.

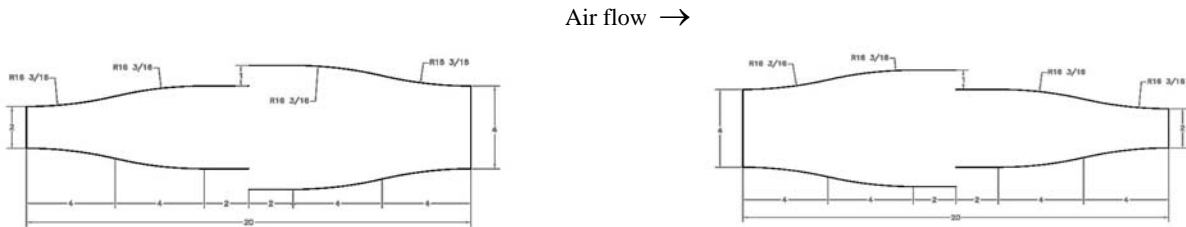


Figure 2. Chambers 2 (left), and 3 (right).

In order to evaluate the airflow through and performance of the spray droplets within the chambers when operated in the wind tunnel a Pressure Survey Rake (PSR) was constructed. This instrument has 18 pressure tubes and two static pressure orifices. These (20) are connected to a manometer board with 23 total tubes. Of the three remaining tubes, two measure static pressure from the wind tunnel aft the RVA chamber and the wind tunnel's pitot tube, and the third tube measures the pitot tube pressure side. The PSR was particularly helpful in evaluating the boundary layer produced in the three chambers (Table 2).

Tests of the three prototype chambers were conducted in the wind tunnel at UC Davis at 100 and 150 mph airspeed. All three chambers were mounted in the same location and orientation in the wind tunnel. The PSR was mounted on a sliding track in the wind tunnel, allowing the investigator to position the PSR precisely within each chamber. T_1 , T_2 , T_3 , and T_4 are equally spaced pressure tubes, top to bottom, on the PSR. The first measurement was taken with the PSR tip at the chamber's exit point. This was point 0. Four additional measurements were taken at 2, 4, 6 and 8 inches (from the exit of the chamber) as the PSR was drawn into the body of the chamber by two inch increments.

As can be seen in Table 2 below, Chamber 1 demonstrated a significant boundary layer. The speed of the air closest to the upper and lower surfaces (T_1 and T_4) was consistently slower than the air in midstream (T_2 and T_3). The airspeed at the midpoint of the chamber (point 8) was much reduced from the 100 mph entrance speed, which was a desired outcome. Chamber 2 showed more consistency between the readings at each point, but there was still a noticeable boundary effect. The higher speed throughout the chamber and particularly at the midpoint (point 8) may not prove acceptable. Airspeed readings in Chamber 3 were remarkably consistent at each point, demonstrating virtually no boundary layer effect along the top or bottom of the chamber. Boundary layer effect(s) on the sides of the chambers have yet to be determined. In addition, the airspeed at the midpoint of the chamber 3 (point 8) was the slowest of the three chambers, which should assist us in attaining our goal of reducing fines.

Based on the results presented in Table 2, Chamber 3, the "Enhanced RVA Chamber", appeared to be the most promising configuration. The upper and lower boundary layers have been virtually eliminated and the airspeed within the chamber (8" point) was the slowest.

Chamber performance was also evaluated compared to external, free stream air velocity. The goal was to reduce the speed of the air within the chamber (8" upstream from the exit, where the nozzle would be located) as much as possible and to subsequently accelerate the air so that at the exit point it is as close to the free stream air velocity as possible. The general design parameters of the chamber are such that the airspeed within the chamber will be approximately half the external speed. Table 3 summarizes the performance of the three chambers in comparison to the free stream velocity. Theoretically, the airspeed ratio should be 0.5. Chamber 3 gave the greatest proportional reduction in air velocity within the chamber, 45.6 mph, and the highest proportional increase in velocity at exit from the chamber, 91.3 mph.

Table 2. Pressure Survey Rake (PSR) Results

PSR readings, in mph, from the four tubes (T_1 - T_4 , in horizontal orientation) at five points, in two inch increments, from the chamber exit (0") into the mid-section (8" from the exit) of the RVA chamber while mounted in the wind tunnel; wind at \approx 100 mph and 150 mph.

Chamber 1	100 mph					150 mph				
	0"	2"	4"	6"	8"	0"	2"	4"	6"	8"
T_1	89.6	87.9	75.5	58.8	55.2	133.8	121.8	102.8	90.7	87.3
T_2	94.0	92.4	79.4	63.8	58.8	143.3	131.5	109.5	93.5	88.5
T_3	96.7	93.5	80.7	68.4	58.8	140.4	129.1	104.8	89.6	86.7
T_4	91.3	87.9	80.0	69.1	57.0	131.8	118.9	93.0	78.8	79.4
0 T_1 , T_4	92.9	90.4	78.9	65.0	57.5	137.3	125.3	102.5	88.2	85.5
Chamber 2	100 mph					150 mph				
	0"	2"	4"	6"	8"	0"	2"	4"	6"	8"
T_1	93.5	91.3	80.0	74.1	67.6	146.5	138.2	123.5	113.2	110.5
T_2	95.7	93.5	82.5	75.5	70.6	147.2	138.2	122.7	111.8	109.1
T_3	97.2	95.1	85.0	76.1	73.4	141.5	133.8	116.7	105.8	103.8
T_4	95.1	92.4	85.0	75.5	71.2	134.5	127.5	106.7	96.2	93.5
0 T_1 , T_4	95.4	93.1	83.1	75.3	73.0	142.4	134.4	117.4	106.8	104.2
Chamber 3	100 mph					150 mph				
	0"	2"	4"	6"	8"	0"	2"	4"	6"	8"
T_1	95.7	88.5	73.4	58.8	51.4	143	130	100	86	76
T_2	95.7	88.5	73.4	58.8	51.4	143	130	100	86	76
T_3	95.7	88.5	73.4	58.8	51.4	143	130	100	86	76
T_4	95.7	88.5	73.4	58.8	51.4	143	130	100	86	76
0 T_1 , T_4	95.7	88.5	73.4	58.8	51.4	143	130	100	86	76

Table 3. Comparison of chamber performance to free stream air velocity

Ratios of average air velocity within the chamber versus wind tunnel air velocity (100 and 150 mph) at 8" upstream and at chamber exit.

Chamber #	Wind tunnel air speed (T), average, mph	8" upstream air speed (U), average, mph	Ratio to tunnel air speed (U/T)	Velocity at exit (E) average, mph	Ratio to tunnel air speed (E/T)	Air speed ratio (U/E)
100 mph						
Chamber 1	101.3	52.5	0.52	89.1	0.88	0.59
Chamber 2	101.6	70.8	0.70	92.1	0.91	0.77
Chamber 3	99.8	45.6	0.47	91.3	0.93	0.50
150 mph						
Chamber 1	151.0	85.5	0.57	137.3	0.91	0.62
Chamber 2	150.0	104.2	0.69	142.4	0.95	0.73
Chamber 3	149.0	76.0	0.51	143.0	0.96	0.53

Based on these data Chamber 3 was determined to be the most appropriate design for the RVA and was used for the subsequent nozzle evaluations. Further refinements and modifications are currently underway.

Objective 4 - Nozzle evaluation

Eight nozzles have been tested to date. The primary criteria for the nozzles was that the spray pattern from the nozzle would not strike the chamber walls (top, bottom or sides).

Nozzle evaluation protocol:

1. Bench test nozzles, outside the chamber, at various spray pressures to assess spray patterns.
2. Bench test nozzles, inside the chamber, under static conditions (without airflow) to assess spray patterns within the chamber.
3. Test nozzles in the wind tunnel at 50, 100 and 150 mph wind speed to assess spray patterns and atomization profiles.
4. Test nozzles in the wind tunnel in the RVA chamber at 100 and 150 mph wind speed to assess spray patterns.
5. Test nozzles in the wind tunnel at five locations within the chamber at 100 and 150 mph to determine optimum location for spray nozzle.

By industry convention, many flat fan and even fan nozzles are numbered or coded based on their degree of fan and gallons per minute rating at 40 psi. For example, a 2505 nozzle is a 25 degree fan that applies 0.5 gallons per minute at 40 psi and a 4010 is a 40 degree fan that applies 1 gallon per minute at 40 psi. Other types of nozzles have similar coding conventions.

Nozzles tested:

Part number, manufacturer, description, performance characteristics, and general comments.

H1/8VV-2505, Spraying Systems Co., Wheaton IL.

A 25 degree flat fan nozzle, this unit worked well, demonstrating a very flat pattern, at the lower pressure of 20 psi, but at 50 psi the spray began to contact the side wall of the chamber. Therefore, data were collected only for the 20 psi setting at 100 mph.

1/8MEG-1503, Spraying Systems Co., Wheaton, IL

An even fan nozzle, this unit has a desirable, narrow lateral spray pattern, but the unit's deep vertical pattern impacted the top and bottom of the chamber at spray pressures greater than 20 psi. However, at 20 psi and 100 mph, the spray did not contact the chamber walls and this nozzle demonstrated a 71% reduction in driftable fines. At 150 mph, the nozzle performed well at both 20 and 50 psi, without any spray contact with the walls of the chamber. Therefore, this nozzle may be appropriate in certain circumstances or for different chamber configurations.

D-5, Spraying Systems Co., Wheaton, IL.

A disc orifice, solid stream nozzle, the spray pattern (jet) brake up takes place past the exit of the chamber. This unit did not perform as well overall as other nozzles, working well at 100 mph, but less satisfactorily at 150 mph. .

Microfoil .013, Bishop Equipment Mfg., Hatfield, PA.

The standard Microfoil nozzle is symmetrical, having micro tubes (jets) in a single row along the aft edge. The cord is two inches long and 0.75 inches thick; overall, the unit is six inches long with 60 micro tubes, each with an inside diameter of 0.013 inches, exiting the aft end. The spray exits this nozzle in a sheet. Because the boundary layers on the walls of the chamber have not been removed (only the top and bottom), this nozzle had to be modified to work in the RVA chamber. Fourteen tubes on each end were plugged and the leading edge of the nozzle was extended 0.5 inch, giving it a sharper leading edge. Both outside and inside the chamber, the sheet of spray on the right side of the nozzle was pushed up or lifted from the horizontal and the spray on the left side was pushed down or depressed from the horizontal. This effect was aggravated with increased airspeed, but illustrates the sensitivity of this type of nozzle to minor misalignments or to chamber irregularities. The nozzle worked at every station except the 12 inches, where the spray began to contact the top and bottom of the chamber. It should be noted that this nozzle operates best at only 5 psi and, thus, this was the rate used for this nozzle, rather than the 20 or 50 psi used with the other nozzles.

H1/8VV-0003, Spraying Systems Co., Wheaton, IL.

A solid stream nozzle, this unit has an extremely tight core spray pattern that holds together for 18-24 inches at low pressures and longer distances under higher pressure.

H1/8VV-1505, Spraying Systems Co., Wheaton, IL.

A 15 degree flat fan nozzle, this unit performed the best of all nozzles tested in the chamber and worked well at both 20 psi and 50 psi. It has a very flat and narrow spray pattern and, if selected, the exit of the RVA chamber could be half the current size with no impact of the spray on the walls.

Monarch, H-535 #.60-15, Monarch Nozzle Co., Pleasantville, NJ.

A 15 degree flat fan nozzle, this unit also has a good spray angle (narrow laterally), but the spray pattern is deep (vertically) and at higher pressures impacted the top and bottom of the chamber at 100 mph. This was not observed at 150 mph. It was also discovered that there were several burs in the cut slot which distorted the spray pattern. This was an important observation. It will be critical for the nozzles in use to be inspected for manufacturing defects of this type and others to insure proper operation of the RVA chamber(s).

TubeJet .0625, a custom-made nozzle, .0625" ID, 2" long tube.

This is a simple tube orifice, solid stream nozzle. Although it operates well at 50 psi and is not prone to clogging, it only demonstrates a 21% reduction in driftable fines at 100 mph and other nozzles were more successful.

Nozzle evaluation results:

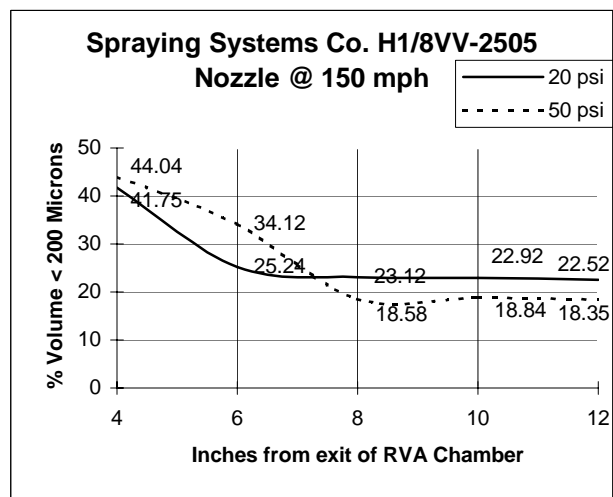
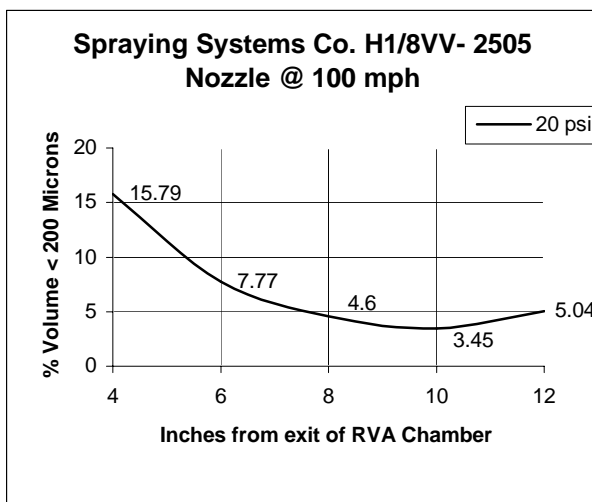
The spray from some nozzles struck the chamber walls under static conditions, but did not with air flow. The air flow over flat and even fan nozzles had a tendency to flatten the spray pattern while narrowing the angle of the spray pattern. This allowed the spray to pass through the chamber without contacting the chamber walls. Similar tendencies were seen with other nozzle types.

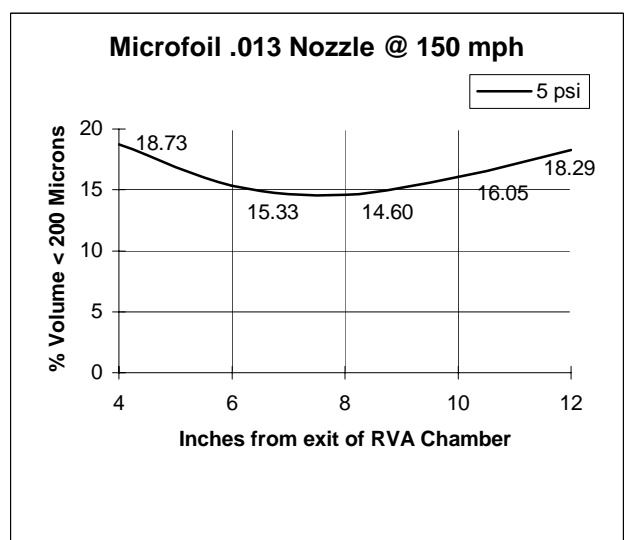
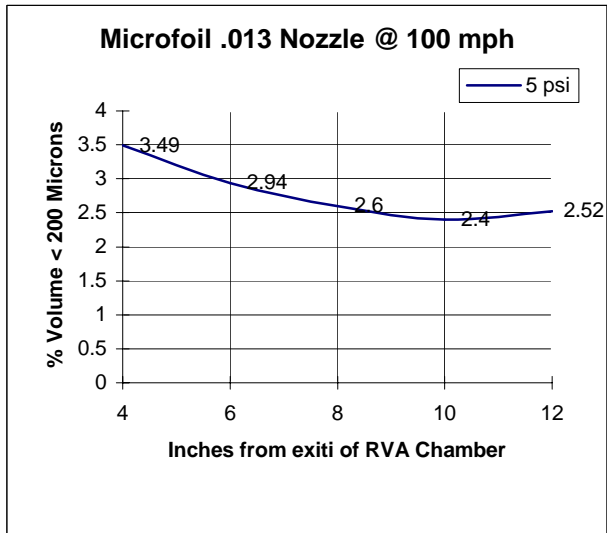
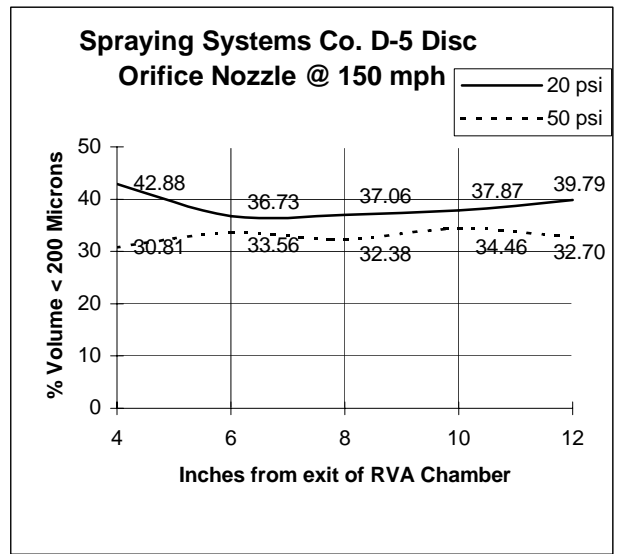
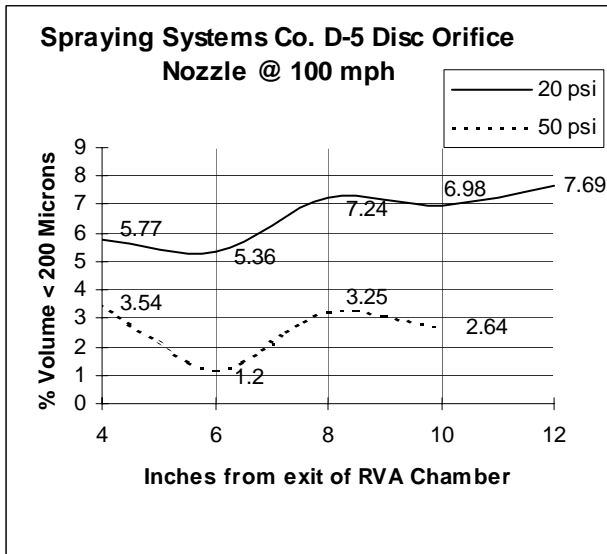
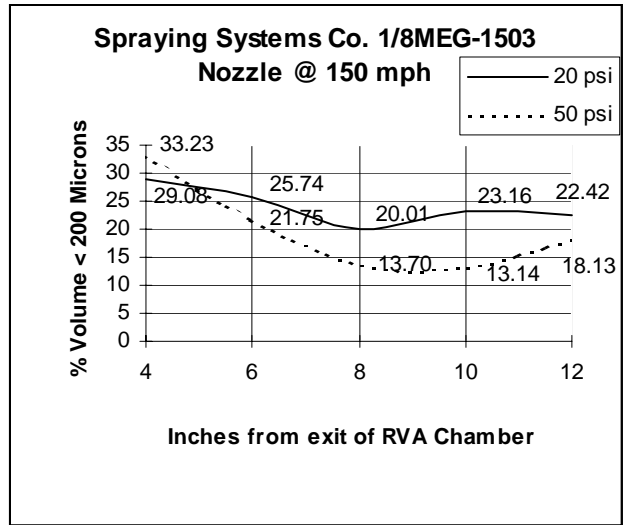
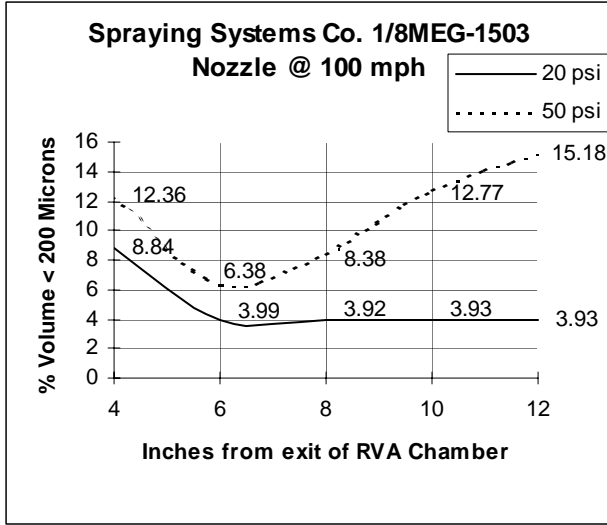
Considering the differences in the various nozzles and their spray patterns, as well as their performance at different pressures, we next investigated the impact that nozzle placement within the chamber would have on the percent of droplets < 200 μ. Depending upon the characteristics of a particular nozzle at a given pressure, it was possible that “mid-chamber” was not the optimal location for the nozzle. A sliding tube was constructed that would position the nozzle along the center axis of the chamber. Two inch increments were selected for nozzle evaluation purposes. Figure 3, below, shows the percent of spray volume < 200 μ at 2 inch increments in the RVA chamber at 20 and/or 50 psi for seven of the eight nozzles tested. The Microfoil nozzle was tested at 5 psi. Note that the scale of the y-axis differs between nozzles due to the range of values obtained. All nozzles were tested in the same manner at about the same time to minimize variation but our goal, although quantitative, was primarily comparative in nature.

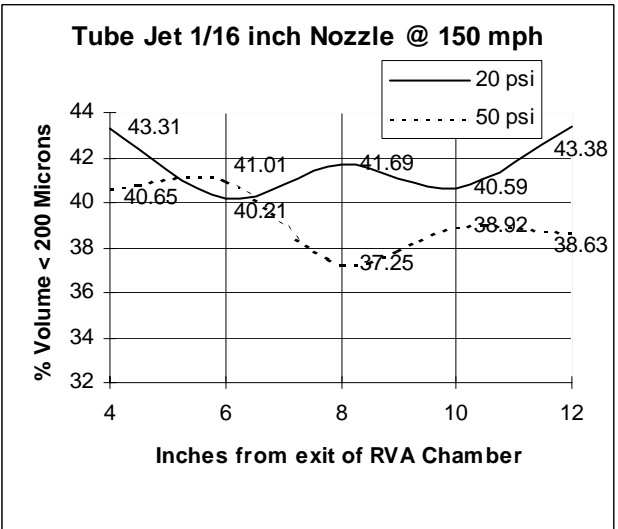
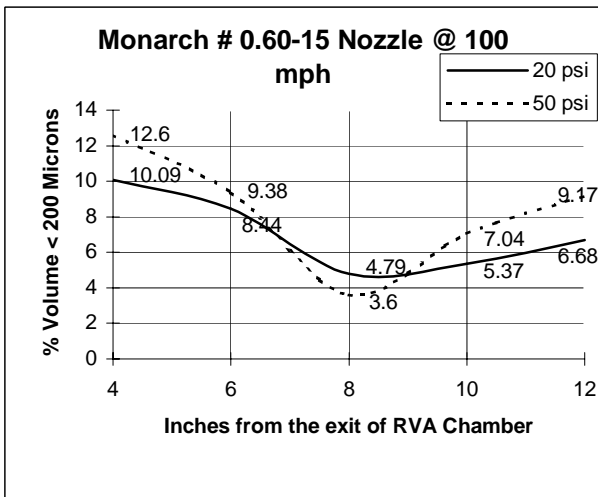
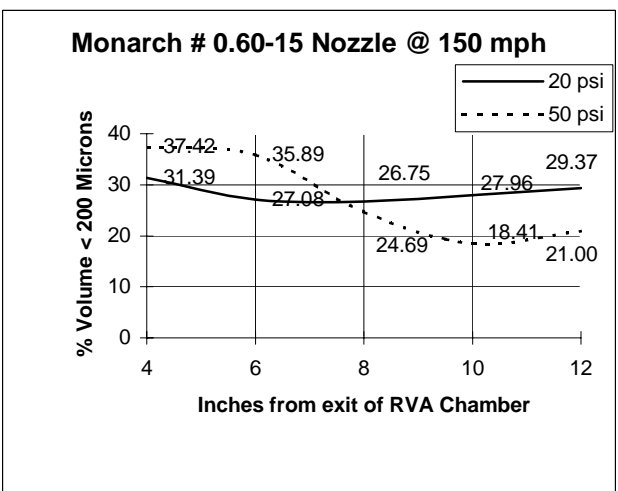
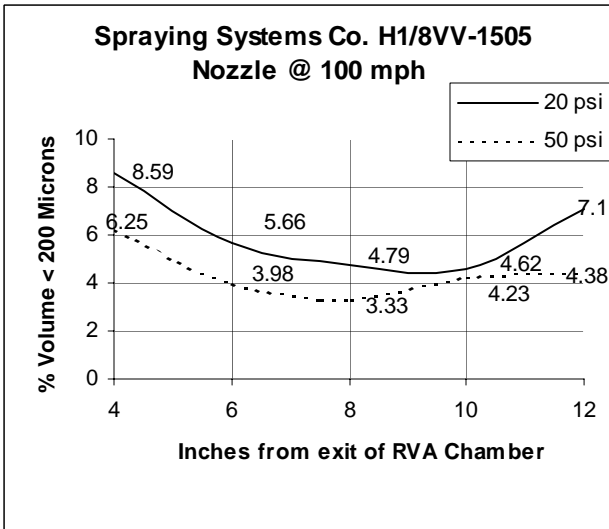
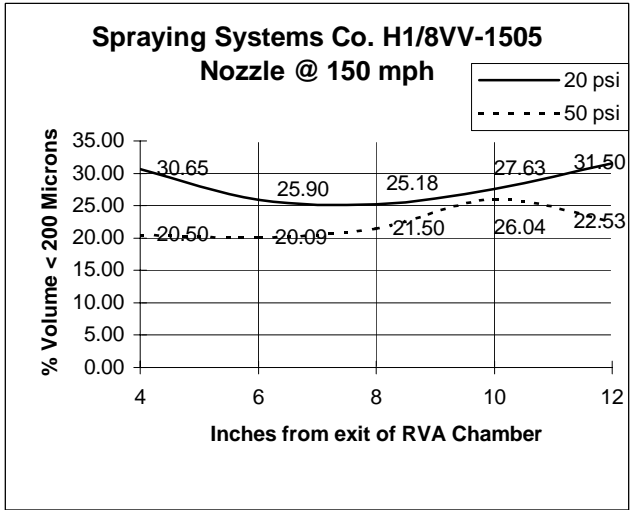
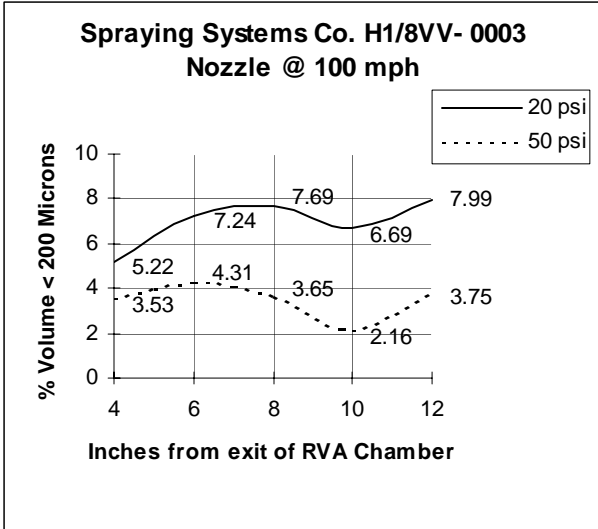
Eight nozzles were tested at both 100 and 150 mph and each demonstrated different but often similar curve characteristics (see Figure 3, below), indicating different optimum placement of the nozzle within the chamber (distance from the exit) at a particular airspeed and fluid pressure. At both airspeeds, most nozzles performed better, demonstrating a lower percentage of fines, at 50 psi than at 20 psi.

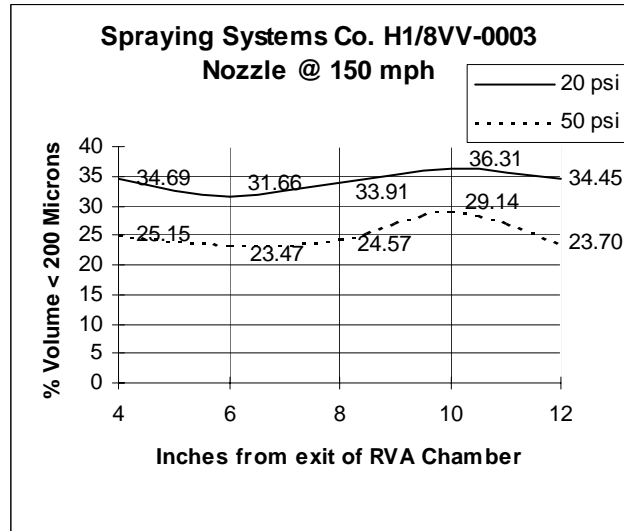
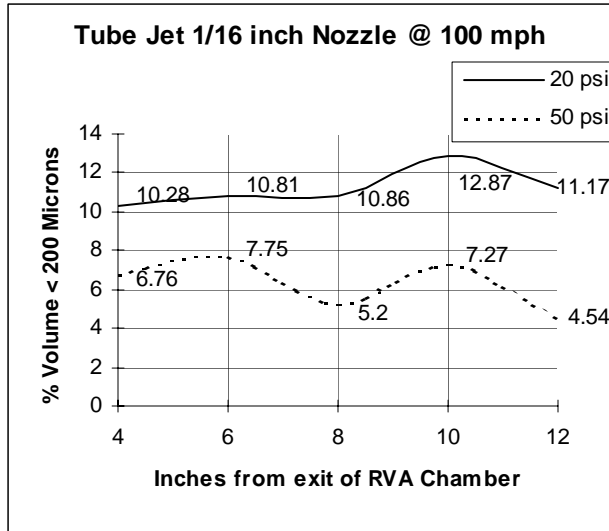
Figure 3. Nozzle performance results

Graphical representation of % volume < 200 μ (fines) produced, using water, in the RVA chamber at 100 and 150 mph airspeed in the wind tunnel. One nozzle was run at 5 psi and the others at both 20 and 50 psi (with one exception, see below). Nozzles were tested from 4 to 12 inches from the exit of the chamber, in 2 inch increments, along the center axis of the chamber. Note: To display the curves well, the y-axes are not consistent between the various nozzles.









The University of California, Davis, wind tunnel uses a basic Particle Measuring Systems Company OAP-2D-GA-1, 2-dimensional analyzer to categorize the spray being tested into 64 channels having a drop diameter size range from 28 μ to 2062 μ . Bench tests established the spray pattern for each nozzle that was then compared with the spectrum obtained when the nozzle was operated in the chamber. Each nozzle was placed in Chamber 3 at five different locations, 4, 6, 8, 10, and 12 inches from the exit end of the chamber, using a sliding mount attached at the throat of the chamber, and evaluated in the wind tunnel at both 100 and 150 mph. The data collected have provided valuable information and an adequate baseline for further study. Tables 5 and 6 present the results of the testing of eight nozzles at the two airspeeds.

In summary, the individual nozzles performed somewhat differently at 100 and 150 mph external air speed. At 100 mph, the 2505 flat fan nozzle demonstrated a 73.8% reduction in fines, the MEG-1503 flat even fan nozzle demonstrated a 71.3% reduction, and the D5 nozzle a 62.3% reduction. At 150 mph, the overall percent reduction in fines was less remarkable, ranging from 58.6 to 1.8%. At 150 mph, the 2505 and MEG-1503 nozzles still reduced fines, 39.4 and 58.6% respectively, but none of the nozzles performed as well at 150 mph as it had at 100 mph. The Microfoil 0.13 that had shown only 42.0% reduction at 100 mph, demonstrated a 55.2% reduction at 150 mph. Interestingly, D-5 nozzle that had shown 62.3% reduction in fines at 100 mph showed almost no reduction (1.5%) at 150 mph. This appears to be due to the fact that this is a solid stream nozzle and, because of the design of the chamber system, the stream does not actually break up into measurable droplets until the stream passed out of the chamber. This allows the majority of the steam to be atomized out of the chamber in the higher air velocity. If the size of the orifice were smaller, as in the micro jet nozzle, atomization would take place in the chamber. This characteristic may or may not turn out to be important in future chamber development.

Deviations between theoretical and actual values in the RVA chamber could have been caused, in part, by air flow flutter or secondary atomization outside of the chamber. These deviations could also have been influenced by or the result of turbulent air flowing over and around the chamber walls. We realize these are complex issues and will draw on the experience and expertise of Will Peschel to determine the best configuration. The effects of turbulence can be corrected / minimized by modifications to the final chamber design and mounting strategy. Several options are being evaluated. Improved chamber design and refinements will mitigate these phenomena. Also, reducing wind velocities within the chamber to less than 50 or 75 mph may also have a significant impact on the reduction of fines. These factors remain to be explored.

Table 5. Spray droplet comparisons of eight nozzles tested in the wind tunnel.

Data represent the average of three tests on each nozzle at 50 and 100 mph. Spray pressures vary, as described in the text. Percent reduction in fines is between the nozzle alone at 100 mph and the nozzle in the RVA chamber at 100 mph in the wind tunnel.

Nozzle	Air Velocity (mph)	Liquid pressure (psi)	Droplet Size Indicators			% of volume <200 μ	R.S.	% ↓ in fines
			Dv 0.1	Dv 0.5	Dv 0.9			
H1/8VV-2505	50	20	554	963	1419	2.32	0.89	
H1/8VV-2505	100	20	172	577	908	13.16	1.30	73.8%
H1/8VV-2505+RVA	100	20	508	924	1311	3.45	0.87	
1/8MEG-1503	50	20	577	952	1346	2.40	0.81	
1/8MEG-1503	100	20	143	533	943	13.67	1.50	71.3%
1/8MEG-1503+RVA	100	20	484	920	1179	3.93	0.75	
D-5	50	50	877	1552	1993	2.09	0.78	
D-5	100	50	590	1549	1995	3.18	0.95	62.3%
D-5+RVA	100	50	958	1904	2026	1.20	0.56	
Microfoil .013	50	5	603	751	928	1.89	0.43	
Microfoil .013	100	5	463	732	907	4.14	0.61	42.0%
Microfoil .013+RVA	100	5	656	846	1021	2.40	0.43	
H1/8VV-0003	50	50	1242	1914	1997	2.14	0.40	
H1/8VV-0003	100	50	550	1504	1865	3.44	0.91	37.2%
H1/8VV-0003+RVA	100	50	928	1857	2019	2.16	0.59	
H1/8VV-1505	50	50	461	884	1289	4.21	0.94	
H1/8VV-1505	100	50	325	717	1094	4.92	1.07	32.3%
H1/8VV-1505+RVA	100	50	492	893	1293	3.33	0.90	
Monarch H-535#.60-15	50	50	340	780	1237	5.98	1.15	
Monarch H-535#.60-15	100	50	310	684	1128	5.02	1.19	28.3%
Monarch+RVA	100	50	410	828	1405	3.60	1.19	
TubeJet .06256	50	50	905	1771	1888	2.77	0.56	
TubeJet .0625	100	50	351	1004	1768	5.77	1.44	21.3%
TubeJet .0625	100	50	448	1329	1948	4.54	1.18	

Table 6. Spray droplet comparisons of eight nozzles tested in the wind tunnel.

Data represent the average of three tests on each nozzle at 75 and 150 mph. Spray pressures vary, as described in the text. Percent reduction in fines is between the nozzle alone at 150 mph and the nozzle in the RVA chamber at 150 mph in the wind tunnel.

Nozzle model	Air Velocity (mph)	Liquid pressure (psi)	Droplet Size Indicators			% of volume <200 μ	R.S.	% ↓ in fines
			Dv 0.1	Dv 0.5	Dv 0.9			
H1/8VV-2505	75	50	301	652	975	6.52	1.03	
H1/8VV-2505	150	50	55	330	617	30.67	1.71	39.4%
H1/8VV-2505+RVA	150	50	79	479	717	18.58	1.34	
1/8MEG-1503	75	50	206	476	708	9.70	1.06	
1/8MEG-1503	150	50	56	310	567	31.71	1.65	58.6%
1/8MEG-1503+RVA	150	50	123	503	732	13.14	1.21	
D-5	75	50	386	1124	1657	7.93	1.13	
D-5	150	50	45	369	746	32.87	1.92	1.5 %
D-5+RVA	150	50	44	480	929	32.38	1.83	
Microfoil .013	75	5	476	664	847	3.58	.56	
Microfoil .013	150	5	51	270	477	34.20	1.47	55.2%
Microfoil .013+RVA	150	5	96	510	696	15.33	1.18	
H1/8VV-0003	75	50	1555	1787	1980	0.35	0.24	
H1/8VV-0003	150	50	71	467	739	19.50	1.43	-
H1/8VV-0003+RVA	150	50	55	504	847	23.47	1.57	
H1/8VV-1505	75	50	429	826	1173	6.89	.90	
H1/8VV-1505	150	50	55	372	619	25.49	1.52	21.2%
H1/8VV-1505+RVA	150	50	70	491	755	20.09	1.40	
Monarch H-535#.60-15	75	50	274	698	1051	7.89	1.11	
Monarch H-535#.60-15	150	50	58	342	592	26.92	1.56	31.6%
Monarch+RVA	150	50	73	516	781	18.41	1.37	
TubeJet .06256	75	50	205	1217	1646	10.43	1.20	
TubeJet .0625	150	50	48	307	710	35.77	2.14	-4.1%
TubeJet .0625	150	50	42	348	755	37.25	2.05	

Conclusions

By atomizing the spray in a controlled environment where the air speed was greatly reduced and then accelerating the droplets (by constricting the size of the chamber) to very close to the external airspeed, droplet shatter or fracture was greatly reduced and the proportion of particles in the Dv 0.5 range was increased.

Previous efforts to reduce fines have tended to create an increase in larger droplets, in effect shifting the Gaussian curve toward larger droplets, with resulting problems with crop coverage. The larger droplets miss the crop and fall to the ground, potentially running off and/or contaminating ground water. We

believe that, with appropriate design and proportions, combined with a nozzle or nozzles producing a narrower droplet spectrum at lower air velocities, the RVA chamber system will compress the curve, minimizing both fines and larger droplets when the chamber is mounted on aircraft traveling faster than 100 mph. With these refinements, the RVA chamber system may provide a more uniform droplet spectrum, reduce the amount of driftable fines, and improve product coverage to the crop.

The RVA chamber system should also reduce the expense to the farmer by reducing the amount of product required and reduce ground water contamination. We believe strongly that this project is leading to commercially viable technology. By reducing off-site spray drift and making it possible to treat more acres in a shorter period of time compared to ground application methods (and perhaps treating them more effectively), it may also be possible to reduce the cost of production of various food crops. This would help make the national food supply more affordable, or at least help contain escalating production costs. By containing escalating crop production costs, reducing off-site spray drift will subsequently help farmers maintain their position in the global agricultural market.

There are approximately 2500 agricultural aircraft operators flying some 3000 aircraft in the United States and all of those responding to the National Agricultural Aircraft Association's survey indicated that they apply liquid materials. The potential for post application utilization of the RVA chamber is significant. Wind is a component of concern for virtually all aerial applications, regardless of the speed at which the aircraft travels. Therefore, by implementing the RVA chamber as a strategy to reduce the percentage of fines produced by aerial applications, this research offers a potential benefit for all aerial applicators. The ability to deliver material in such a way as to minimize off-site drift and to do so under conditions such as light wind would be a significant benefit to both those who need the material applied and those performing the actual application of the material.

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