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In-Swath Spray Deposition Characteristics of a Low Drift Nozzle for Low Volume Aerial Application – Preliminary Results

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Abstract.

CP flat-fan nozzles with selectable tips were evaluated for droplet spectra and coverage using water sensitive papers placed in the spray swath. This study used low application volumes (1, 2, and 3 GPA) at a certain spray application height as measured precisely by laser mounted in the aircraft. Nozzle angles and flowrates were adjusted for the nozzles, and appropriate tips were specified according to required flowrate. With the interaction of these application variables, droplet spectra of the water sensitive papers over the spray swath were calculated to produce $D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$, and relative span. The effects of application flowrate, nozzle angle, and weather variables on the droplet spectrum and coverage were determined statistically. Processed data were compared with output from the available USDA Droplet Spectrum Models at the three low volumes, and spray patterns in the swath were indicated graphically. Baseline data obtained in the swath on droplet characteristics can help aerial applicators verify the correct spray tip for a given flowrate and nozzle angle for a desired droplet spectrum and sufficient spray coverage.

Keywords. spray nozzle, spray deposition, aerial application, spray efficacy .

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Introduction[1]

Reduction of off-target spray drift caused by aerial application of chemical has been recognized as a primary necessity for both cost-effective application and environmental protection. In the application of crop production and protection materials, a complex interaction of variables is involved. The variables include equipment design and configuration, meteorological factors, application parameters, tank mix characteristics, and crop canopy effects. These variables and interactions produce a significant influence on the on- and off- target deposition and the overall effectiveness of an agricultural application operation (Kirk et al., 1991; Salyani and Cromwell, 1992). In order to achieve an accurate portrayal of application dynamics, the relationship between these variables needs to be characterized as accurately as possible. However, complex interactions of so many variables makes complete characterization of spray drift difficult to understand (Smith et al., 2000). Application droplet size and spray mixture significantly affect the performance of aerial applications (Yates et al., 1976; Bouse et al., 1988; Bird et al., 1996; Anon, 1997). Sprays with coarse droplet spectra drift less than the sprays with fine droplet spectra.

In determining a target spray droplet size for aerial application, the spray nozzle needs to be selected first. Then, operational variables that influence nozzle atomization are considered. Determining proper set up of parameters for spray operation is an important aspect of any agricultural application (Wolf et al., 2005). Variations in application rate, application height, nozzle angle and deflection relative to airstream, airplane speed, and spray pressure are commonly considered.

In this study a low-drift CP-11TT flat-fan nozzle was evaluated for coverage characteristics and droplet spectra in the swath using water sensitive paper (WSP). This study varied application rate at low volumes and different nozzle angles. The effects of application flowrate, nozzle angle, and weather variables on the droplet spectrum and % coverage on spray cards were determined statistically. Droplet data from WSP were compared with the output from the United States Department of Agriculture (USDA) Droplet Spectrum Models (http://apmru.usda.gov/downloads/AERIAL%20SPRAY%20NOZZLE%20MODELS%20(Technical%20Version)%202005.html) at all application volumes and nozzle angles. Spray patterns in the swath were also characterized. The baseline data obtained in the swath on droplet characteristics can help aerial applicators verify the correct spray tip for a given flowrate and nozzle angle for a desired

[1] Mention of trademark, vendor, or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

median droplet diameter and sufficient spray coverage. In-swath spray patterns will be useful to compare tips and nozzle types for spray uniformity.

Objectives

The objectives of this study were to:

1. Evaluate the effects of application rate and nozzle angle relative to the airstream of CP flat-fan nozzles on droplet spectra and coverage from fixed wing aerial applications.
2. Compare the measured CP data with output data from the USDA Droplet Spectrum Models

Materials and Methods

Nozzle

Thirty-one CP-11TT flat-fan nozzles (CP Products, Inc., Tempe, Arizona) were mounted on a one set of booms. These nozzles are selectable for a wide range of flowrates, and a range of flat-fan tip styles are available for mounting in a turret selector that allows production of a wide range of droplet sizes. Tips are color-coded for flow rate and click into place with a detent spring and ball. In this study, tip sizes 4006, 4012 and 4020 were configured to deliver application rates of 9.5, 19 and 28.5 L/ha (1, 2 and 3 gal/acre - GPA). CP-06 swivels were used with CP-11TT flat-fan nozzles to adjust the nozzle angle with respect to the airstream in 15° increments. These adjustments are able to create the smaller droplet spectra needed for application of insecticides and fungicides. This study configured three different nozzle angles: 15, 30 and 45 degrees.

Spray System

The field test was conducted using an Air Tractor 402B agricultural airplane (Air Tractor, Inc., Olney, Texas) with a Satloc Airstar M3 guidance system (Hemisphere GPS, Calgary, BC, Canada). Global positioning, airplane heading, and real-time clock data were saved to flash memory during the spray runs. A laser height sensor, LaserTech Universal Laser Sensor (ULS) (Laser Technology, Inc, Centennial, CO), was mounted on the aircraft to measure actual heights of spray release. This laser height sensor was connected by USB to a notebook computer placed in the airplane to log data. A Kestrel 4500 weather tracker (Nielsen-Kellerman, Boothwyn, PA) was configured alongside the test site to record wind speed, wind direction, air temperature, and relative humidity every two seconds. An instrumented weather station with a Campbell CR-21X micrologger was used as backup and for comparison with weather data from the Kestrel unit. Time clocks from the Kestrel unit, notebook PC reading the laser, and the Campbell CR-21X were all synchronized to atomic time. The Satloc registered a peculiar lead of 12-s over atomic time, first noticed by Thomson et

al. (2004). So, Satloc data were offset 12-s to match with the other clock data for analysis.

Study Layout and Field Testing

The field tests were conducted on June 16 and 18, 2008. A 17 acre (6.7 ha) Bermuda grass field for the experiment was located near the Stoneville research station (33°26’28” N, 90°53’16’’ W, and 37 m above mean sea level). This field also served as a landing strip so nozzle tips, spray angles, and the booms containing different nozzle or atomizer complements could be changed rapidly. In-swath deposition of applied material released from the aircraft was measured with seven sampling stations placed across the swath (figure 1). In the sampling line, the sampling stations were evenly spaced 10 ft (3.05 m) apart across the swath. Swath width for flow calculations was set at 60 ft (18.28 m). The aircraft flew over the centerline and WSP were collected after each run. For the convenience of data processing, the seven stations were assigned coordinates of -30 ft (-9.14 m), -20 ft (-6.10 m), -10 ft (-3.05 m), 0 ft, 10 ft (3.05 m), 20 ft (6.10 m), 30 ft (9.14 m) for stations 1, 2, 3, 4, 5, 6, and 7, respectively.

Combinations of nozzle angles and application rate were changed as the aircraft flew three passes for each treatment combination. For a complete CP nozzle test, 27 passes were flown with the product of 3 flow rates (1, 2, and 3 GPA) with nozzle tips 4006, 4012 and 4020 respectively, 3 nozzle angles 15, 30 and 45 degrees, and 3 replications at one target 12 ft (3.66 m) spray altitude. A total of 187 WSP cards were collected (27 passes x 7 stations). Table 1 illustrates the treatment combinations.

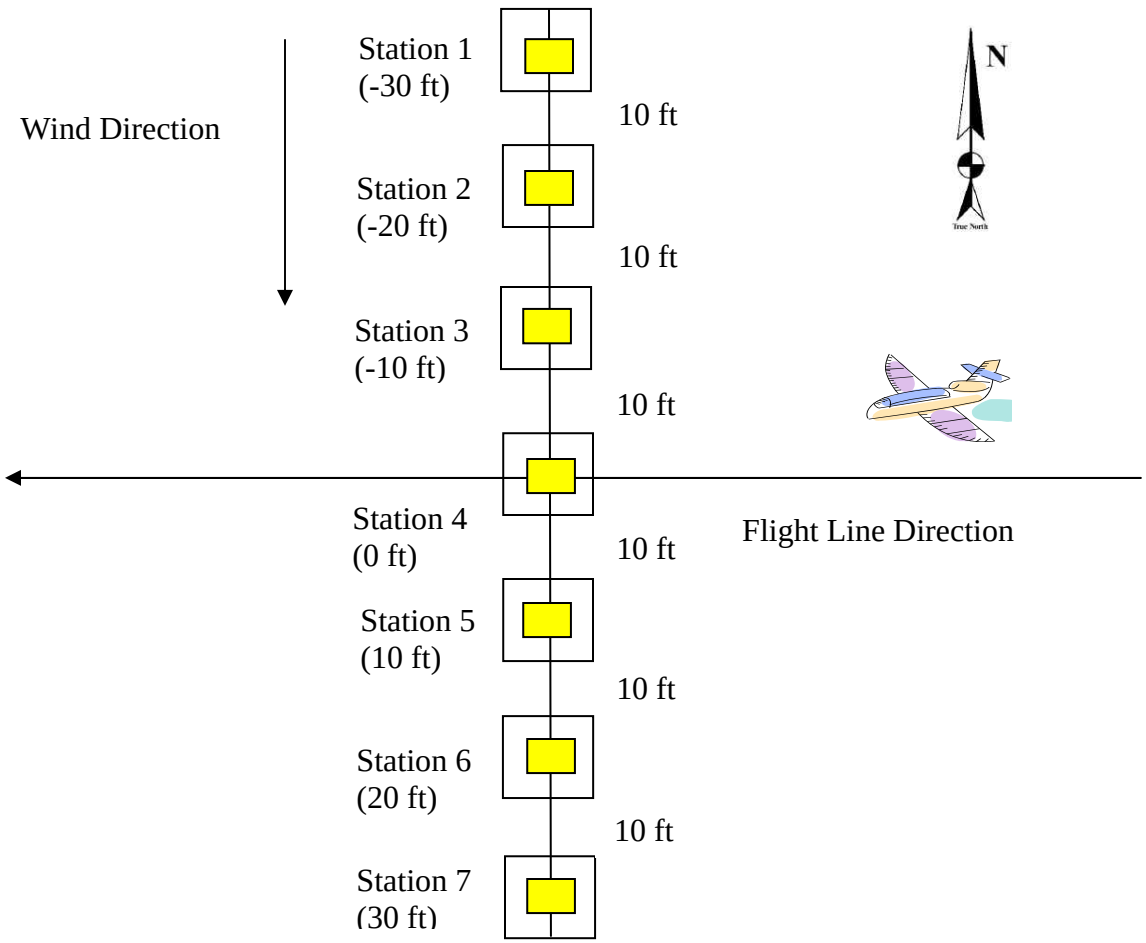


Figure 1. Field test site layout.

Table 1. Complete treatments of the CP-11TT nozzle testing.

Tip Size	Application Rate (L/ha/GPA)	Angle (^{o})	Spray Height (m/ft)	No. of Replications
4006	9.5/1	15	3.66/12	3
4006	9.5/1	30	3.66/12	3
4006	9.5/1	45	3.66/12	3
4012	19/2	15	3.66/12	3
4012	19/2	30	3.66/12	3
4012	19/2	45	3.66/12	3
4020	28.5/3	15	3.66/12	3
4020	28.5/3	30	3.66/12	3
4020	28.5/3	45	3.66/12	3

Data Processing and Analysis

After field test, each WSP card was scanned using a camera-based imaging system and SigmaScan macros to output parameters from each of the cards, including total and percentage card area covered by spray droplets, feret diameter of each droplet, % of droplets showing a “compactness” less than 20, and total number of droplets on cards. Compactness is a measure of droplet “roundness” or the perimeter^2 /area.

After processing by spreadsheet macros to sort the droplet data and determine cumulative droplet areas for calculation of size parameters, the data were fed into a QuickBasic program for further processing. The program was designed to allow screening of droplets below a user-selected compactness threshold and generate parameters $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ before accounting for spread factor. Compactness in this case was set to a value of 22, with 12.57 being a perfectly round droplet. The spread factor equation chosen was the USDA version as used previously by Thomson at al. (2007) and described by Hoffmann and Hewitt (2005). $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ are important parameters to describe spray droplet size spectra. $D_{V0.5}$ is the droplet diameter (µm) where 50% of the spray volume or mass is contained in droplets smaller than this value. $D_{V0.5}$ is also referred as Volume Median Diameter (VMD). Sauter mean diameter $D_{V0.1}$ and $D_{V0.9}$ values describe the proportion of the spray volume (10% and 90%, respectively) contained in droplets of the specified size or less. Relative span [($D_{V0.9}$ - $D_{V0.1}$)/VMD] is a measure of the width of the droplet spectra around the VMD, and this was also calculated.

To study the effects of application operational parameters and weather conditions on droplet spectrum and spray coverage from the CP nozzles, trends were observed both graphically and by statistical analysis using a mixed effects model for SAS 9.13. Operational parameters included nozzle angle, application rate, spray height, and weather variables.

CP nozzle data were organized to compare with the output of the USDA Droplet Spectrum Models. The models require input of nozzle tip size, nozzle angle degree, pressure (PSI), and groundspeed (MPH) to generate corresponding $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$, and relative span. When using the models for the CP flat-fan tips, the default nozzle angle is 8° due to the built-in down angle of the nozzle body. With the CP Swivel, CP-11TT’s can be angled down in 15° increments. This equates to 8° plus 15° (23° angle), 8° plus 30° (38° angle), and 8° plus 45° (53° angle).

Results and Discussion

On June 16, 2008 CP nozzles were tested at 3 GPA flowrate with 15°, 30° and 45° angles and 2 GPA for the 30° angle only (due to unforeseen data acquisition

problems). On June 18, 2008, a complete test of the CP nozzles was conducted as described in Table 1, including some re-runs of June 16 data.

Table 2 illustrates application variables and weather data of CP nozzle test on June 16, 2008. Ground speed data were extracted from the Satloc log file. Pressure data were obtained visually by Satloc meter reading on-board the aircraft. Weather data were obtained from the stationary Kestrel 4500 weather tracker system placed in the field at the time of the test. From the table it is clear that pressure fluctuated during testing at the 2 GPA (28.5 L/ha) flowrate. As indicated, this was one of the main reasons more runs were not conducted on June 16th.

Table 2*. Application variables and weather data of CP nozzle test on June 16, 2008

Application Rate (L/ha)	Angle (^{o})	Rep	Air Speed (m/s)	Pressure (kPa)**	Wind Direction (degrees from true north)	Wind Speed (m/s)	Air Temperature (°C)	Relative Humidity (%)
28.5	30	1	61.8	158.7	320	1.7	30.2	71.5
28.5	30	2	61.9	158.7	278	1.2	30.8	72.7
28.5	45	1	62.4	158.7	296	0.8	31.2	69.4
28.5	45	2	61.4	158.7	327	1.7	31.6	66.6
28.5	45	3	63.9	158.7	335	0.0	31.9	69.9
28.5	15	1	62.6	158.7	343	1.3	30.8	60.9
28.5	15	2	62.6	158.7	298	1.5	30.7	63.9
28.5	15	3	62.2	158.7	338	0.0	33.6	50.7
19	30	1	63.5	104.9	75	0.0	33.6	54.2
19	30	2	62.6	210.1	334	1.8	31.6	61.1
19	30	3	62.3	115.9	301	1.6	30.8	63

* The sequence of variables in all tables follows the order in which they occurred.
** 1 psi = 6.89 kPa

Statistical analysis did not indicate an effect of wind direction on either median droplet size or spray coverage on cards, but the data set is admittedly limited for the test of June 16. The only significant effect on spray coverage per card ($p<0.0001$) was sampler position, and that was to be expected due to the differences across the swath and wind skewing the spray pattern.

An interesting pattern emerged regarding nozzle angle interactions with spray release height. Altitude was measured precisely for every spray run, and the pilot did deviate from the target altitude over the runs since there was no on-board readout for him to follow. There was high variability of VMD (but not influenced statistically by spray release height) at the 15 degree spray angle for the CP flat fan nozzle. VMDs were very consistent across all spray release heights for the 30 and 45 degree spray angles. Mean VMD values followed the expected trend (lower VMD at higher spray angles due to increased droplet breakup). Figure 2 illustrates plots of Satloc output recording of application rates from the CP nozzle testing. The plots indicate that flowrates of the CP nozzle

were relatively stable even for the test of June 16th even though pressure readings (data not shown) were problematic.

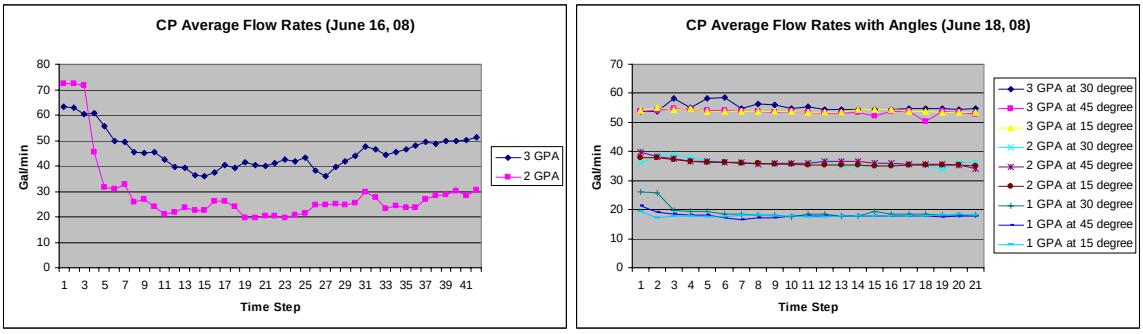


Figure 2. CP nozzle flowrates

Table 3 illustrates application variables and weather data of CP nozzle test on June 18, 2008. From the table it can be seen that ground speed, spray pressure and wind speed were quite consistent but the wind direction varied from the beginning to the end of the test. Simultaneous air temperature increase and relative humidity (RH) decrease occurred during the course of the day.

The effect of application variables and weather on total % spray coverage on cards was evaluated for the June 18 test. A log transformation on % spray coverage was necessary for better model fits, based on statistical iterations. The variables spray angle, gallons/minute of flow (log-transformed), and RH showed significant effects on % spray coverage across all cards ($p < 0.0001$, $p < 0.0001$, $p = 0.0007$ respectively). Interestingly, height of application was not a significant effect on spray coverage ($p = 0.6289$). Model solution for the three variables is illustrated in Figure 3 for the 30-degree spray angle using artificially generated inputs. The model is as follows:

$$\text{coverage} = \exp(-5.784 + 1.5537 * \ln(\text{gpm}) + 0.02933 * \text{RH})$$

Trends indicate that, as expected, higher flowrates increased spray coverage on cards, and higher relative humidity also favored increased deposition. Least Squares Means estimates for the 15, 30, and 45 degree angles were 0.6201, 0.6015, and 0.5089, respectively. It appears that spray deposition coverage was similar for the 15 and 30 degree angles and lower for the 45 degree angle.

Table 3. Application variables and weather data of CP nozzle test on June 18, 2008.

Application Rate (L/ha)	Angle (°)	Rep	Air Speed (m/s)	Pressure (kPa)	Wind Direction (degrees from true north)	Wind Speed (m/s)	Air Temperature (°C)	Relative Humidity (%)
19	30	1	66.6	289.8	94	2.0	23.2	75.7
19	30	2	67.5	317.4	73	2.5	23.2	74.1

19	30	3	66.8	289.8	79	3.2	23.6	74.2
19	45	1	65.1	289.8	94	2.6	23.8	70.7
19	45	2	65.8	289.8	101	2.2	23.9	70.3
19	45	3	65.8	289.8	96	3.0	23.9	68.5
19	15	1	65.5	289.8	108	2.5	24.8	63.3
19	15	2	64.7	289.8	86	2.4	25.8	66.6
19	15	3	65.5	289.8	118	2.8	24.8	63.1
9.5	30	1	67.6	248.4	80	3.8	25.3	62.1
9.5	30	2	67.0	248.4	128	4.0	25.4	58.1
9.5	30	3	67.1	248.4	83	3.7	25.8	60.6
9.5	45	1	66.3	262.2	55	2.9	26.2	56.7
9.5	45	2	65.6	262.2	96	2.5	25.6	56.3
9.5	45	3	65.3	262.2	38	2.3	26.9	58.5
9.5	15	1	65.6	262.2	77	2.1	26.5	54.8
9.5	15	2	65.5	262.2	48	3.5	26.1	55.2
9.5	15	3	66.6	262.2	30	2.3	26.3	55
28.5	30	1	67.4	262.2	245	3.5	26.6	51.3
28.5	30	2	66.4	262.2	259	2.6	26.6	49.4
28.5	30	3	66.9	262.2	254	3.6	27	49.5
28.5	45	1	66.0	262.2	322	3.2	26.7	47.3
28.5	45	2	65.3	262.2	317	3.7	27.4	49.4
28.5	45	3	65.9	262.2	326	1.6	28.7	48.9
28.5	15	1	66.5	262.2	298	2.6	27.9	43.2
28.5	15	2	65.9	262.2	329	2.1	28.6	46.4
28.5	15	3	65.9	262.2	327	4.3	27.2	43.7

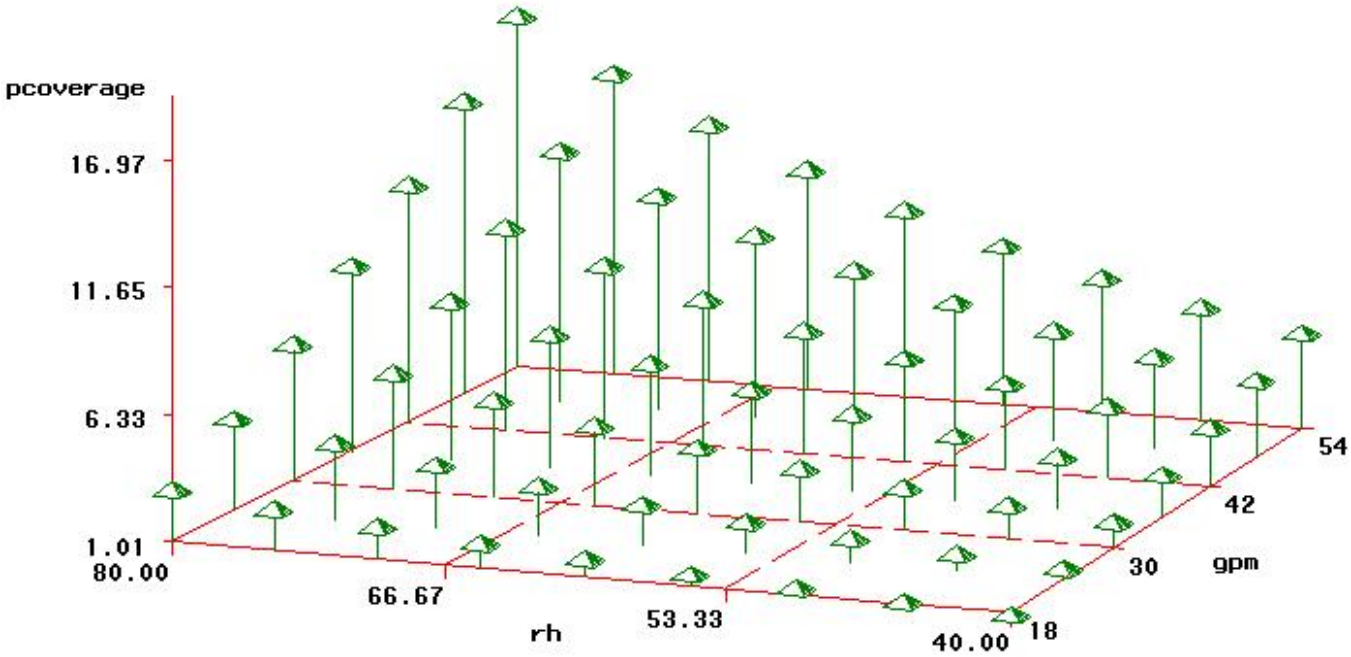


Figure 3. Statistical model output showing the effects of RH and flowrate (gpm) on percentage spray coverage

Table 4 shows the droplet characterization of the CP flat-fan nozzles from USDA Droplet Spectrum Models under the same conditions as the test of June 16, 2008. Table 5 illustrates the droplet characterization of these nozzles from USDA Droplet Spectrum Models under the same conditions as the test of June 18, 2008.

Table 4. Droplet characterization of CP flat-fan nozzles from USDA Droplet Spectrum Models with the test on June 16, 2008.

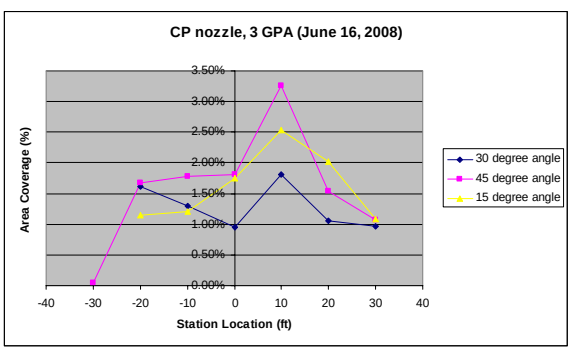
Application Rate (LPH/GPA)	Angle (^{o})	Rep	$D_{v0.1}$ (μm)	VMD (μm)	$D_{v0.9}$ (μm)	Relative Span
28.5/3	30	1	183	272	394	0.78
28.5/3	30	2	182	272	393	0.77
28.5/3	45	1	169	257	366	0.77
28.5/3	45	2	172	261	373	0.77
28.5/3	45	3	164	252	357	0.76
28.5/3	15	1	192	279	413	0.79
28.5/3	15	2	192	279	413	0.79
28.5/3	15	3	193	282	419	0.80
19/2	30	1	108	253	381	1.08
19/2	30	2	112	258	389	1.07
19/2	30	3	113	260	392	1.07

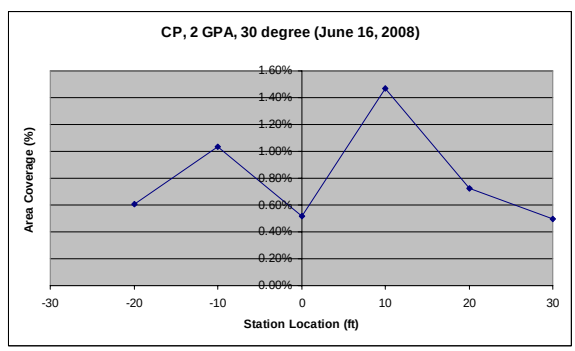
Table 5. Droplet characterization of CP flat-fan nozzles from USDA Droplet Spectrum Models with the test on June 18, 2008.

Application Rate (LPH/GPA)	Angle (^{o})	Rep	Dv0.1 (μm)	VMD (μm)	Dv0.9 (μm)	Relative Span
19/2	30	1	109	264	393	1.07
19/2	30	2	106	263	391	1.09
19/2	30	3	108	263	391	1.07
19/2	45	1	96	253	369	1.08
19/2	45	2	93	251	366	1.09
19/2	45	3	93	251	366	1.09
19/2	15	1	132	286	440	1.08
19/2	15	2	136	291	450	1.08
19/2	15	3	132	286	440	1.08
9.5/1	30	1	63	244	381	1.3
9.5/1	30	2	65	249	386	1.29
9.5/1	30	3	65	248	385	1.29
9.5/1	45	1	55	236	367	1.32
9.5/1	45	2	58	241	373	1.31
9.5/1	45	3	58	243	375	1.30

9.5/1	15	1	87	273	422	1.23
9.5/1	15	2	87	273	422	1.23
9.5/1	15	3	82	266	412	1.24
28.5/3	30	1	177	263	371	0.74
28.5/3	30	2	180	267	379	0.74
28.5/3	30	3	179	265	375	0.74
28.5/3	45	1	168	257	358	0.74
28.5/3	45	2	170	259	361	0.74
28.5/3	45	3	169	257	358	0.74
28.5/3	15	1	195	282	414	0.78
28.5/3	15	2	195	281	413	0.78
28.5/3	15	3	195	282	413	0.78

Figure 4 shows the plots of the in-swath percentage area coverage pattern of CP nozzle tests on June 16 and 18, 2008. The plots indicate that for the CP nozzle test on June 16, 2008, the maximum percentage area coverage occured at the station of 10 ft downwind. So, the 10 ft station is chosen as the comparison point with the model calculation for the CP nozzle test on that day. For the test of June 18, 2008 the plot of 1 GPA indicates that the maximum percentage area coverage occurred at stations located -10 ft, 0 ft and 10 ft for different nozzle angles of 45 ^{o}, 15 ^{o} and 30 ^{o}, respectively. So, the center station is used as the comparing point with the model calculation for the CP nozzle test of 1 GPA on that day. The plot of 2 GPA indicates that the maximum percentage area coverage occured at the station of 10 ft downwind. So, 10 ft station is chosen as the comparing point with the model calculation for the CP nozzle test of 2 GPA on that day. The plot of 3 GPA indicates that the maximum percentage area coverage occured at the station of 10 ft for nozzle angles of 30 ^{o} and 45 ^{o}, and the second highest percentage area coverage happened at the 10 ft station for nozzle angle of 15 ^{o}. So, the 10 ft station is used as the comparison point with the model calculation for the CP nozzle test of 3 GPA on that day.





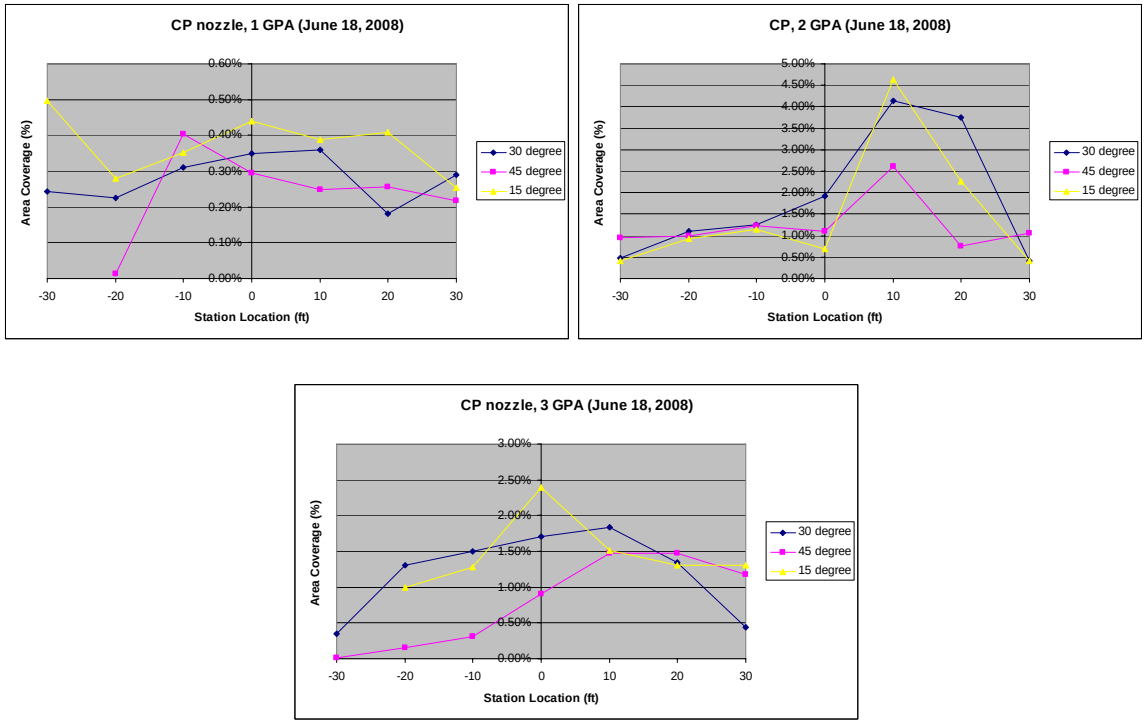


Figure 4. In-swath percentage area coverage pattern of CP nozzle tests on June 16 and 18, 2008.

Figure 5 illustrates a comparison of the measured droplet characterization of CP-11TT flat-fan nozzles with the appropriate USDA Droplet Spectrum Models under the same conditions of the test on June 16, 2008. The plots indicate that in general the measured $D_{V0.1}$, VMD, $D_{V0.9}$, and relative span match magnitudes of $D_{V0.1}$, VMD, $D_{V0.9}$, and relative span from the model, and the measured VMDs follow the trend of the modeled ones such that as the nozzle angles increase, the VMDs decrease. Figure 6 illustrates a comparison of the measured droplet characterization of CP-11TT nozzles with the one from USDA Droplet Spectrum Models with varied nozzle angle at each application rate the same as the test on June 18, 2008. The plots indicate that in general the measured $D_{V0.1}$, VMD and $D_{V0.9}$ follow the trend of $D_{V0.1}$, VMD and $D_{V0.9}$ from the model at 2 and 3 GPA, although at 3 GPA the measured $D_{V0.9}$s are higher than the modeled ones. At 1 GPA the measured $D_{V0.1}$, VMD and $D_{V0.9}$ appeared to match closest at the 30 degree drop angle. Measured relative spans were still not stable by major discrepancies in $D_{V0.1}$ and $D_{V0.9}$. Figure 7 illustrates a comparison of the measured droplet characterization of CP-11TT nozzles with the USDA Droplet Spectrum Model. The plots indicate that in general that measured $D_{V0.1}$, VMD and $D_{V0.9}$ follow the trend of $D_{V0.1}$, VMD and $D_{V0.9}$ from the model at all three nozzle angles although at the 45 degree angle, measured $D_{V0.1}$, VMD and $D_{V0.9}$ were significantly higher than model output values. Correspondingly, measured relative spans were not as stable as the modeled ones across all angles. These variances can be expected to some degree as changing weather and wind effects will alter results.

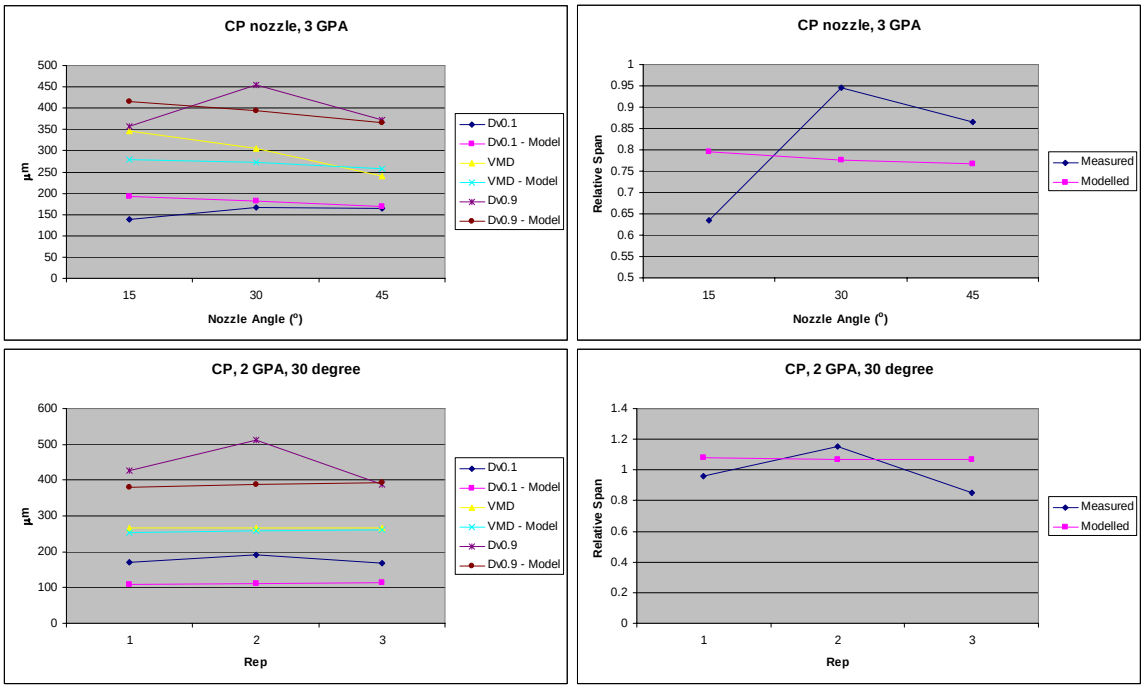


Figure 5. Measured droplet characterization of CP-11TT nozzles on June 16, 2008 compared with the output of USDA Droplet Spectrum Models

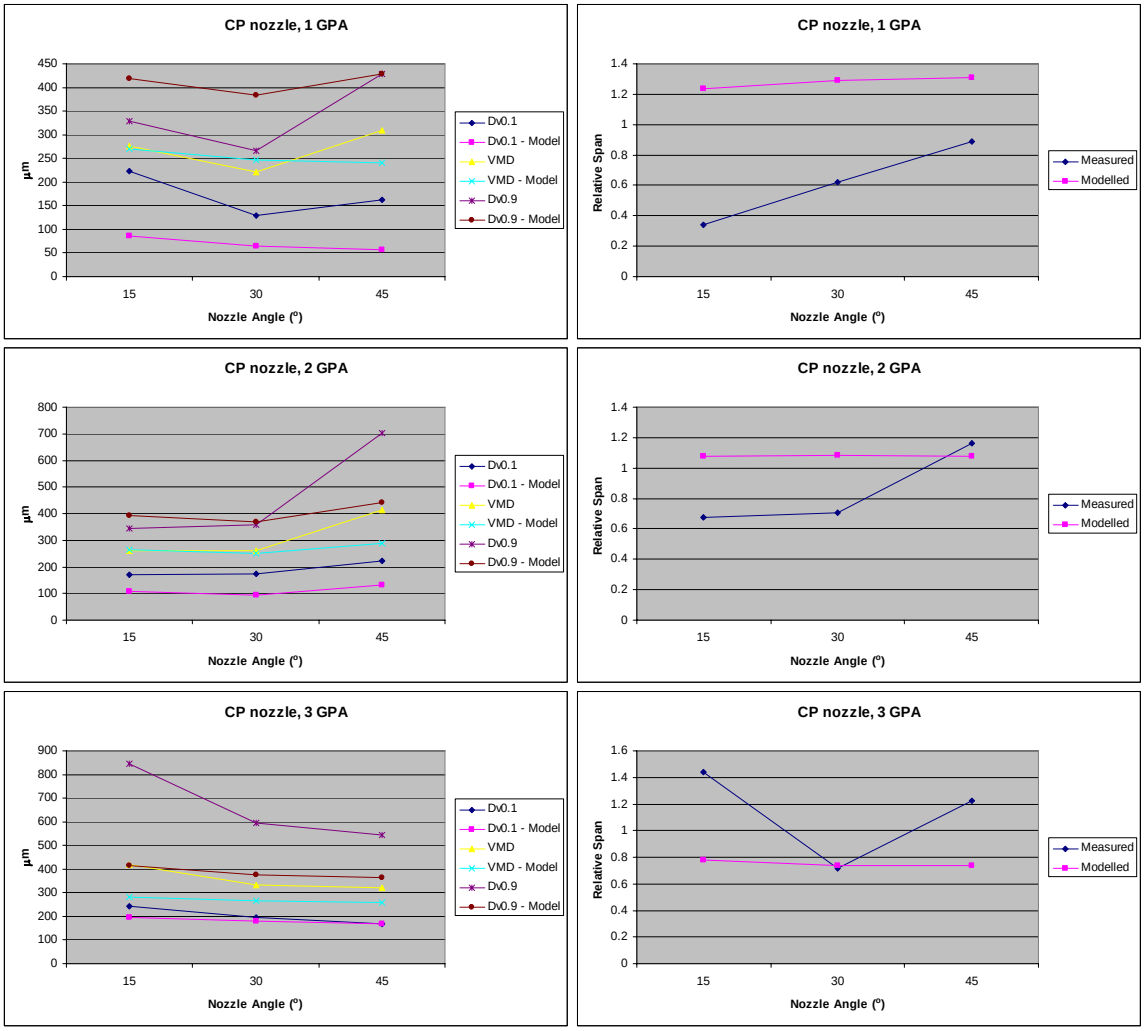


Figure 6. Measured droplet characterization of CP-11TT nozzles on June 18, 2008 compared with the output of USDA Droplet Spectrum Models with varied nozzle angle at each application rate.

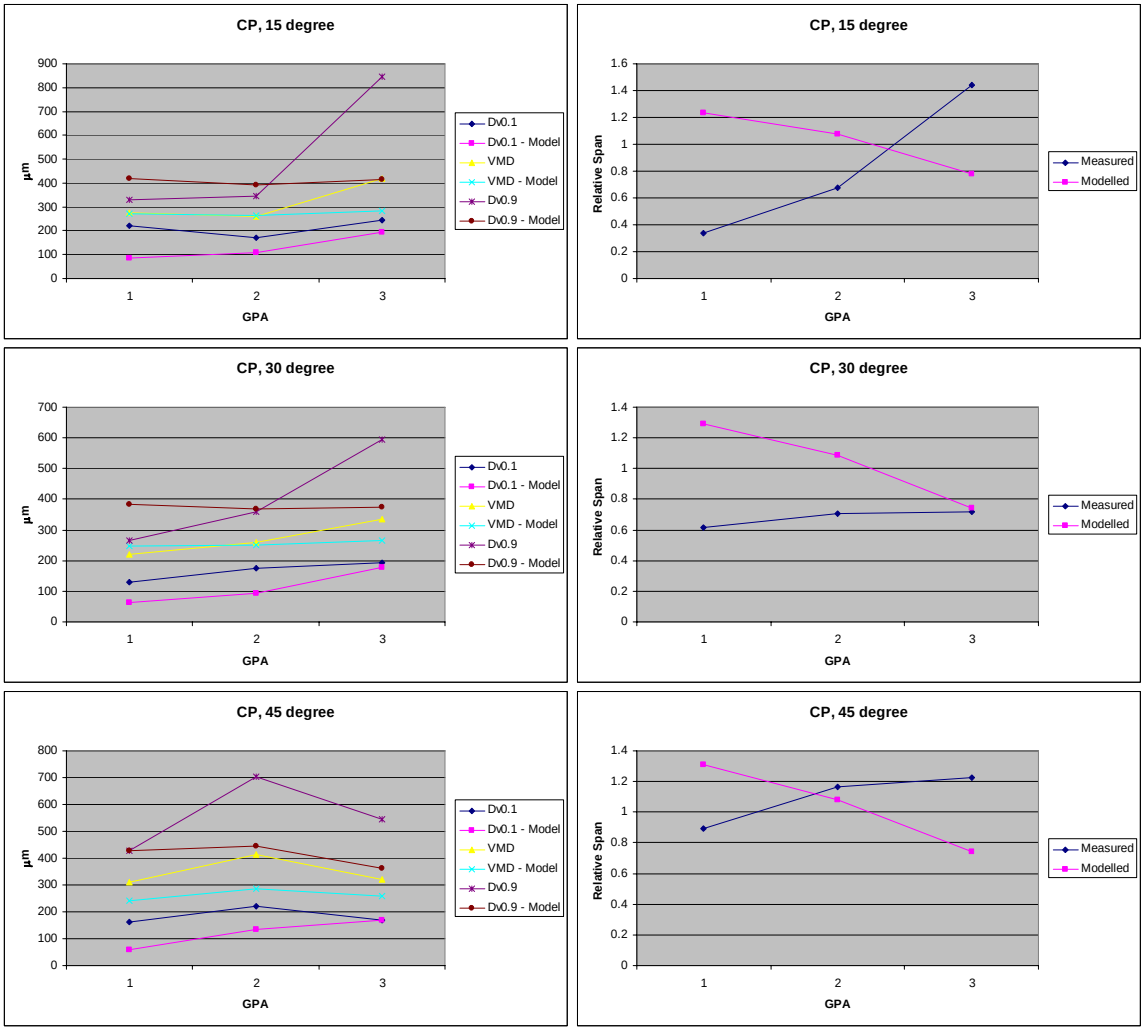


Figure 7. Measured droplet characterization of CP-11TT nozzles on June 18, 2008 compared with the output of USDA Droplet Spectrum Models with varied application rate at each nozzle angle

Summary and Conclusions

In summary, our preliminary field results indicated a good fit with droplet size parameters as indicated by the USDA Droplet Spectrum Models. From visual observation of trends, the VMD appeared to be the best fit of all parameters ($D_{V0.1}$, VMD and $D_{V0.9}$) across flowrates. The $D_{V0.1}$s fit better at the higher flowrate (3 GPA) and appeared not to do as well with decrease in flowrate. The $D_{V0.9}$s fit better overall at the 2 GPA flowrate than the other flowrates. The relative spans performed similarly as the $D_{V0.9}$s at different flowrates. The VMDs fit best at nozzle angles of 15 and 30 degrees, and the $D_{V0.1}$s fit well at all three nozzle angles. The $D_{V0.9}$s seemed to vary the most as compared with modeled results.

The CP flat-fan nozzles performed well in the field, and droplet size ranges (as indicated by the relative span) were quite narrow; lower than many results indicated by the USDA model. As these nozzles are marketed as low drift nozzles, they indicated good potential for drift reduction by their narrow span of droplet sizes.

Statistical results for the June 18 test showed the expected trend of higher flowrates resulting in higher total spray coverage. The 15 and 30 degree angles seemed to provide slightly higher coverage than the 45 degree angle setting, and spray angle had a significant effect on coverage. Of the weather variables, RH was the only variable with a significant effect on spray coverage. It is curious that height of application did not significantly affect spray coverage as it varied as much as 12 feet between runs (as measured accurately by laser). One explanation could be that the coverage from CP flat fans is relatively insensitive to differences in application height; this would be a positive result for these nozzles. Further testing will be conducted to further verify these observations.

An accompanying test was also conducted with the Micronair AU5000 atomizers and Accu-Flo low drift nozzles (72 - 0.016 needles) alongside the CP flat fans. All nozzles and atomizers were set to provide a similar range of droplet sizes, and the purpose was to compare nozzle types with regard to droplet spectrum and spray coverage. The Micronair data also showed a narrow range of droplet sizes as expected, but the Accu-Flo nozzles could not be run reliably at the low flowrates using a full nozzle complement on the booms. We plan to halve the number of nozzles on the boom for the Accu-Flo to better match the CP configuration and to allow higher pressures to be maintained for reliable operation.

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References

Anon. 1997. A summary of aerial application studies. Spray Drift Task Force. For more information contact David R. Johnson at Stewart Agricultural Research Services, Inc., P.O. Box 509, Macon, Missouri 63552.

Bird, S. L., D. M. Esterly, and S. G. Perry. 1996. Off-target deposition of pesticides from agricultural aerial spray applications. *Journal of Environmental Quality* 25:1095-1104.

Bouse, L. F., J. B. Carlton, and P. C. Jank. 1988. Effect of water soluble polymers on spray droplet size. *Transactions of the ASAE* 31(6):1633-1641, 1648.

Hoffmann, W.C. and A. J. Hewitt. 2005. Comparison of three imaging systems for water-sensitive papers. *Applied Engineering in Agriculture.* 21(6): 961-964.

Kirk, I.W, L. F. Bouse, J. B. Carlton, and E. Franz. 1991. Aerial application parameters influence spray deposition in cotton canopies. ASAE Paper No. AA91-007. St. Joseph, Mich.: ASAE.

Salyani, M. and R. P. Cromwell. 1992. Spray drift from ground and aerial application. *Transactions of the ASAE* 35(4):1113-1120.

Smith, D.B., Bode, L.E. and Gerard, P.D. 2000. Predicting ground boom spray drift. *Transactions of the ASAE* 43(3):547-553.

Thomson, S.J. and L.A. Smith. 2004. Performance Evaluation of Low Cost GPS and WAAS-corrected Swathing Systems on Agricultural Aircraft Using Precise Position Triggering. Technical Paper no. 041062, ASAE, St. Joseph, MI.

Thomson, S.J., L.D. Young, J.R. Bright, P.N. Foster, and D.D. Poythress. 2007. Effects of spray release height and nozzle/atomizer configuration on penetration of spray in a soybean canopy – preliminary results. Paper number AA07-008. National Agricultural Aviation Association, Washington, DC.

Wolf, R. E., D. S. Bretthauer, and R. Gardisser. 2005. Determining the affect of flt-fan nozzle angle on aerial spray droplet spectra. ASAE Paper No. AA05-003. St. Joseph, Mich.: ASAE.

Yates, W. E., N. B. Akesson, and D. E. Bayer. 1976. Effects of spray adjuvants on drift hazards. *Transactions of the ASAE* 19(1):41-46.