Best Practices for Aerial Application
Pesticide Spray Drift Series—3 Parts

• March 15, 2018 webinar: “Strategies for Managing Pesticide Spray Drift”
  – Presented by Dr. Greg Kruger, University of Nebraska-Lincoln
  – Covers fundamentals of pesticide spray particle drift management

• Today’s webinar: “Best Practices for Aerial Application”
  – Presented by Br. Bradley Fritz, United States Department of Agriculture
  – Dr. Greg Kruger will join for the Q+A discussion

• October 25, 2018 webinar: “Best Practices for Ground Application”
  – Presented by Dr. Greg Kruger, University of Nebraska-Lincoln
  – Register at: https://www.epa.gov/pesticides/register-oct-25-webinar-best-practices-pesticide-ground-application
  – Dr. Bradley Fritz will join for the Q+A discussion
Greg Kruger, Ph.D.

- Weed science and pesticide application technology specialist
- University of Nebraska-Lincoln, Department of Agronomy and Horticulture
- Director of the Pesticide Application Technology Laboratory
- Areas of research: droplet size and efficacy, spray drift deposition and canopy penetration, influence of nozzle type, orifice size, spray pressure, and carrier volume rate on spray droplet size
Presenter

- Bradley Fritz, Ph.D
- Agricultural engineer and Research Leader, Agricultural Research Service, US Department of Agriculture
- Research areas: examining the role of spray nozzles, spray solutions, and operational settings in resulting droplet size of spray; exploring the transport and fate of applied spray under field conditions
- Numerous publications: https://www.ars.usda.gov/people-locations/person?person-id=33323
Best Practices for Aerial Application

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Disclaimer

The use of trade, firm, or corporation names in this presentation is for the information and convenience of the viewer. Such use does not constitute an official endorsement or approval by the United States Department of Agriculture or the Agricultural Research Service of any product or service to the exclusion of others that may be suitable.
Aerial Application in the U.S.

- More than 1300 aerial application services and 4000+ aircraft in the U.S.;
- Accounts for ~25% of all applied crop protection products on commercial farms
- ~100% of forest protection products
- 71 million acres treated aerially.
- Public health application for control of insects vectoring diseases.
- Wildfire/forest fire suppression.
While aerial applications are made on nearly all US agricultural crops, based on an industry survey, the 5 most predominate crops are:

- Corn
- Wheat/barley
- Soybeans
- Pastures/Rangelands
- Alfalfa
Aerial Equipment in the US

- 88% Fixed-Wing
- 12% helicopter
- 67% turbine, 33% piston
- Industry standards: GPS, flow control, aerial specific nozzles, AIMMS
Aerial Applicators in the US

- Average applicator has over 21 years experience.
- Commercial pilot and applicator license.
- Participation in annual system testing and other training programs.
Spray Droplet Sizing – Understanding the Basics
Scale of Measurement - Micrometer

- Raindrops: 500 to 4000 um
- Agricultural Sprays: 50 to 2500 um
- Human Hair: 20 to 180 um
- Bacterium: 1 to 10 um
Droplet Diameter

\[ V = \frac{1}{6} \pi D^3 \]

\[ D = \text{droplet diameter} \]
\[ V = \text{droplet volume} \]

A droplet of \( \frac{1}{2} \) \( D \), = 1/8 the Volume of \( D \).

\[
\frac{V_1}{V_2} = \frac{D_1^3}{0.5D_1^3} = \frac{1^3}{0.5^3} = \frac{1}{0.125} = 8
\]

8X the Droplets to get the same Volume
Droplet Volume in the Spray Cloud

One 400 µm drop
Droplet Volume in the Spray Cloud

8 - 200 µm drops
Droplet Volume in the Spray Cloud

64 - 100 µm drops
Total Spray Volume

Characteristics of total spray volume.

Volume Distribution to account for A.I.
Droplet Size Definitions

- From ASABE Standard S327.4 - Terminology and Definitions for Applications of Crop or Forestry Production and Protective Agents

- $D_{V0.5}$ or Volume Median Diameter (VMD)
  - Droplet diameter at which 50% of the total spray volume is in droplets of smaller diameter

- $D_{V0.1}$ and $D_{V0.9}$
  - Droplet diameters at which 10% and 90%, respectively of the total spray volume is in droplets of smaller diameter

- Using some measurement system, these data are determined.
**4008 @ 30 psi and 130 mph – Herbicide Mix**

<table>
<thead>
<tr>
<th>particle size / μm</th>
<th>Q35/¢</th>
<th>x0/μm</th>
<th>Q3/¢</th>
<th>x50/μm</th>
<th>Q90/¢</th>
<th>x90/μm</th>
<th>Q50/¢</th>
<th>x0/μm</th>
<th>Q10/¢</th>
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<td>0.00</td>
<td>37.00</td>
<td>0.15</td>
<td>150.00</td>
<td>4.19</td>
<td>610.00</td>
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<td>610.00</td>
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<td>1.02</td>
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<td>1970.00</td>
<td>0.00</td>
<td>9.03</td>
<td>1970.00</td>
</tr>
</tbody>
</table>

Example output from Sympatec HELOS laser diffraction measurement system.

Distribution data and plot.
Relative Span

\[ RS = \frac{D_{V0.9} - D_{V0.1}}{D_{V0.5}} \]

An indicator of the \textbf{width} of distribution.
VMD = 300µm

RS = 0.67
RS = 1.4
RS = 2.2

$D_{V10}$
90 µm

$D_{V10}$
165 µm

$D_{V10}$
200 µm

$D_{V90}$
400 µm

$D_{V90}$
435 µm

$D_{V90}$
510 µm
1 Purpose and Scope

1.1 This Standard defines droplet spectrum categories for the classification of spray nozzles, relative to specified reference fan nozzles discharging spray into static air or so that no stream of air enhances atomization. The purpose of classification is to provide the nozzle user with droplet size information primarily to indicate off-site spray drift potential and secondarily for application efficacy.

1.2 This Standard defines a means for relative nozzle comparisons only based on droplet size. Other spray drift and application efficacy factors, such as droplet discharge trajectory, height, and velocity, air bubble inclusion; droplet evaporation; and impaction on target are examples of factors not addressed by the current Standard.

Table 1 – Classification category threshold values for flat spray nozzles

<table>
<thead>
<tr>
<th>Classification Category Threshold</th>
<th>Nozzle Spray Angle (°)</th>
<th>Nominal Rated Flow Rate¹</th>
<th>Reference Flow Rate²</th>
<th>Reference Operating Pressure²</th>
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<tr>
<td></td>
<td></td>
<td>(L/min)</td>
<td>(gpm)</td>
<td>(L/min)</td>
</tr>
<tr>
<td>XF / VF</td>
<td>IP-16⁴, 30</td>
<td>0.12</td>
<td>0.032</td>
<td>0.036</td>
</tr>
<tr>
<td>VF / F</td>
<td>110</td>
<td>0.38</td>
<td>0.10</td>
<td>0.48</td>
</tr>
<tr>
<td>F / M</td>
<td>110</td>
<td>1.14</td>
<td>0.30</td>
<td>1.18</td>
</tr>
<tr>
<td>M / C</td>
<td>110</td>
<td>2.27</td>
<td>0.60</td>
<td>1.93</td>
</tr>
<tr>
<td>C / VC</td>
<td>80</td>
<td>3.03</td>
<td>0.80</td>
<td>2.68</td>
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<tr>
<td>VC / XC</td>
<td>65</td>
<td>3.78</td>
<td>1.00</td>
<td>3.22</td>
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<tr>
<td>XC / UC</td>
<td>65</td>
<td>5.68</td>
<td>1.50</td>
<td>4.22</td>
</tr>
</tbody>
</table>
Reference Nozzle Curves

Droplet Diameter (µm)

DV10  DV50  DV90

EXTREMELY COARSE

VERY COARSE

COARSE

MEDIUM

FINE

VERY FINE

VF/F  F/M  M/C  C/VC  VC/XC
Take Home

- At equal volume:
  - **Halving the diameter** creates $8X$ droplets
  - **Quartering** creates $64X$ droplets
    - The smaller the diameter, the greater the number of droplets, and the less control you have over them.
- **Volume Distribution** corresponds to available product and efficacy
  - $D_{V0.1}$, $D_{V0.5}$ (VMD), $D_{V0.9}$, RS
- **Droplet Size Classification** provides a relative size rating of a spray.
Aerial Application Nozzles and Droplet Size Trends
Standard Nozzle Types

• Hydraulic Nozzles
  – Flat Fans
  – Straight Streams
  – Anvil Impaction

• Rotary Atomizers
  – Air driven
  – Electrical driven
Hydraulic Nozzles - Airspeed

As airspeed increases, droplet size decreases.
As pressure increases, droplet size increases.
Hydraulic Nozzles - Orifice

Droplet size versus orifice size – Nozzle type dependent.
Hydraulic Nozzles - Deflection

As deflection angle increases, droplet size decreases.
As airspeed increases, rotational velocity increases and droplet size decreases.
Blade angle can be adjusted to maintain rotational velocity with changing airspeed, reducing changes in droplet size.
Adjuvants
Resource for Adjuvants


A google search for Purdue Extension PPP-107 will return the web link.
What is an Adjuvant?

ASTM Standard E1519: “Standard Terminology Relating to Agricultural Tank Mix Adjuvants”

“A material added to a tank mix to aid or modify the action of an agrichemical, or the physical characteristics of the mixture.”
Adjuvant Usage and Benefits

• Improve performance by overcoming issues with:
  – Water quality and other properties;
  – Plant structure and makeup;
  – Spray system limitations;
  – Environmental conditions in field.

• Adjust pH to maintain pesticide efficacy;
• Reduce fine droplet formation;
• Reduce evaporative losses;
• Improve rainfastness;
• Increase plant absorption and uptake;
• Increase retention and spread;
• Etc…
4008 – $D_{V0.1}$ @ 60 psi

![Graph showing the effect of airspeed on $D_{V0.1}$ at 60 psi. The graph is labeled with different particle sizes (Very Coarse, Coarse, Medium, Fine, Very Fine) and various marker lines for different mixtures such as Gly only, Gly + COC, Gly + P1, Gly + ME, Gly + M5O, Gly + Si, and Gly + P2. The graph is used to demonstrate the effect of airspeed on the $D_{V0.1}$ for each mixture. The scales for airspeed (mph) and $D_{V0.1}$ (μm) are provided.]
4008 – $D_{V0.5}$ @ 60 psi

Airspeed (mph)

- VERY COARSE
- COARSE
- MEDIUM
- FINE
- VERY FINE

P1, P2

Aerial Application Technology
4008 – $D_{V0.9}$ @ 60 psi

Airspeed (mph)

<table>
<thead>
<tr>
<th>Airspeed (mph)</th>
<th>VERY COARSE</th>
<th>COARSE</th>
<th>MEDIUM</th>
<th>FINE</th>
<th>VERY FINE</th>
</tr>
</thead>
</table>

Gly only
Gly + COC
Gly + P1
Gly + ME
Gly + MSO
Gly + Si
Gly + P2
4008 – % Vol < 100µm @ 60 psi

Percentage Volume < 100 µm Diameter (%)

Airspeed (mph)

Gly, Si, P1, P2
FINE

COC, ME, MSO

MEDIUM

COARSE

VERY COARSE

Gly only
Gly + COC
Gly + P1
Gly + ME
Gly + MSO
Gly + Si
Gly + P2
AU4000 – @ 40 psi

Aerial Application Technology
General Trends

• Different nozzle/adjuvant combinations may have different effects.
  – Formulation of the active product will change droplet size.
• Air shear is the dominant factor with solution effect lessening past 140 mph.
• Adjuvant type:
  – Oils tend to slightly increase size or have no effect.
  – Thickening type adjuvants tend to increase Relative Span, creating more droplets in the larger and smaller size range.
• Nozzle selection has greatest impact on droplet size.
  – Proper nozzle selection should always be your starting point when setting up an application.
Aircraft Setup
Setting up a System for an Application

• Pesticide product selected based on pest/application needed, grower, producer or crop consultant requirements
  – Label Requirements
    • Droplet Size
    • Weather conditions
    • Tank Mix modifiers
    • Mixing requirements
    • Spray Rate
  – Nozzle and Boom setup
  – Swath Uniformity and Effective Swath Width
Spray System Setup

- Changes to factors alter both droplet size and spray rate.
- Iterative Process

- At this stage and applicator would do an initial boom setup and have their pattern assessed and adjusted.
Pesticide Labels = Law

Labels indicate requirements and limitations associated with the application of a particular product. Applicators must follow guidance provided on product labels.

Application Method, Nozzle types, Spray rate, Droplet Size, Meteorological conditions, Tank mix partners, Number of applications, Etc....
Apply only as a medium or coarser spray (ASAE standard 572) or a volume mean diameter of 300 microns or greater.

**IMPORTANCE OF DROPLET SIZE**

The most effective way to reduce drift potential is to apply large droplets (>150 microns). The best drift management strategy is to apply the largest droplets that provide sufficient coverage and control. The presence of sensitive species nearby, the environmental conditions, and pest pressure may affect how an applicator balances drift control and coverage.

Use sufficient carrier volume and appropriate equipment set-up to form droplets large enough to avoid drift potential. Coarse droplets in the 300 to 500 (VMD) micron range are recommended.

Coarse sprays are less likely to drift; therefore, do not use nozzles or nozzle configurations which dispense spray as fine spray droplets. Do not angle nozzles forward into the airstream and do not increase spray volume by increasing nozzle pressure.

**Aerial Application**: Poor coverage will result in reduced weed control. For optimal weed control, apply Liberty 280 SL Herbicide in a minimum of 10 gallons per acre. Apply Liberty 280 SL Herbicide using nozzles and pressures that generate MEDIUM (about 300 to 400 microns) spray droplets category as reported by the nozzle manufacturer and in accordance to ASABE S 572 based upon the selected air speed. Do not use nozzles and pressures that result in COARSE sprays. FINE sprays should also be avoided to minimize spray drift risk. See the *Spray Drift Management* section of this label for additional information on proper application of Liberty 280 SL Herbicide.
INFORMATION ON DROPLET SIZE: The most effective droplets are large droplets. The best drift management strategy is to apply larger droplets to prevent drift if applications are made improperly, or to apply smaller droplets if applications are made properly. (See Wind, Temperature and Humidity, and Temperature and Humidity)

Volume Median Diameter (VMD) - The VMD value is the median size of droplets that are deposited on a surface. The optimum range for VMD is between 200 and 400 microns. Use sprayer nozzles that meet these VMD guidelines.

CONTROLLING DROPLET SIZE
- **Volume** - Use larger size droplets with higher flow rates to achieve better coverage and control.
- **Pressure** - Do not use smaller droplets if nozzle types lower or nozzles must be pointed toward the rear of the aircraft. The downward angle of the nozzle should not be greater than 20 degrees.
- **Nozzle Orientation** - Use solid stream nozzles for lower drift.
- **Nozzle Type** - Use solid stream or solid spray nozzles. Use high pressure nozzles.
- **Nozzle Pressure** - Use a maximum spray pressure of 40 psi.
- **Buffer Zone** - Establish a buffer zone between the area to be sprayed and sensitive crops.
- **DO NOT** - Spray when wind velocity is greater than 5 mph.

Coarse sprays are less likely to drift; therefore, do not use nozzles or nozzle configurations which dispense spray as fine spray droplets. Do not angle nozzles forward into the airstream and do not increase spray volume by increasing nozzle pressure.
AERIAL SPRAY DRIFT MANAGEMENT

The following drift management requirements must be followed to minimize off-target drift movement during aerial application.

• 1. The distance of the outermost nozzles on the boom must not exceed 3/4 the length of the wingspan or rotor.

• 2. Nozzles must always point backward, parallel with the air stream and never be pointed downwards more than 45 degrees. Where states have more stringent regulations, they must be followed.
Importance of Droplet Size

• The most effective way to reduce drift potential is to apply large droplets. The best drift management strategy is to apply the largest droplets that provide sufficient coverage and control. Applying larger droplets reduces drift potential, but will not prevent drift if the application is made improperly, or under unfavorable environmental conditions, such as in windy, high temperature with low humidity, and/or inversion conditions as described below.
Example – RoundUp PowerMax

Controlling Droplet Size

- **Volume:** Use high flow rate nozzles to apply the highest practical spray volume. **Nozzles with the higher rated flows produce larger droplets.**
- **Pressure:** Operate at a sprayer pressure towards the lower end of the range listed for the nozzle. **Higher pressure reduces droplet size** and does not improve canopy penetration. When higher flow rates are needed, use higher flow rate nozzles instead of increasing the pressure.
- **Number of nozzles:** Use the **minimum number of nozzles that provide uniform coverage.**
- **Nozzle orientation:** Orienting nozzles so that the spray is released backwards, parallel to the air stream, will produce larger droplets than other orientations. Significant deflection from the horizontal will reduce droplet size and increase drift potential.
- **Nozzle type:** Use a nozzle type that is designed for the intended application. With most nozzle types, narrower spray angles produce larger droplets. Consider using low-drift nozzles. Solid stream nozzles oriented straight back produce larger droplets than other nozzle types.
- **Boom length:** For some use patterns, reducing the effective boom length to less than 3/4 of the wingspan or rotor length could further reduce drift without reducing swath width.
- **Application height:** Application must be made at a **height of 10 feet or less** above the top of the largest plants unless a greater height is required for aircraft safety. Making the application at the lowest height that is safe reduces the exposure of the droplets to evaporation and wind.
Example – RoundUp PowerMax

• Annual Weeds:
  – Aerial: 3 – 5 gallons per acre

• Typical fixed-wing aircraft with the following operational characteristics:
  – Typical application airspeeds - 130-150 mph
  – 60-70’ swath

• Based on label we will select nozzles and settings to achieve both a MEDIUM and a COARSE spray application.
Aerial Spray Models

• A set of droplet sizing models were developed by USDA ARS to assist applicators with this process.

http://tiny.cc/DropletSizeModels

• Detailed descriptions and instructions on website.
Select nozzle type

Enter operational settings

Enter spray rate and swath width
### Acceptable Ranges:
- \( D_{vo.1} = 165 \) µm = Droplet size such that 10% of the spray volume is in droplets smaller than \( D_{vo.1} \).
- \( D_{vo.5} = 379 \) µm = Volume median diameter. Droplet size such that 50% of the spray volume is in droplets smaller than \( D_{vo.5} \).
- \( D_{vo.9} = 690 \) µm = Droplet size such that 90% of the spray volume is in droplets smaller than \( D_{vo.9} \).
- RS = 1.39 = Relative Span
- \( %V < 100 \mu m = 0.45 \) % = Percentage of spray volume in droplets smaller than 100 µm diameter.
- \( %V < 200 \mu m = 12.38 \) % = Percentage of spray volume in droplets smaller than 200 µm diameter.

### Nozzle Spectra Classification:
- \( DSC_{vo.1} = \text{COARSE} \)
- \( DSC_{vo.5} = \text{COARSE} \)
- \( DSC_{vo.9} = \text{COARSE} \)

### Disclaimer:
Nozzle numbers provided do not imply swath uniformity or coverage. Applicators are encouraged to attend an Operation S.A.F.E. Clinic.

### Step 3: Enter Spray Rate and Swath Width

<table>
<thead>
<tr>
<th>GPA</th>
<th>ENTER DESIRED SPRAY RATE IN GALLONS PER ACRE (GPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>ENTER DESIRED SWATH WIDTH IN FEET</td>
</tr>
</tbody>
</table>

- 53.0 GPM Total Boom Flow Rate
- 1.49 GPM Per Nozzle Flow Rate at Selected Operating Conditions
- 36 Nozzles Total Number of Nozzle Needed
### Acceptable Ranges:

- **Orifice Size**: 2 to 12
- **Nozzle Angle**: 0 to 45
- **Pressure**: 30 to 90 psi
- **Airspeed**: 120 to 180 MPH

**CAUTION**: Do not enter or clear data in the cells in this box.

#### Droplet Spectra Classification

- **DSCv0.1**: COARSE
- **DSCv0.5**: COARSE
- **DSCv0.9**: VERY COARSE

**RS**: Relative Span

- **%V<100µm**: 3.21%
- **%V<200µm**: 14.18%

**Disclaimer**: Nozzle numbers provided do not imply swath uniformity or coverage. Applicators are encouraged to attend an Operation S.A.F.E. Clinic.

### Step 3: Enter Spray Rate and Swath Width

- **3 GPA**: ENTER DESIRED SPRAY RATE IN GALLONS PER ACRE (GPA)
- **70 Feet**: ENTER DESIRED SWATH WIDTH IN FEET

#### Flow Rates:
- **63.6 GPM**: Total Boom Flow Rate
- **1.41 GPM**: Per Nozzle Flow Rate at Selected Operating Conditions

#### Total Number of Nozzle Needed: 45
Mobile App Formats
Micron Group

http://www.microngroup.com/droplets/models.php

Sign up for a user account to access the models.
Boom Setup and Nozzle Positioning
Field Streaking
Nozzle and Boom Positioning

- The effect of propwash on spray recovery.
- Wing tip vortices affecting spray pattern.
Pattern Measurement
Best Practices to Consider for Drift Mitigation
What Factors Cause Drift?

• Spray Characteristics
  – Droplet Size (formulation, nozzle, operational settings, airspeed)
  – Evaporation Rate (formulation, weather)

• Aircraft
  – Application Height
  – Wing-tip Vortices (nozzle positioning)

• Weather
  – Wind
  – Temperature and Humidity
  – Inversions
Droplet Size and Wind Speed

• Using AGDISP let’s consider:
  – AT-602
  – 75’ swath – 65% boom width
  – 80° F at 50% TH
  – 20 spray passes
  – Fine, Medium, Coarse and Very Coarse
  – 5, 10, 15 and 20 mph
Droplet Size vs Wind Speed

5 mph

20 mph

Deposition (Fraction of Applied)

Distance Downwind (ft)
Nozzle Position on Booms

Farthest nozzle <75% of Wing Span
Downwind Edges

- The majority of off-target movement comes from the downwind edges of the field.
  - Spray when wind speed is lower, or when wind direction changes.
  - Modify application to adjust droplet size or nozzle position.
    - Reduced airspeed – 2 or 3 lower airspeed passes can reduce total off target movement by up to 10%
    - ½ boom shutoffs to reduce entrainment from downwind wing
Evaporation Speed
Off-Target Height
Application
Atomization
Pressure
Labels
Spray
Droplet
Mix
Boom
Airspeed
Temperature
Pesticide
Geography
Deposition
Public
Effective
Wind
Size
Species
Health
Swath
Streaking
Weather
Species
Stewardship
Crop
Safety
Sustainability
Implementation
Technology
THANK YOU FOR PARTICIPATING

https://www.ars.usda.gov/
QUESTIONS