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Research Update: Updating the USDA ARS Spray Nozzle Models for Higher Airspeeds

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Research Objective: To examine the effects of airspeeds up to 200 mph on the atomization of sprays from conventional aerial application nozzles and to develop extended range spray nozzle models for use by aerial applicators.

Research Methods: Initial testing included the CP11TT nozzle body (CP Products, Tempe, AZ) fitted on a CP-06 swivel and outfitted with a series of 40 degree flat fan tips. Similar to the presently available USDA ARS models for the CP 40 degree flat fans, two separate models, one for smaller orifice fans (04 to 12) and one for the larger orifice fans (12 to 30), were developed for airspeeds from 140 to 200 mph. Each model was developed across spray pressure ranges from 20 to 60 psi and orientation angles from 0 to 90 degrees. The model development followed the methods established by Kirk (*Measurement and prediction of atomization parameters from fixed wing aircraft spray nozzles, 2007. Transactions of the ASABE 50(3):693-703*). For each spray model a series of treatments were conducted across 27 unique operational conditions (nozzle orifice, deflection, pressure and airspeed). Atomization testing for these treatments was conducted in the USDA ARS Aerial Application Technology (AAT) groups new high speed wind tunnel which has an operation range across airspeed ranging from 0 to 215 mph (Figure 1). All spray testing was complete using a spray solution of water plus a non-ionic surfactant. Droplet size measurements were made using a Sympatec laser diffraction instrument. For each treatment a minimum of three replicated measurements were made. Additional measurements were made for nozzles and operational conditions not a part of the model treatments to provide a check on the resulting models.

Figure 1. USDA ARS Aerial Application Technology high speed wind tunnel and nozzle testing facility.

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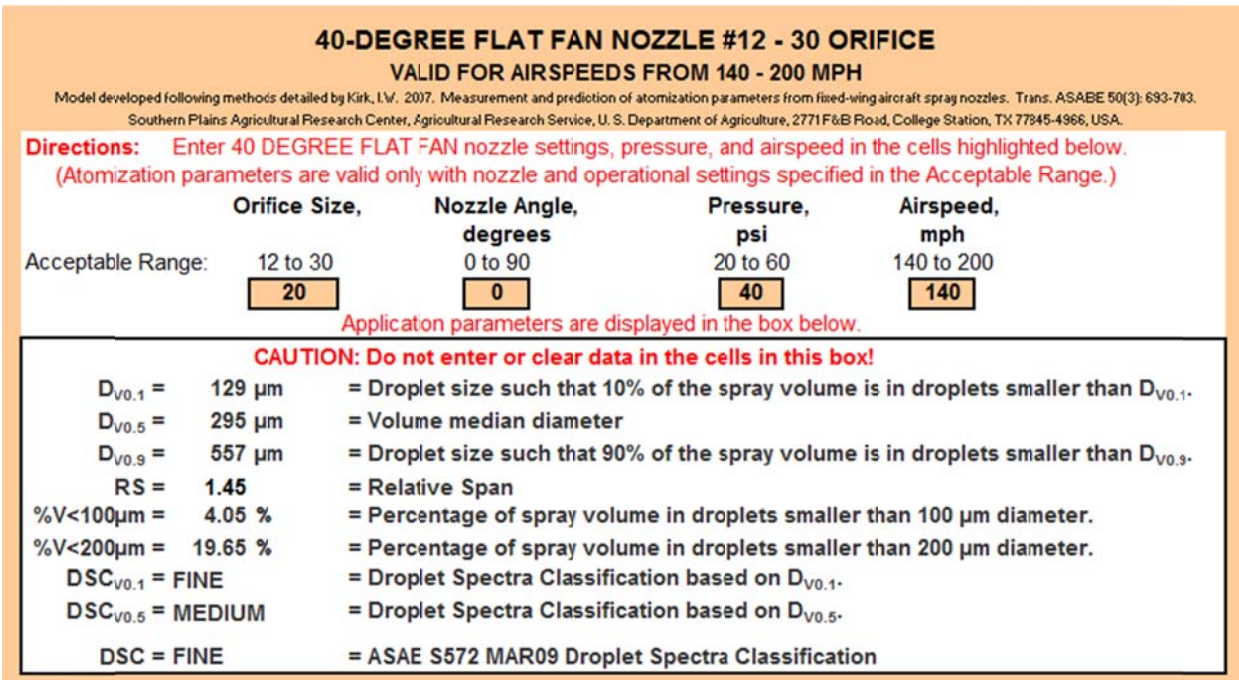
The measured data was then analyzed in SAS to develop a response surface model that allows users to input their operational conditions and return estimates of spray droplet size parameters which include Dv10, Dv50, Dv90, relative span, and percent of spray less the 100 and 200 µm.

Research Results: Using the measured data, models were developed for the CP 40 degree flat fans fitted into the CP11TT body. Interactive Excel workbooks allow users to enter operational information to determine spray droplet size that results (Figure 2). The modeled data for the check nozzles and setups that were tested as checks, matched very closely with the measurement data.



40-DEGREE FLAT FAN NOZZLE #12 - 30 ORIFICE

VALID FOR AIRSPEEDS FROM 140 - 200 MPH

Model developed following methods detailed by Kirk, I.W. 2007. Measurement and prediction of atomization parameters from fixed-wing aircraft spray nozzles. Trans. ASABE 50(3): 693-703.
Southern Plains Agricultural Research Center, Agricultural Research Service, U. S. Department of Agriculture, 2771 F&B Road, College Station, TX 77845-4966, USA.

Directions: Enter 40 DEGREE FLAT FAN nozzle settings, pressure, and airspeed in the cells highlighted below.
(Atomization parameters are valid only with nozzle and operational settings specified in the Acceptable Range.)

	Orifice Size,	Nozzle Angle, degrees	Pressure, psi	Airspeed, mph
Acceptable Range:	12 to 30	0 to 90	20 to 60	140 to 200
	20	0	40	140

Application parameters are displayed in the box below.

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

$D_{V0.1}$ =	129 µm	= Droplet size such that 10% of the spray volume is in droplets smaller than $D_{V0.1}$.
$D_{V0.5}$ =	295 µm	= Volume median diameter
$D_{V0.9}$ =	557 µm	= Droplet size such that 90% of the spray volume is in droplets smaller than $D_{V0.9}$.
RS =	1.45	= Relative Span
%V<100µm =	4.05 %	= Percentage of spray volume in droplets smaller than 100 µm diameter.
%V<200µm =	19.65 %	= Percentage of spray volume in droplets smaller than 200 µm diameter.
$DSC_{V0.1}$ =	FINE	= Droplet Spectra Classification based on $D_{V0.1}$.
$DSC_{V0.5}$ =	MEDIUM	= Droplet Spectra Classification based on $D_{V0.5}$.
DSC =	FINE	= ASAE S572 MAR09 Droplet Spectra Classification

Figure 2. Spray nozzle model interactive Excel workbook.

One of the first things apparent from the results was the significant spray atomization at airspeeds above 160 mph. Above 160 mph, the majority of the operational setups result in sprays with percent fines (%V<100µm – which is the percent of the spray volume that is contained in spray droplet of a 100 µm or less and is much more prone to off-target movement) that is above 10% and reaching upwards of 40 to 50% at worst case conditions (90 degree deflection, 200 mph airspeeds and low spray pressure). Obviously these worst case conditions are not likely to occur in the field, but even under the best operational practices, minimizing off-target movement through nozzle selection and setup becomes difficult beyond 160 mph.

The developed models can be used to gain an understanding of how the different nozzle setups and airspeeds interact. For example, increasing spray pressure from 20 to 60 psi for the 4020 FF operating in 180 mph with 0 degrees deflection increases the Dv10 from 76 to 83 µm and decreases the percent fines from 19 to 14%. Increasing the orifice size from 4 to 30 for the 40 degree FFs operating at 50 psi, 0 degree deflection in 180 mph airstream has not significant effect on Dv10 (84 down to 79 µm) or percent fines (13.8 to 15.9%). Increasing airspeed from 140 to 200 mph for a 4012 FF operating at 50

psi, 0 degree deflection decreases the Dv50 from 288 µm down to 171 µm and increases the percent fines from 5 to over 20%. Increasing the deflection from 0 to 90 degree for a 4012 FF operating at 50 psi in 180 mph airstream decreases the Dv50 from 203 down to 102 and increases the percent fines from 13 to 45%. It should be noted that for all operational setups mentioned above the spray classifications are fine to very fine.

There were also a number of issues observed with the nozzles operating in these higher airspeeds. The nozzle structure itself can become an obstruction to the spray at the higher airspeeds. With the CP11TT operating at 180 mph or greater and 90 degree deflection (while not a likely real work operational scenario, mentioned as an example of potential issues with other nozzles), the retaining nut can become an obstruction and destroy the continuity of the spray fan structure (Figure 3). During the testing, the thumb tab on the nozzle (yellow structure in Fig. 3) acted as a block to the airflow causing the nozzle to rotate in the highspeed airstream. At the higher airspeed, the flat fans were also compressed to less than their designed angle. In the case of the 40 degree FFs tested, at 200 mph the angle was compressed to 20 degrees (Figure 4). This narrowing of the fan angle at the higher airspeeds will necessitate changes in the way booms are setup to insure acceptable sprays patterns.

Figure 3. Nozzle structure an impedment to spray at very high airspeeds.

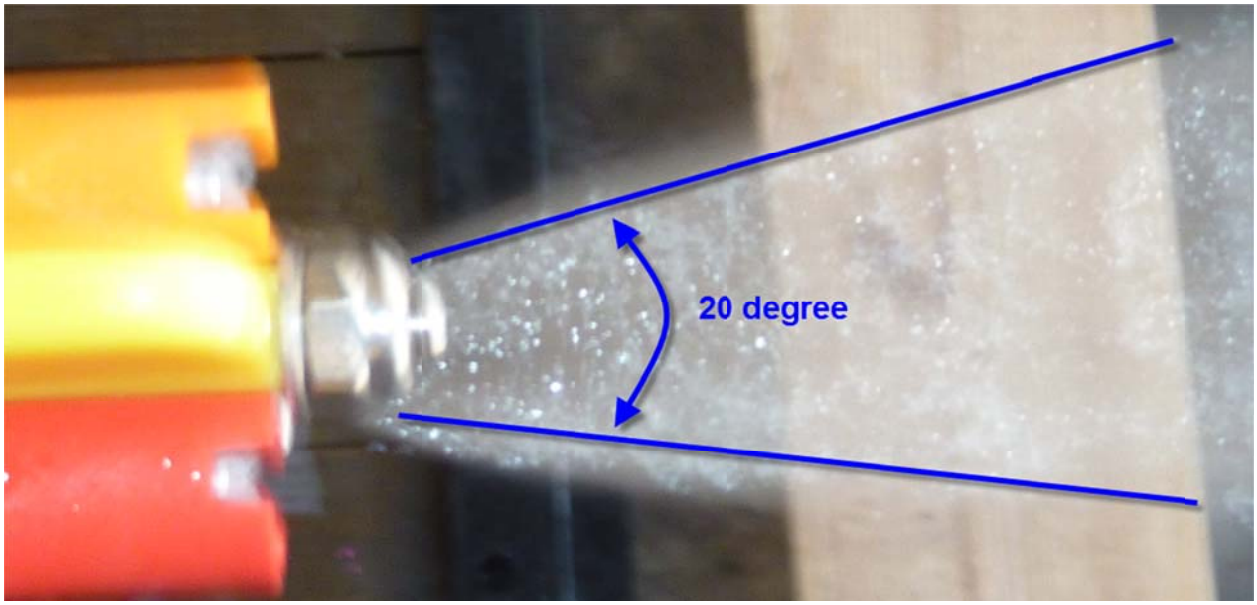


Figure 4. Narrowing of a 40 degree flat fan when operating in a 200 mph airstream.

Further Development:

All of the presently available models, which are available for download at – http://apmru.usda.gov/downloads/AERIAL%20SPRAY%20NOZZLE%20MODELS%20%28Technical%20Version%29%202005.html) are being updated for both the lower airspeeds (less than 140 mph) and with new models for the higher (140 up to 200 mph) airspeeds and will be available on the website in place of the present models. As we progress through the development of these models, we expect to see a number of issues with present nozzle designs that may need to be addressed prior to usage at higher airspeeds. We also expect to test a variety of alternative operational conditions and nozzles in an effort to provide information on methods for achieving desired spray qualities when applying at higher airspeeds. Additionally, we plan to examine the impact of active ingredients on spray atomization along with developing correction factors for present models or additional models for estimating atomization from active ingredient sprays.