2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Field Evaluation of Commercially Available Small Unmanned Aircraft Crop Spray Systems

Woldt W.[1], Martin, D.[2], Latheef, M.[2], Kruger, G.[3], Wright, R.[4], McMechan, J.[4], Proctor, C.[3], and Jackson-Ziems, T.[5]

[1]Department of Biological Systems Engineering, University of Nebraska, Lincoln, NE, 68583
[2] USDA-ARS Aerial Application Technology Research Unit, College Station, Texas, 77845
[3]Department of Agronomy and Horticulture, University of Nebraska, Lincoln, NE, 68583
[4]Department of Entomology, University of Nebraska, Lincoln, NE, 68583
[5]Department of Plant Pathology, University of Nebraska, Lincoln, NE, 68583

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ABSTRACT. *Agricultural research and development on small unmanned aircraft systems (UAS) has been directed toward UAS enabled sensing to detect features of interest. While compelling, there is an immediate need to increase the breadth and depth of UAS-based research, to move beyond sensing, and explore active intervention in agricultural production systems. This paper is focused on the concept of crop protection through ultra-precise, unmanned aerial application systems, and seeks to initiate research discussion in this important area of opportunity. Toward this end, two different, commercially available, small Unmanned Aerial Application Systems (sUAAS - defined as less than 55 lbs. maximum take-off weight) were evaluated for operational techniques and application system efficacy under dynamic field conditions. The performance of the factory supplied spray equipment systems are documented using traditional aerial spray testing methods that have been modified for UAS enabled application systems, referred to as small Unmanned Aerial Application Systems (sUAAS). Results from initial testing protocols indicate that the factory supplied systems are quite different in design and implementation, with spray test results that reflect this difference in design, in both deposition and spray swath. Further, it is apparent that with the advent of unmanned aerial application systems, and the unique characteristics of the integrated aircraft and application systems, there is a very real need for the development of standardized sUAAS testing procedures.*

Keywords. *Unmanned aircraft, unmanned aerial application systems, unmanned aerial spray systems, spray pattern testing, drone sprayer, wind tunnel testing*

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Introduction

The opening of National Air Space to small unmanned aircraft is already becoming a “game changer” for agriculture. Unmanned aircraft systems (UAS) will offer an unparalleled opportunity to place sensors, robotics, and advanced information systems at desired locations for increasing production and improving efficiency of agricultural operations. Research on deployment of UAS for sensing agricultural systems continues to expand, with emphasis on early detection of stress, informing precision agriculture, and advances in phenotyping (Woldt et al., 2016).

At the same time, it is possible to envision unmanned aircraft systems that allow direct interaction within their proximal environment. These systems represent active engagement of the UAS in the agricultural production system and have the potential to continue the evolution of unmanned aircraft in agriculture. One area of promise is the use of unmanned aircraft for application of beneficial products for crop and/or animal agriculture. Toward this vision, this paper is focused on the concept of crop and/or animal protection through ultra-precise small unmanned aerial application systems (sUAAS -- or simplified to UAAS). As such, it seeks to initiate exploration and begin to solve fundamental science and engineering challenges, as these new aerial spray technologies continue to evolve.

While ultra-precise unmanned aircraft spray technologies exist and can be purchased, the technology is so new that standard methods for testing UAS spray system performance have not yet been developed. As a result, vendors are providing equipment that offers somewhat coarse guidance on achieving a desired application rate. This is understandable, given the lack of UAAS testing methods. The purpose of the research reported in this paper is to document the use of spray testing methods that have been modified from traditional piloted aerial testing protocols, to allow for use with UAAS. Two different, factory supplied UAAS were deployed, without any modifications, and results of the field-based research using the modified protocol for spray testing has been documented and reported.

Opportunities

Small unmanned aerial application systems will offer many opportunities for agriculture. Some of these opportunities are noted from agronomic prospects, entomology points of view, and plant pathology perspectives. As resistant weed populations continue to increase, a multifaceted approach to weed management will only become more critical. An important component of resistance management is early detection and rapid response. If resistant populations can be detected early they are often contained to a relatively small area of a field. These small 'patches' of resistant weeds provide an ideal opportunity for targeted herbicide applications. If unmanaged and allowed to go to seed, these patches will often spread over an entire field by the subsequent growing season. The potential economic gain from targeted herbicide applications to small resistant weed populations could be great when compared with the cost of field-wide herbicide programs.

Insect and mite infestations in crops often are not uniform, particularly when the pest colonizes the field from outside areas. Many examples of this exist, including grasshoppers which move into crop fields from nearby untilled areas where eggs overwinter, pivot corners or south facing portions of fields where spider mites may first develop, or infestations by aphids which fly into fields from a distance. Early detection of plant stress or injury by UAS may allow treatment of pest ‘hot spots’ by UAAS before the infestation becomes more widespread and increasingly costly to treat. Limiting the amount of pesticide applied would have economic benefits as well as ecological benefits by limiting the potential disruption by pesticides of natural biological controls in a field.

Like other pests, plant diseases often develop in seemingly random spots in fields that may be due to a number of conditions, such as wet spots in fields, recent pathogen introductions, spore showers, etc. Often, the pathogen continues to spread from these areas much further into growing crops dramatically increasing their impacts. The same advantages that early detection of diseases in fields of insects/mites and treatment of those spots with UAAS to limit spread, could also help to reduce mitigate overall impacts of disease. Spot treatment for some diseases may prevent or delay the need for widespread treatment of entire fields. Some examples may be the initial development of diseases, such as southern rust in corn, that often develop quickly. Southern rust is often treated with foliar fungicides because there is little plant resistance to it in commercially available corn hybrids and this disease has the potential to rapidly spread and cause severe yield loss under favorable weather conditions. Early detection and spot treatment may allow for more effective and economical control.

Background

Perhaps one of the earliest reported efforts to advance small unmanned aerial application systems can be found in the research reported by Huang et.al. in 2008 and 2009, in which the development of an unmanned aerial spray vehicle for highly accurate application of product is described in an ASABE conference proceeding, followed by an ASABE Applied Engineering in Agriculture journal article, respectively. The emphasis was on the enabling technology that would support a small unmanned aerial application system. Following this early work on enabling technology, Qiu et.al. (2012) describe research in which a strong correlation is observed between unmanned helicopter flight altitude and speed, and the resulting spray deposition and uniformity. Continuing to build on their early work, a more exhaustive exploration of unmanned aerial application technologies can be found in the work by Huang et.al. (2013).

In order to improve spray uniformity, when using an unmanned helicopter, Bae and Koo (2013) developed a different airframe configuration in which roll balancing was pursued, with somewhat improved results. Additional research on spray drift and deposition can be found in the work by Xinyu et.al. (2014), in which effectiveness of the UAAS spray deposition was tested on a paddy field. Their results tend to indicate that the UAAS deposition efficiency is better than traditional spray systems. Additional research on spray efficiency has been reported by Qin et.al. (2014) in which water sensitive cards were placed at four different levels within a maize canopy. Their results pointed to recommendations for working height of the UAAS above canopy and a recommended spray swath width to achieve the maximum efficiency for the given aircraft/spray system.

Extending the technological and field testing further, Zhang et.el. (2015) developed a simulation model to predict aerial spray drift from an unmanned helicopter, and then ran an experimental verification test to evaluate the model performance. Comparison of the predicted and observed drift curves revealed a promising coincidence. Continuing to explore advances in UAAS, Ru et.al. (2015) developed and conducted flight testing on an electrostatic UAAS. Their results tend to indicate that flight height above canopy had a much greater impact on spray drift, and the electrostatic system offered negligible improvement in drift control. Given the flight characteristics of multi-rotor UAAS, Wang et.al. (2016 and 2016) explored the downwash flow field distribution and found it to be a viable method for analysis of spatial spray deposition distribution under various conditions of flight altitude and crosswind. Zhou and He (2016) report similar research in which water sensitive papers were placed in a crop, and the UAAS was flown at three different velocities. Results indicate that uniformity was improved while droplet density and percentage of spray coverage were decreased as the flight velocity increased.

More recently, Wang et.al. (2017) conducted spray drift research for a single rotor airframe, and concluded that more research is needed provide data to support spray drift control, and to establish aviation spray standards. Research by Chen et.al. (2017) evaluated different methods for testing effective spray width of UAAS, and provides guidance on selecting the more suitable protocols for evaluation of spray swath pattern. A fairly exhaustive study was conducted by Wang et.al. (2017) in which four different aircraft were tested with multiple trials, to develop more of a statistical approach to testing. The results of this study provide insight into the determination of spraying parameters, environmental conditions of UAAS operation, and the formulation of working practices for aerial spraying. A rather unique approach to aerial application is reported by Rodriguez et.al. (2017) in which Herbicide Ballistic Technology (ie, paintball gun type of system) is affixed to a UAAS and highly targeted application of herbicides is achieved in areas that are very difficult to access, and yet the ecosystems are extremely sensitive to herbicides. Finally, Teske et.al. (2018) are reporting on the use of simulation models CHARM+AGDISP to predict the drift and deposition of sprays released from rotary wing UAAS.

Brief comment on regulations

Upon a more in-depth review of the UAAS literature, it becomes apparent that most of the research has been conducted and reported in the Transactions of the Chinese Society of Agricultural Engineering. Perhaps one of the reasons for this can be traced to the regulatory environment for unmanned aircraft. The U.S. Federal Aviation Administration only recently allowed commercial flight of unmanned aircraft in the National Airspace System, through the promulgation of Part 107 rules and regulations for unmanned aircraft systems (FAA, 2016). While it is recognized that Part 107 does permit flight of UAS for commercial purposes, the regulations do not allow for using unmanned aircraft for aerial application systems. At the same time, the Part 137 FAA rules that govern agricultural aircraft operations (FAA, 2018) do not provide for the use of unmanned aircraft systems for aerial application of economic poisons. As a result, the use of unmanned aircraft for aerial application of economic poisons requires specific waivers to both sets of regulations (Part 107 and Part 137), and a certified pilot, or pilots, that hold appropriate pilot certifications for unmanned aircraft and aerial application. Currently, these requirements lead to confusion and difficulty in achieving legal status to fly unmanned aircraft with economic poisons as a payload. These challenges have resulted in minimum progress on UAAS research and development in the United States.

There is a long history of research, development and testing of piloted aerial application systems, including ASTM standards, and an in-depth base of literature on the topic. Piloted aircraft are large, perhaps up to 3,000 liter carrying capacity, and move at a rapid pace, with airspeeds up to 160 kts. At the same time, there is a similar depth of research and literature on spray nozzle testing in wind tunnel environments, to understand more about nozzle performance under dynamic conditions, in fast moving air streams, to emulate spray aircraft. However, with the emerging potential for sUAAS, there is a corresponding need to engage in research and development, to learn more about the performance of these new systems, including the types of applications for which they are most suited. This might include spot spraying of weed patches, edge spraying, spraying small infestations of invasive species in wetland ecosystems, application of dry granular product for mosquito control, as well as a host of other applications that fit the mission profile of a sUAAS platform. This research seeks to develop an initial exploration into field testing of commercially available sUAAS, without any modifications to the factory configuration.

Methods

Field / Flight Test

This study was conducted in an unpaved area surfaced with gravel in Burleson County, near College Station, TX (30° 40´ N, 96° 18´ W). Two UASs, DJI Agras MG-1 (Dà-Jiāng Innovations, Shenzhen, Guangdong, China) and V6A (Homeland Surveillance and Electronics, Seattle, WA), were launched to determine the effect of application height and ground speed on spray pattern uniformity and spray droplet spectra characteristics. The MG-1 platform was equipped with XR11001 nozzles (TeeJet Technologies, Wheaton, Ill.) and V6A platform was equipped with CR80005 nozzles (Lechler). The nozzle pressures were 226 and 517 kPa, respectively, for the MG-1 and V6A models. The nozzle configuration was different for each airframe. The MG-1 has a “square nozzle pattern” with two nozzle following two nozzles along the flight path. The V6A has a more conventional boom, with the four nozzles in a single line, perpendicular to the direction of flight (see Table 1).

Table 1. UAS spray application system parameters.

Platform	Nozzle	# of nozzles	Pressure (kPa)	Flow Rate (ml/min.)
MG-1	XR11001	4 (square)	226	354
V6A	CR80005	4 (in line)	517	197

The treatments comprised of three application heights, 2, 3 and 4 m in cohort with four ground speeds, 1, 3, 5 and 7 m/s. Each treatment was replicated four times. A spray mix of tap water with Vision Pink™ dye (GarrCo Products, Converse, IN) at 20 ml/l was sprayed parallel to the prevailing wind over the centerline of an 11 m long x 1 mm diameter cotton string, suspended 1 m above the ground. The amount of fluorescent dye deposited on the cotton string was analyzed fluorometrically using the USDA Swath Analysis System (Hoffmann and Jank, unpublished). Fluorometric response on cotton string was used to assess pattern uniformity and effective swath.

The spectrometer (fluorometer) used for the system has a wavelength measurement range of 200-850 nm at a resolution of 1.5 nm. As the string went through the photocell, the strength of the emission signal at 405 nm would vary depending out how much dye had deposited on the string. The analysis software that was developed only read the signal strength at the 405 nm wavelength, which meant that ambient light did not interfere with the string signal. The string patterns were analyzed with custom USDA-ARS pattern analysis software. Each pattern from each replication first was evaluated individually to determine if the integrity of the deposition data was sufficient to be included in the analysis. The best example of this is if a strong crosswind were to move more than half of the spray off of the string. Those data would then not be included. In all cases, at least two patterns were used for the analysis. It was rare to have less than three replications included for the analysis. The good patterns were first centered using the centroid feature in the software. This feature determines the area under the curves and places the center of the area on the centerline. This helps to correct for the effect of crosswinds. The corrected patterns then were averaged and an effective swath was determined objectively by choosing the widest effective swath with a CV less than 25%. The data also were analyzed by documenting the CV for all treatments at a set effective swath of 4.6 m. This was another way to perform a direct comparison of the two application systems.

Spray droplet spectra were determined using water sensitive paper (WSP) samplers (26 x 76 cm) (Spraying Systems, Wheaton, Ill.). Five WSPs were inserted each into a paper clip attached to separate wooden blocks, and were placed 1-m apart on a table oriented parallel to the cotton string. Soon after spray application was conducted, WSPs were placed inside photographic negative sleeves and transported to the laboratory for analysis. Spray droplet spectra data were analyzed by the DropletScan™ scanner-based system (Whittney and Gardisser, 2003). The droplet spectra parameters measured were $D_{v0.1}$, $D_{v0.5}$, $D_{v0.9}$, percent area coverage and spray application rate. $D_{v0.1}$ is the droplet diameter (µm) where 10% of the spray volume was contained in droplets smaller than this value. Similarly, $D_{v0.5}$ and $D_{v0.9}$ are droplet diameters where 50% and 90% of the spray volume, respectively, contained droplets smaller than these values. $D_{v0.5}$ is commonly known as the Volume Median Diameter (VMD).

Spray Nozzle Test in Wind Tunnel

The spray-droplet spectrum for each UAS spray nozzle was evaluated using the low-speed wind tunnel at the Pesticide Application Technology Lab in North Platte, NE. The droplet spectrum for each treatment was analyzed using a Sympatec HELOS- VARIO/KR laser diffraction system with the R7 lens. The laser is controlled by WINDOX 5.7.0.0 software, which was operated on a computer adjacent to the wind tunnel. This lens is capable of detecting droplets in a range from 9 to 3,700 um. The laser consists of two main components, an emitter housing containing the optical box and the source of the laser and a receiver housing containing the lens and detector element. The two laser housings were separated (1.2 m) on each side of the wind tunnel and mounted on an aluminum optical bench rail that connected underneath the wind tunnel to ensure proper laser alignment. The spray plume was oriented perpendicular to the laser beam and traversed through the laser beam by means of a mechanical linear actuator. The actuator moves the nozzle at a constant speed of 0.2 m/s, such that the entire spray plume would pass through the laser beam. The distance from the nozzle tip to the laser was 30 cm. Treatments in this study were compared using the $D_{v0.1}$, $D_{v0.5}$, and $D_{v0.9}$ parameters (Creech et al., 2016).

Data Analysis

Data were sorted by aircraft platform type and were analyzed using Proc GLM procedure (SAS, 2012). Means with significant *F*-values were separated using Duncan's Multiple Range Test (DMRT) at P = 5%.

Results

Field / Flight Test

The spray droplet spectra data presented in Tables 2 and 3 shows that the differences in droplet parameters were caused by the differences in nozzle type, nozzle orifice size, spray pressure and flow rate. The V6A model was equipped with lechler nozzle, CR80005, with a flow rate of 197 ml/min., while the MG-1 model was equipped with XR11001 nozzle with a flow rate of 354 ml/min. Flow rate has a direct relation to drop size. An increase in flow rate will increase the drop size; similarly a decrease in flow rate will decrease drop size. Pressure has an inverse relationship effect on drop size. An increase in pressure will reduce the drop size. A reduction in pressure will increase the drop size. The atomization of liquids into spray droplets depends upon a number of factors among others, such as spray volume and nozzle type (Creech et al., 2015; Hoffmann and Kirk, 2005; Whisenant et al., 1993). As expected, MG-1 model aircraft with a larger orifice size and flow rate produced larger spray droplets than those of V6A aerial delivery system.

Table 2. Effect of application height and ground speed on spray droplet spectra for UAS model MG-1.

Application Height (m)	$D_{v0.1}$	$D_{v0.5}$	$D_{v0.9}$	Coverage (%)	Liters/ha
2	152.7a	260.4a	371.9a	4.2a	15.3a
3	167.9a	265.1a	373.1a	5.6a	16.7a
4	148.6a	244.1a	347.3a	3.2a	11.5a
df =2,188	F=2.4 P>0.1	F=1.5 P>0.2	F=1.6 P>0.2	F=2.3 P>0.1	F=1.0 P>0.4
Ground Speed (m/s)	$D_{v0.1}$	$D_{v0.5}$	$D_{v0.9}$	Coverage (%)	Liters/ha
1	155.3ab	274.9ab	420.2a	9.4a	34.4a
3	146.7b	245.0bc	340.0c	2.5b	9.1b
5	184.9a	279.2a	379.3b	4.01b	9.3b
7	142.7b	231.2c	321.6c	1.4b	4.8b
df=3,188	F=4.3 P>0.0056	F=5.0 P>0.0024	F=13.5 P<0.0001	F=14.5 P<0.0001	F=29.1 P<0.0001

Means followed by the same lower case letters are not significantly different (P = 5%).

Table 3. Effect of application height and ground speed on spray droplet spectra for UAS model V6A.

Application Height (m)	$D_{v0.1}$	$D_{v0.5}$	$D_{v0.9}$	Coverage (%)	Liters/ha
2	124.7a	206.1a	292.7a	2.1a	7.0a
3	108.9b	174.1b	252.6b	2.0a	6.1a
4	111.9b	172.3b	242.1b	0.9b	2.7b
df=2,180	*F*=11.8 *P*<0.0001	*F*=28.5 *P*<0.0001	*F*=24.6 *P*<0.0001	*F*=7.3 *P*>0.0009	*F*=7.6 *P*>0.0007
Ground Speed (m/s)	$D_{v0.1}$	$D_{v0.5}$	$D_{v0.9}$	Coverage (%)	Liters/ha
1	116.3a	195.2a	291.9a	3.8a	12.3a
3	118.3a	192.0a	275.5b	1.6b	4.9b
5	116.1a	178.2b	246.3c	1.0bc	3.0bc
7	111.2a	174.3b	241.4c	0.4c	1.3c
df=3,180	*F*=1.5 *P*>0.2	*F*=6.6 *P*>0.0003	*F*=17.1 *P*<0.0001	*F*=31.7 *P*<0.0001	*F*=30.4 *P*<0.0001

Means followed by the same lower case letters are not significantly different (*P* = 5%).

Application height significantly influenced spray droplet spectra for V6A; however the opposite was true for MG-1. Ground speed significantly influenced spray droplet spectra parameters for both aircraft systems. Spray coverage was higher at 1 m/s ground speed compared to 3 m/s for both aircrafts. While ground speed higher than 3 m/s did not increase coverage for MG-1 aircraft, increased ground speed did decrease coverage for V6A aircraft. Using N-3 UAV, 6 Pan et al. (2016) obtained better droplet distribution with higher spray coverage, increased deposition, smaller droplets and smaller coefficient of variation when a rotor UAV was flown at 1.0 m height over citrus trees. Qin et al. (2016) reported that an application height of 1.5 m and spraying speed at 5 m/s with HyB-15L UAV produced improved penetration and distribution of spray droplets on rice canopy. Qin et al. (2018) applied triadimefon fungicide on wheat canopy against powdery mildew and reported uniform distribution of spray droplets when N-3 UAV was launched at 5.0 m height at a speed of 4 m/s.

When analyzing the effect of application height on pattern uniformity for both platforms, the CV was determined with the swath fixed at 4.6 m (Table 4). This allowed for a direct comparison of each application system. Based on the results, overall, the CV for the MG-1 platform was best at 2 m application height. For the V6A, for the 2 and 3 m applications, resulted in very good spray application patterns. The CV for the 4 m application height was much higher most likely due to the smaller droplets from the spray being carried away from the target string. Similarly, the effect of ground speed for the two application systems on pattern uniformity at 4.6 m swath is presented in Table 5. Here, a ground speed of 3 m/s for the MG-1 resulted in the best pattern uniformity of 10.3% with all values less than 14%. For the V6A, the highest groundspeed of 7 m/s provided the best pattern uniformity with a CV of 14.7%. All other values were less than 20%.

Table 4. Swath pattern uniformity at 4.6 m swath at different application heights as indicated by coefficient of variation (%) for two commercially-available unmanned aerial application systems.

UAS models	Application Height (m)	CV (%)
MG-1	2	7.0b
	3	15.5a
	4	13.0a
F=16.8; df=2,9		*P* > 0.0009
V6A	2	15.5a
	3	13.5a
	4	22.3a
F=2.3; df=2,9		*P* > 0.15

Means followed by the same lower case letters are not significantly different at *P* = 5% (DMRT).

Table 5. Swath pattern uniformity at 4.6 m swath at different ground speeds as indicated by coefficient of variation (%) for two commercially-available unmanned aerial application systems.

UAS models	Ground Speed (m/s)	CV (%)
MG-1	1	11.0a
	3	10.3a
	5	13.3a
	7	12.7a
F=0.27; df=3,8		*P* > 0.85
V6A	1	19.7a
	3	18.0a
	5	16.0a
	7	14.7a
F=0.26; df=3,8		*P* > 0.85

Means followed by the same lower case letters are not significantly different at *P* = 5% (DMRT).

The effect of application height on effective swath for both application systems is presented in Table 6. For this analysis, the largest effective swath was chosen for each height which resulted in a CV of less than 25%. For the MG-1, the best effective swath (7.3 m) was achieved at the 2 m application height. Since spray drift increases with application height, being able to have the best effective swath at the lowest application height is an advantage. For the V6A, the 2 m application height also provided the largest effective swath (5.6 m). The effect of ground speed on effective swath was also determined (Table 7). This effective swath also was chosen where the CV remained below 25%. For the MG-1, the best effective swath (6.8 m) was at a groundspeed of 3 m/s, while for the V6A, the highest groundspeed of 7 m/s resulted in the largest effective swath (5.8 m).

Table 6. Effect of application height on effective swath for two commercially-available unmanned aerial application systems. Coefficient of variation was less than 25% for each effective swath.

UAS models	Application Height (m)	Effective Swath (m)
MG-1	2	7.3a
	3	6.6a
	4	5.5b
F=9.34; df=2,9		*P* > 0.0064
V6A	2	5.6a
	3	5.3a
	4	5.0a
F=2.3; df=2,9		*P* > 0.70

Means followed by the same lower case letters are not significantly different at *P* = 5% (DMRT).

Table 7. Effect of ground speed on effective swath for two commercially-available unmanned aerial application systems. Coefficient of variation was less than 25% for each effective swath.

UAS models	Ground Speed (m/s)	Effective Swath (m)
MG-1	1	6.6a
	3	6.8a
	5	6.0a
	7	6.4a
F=0.32; df=3,8		*P* > 0.81
V6A	1	5.2a
	3	5.2a
	5	5.2a
	7	5.8a
F=0.25; df=3,8		*P* > 0.86

Each of the strings for each of the treatments were analyzed with the USDA String Analysis software. Many factors play into the quality of the spray pattern such as height, droplet spectra, wind speed and direction. Figure 1 shows an example of a pattern from the V6A at 3 m height and a groundspeed of 7 m/s where all the conditions were near optimal, resulting in a "good" pattern. Here, the effective swath for this particular combination of application height and groundspeed would be 17' as the CV still remains below 25%. A 19' swath would exceed this CV limit.

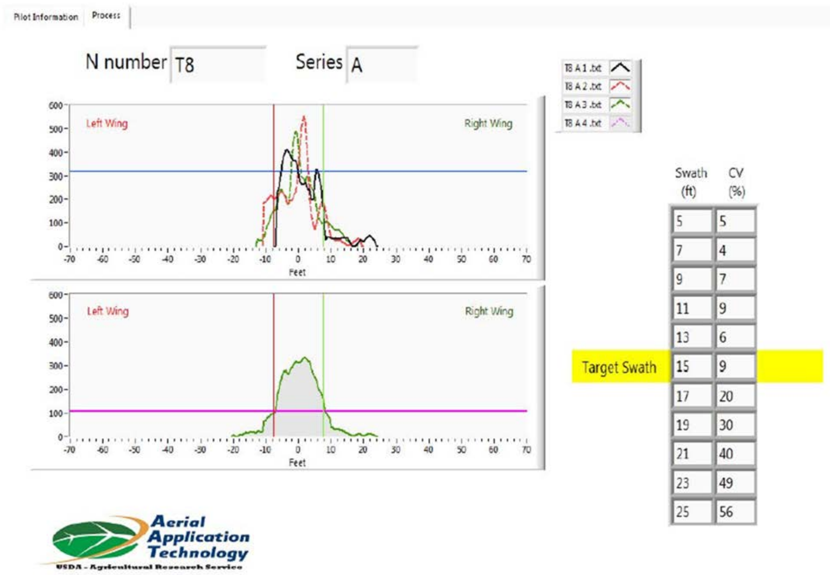

Figure 1. Sample average good pattern from the V6A at 3 m application height and a groundspeed of 7 m/s. The pattern is nice and symmetrical, but has fairly sharp edges around 18'. A good swath for this setup would be around 17'.

Figure 2 is from the same aircraft but at 4 m application height and a groundspeed of 1 m/s. The main issue with this setup is that there was a crosswind from both the left and the right on different passes. Since the aircraft was flying relatively high and has a smaller droplet spectrum, many of the spray droplets were not able to land on the 11 m string target. In one case, we see only the left side of the pattern. In another, the right side of the pattern. These environmental conditions contributed greatly to a "bad" pattern where the CV at 15' was 58%.

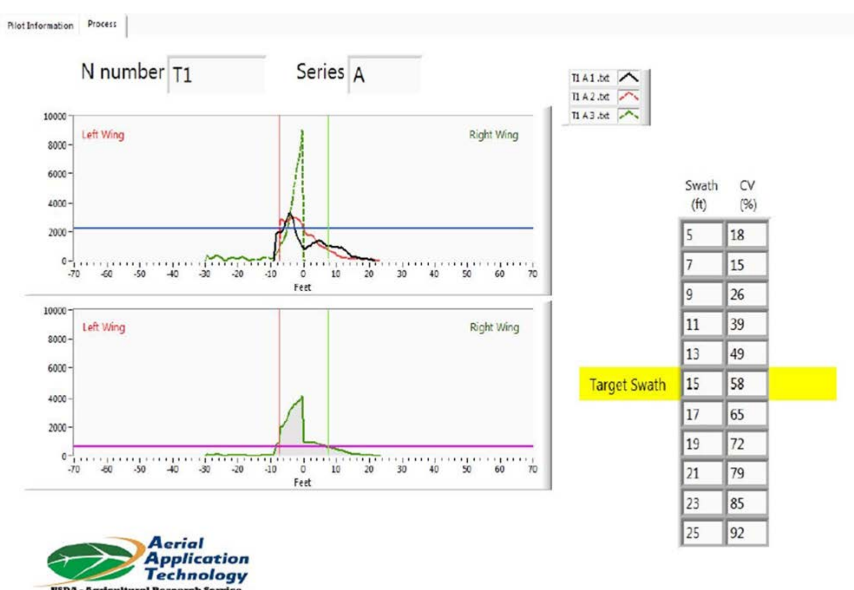

Figure 2. Sample average "bad" pattern from the V6A at 4 m height and 1 m/s. Due to the height, a smaller droplet spectra and crosswind from the left, many of the droplets were not able to land on the target string and thus, resulted in a "poor" pattern and large CV.

A nice sample pattern from the MG-1 at 2 m application height and a groundspeed of 7 m/s is shown in Figure 3. This pattern is broad and symetrical, resulting in a very "good" pattern with an effective swath of 25' at a 20% CV. The application height was low and the winds were light and in line with the sampling string, resulting in good deposition on the string target.

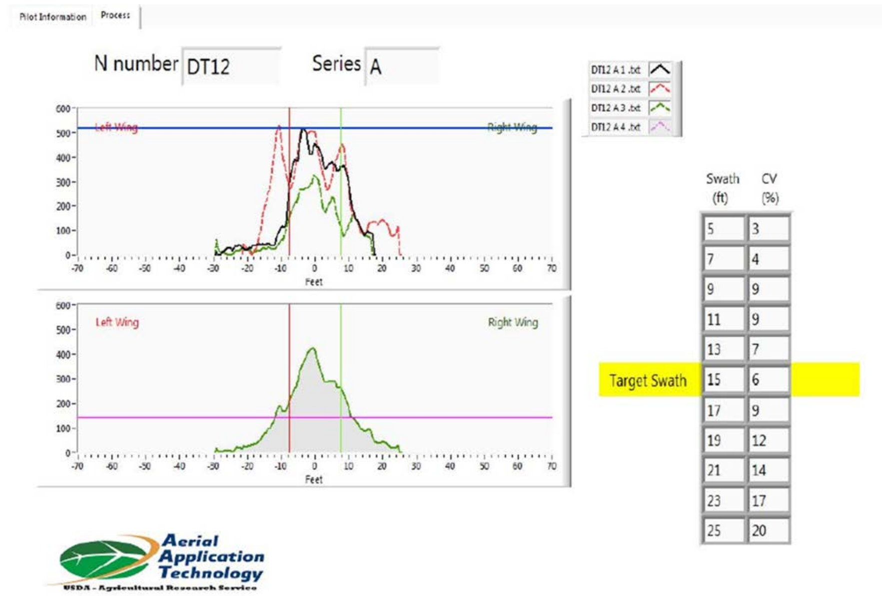

Figure 3. Sample average good pattern from the MG-1 at 2 m application height and a groundspeed of 7 m/s. The pattern is broad and symmetrical. A good pattern (20% CV) could be obtained even at a swath of 25'.

Figure 4 shows the results of the same aircraft flying at 4 m application height and 3 m/s groundspeed. Even with a larger droplet spectrum than the V6A, crosswinds from the left and the right caused portions of the spray to miss the string target, resulting in a "bad" spray pattern with a CV of 28% at 17'.

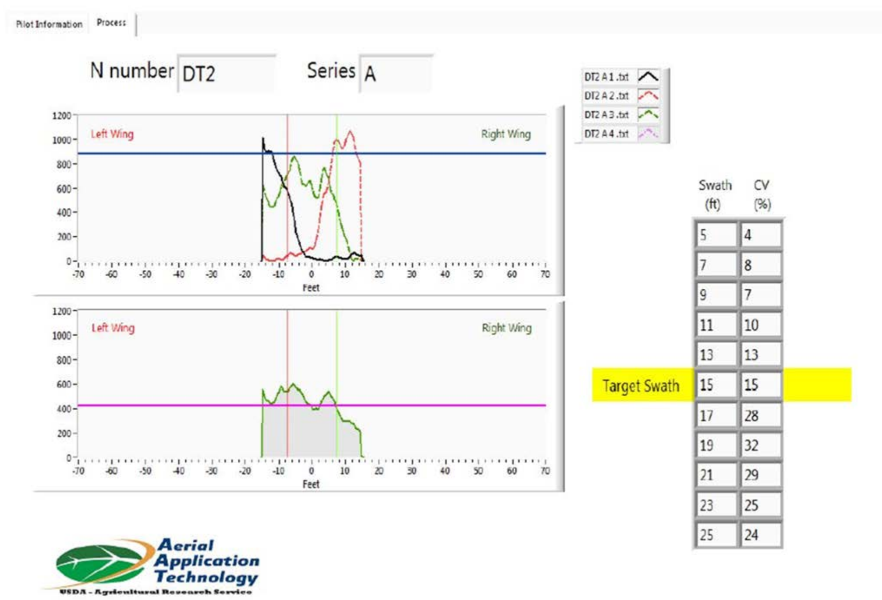

Figure 4. Sample average "bad" pattern from the MG-1 at 4 m height and 3 m/s. Due to the height and crosswind from both the left and the right, many of the droplets were not able to land on the target string and thus, resulted in a "poor" pattern and large CV.

Spray Nozzle Test in Wind Tunnel

Results from the spray nozzle test in the wind tunnel tend to indicate that both nozzles are quite different, with the CR80005 producing smaller droplets, and both nozzles producing very small droplets, when compared to traditional aerial application nozzles (Table 8). The relative span (RS) for both nozzles are fairly comparable. The percentage of droplets less than 100um, and 200um convey the small droplet size from both nozzles, with the CR80005 representing the smaller.

Table 8. Spray nozzle performance in wind tunnel test

Nozzle	Orifice (mm)	Pressure (kPa)	Dv0.1	Dv0.5	Dv0.9	RS	V<100 µm	V<200 µm
XR11001	0.10	226	72.74	161.37	286.86	1.33	20.55	66.91
CR80005	0.05	517	54.14	112.71	190.05	1.20	40.61	92.36

Discussion and Conclusions

Aerial pesticide applications with current commercially available UAASs is definitely possible. Based on the results from this study, most of the application rates required on pesticide labels can be achieved with these platforms, provided they are operated at the correct groundspeed. The effective swath, given the original manufacturers setup, may vary anywhere between 5 and 7 m depending upon platform, application height and groundspeed. Good spray patterns based upon a coefficient of variation less than 25% have been demonstrated. However, the droplet spectra, overall, for both of these platforms is relatively small, which will make the spray more prone to drift. While the driftability of the sprays was not investigated in this study, previous research has shown a direct strong correlation between droplet size and spray drift. Depending on the target pest and the pesticide class (fungicide, insecticide, herbicide, etc.), the user may want to replace the OEM nozzles for other nozzles that may be more appropriate for their particular application. Traditional aerial application testing procedures were modified for this sUAAS spray test research, and as a result it is apparent that there is a need for standardized testing protocols, as interest in deployment of these systems continues to evolve.

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