TEST REPORT

Qualitative Evaluation of Unmanned Aircraft Visibility during Agricultural Flight Operations

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EXECUTIVE SUMMARY

The purpose of this test was to assess Unmanned Aircraft System (UAS) visibility and the ability of manned aircraft operators to visually acquire UAS during combined manned-unmanned aerial application operations. A secondary purpose was to qualitatively demonstrate the effectiveness of various markings for UAS ground crews. The test program was conducted under the Think Before You Launch (TBYL) safety coalition, with Dr. Jeffrey Forrest from Metropolitan State University of Denver acting as research advisor.

Testing took place on 02 October 2015 at five private fields in southern Colorado. The test program included five manned agricultural aircraft, comprising four fixed-wing aircraft and one helicopter, and two multi-rotor agricultural drones (UAS) at the test fields. With no prior knowledge of the test setup at each field, operators of the manned aircraft were instructed to fly an overhead clearing turn at each of the test fields, performing a normal visual inspection for obstacles, people, vehicles, and other hazards, while remaining at a fixed altitude of 250 ft above ground level (AGL).

Unbeknownst to these operators, the first field was empty. The second and third fields contained one UAS each, operating at an altitude below the manned aircraft, resulting in 'look-down' visual acquisition opportunities at both fields. The last two fields contained prototype ground markings, intended to alert observers to the presence of UAS operating in the field.

Of the eight UAS visibility test points involving four fixed-wing manned aircraft, only one test point resulted in a positive sighting, and that was when the sun momentarily glinted off the UAS. The pilot was unable to maintain sight of the unmanned aircraft. The pilot of the helicopter was able to acquire both UAS but had difficulty maintaining visual contact.

All pilots were easily able to see the prototype ground crew markings. However, the markings were similar to tarps used in agricultural applications, and two of the pilots almost disregarded the markings after visually acquiring them because of this similarity.

The test showed UAS were significantly more difficult to see in an agricultural environment than the pilots expected. Searching for UAS as a separate, dedicated task increased cockpit workload and significantly detracted from the pilots' ability to perform other safety-related tasks. The test also confirmed it is much easier for a UAS ground crew to visually acquire a manned aircraft than for an airborne operator to visually acquire a UAS.

While none of the operators were averse to the potential technological benefits that UAS can offer, none felt comfortable sharing the same airspace with them during agricultural operations until technological or procedural solutions can be developed and tested.

Based on the test results and conclusions, recommended near-term mitigations include procedural deconfliction between manned and unmanned operations; development of web-based 'operations centers' to enhance participant situational awareness and assist with deconfliction; continued development and testing of prototype ground crew markings;

renewed emphasis on 'see and avoid' responsibilities of UAS ground crews, including recreational users, through educational campaigns; and the development of a stronger regulatory environment that addresses training certifications of UAS operators and instills a culture of accountability in all user groups.

Recommended long-term mitigations include research, development, and regulation of UAS visibility enhancements, including considerations such as external UAS lighting, faceted mirrors, and bright colors, with further follow-on testing to verify effectiveness. Further testing is also recommended for long-term technological solutions, such as transponders to be installed on all manned and unmanned aircraft, and continued development of sense/detect-and-avoid systems.

1.0 INTRODUCTION

1.1 Background

1.1.1 The rapid advancement of UAS, or 'drones,' has resulted in significant opportunities to exploit their unique capabilities to benefit society. These capabilities include, but are certainly not limited to, high-resolution aerial mapping; aerial photography; crop health analysis; search and rescue; firefighting; power line, pipeline, and railway inspections; and precision aerial application of pesticides, fertilizers, and seed.

1.1.2 The UAS industry projects 80% of commercial UAS flights will support agriculture. UAS agricultural operations are normally flown between 10 ft and 400 ft AGL, depending on factors such as the type of sensor used. This presents a likely scenario in which both manned and unmanned aircraft are operating together in the same airspace, or in close proximity, in the low-altitude environment from 0-400 ft AGL. Deconfliction between aircraft in such scenarios is paramount to ensure the safety of all participants.

1.1.3 The test team is unaware of any previous testing to assess the ability of manned aircraft pilots to visually acquire UAS during combined manned-unmanned operations in the low-altitude regime. New Mexico State University and AeroVironment conducted testing in 2012 to determine the ability of ground-based pilots/observers to visually assess the positions and flight paths of small UAS and manned aircraft to ensure safe separation in the same operating environment (Dolgov et al. 2012).

1.1.4 This test program was conducted under the TBYL safety coalition, with Dr. Jeffrey Forrest from Metropolitan State University of Denver acting as research advisor.

1.2 Purpose

The purpose of this test was to assess UAS visibility and the ability of manned aircraft operators to visually acquire UAS during combined manned-unmanned aerial application operations. A secondary purpose was to qualitatively demonstrate the effectiveness of various prototype markings for UAS ground crews.

1.3 Description of Equipment

1.3.1 Manned aircraft

Five manned aircraft, comprising four fixed-wing and one rotary-wing, participated in the visibility testing. The aircraft were designated as 'Duster 1-5' for communication purposes.

'Duster 1' and 'Duster 5' were Cessna T188C Huskies, a low-wing agricultural aircraft with a horizontally opposed, turbocharged piston engine, 280 gallon capacity, and working speed of approximately 120 mph. See figure 1.

Figure 1. Cessna T188C Husky

'Duster 2' and 'Duster 3' were Air Tractor (AT) 402Bs, a low-wing, turbine-engine agricultural aircraft with a 400-gallon capacity and working speed of 120-140 mph. See figure 2.

Figure 2. AT402B aircraft

'Duster 4' was a Robinson R44, a piston-engine, light utility helicopter with a maximum gross weight of 2,500 lbs and a maximum cruise speed of approximately 130 mph. See figure 3.

Figure 3. R44 helicopter

1.3.2 Manned aircraft modifications

A GoPro® camera was mounted inside the cockpit on the canopy rail of each aircraft for post-flight video and audio analysis. The field of view of the camera was offset approximately 10 degrees to the left of the aircraft flight path to give a better view of the ground in a left-hand turn. For the purpose of this test program, the manned test aircraft were considered production and operationally representative.

1.3.3 UAS

The Agribotix Enduro was a multi-rotor platform with a rotor-to-rotor span of 2.3 ft (28 inches), weight of 6 lbs, and cruise speed of 30 mph. The aircraft was dark in color. The platform was designed for long-endurance, precision agriculture operations, such as infrared imaging. The aircraft could be flown by a laptop or by an operator using a radio-control transmitter. See figure 4.

Figure 4. Agribotix Enduro [image courtesy of Agribotix]

1.3.4 UAS modifications

Unmanned test aircraft were unmodified for this test program and were considered production and operationally representative.

1.4 Test Criteria

Without a standard against which to measure test results, there were no evaluation criteria for this test program.

1.5 Limitations to Test

For safety, manned aircraft were assigned an operating altitude of no lower than 250 ft AGL. This altitude was operationally representative of a standard clearing turn but resulted in a significantly lower pilot workload than is typical during normal aerial application operations at 10-20 ft AGL.

Due to UAS availability constraints, the UAS available for test were limited to Agribotix Enduros, which were small multi-rotors. Because of this, and for safety, test scenarios were limited to look-down scenarios only (i.e., with the test UAS assigned an operating altitude of no greater than 100 ft AGL, to ensure vertical separation from the manned test aircraft).

Due to miscommunication, the UAS at field B flew at 50 ft AGL vice 100 ft AGL for Dusters 2-5. This potentially impacted visibility testing, as the lower altitude could make it more difficult for manned aircraft operators to visually acquire the UAS, and added an undesired variable to test.

No precision instrumentation was available, limiting the ability to accurately measure distance and aspect angle between the manned and unmanned aircraft when the pilot visually acquired the UAS.

2.0 METHODS

2.1 Test and Test Conditions

The test program consisted of five manned aircraft flights out of La Junta Municipal Airport (LHX). The test route took the manned aircraft over five privately owned fields (labelled 'A-E') located between Hawley, CO and Fowler, CO. Testing was conducted on 02 October 2015.

Field A had a safety observer on the ground with a handheld radio. However, Field A did not have a UAS, as the one planned for that field was not available for testing. The field did not have any ground markings.

Fields B and C each had five personnel: a UAS pilot in command, a UAS visual observer a safety observer with a handheld radio, a data collector, and a photographer. Fields B and C also each had a single Agribotix Enduro UAS airborne.

Pilots of the manned test aircraft targeted an altitude of 250 ft AGL for all test points, with a 50-foot tolerance band biased away from the UAS (see Table 1). Meanwhile, the UAS flew pre-programmed, automated patterns at 100 ft AGL, providing a nominal vertical separation of 150 ft between manned and unmanned test aircraft at all times. This 150-ft vertical separation was established as a necessary artifact of test to ensure flight safety. As discussed in section 1.5 above, the UAS at field B flew at 50 ft AGL vice 100 ft AGL for Dusters 2-5 due to miscommunication.

Fields D and E were unmanned with no airborne UAS. Each had prototype ground crew markings, consisting of an orange tarp with 'UAV' printed in large black letters, along with a blue tarp laid flat on the ground to make the work site more visible. See figure 5.

Figure 5. Ground markings

Table 1 summarizes the test conditions at each test site.

A preflight brief was conducted with all participants, including ground crews. The brief covered administration, test procedures, hold/no-go criteria, and safety, including emergency procedures, lost-communication procedures, and UAS lost-link programming.

Table 1. Test Condition Summary

Test Site	Manned Altitude/Tolerance Band	UAS Altitude	UAS Quantity/Type	Notes
Field A*	250 ft AGL (4520 ft MSL)/ +0/-50 ft	N/A	N/A	No UAS or ground markings
Field B	250 ft AGL (4580 ft MSL)/ +50/-0 ft	50-100 ft AGL	One Agribotix Enduro	Multi-rotor, look-down
Field C	250 ft AGL (4630 ft MSL)/ +50/-0 ft	100 ft AGL	One Agribotix Enduro	Multi-rotor, look-down
Field D	250 ft AGL (4520 ft MSL) +50/-0 ft	N/A	None	Ground marking assessment, look-down
Field E	250 ft AGL (4450 ft MSL) +50/-0 ft	N/A	None	Ground marking assessment, look-down
*Field A was originally intended to be a 'look-up' test point with the UAS above the manned aircraft. However, the UAS planned for that field was not available on the day of testing.				

The manned aircraft were launched at 30-minute intervals by the test coordinator for deconfliction, thereby ensuring only one manned aircraft was airborne on the test route at any given time. Pre-flight checks included proper installation and operation of a GoPro® camera, standard radio checks, and altimeter error less than 75 ft.

2.2 Test Methods and Procedures

Pilots of the manned aircraft were instructed to fly a 250' AGL overhead clearing turn at each of the five test fields, performing a visual inspection for obstacles, people, vehicles, and other hazards. This represented their normal clearing pass prior to descending for spray runs, which were not performed during the test events. With no prior knowledge of the test setup at each field, pilots were instructed the UAS could be above or below them.

Pilots flew an operationally representative working speed between 120-140 mph and maintained that speed for all test points. The UAS flew a preplanned, operationally representative, automated pattern centered on the test field waypoint, remaining inside the test field boundaries until the manned aircraft had departed the test field. See figure 6.

An initial point (IP) was established approximately 2.1-2.5 miles prior to Fields A-C for coordination and deconfliction. Pilots were required to be on altitude (250 ft AGL) at the IP and report reaching the IP to the Safety Observer positioned at the field. The pilots were held at the IP until the UAS ground crew was ready for them and cleared to proceed by the field's safety observer.

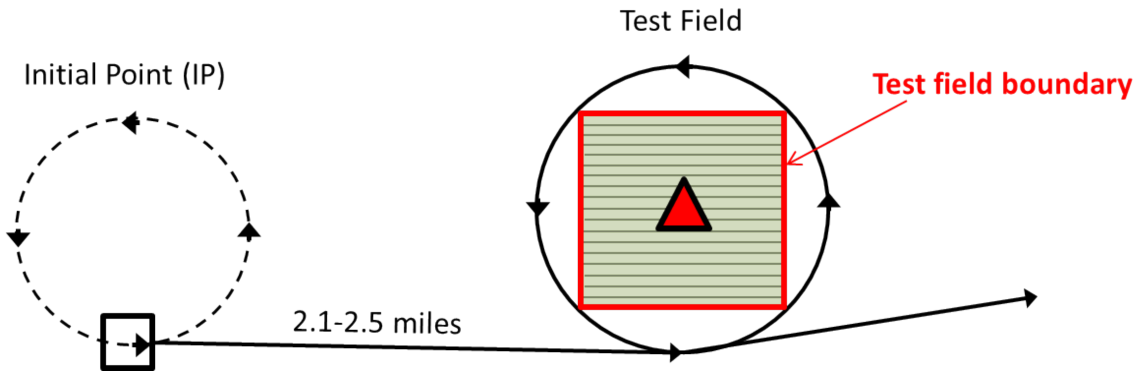

Figure 6. Test Maneuvers (Fields A-C)

The data collector at the field noted the time at which the ground crew acquired the aircraft as it approached the test field. The pilot flew a standard left-hand clearing turn, centered over the test field waypoint, while being required to remain outside the test field boundaries at all times. During the clearing turn, the pilot attempted to visually acquire the UAS, scanning above and below him.

Upon seeing the UAS, the pilot made a radio call, at which time the data collector on the ground marked the time and locations of both the UAS and the manned aircraft. If unable to visually acquire the UAS, the pilot called 'no joy' as he departed the field.

Fields D and E were unmanned and did not have an IP. For the ground marking assessment at those fields, the pilots performed a standard clearing turn around the field at 250 ft AGL and attempted to visually acquire any ground-crew markings, noting the relative difficulty of that task.

3.0 RESULTS

3.1 Visual Acquisition of UAS

The first flight of the day was 'Duster 1' in a Cessna T118C. Duster 1 was unable to visually acquire any UAS.

The second flight was 'Duster 2' in an Air Tractor. Duster 2 was unable to visually acquire any UAS.

The third flight was 'Duster 3' in another Air Tractor. Duster 3 was able to visually acquire the UAS at field B, aided by the sun glare on the UAS and by observing the ground crew looking at it. Lateral separation between Duster 3 and the UAS at the time of visual acquisition was less than 50 ft. As soon as the sun glare dissipated, the pilot lost visual contact with the UAS. Duster 3 was unable to visually acquire the UAS at field C.

The fourth flight was 'Duster 4' in the Robinson R44 helicopter. Duster 4 was able to visually acquire the UAS at field B; lateral separation between Duster 4 and the UAS at the time of initial visual acquisition was approximately 100 ft. Duster 4 was also able to visually acquire the UAS at field C; lateral separation was not measured.

The last flight was 'Duster 5' in another Cessna T118C. Duster 5 was unable to visually acquire any UAS.

GoPro® footage was not used for data reduction but provided video documentation of test methods and served as a backup data source for corroboration of test results.

3.2 Visual Acquisition of Ground Crew Markings

All the pilots were able to visually acquire the UAS ground crew markings. Qualitative observations are given below.

3.3 Visual Acquisition of Manned Aircraft by Ground Crews

Without exception, the ground crews were able to detect and visually acquire the manned aircraft as they approached the test fields.

3.4 Qualitative Data from Post-Flight Questionnaires

During post-flight debriefing, Duster 1 stated he was concerned about manned-unmanned midair collisions and, based on what he observed during testing, was not comfortable sharing the same airspace with unmanned vehicles during agricultural operations. He also stated the greatest challenge for him was trying to spot the UAS while simultaneously looking for other obstacles. Duster 1 stated a strobe light on the UAS would be helpful in making the unmanned aircraft more visible. He believed UAS should be controlled by line-of-sight, so the ground operator can be responsible for collision avoidance ('see and avoid') just as the pilot of a manned aircraft. Duster 1 stated there are a lot of questions and problems that need to be addressed before implementing UAS into his agricultural operations. However, he also wanted to look at all options to make agricultural operations more efficient and therefore more profitable.

In putting his sole focus into finding the unmanned aircraft, Duster 2 stated his 'caution level went up' – in other words, he felt vulnerable to other safety hazards as he fixated on performing a single task, acquiring the UAS. Nevertheless, Duster 2 was optimistic about the technology that UAS can provide and believed unmanned aircraft can benefit agricultural operations. He stated the operator of an unmanned aircraft should go through instrument training, and only manned aircraft should occupy the airspace until a safe solution is demonstrated. He believed unmanned aircraft can be integrated into agricultural operations once the safety issues are resolved, though UAS operators need to have the same qualifications as pilots of manned aircraft.

Duster 3 did not feel comfortable sharing airspace with a UAS while not being aware of its location. He attributed challenges in visually acquiring the unmanned aircraft to their small size, lack of lighting, and background clutter on the ground. He was concerned about his ability to visually scan for a UAS while still performing other safety-related tasking. Duster 3 stated UAS could benefit certain areas of agricultural operations but, at the very least, the UAS operator needs to have a private pilot's license. This testing was useful to him because it gave him an appreciation for the additional stresses that are involved in diverting his attention from flying his aircraft to focus on looking for a UAS. He stated that if the airspace were to accommodate both manned and unmanned aircraft, the UAS would have to give way immediately to the manned aircraft. Some general rules and regulations he would like to see the Federal Aviation Administration (FAA) implement would be flight planning and communication guidelines.

Duster 4 stated initial contact of the UAS was the greatest challenge for him, but he also found it extremely challenging to maintain visual contact. Even though he was able to acquire the UAS, he believed that both types of aircraft should not work in the same field simultaneously, and it will be complicated to integrate UAS into agricultural aviation. Duster 4 also stated the technology still needs to advance so the UAS can be safely integrated into these operations.

Duster 5 did not feel safe at all sharing the same airspace with unmanned aircraft, because none of them were visible to him during the test events. He also believed the operator of a UAS needs to know the airspace system, communication procedures, and the right-of-way rules of aviation. Duster 5 expressed that human life is more valuable than equipment, and UAS need to be kept separated from manned aircraft.

All pilots were easily able to visually acquire the ground crew markings. However, two of the pilots, Dusters 1 and 2, almost disregarded the orange tarp as an irrigation dam for a cement ditch. Duster 1 was able to clearly read the 'UAV' printed on the tarp, but Duster 4 stated he needed to be almost directly overhead to be able to read it.

All five pilots believed the testing was beneficial because it demonstrated to them the unmanned aircraft were more difficult to see than anticipated. While none of the pilots were averse to the potential technological benefits that UAS can offer, none felt comfortable sharing the same airspace with UAS during agricultural operations until technological or procedural solutions can be developed and demonstrated to be safe.

4.0 CONCLUSIONS

In general, the unmanned aircraft were much more difficult to visually acquire than the pilots anticipated. Bright colors, faceted mirrors, and external lighting would ostensibly make them easier to see, but it's uncertain whether those measures would be sufficient to enable visual acquisition by pilots, particularly for small UAS.

Searching for unmanned aircraft as a separate, dedicated task increased cockpit workload and significantly detracted from the pilots' ability to perform other safety related tasks, such as flying the aircraft and avoiding obstacles. This is significant, considering the 250-foot clearing turns performed in this testing had very low pilot workload relative to typical spray runs at 10-20 ft AGL.

It was much easier for the pilots to detect the presence of UAS ground crews than to spot the UAS themselves. Regardless, UAS ground markings should be large, brightly colored, and distinct.

As expected, it was significantly easier and faster for UAS ground crews to acquire the approaching manned aircraft than for the pilots to detect the UAS.

5.0 RECOMMENDATIONS

5.1 Near-Term

This testing demonstrated the difficulty of visually acquiring UAS by manned aircraft operators. Dual use of airspace increases the potential for conflicts during simultaneous manned-unmanned agricultural operations. An obvious near-term mitigation of these airspace conflicts is through procedural deconfliction. For example, simultaneous operations on a single field, or even adjacent ones, must be avoided. This can be facilitated via prior phone or face-to-face coordination, scheduling, and software applications which allow all airspace users to self-report their presence and planned aviation operations in the low-altitude environment. Another idea that deserves further study is the use of real-time, web-based 'operations centers' that could be updated with known locations and times of manned and unmanned agricultural aviation operations.

When manned and unmanned aircraft share the same airspace, the UAS ground crew should have same responsibility to 'see and avoid' as any pilot operating under Visual Flight Rules. Given the higher likelihood that the UAS ground crew will observe a manned aircraft approaching (rather than the manned aircraft operator observing the UAS), UAS operators need to take this responsibility very seriously and be prepared to take immediate evasive action to avoid midair collisions once an airspace conflict is recognized. The same message needs to get out to recreational and hobbyist UAS users through education and awareness campaigns.

Near-term mitigation may also include the continued development of large, brightly colored, distinct UAS ground crew markings. These could be portable ground markings or even mounted on ground crew vehicles.

UAS regulations should continue to address training certifications of all users, from commercial operators to recreational hobbyists, to ensure understanding of the hazards associated with UAS operations in the low-altitude airspace; relevant airspace regulations; and best practices like the 'see-and-avoid' responsibility discussed above. Moreover, the UAS community needs to have the same culture of accountability that manned aviation has. UAS registration regulations have the potential to instill this culture in all UAS user groups.

5.2 Long-Term

If further testing verifies the visibility of UAS can be increased substantially through mandatory colors, external lighting, or similar measures, these enhancements should be required for all UAS that will operate in the low-altitude regime from 0-400 ft AGL.

Long-term technological solutions may also include transponders installed on all aircraft (including unmanned) to enable a Traffic Alert and Collision Avoidance System (TCAS), Automatic Dependent Surveillance-Broadcast (ADS-B), or similar solution. Other technological solutions include sense/detect-and-avoid systems, such as those being developed by the FAA and National Aeronautics and Space Administration.

5.3 Further Testing

Near-term testing should address the stated limitations of this test program and include larger UAS, fixed-wing UAS in 'look-up' and 'look-down' scenarios, and higher-workload environments. For example, the climb-out from an aerial application run may be associated with a high probability of collision with a UAS. This is an area that should be investigated in a future test program.

Based on the difficulty in visually acquiring the unmanned aircraft in this test program, visibility enhancements discussed above, such as bright colors, faceted mirrors, and strobe lights, may or may not be effective. Near- to mid-term testing should investigate whether these mitigations would substantially increase the visibility of unmanned aircraft.

Near-term testing could also evaluation the effectiveness of real-time display of UAS operations on electronic kneeboards, which are commonly used by agricultural pilots.

Finally, long-term testing should investigate the effectiveness of technological solutions such as ADS-B, TCAS, and sense/detect-and-avoid systems.

REFERENCES

1. I. Dolgov *et al.,* “Final Report of the Evaluation of the Safety of Small Unmanned Aircraft System (sUAS) Operations in the National Airspace System (NAS) at Night,” New Mexico State University and AeroVironment, 2012.