Moving towards Unmanned Aircraft Systems Integration into the National Airspace System: Evaluating Visual Observers' Imminent Collision Anticipation during Day, Dusk, and Night sUAS Operations

Igor Dolgov
Department of Psychology, New Mexico State University, USA
id@nmsu.edu

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Abstract
An experiment was conducted in an austere desert location (entirely lacking artificial light pollution) to evaluate visual observers' ability to maintain line of sight with a light-sport manned aircraft and a small unmanned aircraft system (sUAS; Raven RQ-11B or Wasp III) and predict imminent collisions between them. We investigated the impact of night and dusk operational settings on observers' performance as compared to daytime and manipulated the placement of the critical visual observer in relation to the sUAS pilot. Analyses revealed that the light-sport aircraft was identified at significantly farther distances at night and dusk than during the day, and that observers tracked the sUAS better at night and at dusk than during the day. Furthermore, signal detection theory analyses revealed superior collision anticipation rates when the critical visual observer was co-located with the sUAS pilot. Implications for night flight safety and sUAS integration into the National Airspace System are discussed.

Introduction
Recent purchases of unmanned vehicle manufacturers by online giants Amazon, Facebook, and Google speak to the rising role such technologies are set to play in our nation's foreseeable future (Solomon, 2014). Based on the relatively low initial cost of small unmanned aircraft systems (sUAS) and low operating expense, as well as their versatility for aerial photography and other sensing applications, it is expected this industry will experience rapid near-term growth in the civil/commercial sector (North Central Texas Council of Governments, 2011). Another impetus for expansion is the interest of public safety entities (federal and local law enforcement, border patrol, first responders, etc.) to acquire and operate sUAS to establish/augment their aviation capabilities (Congressional Budget Office, 2011; Library of Congress Washington DC Congressional Research Service, 2012; US Air Force, 2009). While unmanned aircraft systems offer great advantages, their integration into the National Airspace System entails a number of technical, safety, security, privacy, legal, and regulatory challenges (Anand, 2007; Carr, 2013; Dalamagkidis, Valavanis, & Piegl, 2008, 2011; DeGarmo and Nelson, 2004; International Civil Aviation Organization, 2011; Ravich, 2009) that were recently reviewed in the Federal Aviation Administration's (FAA, 2013a) *Roadmap for Integration Of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS)*. The urgent need for research, reforms and regulations outlined by the roadmap was brought to the public's eye with news of two near

midair collisions between civilian-operated sUAS and commercial jet liners ("FAA investigates report of drone seen near NYC," 2013; "Near miss over Denver," 2012).
Due to the lack of an onboard pilot, one of the biggest challenges of integrating UAS into the NAS is becoming compliant with U.S. Code of Federal Regulations (CFR) 14, Parts 91.111, 91.113, and 91.115, effectively ensuring midair collision avoidance. Various approaches are being developed to achieve this goal, including numerous sense and avoid techniques (Consiglio, Chamberlain, Muñoz, & Hoffler, 2012; Karhoff, Limb, Oravsky, & Shephard, 2006; Korn & Edinger, 2008; Utt, McCalmont, Deschenes, 2005; Shakernia et al., 2007; Suwal, Chen, Molnar, 2005; Wilson, 2012). While these may potentially offer a higher degree of accuracy and reliability than the naked eye, they are costly and several years away from being implemented on a national level (Lachler et al., 2011).

As stated in the *Unmanned Aircraft Systems (UAS) Operational Approval* policy notice (publication N8900.227, FAA, 2013), visual observers (VOs) are expected to be responsible for 1) helping UAS pilots keep the aircraft with visual line of sight (VLOS), 2) exercising see-and-avoid responsibilities by maintaining compliance with 14 CFR Parts 91.111, 91.113, 91.115, and 3) preventing the unmanned aircraft (UA) from creating a collision hazard. To ensure that these functions can be performed adequately, VOs must be able to scan the airspace effectively and make accurate and reliable estimates of relative aircraft position, assess the need for a potential avoidance maneuver, and communicate that need to the UAS pilot in a timely manner.

These guidelines, along with a number of others were reiterated in the FAA's recent notice of proposed rulemaking (NPRM; 14 CFR Part 107) for civil UAS operations. The proposed language states that flights are limited to small UAS (sUAS; 55 pounds or less) operated within VLOS for the UAS pilot *during daylight hours* in visual meteorological conditions (14 CFR Part 107, as cited in Williams & Gildea, 2014). The restriction on night flights stems from a lack of prior research establishing a safety case for such scenarios, and, likely, a presupposition that detectability of unmanned/manned aircraft by sUAS pilots and VOs is somehow limited at night.

While there are numerous differences between photopic (diurnal) and scotopic (nocturnal) vision (Mather, 2009), no study has empirically evaluated how these visual systems perform in maintaining VLOS. In addition to maintaining VLOS to the UAS, VOs are tasked with detecting other aircraft in the operations airspace and advising the pilot when these aircraft are on potentially dangerous approach vectors. This appears to be the harder task, particularly because visual observers are typically in communication with the UAS pilot and can reestablish visual contact with the unmanned aircraft when provided with telemetry information. Moreover, identification of approaching aircraft needs to be done in a timely manner, allowing the UAS pilot enough time to make evasive maneuvers.

The key objective of the current study was to compare VOs' performance during day, dusk, and night sUAS flights by adapting an extant experimental paradigm, perceptual anticipation, for examining VOs' collision detection ability. In typical perceptual anticipation tasks (also called coincident anticipation), participants are asked to predict when a moving object is going to reach particular point in space after some period of occlusion and respond accordingly, usually with a

button press or some other coordinated physical movement (Gottsdanker, 1952; Harold & Kozar, 2002; Slater-Hammel, 1955). In the context of UAS, providing a response at the time of collision is not a viable strategy due to the inherent danger of actual and near midair collisions. Moreover, VOs need to predict the trajectories of two moving objects, their potential intersection point, and their coincidence at that point, which is a much more demanding task. Therefore, we modified the standard perceptual anticipation procedure for the purposes of the current study, which we will refer to as midair collision anticipation[1].

In a preliminary evaluation of our methods, VOs were instructed to verbally respond if they predicted that two aircraft would collide in midair, ignoring altitude differences (the two aircraft were always separated by approximately 300m vertically for safety) and assuming they continued travelling along observed trajectories. These specific instructions resulted in poor initial collision detection rates among all tested observers. Consequently, in the updated procedure, VOs were instructed to respond if they anticipated the two aircraft coming within 100m of each other in horizontal space, again ignoring altitude differences. Moreover, this pilot experiment illustrated that observers maintained VLOS better at night (with the unmanned aircraft's operational lights turned on) than during the day, which prompted us to pose competing alternative main hypotheses for the current study.

In line with the results of the pilot study, we hypothesized (H1A) that VOs' performance at night and at dusk (sUAS lights on for both) would exceed daytime performance along metrics of visual acquisition distance (VAD), maintaining VLOS, and midair collision anticipation of a manned aircraft and a sUAS. Alternatively, and in line with current regulatory limitations on UAS operations, we hypothesized (H1B) that VOs would perform better during the day than at night/dusk. An additional, secondary, hypothesis (H2) was that the critical VO would perform best when located adjacent to the sUAS pilot, rather than being located remotely and communicating via radio. Two different sUAS platforms were utilized in the study to improve the generalizability of the results.

Methods

The experiment occurred at the Jornada Experimental Range (located in Las Cruces, New Mexico, in White Sands Missile Range airspace), an austere desert setting with no artificial light pollution (Figure 1). To ensure the design achieved a high degree of ecological and face validity, VOs were informed of the location of the operations area in which the sUAS was stationed, via radio calls before each trial. Furthermore, VOs were tasked with anticipating potential midair collisions even if they lost visual contact with the sUAS, as would be the case in the field. This study was approved by the New Mexico State University Institutional Review Board (IRB#10298-A).

[1] While collision anticipation has been studied extensively in the context of motor vehicles, the current paradigm is quite different in that the person anticipating collisions is neither the operator/driver, nor inside a moving vehicle. An entirely different set of perceptual cues is utilized in such tasks.

Figure 1. Photograph of sUAS control station and pilot at Jornada Experimental Range during the daytime data collection session, illustrating the landscape and meteorological conditions. Photo credit: Dolgov, 2014.

Figure 2. Stock images of the Wasp III and Raven RQ-11 unmanned aircraft that were used in the study. Images provided courtesy of AeroVironment, Inc., the manufacturer of these sUAS. Images are not to scale; the Raven RQ-11 has a wingspan that is approximately double that of the Wasp III.

Participants

Three male VOs participated (ages 22-32). All had completed a VO training course within two years prior to the experiment and had class 2 medical certificates. All three participated in the prior pilot study and had real-world experience performing VO duties for several extended UAS operations (small and large UAS platforms flown during daylight) at the Jornada Experimental Range and the New Mexico State University UAS Test Flight Center (Las Cruces, NM). None were certified pilots.

Materials and Personnel

The study involved a *Flight Design CT* light-sport (CTLS; high-wing, tricycle undercarriage, two seat aircraft of 8.5m wingspan, 6.2m length, 2.2m height) manned aircraft with two on-board GPS recorders (for redundancy), a Raven RQ-11B sUAS (hand launched, 1.4m wingspan, 1.9kg weight, standard lighting system) and a Wasp III sUAS (hand launched, 72 cm wingspan, 430 gram weight, standard lighting system; Figure 2). Microphones and digital audio recorders were

used to collect data from VOs. The operations team included a mission commander (who also served as an on-ground safety VO), on-ground flight coordinator, sUAS pilot, manned aircraft pilot, lead experimenter, and an on-board midair safety VO that was not a participant in the study. To assist in the task, participants were outfitted with binoculars during the day and at dusk, and night vision goggles (NVGs) at night. VOs were instructed that the use of assistive technologies was optional, again, similar to real-world practices.

Procedure

The CTLS was flown at an approximate altitude of 400 m above ground level (AGL) and approached the experimental area, which was a circle with an approximately 2km radius, in trajectories that crossed over or were tangent to the unmanned aircraft's area of operations. Only one sUAS was operated at any given time. To ensure the CTLS and unmanned aircraft were de-conflicted in vertical space, the unmanned aircraft was flown at an approximate altitude of 100m AGL. The sUAS (either Wasp or Raven) simulated a reconnaissance mission at one of six potential locations located between 1 and 1.4 km from the center of the experimental area. Daytime data collection occurred in the morning, from approximately 0900 to 1100 hours, dusk data collection began an hour before sunset at approximately 1900 hours and lasted for approximately one hour, and night data collection occurred two hours after sunset from approximately 2200 to 0000 hours. All sessions were held on different days in the following order: day, night, dusk. Counterbalancing was not possible due to the constraints on the logistics; however, based on VOs training and participation in the pilot study, their skills should have remained stable during the course of the current study.

Participants' responses were gathered using headset microphones attached to digital audio recorders placed in their breast-pockets. For each trial, VOs monitored the sky for the sUAS and the intruder aircraft, and reported when they established and lost VLOS. Additionally, in the midair collision anticipation component of the task, VOs identified potentially dangerous approach vectors, defined as those that entailed the two aircraft coming within 100m of each other. VOs were told to ignore the vertical separation between the aircraft. The critical observer, who was the only VO to communicate with the sUAS pilot, was co-located with the sUAS pilot in half of the trials. In the other half of the trials, the critical VO communicated with the sUAS pilot via radio and was remotely located in a dispersed grouping along with the other observers, outside of audible range of each other and the operations team. The sUAS pilot was tasked with executing a safe avoidance maneuver if instructed by the critical observer. Field notes describing the pilot's and VOs' behavior during trials were dictated by the lead experimenter into a digital audio recorder. Informal interviews were also conducted regarding the use of assistive technologies.

Results

Twenty-four trials (two along each planned CTLS trajectory, crossing the operations area) were planned in each of the day, night, and dusk conditions, which were conducted on different days. Data collection was successfully completed during the day session (light levels were between 2,000 and 2,500 lux; the sky was overcast), but weather limited the experiment to only nine trials at dusk (light levels dropped from 150 to 50 lux during the session; the sky was partly cloudy)

and twenty-two at night (light levels were below 1 lux; the sky was cloudy). GPS data for the first trial for the day and dusk sessions were unavailable due to human error. Percentage of time VOs maintained VLOS, VADs and accuracy of collision estimates were calculated offline by synchronizing observers' verbal identifications of the aircraft with GPS position data from the CTLS and sUAS.

Mean VADs and percentage of trial time that the VOs maintained VLOS with the CTLS and sUAS are shown in Tables 1-2; these served as the dependent variables in subsequent analyses of variance (ANOVAs). A one-way repeated-measures ANOVA was conducted on the percentage of time that VOs maintained VLOS to the CTLS; time of day (day/dusk/night) was the sole within-subjects variable. The analysis showed no statistically significant differences in VOs' performance between day (M = 82.0%), dusk (M = 89.8%), and night (M = 87.4%), $F(2, 4) = 1.71$, $p > 0.1$.

Table 1: Averages for percent of each trial that VOs maintained VLOS, for each of the day, dusk, and night data collection sessions, for each aircraft. Average values are *italicized* for readability.

		% of total trial time that VLOS was maintained		
Aircraft	**Observer #**	**Day**	**Dusk**	**Night**
CTLS	1	87.1%	89.0%	97.3%
	2	78.6%	85.6%	82.5%
	3	80.4%	94.6%	82.3%
	Avg.	*82.0%*	*89.8%*	*87.4%*
Raven	1	65.2%	100%	76.6%
	2	17.1%	81.1%	51.3%
	3	25.7%	70.4%	92.8%
	Avg.	*36.1%*	*83.9%*	*73.6%*
Wasp	1	57.7%	78.2%	90.7%
	2	6.6%	14.4%	59.9%
	3	24.0%	62.8%	74.3%
	Avg.	*29.5%*	*52.1%*	*75.0%*

The VLOS values for the Raven and Wasp were used as dependent variables in a multivariable analysis of variance (MANOVA), which also utilized time of day (day/dusk/night) as the only within-subjects factor. The analysis showed a large and statistically significant effect of time of day (Wilks' $\lambda = 0.046$, $F(4, 6) = 5.52$, $p = 0.033$, $\eta_p^2 = 0.69$). Univariate analyses showed that time of day was significant for the Wasp ($F(2, 4) = 12.66$, $p = 0.019$, $\eta_p^2 = 0.86$) and approached statistical significance for the Raven ($F(2, 4) = 6.29$, $p = 0.058$, $\eta_p^2 = 0.76$). In both cases, VOs maintained VLOS better at night and at dusk than during the day (all Sidak-adjusted pairwise comparison ps < 0.10), and their performance at night and at dusk was equivalent.
A one-way repeated measures ANOVA was conducted on the CTLS VADs. Again, time of day (day/dusk/night) was the sole within-subjects variable. The analysis showed that the effect of

time of day approached statistical significance and was, again, large in size, $F(2, 4) = 5.67$, $p = 0.068$, $\eta_p^2 = 0.74$. Pairwise comparisons showed that CTLS VADs were significantly farther at night ($M = 2.09$km, $p < 0.001$) and at dusk ($M = 2.02$km, $p < 0.01$) than during the day ($M = 1.28$km); dusk and night did not differ from each other. VADs for both sUAS were used as dependent variables in a MANOVA that, again, utilized time of day (day/dusk/night) as the only within-subjects factor. The analysis showed a large, statistically significant effect of time of day (Wilks' $\lambda = 0.039$, $F(4, 6) = 6.13$, $p = 0.026$, $\eta_p^2 = 0.80$). Consequent univariate analyses showed that time of day was statistically significant for Raven VADs ($F(2, 4) = 11.93$, $p = 0.021$, $\eta_p^2 = 0.86$), but not for the Wasp ($F(2, 4) = 1.33$, $p > 0.1$). Pairwise comparisons showed that Raven VADs were significantly farther ($p < 0.05$) at dusk ($M = 1$km) than at daytime ($M = 0.72$ km); night VADs ($M = 0.83$ km) did not significantly differ from dusk or day (ps > 0.1).

Table 2: Visual Acquisition Distances for each aircraft used in the study. The observers occasionally failed to identify aircraft, thus the number of trials included in each observer's average VAD is provided in parentheses. The critical observer was #1. Average values are *italicized* for readability.

		Visual Acquisition Distance (km)		
Aircraft	**Observer #**	**Day**	**Dusk**	**Night**
CTLS	1	1.41 (23)	2.09 (8)	2.21 (22)
	2	1.13 (22)	0.86 (6)	1.96 (21)
	3	1.31 (22)	1.79 (8)	2.09 (21)
	Average	*1.28*	*2.02*	*2.09*
Raven	1	0.91 (10)	1.08 (3)	0.90 (12)
	2	0.63 (4)	0.88 (3)	0.75 (10)
	3	0.64 (5)	1.05 (3)	0.86 (11)
	Average	*0.72*	*1.00*	*0.83*
Wasp	1	1.06 (10)	0.70 (4)	0.79 (10)
	2	0.57 (2)	0.23 (1)	0.76 (10)
	3	0.67 (4)	0.74 (4)	0.74 (9)
	Average	*0.76*	*0.56*	*0.76*

A total of 41 potential collision events (day: 15, dusk: 7, night: 19) were identified after examining the GPS data. These were defined as instances when the two aircraft came within 100m of each other (as specified to the participants at each pre-flight briefing). The numbers of hits (correctly identified collision vectors, which allowed enough time for the sUAS pilot to maneuver out of the way), misses (unidentified collision vectors or collision vectors that were detected too late), false alarms (FAs, safe approach vectors incorrectly identified as potential collisions), and correct rejections (CRs, correctly identified safe approach vectors) were tabulated for the critical observer that communicated with the sUAS pilot. Signal detection theory (SDT, Wickens, 2002) formulas were then used to compute the sensitivity (d') and bias (C) for the individual times of day and each critical observer location and are summarized in Table 3. Upon recommendation from the critical VO, the sUAS pilot maneuvered the aircraft away from a potential collision. This recommendation was broadcast over the radio and was

heard by the other (remotely located) participants whose anticipation of an imminent midair collision may have been biased by these announcements. Thus, SDT-based analyses were only conducted for the critical visual observer.

Table 3: Numbers of hits, misses, FAs, and CRs for day, dusk, and night for the critical observer. Hit rate is calculated by dividing the number of hits by the total number of trials. FA rate is calculated by dividing the number of FAs by total number of trials.

Time of Day	# of Hits	# of Misses	# of FAs	# of CRs	Hit Rate	FA Rate	*d'*	*C*
Day	10	5	2	7	0.67	0.22	1.20	0.17
Dusk	5	1	1	1	0.83	0.50	0.97	-0.48
Night	13	6	1	2	0.68	0.33	0.91	-0.02
Critical VO Location	**# of Hits**	**# of Misses**	**# of FAs**	**# of CRs**	**Hit Rate**	**FA Rate**	***d'***	***C***
Co-Located	14	4	2	5	0.77	0.14	1.83	0.15
Remote	15	8	2	4	0.65	0.17	1.36	0.29

An estimate of the amount of time that the sUAS pilot had to execute an avoidance maneuver was obtained by dividing the observers' average VAD by the observed average speed of the CTLS, which was approximately 40 m/second (78 knots/hour). This computation results in values of approximately 32, 51, and 52 seconds of pre-collision time for day, dusk, and night, respectively.

Discussion

H1A was generally supported, whereas H1B was never supported. Accordingly, the results were akin to those observed in the preliminary study and those reported in Dolgov, Hottman, and Elliot (2010), both of which were also conducted at Jornada Experimental Range. The CTLS was acquired nearly a kilometer further away at night than during the day. This finding could potentially be explained by the fact that the sky was overcast during the daytime data collection session, reducing the contrast between the CTLS and the background against which it was being judged. While this difference was not reliably observed for the Raven or the Wasp, those aircraft orbited points approximately 1km away from the base of operations, allowing for less variability in their position.

Analyses of variance also showed that time of day did not significantly impact the extent to which observers were able to visually maintain VLOS to the CTLS, but did significantly impact their performance tracking the Raven and Wasp. Tracking performance was worse during the day for both sUAS, whereas dusk and night were not statistically different from one another. This difference can be explained by the fact that in the dusk and night conditions, VOs had the advantage of using the unmanned aircrafts' lighting systems.

SDT analyses of critical observer performance revealed trivial differences between day, dusk, and night conditions, supporting neither of the main alternative hypotheses. Sensitivity (*d'*)

approached 1 for both dusk and night observations, and somewhat exceeded 1 for day observations. The critical observer was generally unbiased during the day and night sessions, but exhibited a more liberal bias for dusk observations.

The importance of the placement of the critical observer was apparent in the superior sensitivity (*d*') when he was co-located with the sUAS pilot, so hypothesis 2 was supported. Field notes identify the potential origin of this advantage in the observation that when the critical VO and sUAS pilot were co-located, they were was able to engage in interactions that were not broadcast over the radio as well as in non-verbal communication, such as gestures and pointing. This allowed for better operational flow and increased their situational awareness. When standing next to the sUAS pilot, the critical VO had the benefit of position telemetry with minimal communication barriers, i.e., the pilot could point to the unmanned aircraft's general location when the VO inquired. And, conversely, the VO could simply point to the CTLS's position upon initial detection and whenever the pilot desired (or last known position, if the aircraft was no longer being tracked).

The estimations for time available for avoidance maneuvers by sUAS pilots were 32 seconds for day, 51 seconds for dusk, and 52 seconds for night. Examining these values in terms of the Traffic Collision Avoidance System (TCAS)-defined *traffic alert* and *resolution advisory* zones (FAA, 2011), day CTLS detections were made when the CTLS was already within the resolution advisory zone (defined as 35 seconds or less to near midair collision); whereas, dusk/night CTLS identifications were made in the traffic alert zone, with a much greater margin to plan and execute evasive maneuvers.

Field notes and interviews included remarks that the use of visual assistive technologies was not consistent among VOs at night, but was fairly similar during the day. One remotely located observer used NVGs regularly and systematically. The other two VOs took an as-needed approach. Additionally, whereas NVGs were used both for spotting and maintaining visual contact with the aircraft, binoculars were more typically used for resolving the identity of an ambiguous aircraft. The magnification of the binoculars, and limited viewing angle of both binoculars and NVGs, made them impractical for engaging in the midair collision anticipation task and greatly reduced observers' situational awareness. Additionally, VOs stated that instructions to ignore the vertical separation (in place to make the study safe) made the task particularly challenging.

Remarks by the sUAS pilot and the data suggest that VOs are successfully using trajectory estimation strategies (Duke & Rushton, 2012) to effectively accomplish collision anticipation tasks. These strategies are similar to tracking an object on a flat projection plane, rather than in depth, such as maintaining a linear optical trajectory (Shaffer, Marken, Dolgov, & Maynor, 2013). Whenever the two aircraft appear to approach one another, this is evident in the angular relationship between the trajectories in the visual projection plane, and VOs can quickly notify the sUAS pilot of the *relative* approach direction. The pilot can then respond accordingly, again using simple strategies based on visual projection plane geometry, not depth cues, to determine a safe course of action.

Limitations

This study is the first step in a sequence of experiments aimed at establishing a safety case for sUAS operations at night. The small number of participants and austere settings in which the study occurred make it impossible to generalize the findings to all potential sUAS operational scenarios. Moreover, only small UAS were utilized, limiting our conclusions to platforms of similar size. However, more than twenty trials were collected in each of the night and day conditions, assuring an accurate estimate of VOs' performance in the tested scenario. While the initial results are encouraging, to improve the ecological and test validities of future experimental designs, follow-up studies examining the impact of artificial light pollution on visual observers' performance are forthcoming. Additionally, experiments with larger UAS platforms will be conducted to further improve the generalizability of the findings.

General Discussion

With the FAA's goal to achieve complete UAS integration into the national airspace by 2020 and sUAS integration even sooner (FAA, 2013a), the human factors of unmanned operations remains a critical research topic (see Dolgov & Hottman, 2011, for a review). In the current study, analyses of VOs' performance illustrated that sUAS operations in an austere context without light pollution saw no degradation in safety when operating at night/dusk compared to operating during the day. As Table 1 illustrates, the aircraft were always tracked a greater proportion of the time at night and at dusk than during the day. Moreover, whenever statistically significant differences in observers' performance were identified, the results favored night and dusk operations over daytime across the board.

It can also be argued that the risks inherent in flying sUAS at low altitude at night are of a lesser magnitude than for manned aircraft. The major historical reasons that the degree of risk is perceived to be higher for operating manned aircraft at night are 1) the potential for collision with unlit terrain or ground based obstructions, such as power lines, and 2) the greatly decreased situational awareness in the event of a forced landing. In contrast to manned aircraft, the light weight and low speed of the typical sUAS greatly decreases risk to persons and property, and most are designed to land on unimproved ground. Moreover, 14 CFR Part 91.113 makes no distinction between day and night flights, and the only regulatory requirements concerning night flying relate to pilot qualifications under 14 CFR Part 61 and exterior position and anti-collision lights required by 14 CFR Parts 23, 25, 27 and 29.

The data generated by this study strongly suggest that, under near-optimal viewing conditions, it is easier to detect and track manned and unmanned aircraft at night than during the day. This is consistent with the fact that a point light source has much greater contrast against a dark night sky than an aircraft profile during the day, especially when the sky is overcast. These tests also demonstrate that the standard lighting systems on the Raven and Wasp make them visible to ground observers at non-trivial distances. This is an important result considering that these lighting systems were never optimized for visual detection. The only design requirement for the lights was to allow the sUAS pilot to see the aircraft during final approach and landing, and to find it on the ground in the dark. Generally, the distance at which an aircraft can be seen in

daylight depends on its physical size and contrast against the sky and clouds, whereas, the distance at night depends on its lighting system. Additionally, during the course of the study, the safety VO on board the CTLS sighted the Raven three times at night (at distances of 0.6-1.2 km), but never during the day or at dusk. The Wasp was never seen by the midair safety VO due to its small airframe and lighting system. While there is practically no chance that manned aircraft pilots would see an unmanned aircraft flying below them during the day, it is not out of the question at night – especially if lighting systems were designed specifically for this kind of identification.

Another aspect of night operations that may impact overall risk is the observation that there are many fewer manned aircraft flying close to the ground at night (class E/G airspace); these are specifically the circumstances that manned aircraft avoid. Therefore, based on the reduced potential for midair encounters, it is arguably much safer to fly sUAS close to the ground at night than having a manned aircraft perform the equivalent operation. For example, the safety limitations imposed on this experiment limited the manned aircraft to operating no lower than 315m (1,000 feet) AGL at night. This is typical of safety rules applied to manned aircraft operations, and one of the many reasons why there is a desire to use sUAS for night missions at low altitudes by government, private, and public sectors.

Conclusion

The current study adapted the paradigm of perceptual anticipation to measure visual observers' ability to effectively detect incoming aircraft traveling along potential midair collision vectors. Tracking performance and visual acquisition distances generally favored dusk and night operations over daytime (overcast meteorological conditions). However, this difference was not borne out in signal detection analyses, which did reveal the superiority of positioning visual observers next to a sUAS pilot rather than having them communicate via radio.

Many potential users of sUAS, particularly the public safety community, could immediately benefit from an increased ability to fly sUAS at night. This is due to these systems' potential for use in times and locations where manned aircraft may be prohibited from flying, such as in unfavorable meteorological conditions or over a forest fire, as well as their relatively low cost compared to manned aviation assets. Considering the results of the present experiment and the degree to which night air traffic is reduced at low-altitudes, typical sUAS operations in contexts lacking light pollution are likely to be as safe at night as during the day and perhaps even safer.

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Author Note

Correspondence concerning this article should be addressed to: Dr. Igor Dolgov, New Mexico State University, Box 80001 / MSC 3452, Las Cruces, NM 88003. Email: id@nmsu.edu.

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Biography

Dr. Igor Dolgov attained a BSE in Computer Science from Princeton University, with a certificate in Intelligent Systems and Robotics. He continued his education at Arizona State University where he received the University Graduate Scholar Award while earning a Ph.D. in Psychology as part of the Cognition, Action, & Perception Program in the Department of Psychology, and serving as an NSF IGERT fellow with the School of Arts, Media, & Engineering. Dr. Dolgov is currently a tenured associate professor of Engineering Psychology at New Mexico State University, and has established the “pacman” laboratory which investigates Perception, Action, and Cognition in Mediated, Artificial, and Naturalistic Environments (PACMANe). He also collaborates extensively with NMSU’s Physical Sciences Laboratory and their 21st Century Aerospace Program. His interdisciplinary applied research is funded by NASA and the FAA, and is focused on the human factors of unmanned aircraft system (UAS) operators, visual observers, and other crewmembers. Along with Dr. Dolgov’s applied research activities, his theoretical work focuses on the interplay between perception, cognition and action, in mediated and naturalistic environments. He has recently published in the areas of visual search, interaction design, navigation algorithms, affective computing, trust in automated systems, and collaborative gaming.