ENABLING BEYOND LINE OF SIGHT WITH THE FAA PATHFINDER PROGRAM: EXTENDED VISUAL LINE OF SIGHT

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The Pathfinder project is a Federal Aviation Administration (FAA) and industry led initiative to facilitate the early introduction of small Unmanned Aircraft Systems (UAS) low-altitude operations in the National Airspace System (NAS) beyond what is currently outlined in the Small UAS Notice of Proposed Rulemaking (NPRM). The purpose of Pathfinder Focus Area 2, currently being conducted by PrecisionHawk, is to define flight Standard Operating Procedures for localized beyond visual line-of-sight operations, as well as the exploration of traffic management of low-altitude airspace through emerging technologies, ultimately facilitating the routine, commercial use of small UAS. The second phase of Pathfinder Focus Area 2 experiments, conducted in 2016, was aimed at understanding the safe operating parameters for extended visual line-of-sight (EVLOS). EVLOS is defined as a UAS operation whereby the Pilot in Command (PIC) and/or the observer maintains an uninterrupted visual situational awareness of the airspace in which the UAS operation is being conducted for encroaching aircraft. The UAS may be operated out of sight of the PIC and observer (if used), but must be kept in a defined area of operation with control authority being maintained by the PIC at all times. EVLOS is therefore a subset of BVLOS operations, and an initial step towards more broad-based BVLOS flights. The present work discusses the research outcomes from the PrecisionHawk Pathfinder experiments and provides a set of recommendations based on those outcomes usable by sUAS operators considering EVLOS operations. Further work is also recommended, focusing on the introduction of assistive technologies.

INTRODUCTION

PrecisionHawk is an unmanned aerial systems (UAS) and remote sensing company founded in 2010. The company provides an end-to-end solution for aerial data gathering, processing and analysis to provide actionable information to clients across a wide range of civilian industries. The team is comprised of professionals with backgrounds in remote sensing, unmanned aircraft operations, software development, data processing and GIS systems development.

In 2015, PrecisionHawk signed a Collaborative Research and Development Agreement (CRDA) with the FAA to participate in the Pathfinder Initiative as the designated industry partner for Focus Area 2, with the initial goal of studying extended visual line of sight (EVLOS) operations. EVLOS is defined as a UAS operation whereby the Pilot in Command (PIC) and/or the observer maintains an uninterrupted visual situational awareness of the airspace in which the UAS operation is being conducted for encroaching aircraft. The UAS may be operated out of sight of the PIC and observer (if used), but must be kept in a defined area of operation with control authority being maintained.

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The primary goal of the Pathfinder Focus Area 2 program is to define flight Standard Operating Procedures as well as the exploration of traffic management of low-altitude airspace through emerging technologies, ultimately facilitating the routine, commercial use of small UAS in localized beyond visual line of sight (BVLOS) operations. In order to accomplish this goal, sufficient research data on these operations must be gathered so safety risks can be quantified. A phased approach to the research was adopted to ensure requirements and safe operation could be maintained in all scenarios.

In Phase I, conducted November/December 2015 with PrecisionHawk pilots in North Carolina, the primary purpose was to obtain preliminary estimates of the boundaries and conditions of EVLOS operations (i.e., size of airspace volume in which such operations can safely take place) for a solo PIC. To define these operational limits, we made the following assumption: the total volume of airspace in which the PIC can maintain sufficient situational awareness to ensure an acceptable level of safety can be parametrized by $D_{EVLOS}$, the maximum distance at which the PIC can detect an intruder aircraft. In Phase II, the field experiments were expanded to both pilot and non-pilot populations, and the participants were asked to both detect an incoming manned aircraft and decide to act (or not) to avoid potential collision.

In August 2016, research outcomes from the Pathfinder Focus Area 2 effort were used to develop an EVLOS Concept of Operations (CONOPS) and operational risk assessment (ORA) resulting in PrecisionHawk being the first commercial UAS operation to receive a waiver to the visual line of sight requirement of Part 107.

These experiments and the resulting insight into safe EVLOS operations are discussed below in the main section of the paper, along with the set of recommendations generated by the operational risk assessment procedure. An overview of the planned Phase III activities in 2017 will also be provided.

**PHASE II: DETECT AND DECIDE**

As described in the introduction, EVLOS operation require the PIC and, if used, a Remote Visual Observer (RVO) to maintain continued diligence in visually observing the operational airspace for other air traffic or hazards. Because the UA may be operated beyond the visual range of the PIC and RVO, it must be contained in a defined area of operation within an accepted EVLOS distance, and control authority maintained by the PIC at all times. This operational area is shown in Figure 1 for both operations with solo PIC (left diagram) and with a single RVO (right diagram):

![Figure 1: $D_{EVLOS}$ Is The Maximum Distance At Which The PIC Can Detect A Manned Intruder.](image-url)
Risk Assessment Framework

With the Phase I results supporting an appropriate flight plan design for experimental EVLOS operations, the Phase II research effort was designed to address the following: What operational requirements must exist to ensure an equivalent level of safety (ELOS) to manned aircraft operation for a solo PIC operating in EVLOS?

The leading concerns to public safety from UAV operation are anticipated to be ground impact accidents and midair collision with manned aircraft, and therefore ELOS can be expressed as:

\[ ELOS = f_{GI} + f_{MAC} \]  

(1)

Where \( f_{GI} \) = frequency of fatality due to ground impact and \( f_{MAC} \) = frequency of fatality due to mid-air collision. The intention behind the experimental design is to ultimately use the same method proposed by Weibel and Hansman\(^1\) to develop a quantitative conditional probability model of the expected magnitude of each risk and the implications for both design/operational requirements on the UAS and training/skill set of the PIC. The methodology used in the reference is in accordance with Federal Aviation Administration (FAA) system safety analysis guidelines.\(^2\)

To quantify an achievable level of safety we need a direct metric related to the PIC’s situational awareness that we can relate back to the calculation of the terms in the conditional probability model. The proposed metric is PIC response time to a perceived threat, in this case a manned intruder aircraft (hereafter referred to as the Intruder). This response time, or the time from detection of a perceived threat to action, encompasses a series of activities often described in manned aviation literature as the OODA loop: Observe, Orient, Detect and Act. There are numerous different factors that can affect the various steps in this loop, and therefore the response time, many of which are related to characteristics (physiological, cognitive and experience-based) of the PIC.

Experimental Locations

Field testing was undertaken over several weeks from July to September 2016 at two locations: Gypsum, KS and Sanford, NC (Figure 2). Experiments at the former were conducted in collaboration with the researchers and staff from the Applied Aviation Research Center at Kansas State Polytechnic.

![Figure 2: Experimental site near Gypsum, KS (left panel) and Sanford, NC (right panel). Place-marks show on-field locations of experimental participants.](image-url)
To permit the EVLOS operation for research purposes, experimental certificates valid at both designated experiment sites were obtained for six PrecisionHawk HawkEye Mark III Lancaster Rev. 4 sUAS in July 2016. Prior to receipt of the experimental certificate, experiments were conducted using a hardware-in-the-loop simulation of the sUAS (experiment dates July 20 and July 21, 2016). Participants were aware that the sUAS was simulated during this time, and they received some instruction regarding how to “act as if” the sUAS was actually in flight, including reminders to periodically check on the sUAS via the ground control station during the operation.

Field Test Design

The field test is structured such that the sUAS is flying at a pre-determined location beyond the experimental subject’s line of sight, but within DEVLOS. A manned "intruder" aircraft (hereafter referred to as the Intruder) was introduced from a direction unknown to the participant, representing actual conditions that may be experienced during operation.

Variables to be measured for future inclusion in the conditional probability model are:

- Non-Detection Events ($NDE$, $TVE$): Count and other properties of intruder incursions which were not detected by the participant, or represent a threshold violation.
- $D_{EVLOS}$: The distance at which the intruder is detected by the participant
- $t_R$: The response time as described above, defined as the time between detection of the intruder and participant decision to enact collision avoidance action, if necessary.
- $CAA$: Collision avoidance action chosen by participant (includes “Do Nothing” option).

Factors to be recorded as they may influence the proposed variables are:

- Environmental: View angle, sun angle, ambient light, ambient noise, ceiling and visibility
- Aircraft: Intruder altitude and bearing relative to experimental participant
- Human - Physiological: Visual acuity, contrast sensitivity, hearing
- Human - Cognitive/Experience: pilot experience, UAV flight experience

Trajectories for the sUAS were extracted from the telemetry logs of the sUAS post-flight. The Intruder was equipped with an aviation-rated Garmin GLO GPS unit from which the trajectory files were extracted after the sortie. A representative set of trajectories collected at the Sanford, NC experimental site for both sUAS and Intruder are depicted in Figure 3.

For each approach, a given participant was required to perform the following sequence of tasks for each planned approach of an intruder aircraft within $D_{EVLOS}$ of the participant:

1. Identify the intruder aircraft (record time of detection)
2. Choose one of the following courses of action for the UAV (record decision and time of action) to resolve any apparent collision:
   a. Ground aircraft
   b. Return home and land
   c. Loiter at current altitude
   d. Return home and loiter at current altitude
   e. Descend and loiter
   f. Climb and loiter
   g. Do nothing.

*While this is not detailed explicitly in the Results section below, results from both simulated and non-simulated flight were compared and examined for any bias in the measurements. None was detected.*
These tasks were performed using an application called ClockPuncher (available through the ground control station) and did not result in any change in the flight of the UAV. The application would simply record the time at which the appropriate buttons for both detection and decision-making were clicked by the participant (as well as which action was picked). Combining the Intruder and sUAS trajectories with the Clock Puncher output yields the required metrics of $D_{EVLOS}$, $t_R$ and CAA, as well as other trajectory related measurements from the above list of factors such as Intruder altitude and Intruder to Participant bearing.

![Figure 3: Sample trajectories for Intruder (dark blue) and sUAS (light blue) VLOS and EVLOS limits are shown as green and yellow circles around the pilot-in-command (PIC) location.](image)

Each participant was given their own “ground control station” (laptop) which allowed access to both the ClockPuncher app and the MissionPlanner screen displaying the sUAS trajectory. The “real” GCS was of course in the possession of the pilot-in-command (PIC) operating the sUAS, any remaining participants were simply receiving the same telemetry on their respective mock-GCS and could not effect any change in the sUAS.

Over the course of a given trial, the task required remained the same, with sampling over the relevant factors achieved through experiment design over controllable factor levels and sufficient numbers of participants. A given participant experienced 8-9 approaches of the manned aircraft during the experiment, which would last about 2.5-3 hours.

**Participant questionnaires.** Aside from the field test itself, participants had a pre-evaluation session consisting of a series of survey questions about factors that may affect their detection and decision-making process (i.e. fatigue), as well as visual acuity and hearing tests. A brief training session to familiarize them with the test software (MissionPlanner display and ClockPuncher app) and field environment also occurred at this time. During the training session, the different collision avoidance choices were described, along with short example scenarios in which each might be
applicable. Participants were instructed on the concept of near mid-air collision (NMAC) as the collisional “event” they were aiming to prevent.

The training session was kept short on purpose as the experiment was designed to assess both experts and non-experts at their current level of skill, so an effort was made not to introduce “new” strategies to participants with limited field experience. At the completion of each approach, participants were asked to fill out a short mid-test questionnaire to capture qualitative information associated with that specific approach. Specifically, participants were asked to rank the effect of the following potential factors on the Intruder detection process on a scale of 1 (not important) to 5 (very important):

1. View angle/obstacles
2. Ambient light
3. Direct light (i.e. sun in eyes)
4. Ambient sound
5. Weather Conditions
6. UAV Monitoring

Participants were also asked to expand on the process of detection and decision-making for that approach, and identify any distractions.

At the completion of the field test, a longer post-test questionnaire was administered after the flight tests were complete. Questions on this test aimed to capture effects that might be active and/or changing in time over the course of the 2-3 hours for a given participant, including such difficult-to-quantify effects like boredom, frustration or anxiety.

RESULTS AND ANALYSIS

A synopsis of the Phase II experimental results are presented below. The full set of results and extended analysis is available in the final Phase II report, available on the PrecisionHawk website.

**Non-Detection and Threshold Violation Events**

“Non-detection” of a manned Intruder entering the operating area of the sUAS can be defined in two ways:

1. The participant never sees the incoming Intruder during the surveillance window.
2. The participant sees the Intruder within the surveillance window, but not before the proximity of the Intruder to the sUAS violates some threshold, either:
   a. NMAC: sUAS to Intruder distance < 500 ft horizontally, 100 ft vertically
   b. Well-Clear: sUAS to Intruder distance < 2000 ft horizontally, 200 ft vertically

While participants were instructed that the aim of the detect-and-avoid process was to prevent the sUAS from entering the NMAC range of the Intruder, they were not expected to evaluate if that had occurred during the experiment. Additionally, participants were not introduced to the concept of well-clear for sUAS at any time as the definition in use was published after the completion of the field trials, but in time for use in the analysis of the experimental data.

Participant-identified non-detection events (Category 1, above) were primarily related (per the questionnaires filled out by the participants) to environmental factors that exceeded some threshold,

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* Forthcoming
† Andrew Weinert, Scot Campbell and Rodney Cole, “Small UAS Well Clear Study”, presented at UTM Conference, Syracuse NY, November 9, 2016 © 2016 Massachusetts Institute of Technology
such as a tall obstacle/building or excessive level of ambient sound. In the case of the second category, the trajectory information of the sUAS and Intruder can be used to calculate the distance between the two vehicles at the point of detection. Removing the reported non-detect events, the distribution of these distances is shown in Figure 4.

Figure 4: Histograms of horizontal Intruder aircraft distance to sUAS at the time of Intruder detection by the participant. (Left) All observations where detection within the surveillance window occurred. (Right) All observations where the Intruder to sUAS distance was less than 1 km.

Note that the distances above are the horizontal distance between the two vehicles only: as described in the methodology the Intruder pilot was aware of the survey area and altitude of the sUAS and a vertical separation of at least 200 ft was maintained. Additionally, the trajectory of the Intruder was designed to violate horizontal separation more frequently than would be expected for air traffic in normal operations. With those caveats, threshold-violation events (TVEs) occur within the distribution of observations at a rate of 0.7% for NMAC TVEs (3 out of 406 observations) and 8.9% for well-clear TVEs (36 out of 406 observations).

Figure 5: Scatter plot comparing the distance of the intruder Aircraft to both the sUAS and the participant for threshold-violation non-detection events. Green circles indicate the intruder Aircraft was closer to the participant than the sUAS at the time of detection, red circles indicate the converse. The solid blue line is the mean distance of the sUAS from the participant and is provided as a check. The dashed line is the mean result for $D_{EVLOS}$ obtained in Phase 1 (2.54 nm = 4.63 km).
Figure 5 shows the TVEs in more detail. Specifically, as the sUAS is located approximately 2.5-3 km away from the participant, are threshold-violation non-detections occurring due to the Intruder approaching the sUAS from the side opposite the participant? Figure 5 indicates that this is not the case; TVEs occur at participant to Intruder distances that are evenly distributed about the mean position of the sUAS (indicated by the solid blue line). Moreover, all TVEs occur at participant to aircraft distances that are well below the $D_{EVLOS}$ value measured in Phase I (dashed blue line).

Evaluations of the TVE population did not reveal any statistically significant differences between measurements of ambient light/sound for the distribution of TVEs vs. the rest of the collected observations. Examination of this same TVE population did reveal a potential correlation between sun position and number of TVEs observed. This effect is observable as a “clustering” of TVE events around the 30° mark in the distribution of TVE vs. remaining observations by sun altitude angle in Figure 6.

![Figure 6: Comparison of TVE (left-hand charts) and remaining observations (right-hand charts) for sun angle (altitude) above horizon at the time of Intruder detection.](image)

The practical result of this observation is that if the sun is too close to the horizon (< 45° altitude angle), TVE frequency increases. Additionally, the rate of observed TVE increases further if the participant is attempting to detect the Intruder in a section of the sky which contains the sun ((< 45° altitude angle, bearing from participant to Intruder is within 30° of the azimuthal sun angle).

**$D_{EVLOS}$**

Results for $D_{EVLOS}$ values are consistent with those observed in Phase I: 4.39 ± 3.0 km (2.37 ± 1.6 nautical miles). As in the Phase I study\(^1\), environmental factors such as obstacles and sun position create thresholds beyond which the detection distance can be significantly reduced; the reported result is calculated for operations occurring on the correct side of these thresholds (obstacles < 5°, sun angle altitude > 45°).

No differences of statistical significance were detected between pilots and non-pilots, although the distribution means showed the expected dependence. The $D_{EVLOS}$ distributions in both cases exhibit a greater proportion of high $D_{EVLOS}$ than would be predicted by a normal distribution, the lack of any observable statistical significant differences appears to be related to this phenomenon.

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Additionally, by looking at the distribution of mean $D_{EVLOS}$ by participant (Figure 7) it is possible to identify a subset of the population with a natural “talent” for the detection task; these participants (aka the “hotshots”) could consistently detect the Intruder much farther away than the rest of the participant population, with no apparent correlation between pilot status or physiological factors. The hotshots were removed from the distribution prior to calculating the result for $D_{EVLOS}$ to avoid overestimation.

![Histogram of Mean $D_{EVLOS}$ for All Participants](image)

**Figure 7: Histogram of Mean $D_{EVLOS}$ For All Participants.**

The remaining factors assessed were participant hearing and visual metrics, intruder heading and altitude. None of these variables show any significant correlation with $D_{EVLOS}$ values (although extremely low Intruder altitudes were not introduced and would no doubt have an observable effect).

**Response Time**

The primary variables affecting response time are the pilot status of the participant, and the heading category of the Intruder aircraft. These two are non-trivially related; statistical significance is only observable upon calculation of p-values from 2-way ANOVA. Examination of the interaction reveals that while pilots have shorter response times than non-pilots for all orientations of the Intruder aircraft, the difference between pilots and non-pilots is especially pronounced when the Intruder is approaching at a head-on trajectory to the participant. The mean response times as a function of these two factors are listed below in Table 1.

<table>
<thead>
<tr>
<th>Head-On</th>
<th>Pilot</th>
<th>Non-Pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Head On (i.e. Oblique)</td>
<td>12 s</td>
<td>14 s</td>
</tr>
</tbody>
</table>

It is generally true that assessing the velocity of an object approaching an observer head-on is more difficult to perform than an object moving across the observer’s field of view. As the set of tasks captured by the response time depend on a visual assessment of the Intruder trajectory, it is not unreasonable to postulate that pilots may be able to make an assessment more rapidly than non-pilots especially in the more difficult head-on case.
As for DEVLOS, subsets of the participant population demonstrating consistently lower than average response times, and consistently higher than average mean response times can be identified (“Fast” and “Slow” populations, respectively). Also, as in the hotshot population, Fast and Slow participants showed no apparent correlation between pilot status or physiological factors. While the differences here were not enough to skew the result, and were therefore not removed from the assessment, it is also important to note that it is not clear that one or both populations has a significant advantage over the population of participants with more “typical” response times. Rapid response, for example, is only favorable if the decision reached is the correct one.

Finally, if we examine the response time as a function of the collision avoidance action chosen (Figure 8), the only observable difference is that the decision to ground the UAV has shorter response times compared to the other options. This is consistent with the “emergency” nature of the Ground UAV option.

![Figure 8: Boxplot of response times by collision avoidance action chosen. Cyan boxes are for pilots, blue boxes are for non-pilots.](image)

**Collision Avoidance**

Signal detection theory (SDT) was used to model the collisional trajectory identification part of the collision avoidance decision-making process. Since none of the real trajectories would have resulted in NMAC (by design, to ensure safety during the experiment), “collisional trajectory” was defined as a trajectory violating the horizontal separation threshold for NMAC (500 feet).

SDT has an extensive history of use in psychology and is often used when researchers want to measure the way participants make decisions under conditions of uncertainty, such as the current experiment. SDT assumes that the decision maker is not a passive receiver of information, but an active decision-maker who makes difficult perceptual judgments under conditions of uncertainty. To apply signal detection theory to a data set where a stimulus (in this case, the presence of a
collisional trajectory) was either present or absent, and the observer categorized each trial as having the stimulus present or absent, the trials are sorted into one of four categories as shown in Table 2:

<table>
<thead>
<tr>
<th>Collisional Trajectory</th>
<th>Identify Collisional Trajectory</th>
<th>Do Not Identify Collisional Trajectory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hit</td>
<td>Miss</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-Collisional Trajectory</th>
<th>False Alarm</th>
<th>Correct Rejection</th>
</tr>
</thead>
</table>

Numerical estimates of sensitivity can be obtained by comparing the hit rate (proportion of trials where a hit was recorded) to the false alarm rate (proportion of trials where a false alarm was recorded). The approach used in the present work is that of Dolgov et al\(^3\), where discriminability and bias are quantified via the sensitivity index \(d'\) and response bias \(C\). All results are recorded in Table 3 below.

<table>
<thead>
<tr>
<th></th>
<th>Pilot</th>
<th>Non-Pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hits</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Misses</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>FA</td>
<td>335</td>
<td>339</td>
</tr>
<tr>
<td>CR</td>
<td>111</td>
<td>109</td>
</tr>
<tr>
<td>Hit Rate</td>
<td>0.818</td>
<td>0.555</td>
</tr>
<tr>
<td>FA Rate</td>
<td>0.751</td>
<td>0.757</td>
</tr>
<tr>
<td>Sensitivity Index (d')</td>
<td>0.230</td>
<td>-0.556</td>
</tr>
<tr>
<td>Response Bias (C)</td>
<td>0.793</td>
<td>0.417</td>
</tr>
</tbody>
</table>

**Sensitivity.** The sensitivity index \(d'\) can be estimated by

\[
d' = Z(\text{hit rate}) - Z(\text{false alarm rate})
\]

where \(Z(p), p \in [0,1]\) is the inverse of the cumulative distribution function of the Gaussian distribution as usual. Conceptually, \(d'\) quantifies how hard or easy it is to detect that a target stimulus (collisional trajectory) is present from background events (non-collisional trajectories). The higher the \(d'\), the more effective the population is at correctly identifying stimulus when it is present.

Significant differences in the sensitivity index \(d'\) were seen between the populations of pilots vs. non-pilots \((d' = 0.230 \text{ vs } d' = -0.556\) respectively), indicating an overall better performance by pilots in correctly identifying Intruder trajectories resulting in NMAC.

**Response Bias.** The response bias \(C\) can be similarly estimated using the hit rate and false alarm rate as:

\[
C = - \left( \frac{Z(\text{hit rate}) + Z(\text{false alarm rate})}{2} \right)
\]

For both populations, response bias \(C\) indicates a conservative bias \((C(\text{pilots}) = 0.793, C(\text{non-pilots}) = 0.417)\) because of high false alarm rate in both cases (i.e. participants tended to choose to
change the sUAS trajectory to avoid collision even when the Intruder was not on a collisional trajectory).

In all cases where a collisional trajectory was correctly identified, the collision action chosen successfully prevented the NMAC.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, EVLOS operations, while simple in principle to execute, are subject to a myriad of complex inputs. Some of these inputs can be quantified and evaluated, as demonstrated in the analysis above, while others are more elusive.

Recommended EVLOS Requirements

Despite this complexity, a reasonable safety case can be demonstrated provided the following requirements are met:

Environmental Conditions. The operating environment should meet the stated requirements of Part 107, in addition to the following considerations:

- Sun Position: Altitude of sun > 45° above the horizon
- VFR meteorological conditions
- Visual angle < 5 degrees in quadrant centered on UA location
- PIC location free of significant noise pollution (i.e. generators, farm equipment, trucks)

PIC qualifications. In addition to stated requirements in Part 107, PICs intending to operate in EVLOS should meet the following requirements:

- Sufficient VLOS flight time in desired operating environment on the specific UAS (both aircraft and GCS). This provides the PIC with the ability to selectively “tune out” distractions such as people, equipment or animals. Current estimate based on pilot observation is 15-20 flight hours in VLOS before EVLOS should be attempted.
- In-field flight training in EVLOS operation from an EVLOS-experienced operator. This is especially important to avoid the PIC focusing exclusively on the specific direction taken by the UAV as it flies outside the visual line-of-sight, or on the GCS. Current estimate based on pilot observation is that a single day of training comprising 2 or 3 short sorties and 2 or 3 longer ones is enough to establish the appropriate awareness strategies necessary for EVLOS flight (i.e. segment mapping).

Aircraft requirements. Beyond Part 107 requirements, which are minimal, safe EVLOS operations are not dependent on the aircraft platform but rather the flight control and navigation systems aboard the aircraft. Specifically:

- Flight control system: Control of the aircraft should be principally via preprogrammed flight specified by waypoints and commands from users through the ground control station software. The aircraft should be able to automatically maintain stability through the onboard APM. Once in-flight, typical in-flight operations (i.e. payload control, diagnostics, threshold monitoring) and automatic stability control are automated and should not require significant awareness time from the PIC. Note this is not a requirement for full automation, as the goal is to significantly reduce the amount of time the PIC needs to spend managing the system vs. surveying the airspace.
- C2 Link: A redundant control structure (i.e. primary and backup links) significantly reduces the chance of flyaway. Use of a spectrum analyzer prior to flight to assess any potential interference with the C2 link is strongly recommended.
Future Work

Overall, while some relationships between the metrics measured and the observed variables were evident and provide useful insight, the amount of variation (in DEVLOS and response time in particular) still not accounted for is substantial. This is not uncommon in human factors studies, but there is a practical consequence in this context: while training and operational constraints such as time of day or location restrictions can help to reduce some of the variation (and should be employed), the EVLOS operation is fundamentally highly variable. The variation observed in the distributions shown above is the true variation likely to be experienced in the field, making risk-based predictions on how this operation may look when generally deployed more difficult. Additionally, from a commercial applicability standpoint, EVLOS operations are limited in scope: an increase from ~1 nm to 2-3 nm is an impressively larger amount of area that can be flown from a single location, but not yet sufficiently large to accommodate linear flight applications such as power lines.

Likely the best possibility for reducing the observed variation and increasing the range lies not in further exhaustive exploration of the factors affecting EVLOS related quantities (if that was even possible), but in employing an assistive technology that removes as much of the field-varying human and environmental dependence as possible. These technologies are available in various stages of development, but with the introduction of technology comes the necessity of assessing new risk modes introduced into the system. Provided these technologies or combinations thereof can be demonstrated to have acceptable levels of safety, the EVLOS case studied in the present work still has useful applicability as a potential operational mitigation in the case of assistive technology failure during flight. Despite the observed variation in EVLOS related metrics, participants of all experience levels were generally successful at preventing mid-air collision as defined by NMAC. The impact of the observed variation on the predictive capability of risk models may only be relevant in the case of general deployment in the NAS, when the number of EVLOS operations could considerably increase. Therefore, Phase III of the Pathfinder Focus Area Two research will be focused on creating and verifying an operational risk assessment (ORA) of the technology-assisted, “localized” BVLOS case. Flight heritage data will be gathered to inform the ORA throughout 2017 during multiple sUAS survey operations nationwide.

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