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Atlantic City International Airport, NJ 08405

# Assessments of Flight and Weather Conditions during General Aviation Operations

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Technical Report

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**16. Abstract**

**Objective**: We investigated pilot weather assessments and pilot ability to assess the out-the-window visibility. Specifically, we assessed if sectional map distance training or the use of a slant-range rule of thumb could improve pilot visibility assessments. **Background**: One of the causes behind VFR into IMC flights is GA pilot difficulty in correctly assessing the out-the-window visibility. Simulation studies frequently find that pilots fly into areas with rapidly decreasing visibility or fly into areas of IMC where VFR-only pilots are not permitted to fly. This indicates that pilots have difficulty assessing weather conditions and determining if their flight is compatible with VFR requirements. **Method**: Sixty-six private pilots participated in the study. The pilots were randomly allocated to one of three simulation conditions (Map distance training, Slant-range training, or Control). **Results**: The result showed that the visibility estimate errors for the Slant-range group were on average half the size compared to the visibility estimate errors for the Control and the Map distance training groups. This shows a benefit of using the Slant-range rule of thumb when estimating in-flight visibility. **Conclusion**: Based on the lack of weather training reported in the current pilot sample (9%), we believe there is a need for training in both how to correctly interpret weather conditions and how to translate these interpretations into flight decisions. We believe that with training on the Slant-range rule of thumb, coupled with a set of decision-making rules, pilots would be in a much better position to correctly assess the out-the-window visibility and make more informed flight decisions rather than continue flight into IMC. **Applications**: We recommend that weather interpretation training and Slant-range rule of thumb should be incorporated into basic pilot training.


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# Acknowledgments

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## Research Team

| Name | Role | Responsibility |
|---|---|---|
| Ahlstrom, Ulf | Test Lead | Lead developer of test plan, test conductor, data analysis. |
| Ahlstrom, Ulf | Data Analysis | Analyze data for Quick Look and Final Report. |
| Cecan, Cynthia | Software Engineer | Implements simulator system, routes, weather conditions, and supports cockpit data recordings. |
| Doucett, Scott | Cockpit Simulator Laboratory Manager | Identify and provide resources for study development and data collection. |
| Hallman, Kevin | Human Factors Specialist | Co-developer of test plan, test conductor, data analysis. |
| Johnson, Ian | WTIC Human Factors Lead | Coordinate on test plan and test effort, technical review of test products and deliverables. |
| Kukorlo, Matt | Pilot Subject Matter Expert | Flight Scenario Developer. Simulation SME. |
| Pokodner, Gary | WTIC Program Manager | Track project, conduct interim reviews, final acceptance of Deliverables. |
| Racine, Nicole | Human Factors Specialist | Co-developer of test plan, test conductor, data analysis. |
| Vary, Kimberly | Software Engineer | Implements simulator system, routes, weather conditions, and supports cockpit data recordings. |

# Executive Summary

One of the causes behind Visual Flight Rules (VFR) into Instrument Meteorological Conditions (IMC) flights is General Aviation (GA) pilot difficulty with correctly assessing the out-the-window visibility. In the present study, we investigated pilot weather assessment and accuracy of the out-the-window visibility estimates.

Sixty-six private pilots participated in the study. The pilots were randomly allocated to one of three simulation conditions (Map distance training, Slant-range training, or Control). We provided two pilot groups with specific training (map distance training and Slant-range training) and compared their visibility assessments with a third pilot group that did not receive any training (Control group). In addition to the simulation, pilots participated in a part task study to estimate the accuracy of out-the-window visibility estimates.

The result from the simulation showed that the visibility estimate errors for the Slant-range group were, on average, half the size of the visibility estimate errors for the Control and the Map distance training groups. This shows a clear benefit of using the Slant-range rule of thumb when estimating in-flight visibility. The result also demonstrates the difficulty of using map distances when estimating forward visibility as the visibility estimates for the Map distance training group were not credibly better than the visibility estimates of the Control group.

We also found that pilot visibility assessments are not equally accurate at all visibility levels. At greater visibilities (> 10 miles), pilots, on average, under-estimate the forward visibility. Although this foreshortening reflects a faulty assessment, the operational impact is likely negligible as it makes pilot visibility assessments more conservative. For lesser visibilities (≤ 5 miles), however, it seems like pilots are over-estimating the forward visibility. This is not desirable as it can cause VFR flight into IMC (Wiegmann, Goh, and O'Hare, 2002).

Based on interview data from the present study, it seems that very few GA pilots are aware of the simple Slant-range rule of thumb. When we asked the pilots how they performed their visibility assessments, none of the pilots in the Map distance training group or the Control group described using something similar to a slant-range rule of thumb. While all Map distance training pilots used map and terrain distances to aid their assessments, 33% of the Control group pilots admitted to using techniques that amounted to simply guessing the forward visibility.

While the Slant-range group performance exceeded (i.e., more accurate visibility estimates) that of the Control and Map training groups, pilot performance still needs improvement. During the simulation, 42% of the pilots *who turned around* at the end of the scenario were in violation of the VFR rules due to insufficient forward visibility. Furthermore, based on post-scenario feedback, we suspect that a large portion of the pilots used a 3-mile VFR visibility rule of thumb regardless of the altitude.

Based on the reported lack of weather training in the current pilot sample (9%), we believe there is a need for training in both how to correctly interpret weather conditions and how to translate these interpretations into flight decisions. We believe that with training on the Slant-range rule of thumb, coupled with a set of decision-making rules, pilots would be in a much better position to correctly assess the out-the-window visibility and make more informed flight decisions rather

than continue flight into IMC. We recommend that the simple Slant-range rule of thumb and weather interpretation training should be incorporated into basic pilot training.

## 1. INTRODUCTION

This study was part of a larger project where the goal was to assess the effect of weather information on General Aviation (GA) pilot performance and decision-making. In this study, we specifically addressed the use of pre- and in-flight weather information and pilot weather assessments to reduce Visual Flight Rules (VFR) flights into Instrument Meteorological Conditions (IMC).

### 1.1 Background

During VFR flights (Table 1), GA pilots must navigate and avoid other aircraft by what is called *see and avoid*. This means that pilots must actively avoid collisions with other aircraft and maintain a minimum cloud clearance while maintaining a visual reference with the ground. Despite this *see and avoid* requirement, accident data shows that GA pilots are involved in accidents caused by continued flight operations under VFR toward deteriorating weather, leading to flights into areas of IMC (Ison, 2014).

**Table 1. Flight Categories**

| Category | Ceiling | | Visibility |
|---|---|---|---|
| **Low Instrument Flight Rules**<br>**LIFR** | below 500 feet AGL | And/Or | less than 1 mile |
| **Instrument Flight Rules**<br>**IFR** | 500 to below 1,000 feet AGL | And/Or | 1 mile to less than 3 miles |
| **Marginal Visual Flight Rules**<br>**MVFR** | 1,000 to 3,000 feet AGL | And/Or | 3 to 5 miles |
| **Visual Flight Rules**<br>**VFR** | greater than 3,000 feet AGL | And/Or | greater than 5 miles |

*Note*. Table adapted from FAA & NOAA, 2010.

Among the potential causes behind VFR into IMC flights, simulation studies have found gaps in the GA pilot's ability to correctly assess the out-the-window weather, to accurately determine in-flight visibility, and to maintain recommended aircraft-to-cloud separations. Pilots fly into areas with rapidly decreasing visibility (where pilots should turn around), with many pilots (24%) flying into areas of IMC where VFR-only pilots are not permitted to fly (Ahlstrom, Racine, Caddigan, Schulz, & Hallman, 2019). Furthermore, pilots frequently fly much closer to adverse storms than the recommended safe distance of 20 miles (FAA & NOAA, 2010; FAA, 2017 (section 7-1-28, page 7-1-56); also see Ahlstrom, Caddigan, Schulz, Ohneiser, Bastholm, & Dworsky, 2015a; 2015b, and Ahlstrom, Racine, Caddigan, Schulz, & Hallman, 2019).

Wiegmann, Goh and O'Hare (2002) found that pilots had great difficulty in estimating the out-the-window weather visibility conditions. Using a GA cross-country weather scenario, they found that only *35.3% of the pilots were accurate in their estimates of out-the-window visibility* (26.5% overestimated the visibility, and 38.2% under-estimated the visibility). These results clearly indicate a gap in the ability of pilots to accurately judge the out-the-window visibility conditions and determine if conditions are compatible with VFR requirements. This is problematic as pilots use horizontal visibility and cloud concentration information to assess VFR conditions (Wiggins & O'Hare, 2003). This brings up questions about pilot preparations prior to

VFR flights as well as the use of weather information in-flight (and subsequent decision-making) to maintain visual meteorological conditions (VMC).

During VFR flights, pilots acquire weather information by looking out-the-window and by receiving information from weather-reporting facilities and information from other pilots on the radio frequency. Pilots can also receive weather information and request *flight following* by contacting air traffic control (ATC). Similar to the weather preparation before a flight, pilots can contact FSS to receive a weather-briefing while in flight. In addition, pilots can use cockpit-mounted weather displays (certified installed display systems) or portable weather displays (Ahlstrom, Ohneiser, & Caddigan, 2016). These weather displays allow GA pilots to receive important aircraft, terrain, and weather information while in flight (Zimmerman, 2013).

Despite all of the sources of weather information, VFR flight into IMC, where pilots inadvertently enter clouds or haze and can no longer see the horizon or the terrain, is still a major safety hazard for GA pilots (Goh & Wiegmann, 2001). This dangerous situation can lead to spatial disorientation whereby pilots lose control of the aircraft (Wiggins, Hunter, O'Hare, & Martinussen, 2012; Wilson & Sloan, 2003). Some of the underlying VFR into IMC causes include the ability of pilots to detect, incorporate, and respond to cockpit and out-the-window information, and the ability of pilots to understand the potential effect of forecasted weather conditions (O'Hare & Stenhouse, 2009; Wiegmann, Goh, & O'Hare, 2002; Wiggins, Azar, Hawken, Loveday, & Newman, 2014). Therefore, there is a need to assess gaps in GA pilot ability to assess weather factors/conditions to determine VFR conditions.

### 1.2 Purpose

The overall purpose of this study was to explore ways to reduce inadvertent VFR flights into IMC. In this Weather Technology in the Cockpit (WTIC) effort, we focused on the evaluation of and the use of heuristics like the cockpit cut-off angle and sector map/terrain knowledge to enhance the ability of GA pilots to accurate assess the out-the-window weather conditions and visibility.

## 2. METHOD

In this section, we describe the methods used this study.

### 2.1 Participants

Sixty-six pilots (recruited by EIT, Inc.) were participants in this study. Half of the pilots were VFR-only while the other half had an Instrument Flight Rules (IFR)-rating. For the study, each pilot was randomly assigned to one of three groups (i.e., Control, Slant-range tool, or Map training group). Each pilot participated in one simulation flight, one part-task (i.e., a static visibility evaluation [Boeing 737 simulator] or a Current Icing Product [CIP]/Forecast Icing Product [FIP] symbology evaluation), and completed the pre-/post-test questionnaires.

### 2.2 Informed Consent

Upon arrival at the CSF, participants received an Informed Consent Form briefing. A member of the research team discussed the study and Informed Consent Form with potential participants and ensured they had no questions and were fully aware of what their participation involved, including a reminder that their participation in the study was voluntary and that the participant could withdraw at any time without penalty, prior to having them sign the Informed Consent Form (Appendix A). Participants were given as much time as needed to review and ask the experimenter questions concerning the consent form. After this process, participants who chose to participate in the study signed the informed consent form. We protected all participant-provided information from release, including Personally Identifiable Information (PII), except as may be required by statute. Signing the form indicated that the participant understood his or her rights as a participant in the study and their consent to participate. Each participant read and signed an informed consent statement before beginning the study.

### 2.3 Research Personnel

The research team prepared briefings, performed initial testing of experimental systems, data collection, and analysis of the data.

### 2.4 Facilities

The research team conducted the study at the William J. Hughes Technical Center Cockpit Simulation Facility (CSF).

### 2.5 Aircraft Simulator

We used a single-engine GA MicroJet (fixed base) simulator (Figure 1). The simulator was equipped with 180° out-the-window view, electronic flight displays, a stand-alone portable weather display running on a Windows Surface Pro 3, and a voice communication system that provided a link between the pilots and the air traffic controller through a Push-To-Talk (PTT) capability. In addition, the cockpit was equipped with three cameras (front view, top view, and side view) for video recordings and specialized hardware for capturing the flight display outputs.

*Figure 1*. Left: an exterior view of the MicroJet fuselage. Right: the cockpit out-window view, the G1000 type GA glass cockpit control display, the instrument (radio) stack, and the stand-alone weather display running on a Windows Surface Pro 3.

During the study, the cockpit simulator was equipped for video recording (H.264 format) and sound recording with playback capability. To capture pilot behavior, three cockpit-mounted cameras were used to provide a top view (dome camera, 360°), a front view (bullet camera), and a side view (fisheye camera). These three camera views captured the entire cockpit environment. The videos, therefore, were suitable for behavioral analysis of pilot actions during flight. During the video recordings, the front view camera recorded the torso and face of participants. The camera recordings were tagged with the coded identifier, not the name or any other personal identifying information of the participants. The camera files were securely stored on an external hard drive and locked up in a cabinet. In addition to the camera views, the display of the G1000 type GA glass cockpit control display and the auxiliary weather display (Microsoft Surface Pro 3) was also captured and recorded.

The cockpit simulator was on a separate Local Area Network and used Real Time Streaming Protocol to capture live Internet Protocol camera streams of weather data. We used the iSpy surveillance software for recording as well as for video playback at the researcher control station (Figure 2). The iSpy software synchronized the recordings of video and sound, and displayed the five individual video streams from the cockpit simulator. The cockpit sound system captured voice recordings from pilots and air traffic control (ATC), and allowed playback of pre-recorded Automated Weather Observing System (AWOS) weather messages.

*Figure 2.* The researcher control stations.

### 2.6 Radio Simulator Software

For the study, we used the PLEXYS software to simulate the radio PTT communication between the pilot and ATC. PLEXYS also managed the playback of pre-recorded live ATC/pilot sector communication and managed the synchronization and playback of AWOS messages during the simulation flights.

## 2.7 Questionnaires

Participants completed a brief biographical questionnaire (Appendix B). This consisted primarily of questions related to pilots' flight experience, but also used to collect information about previous experience with weather displays. Participants then completed a Weather Knowledge Questionnaire (WKQ) (Appendix C).

After flying each data collection scenario, participants completed the Post-Simulation Questionnaire (Appendix D). Each biographical information form and WKQ was approximately 15 minutes in length, the simulation flight was approximately 55 minutes, each part-task approximately 45 minutes, each group training session approximately 45 minutes, each post-flight questionnaire approximately 15 minutes.

## 2.8 Simulation Procedure

The study began with a formal pre-flight briefing to participants. Following this briefing, half of the pilots performed the simulation flight first, while the other half of the pilots performed one of two part-tasks (before the simulation flight). Prior to flying the first data collection flight in the simulator, participants received training on their assigned simulation condition (i.e., using the 'Slant-range' tool or receive training on sectional map distances between waypoints and terrain along the route). The Control group did not receive any relevant 'training' – instead they viewed the first half (~ 30 min) of an AOPA online webinar for pilots: Aircraft Ownership Series: Part 1 Co-ownership (AOPA, 2017). This educational movie was totally unrelated to assessing weather conditions and providing visibility estimates. After the specific condition training, pilots flew a scenario to practice basic flight maneuvers (roughly 15 minutes in length). The training scenario included all the basic maneuvers required in the scenarios and interactions with ATC (air traffic control).

## 2.9 Simulation Flight and Route

The flight departed from RQE (Window Rock, New Mexico) under flight-following, to destination airport E80 (Alexander, New Mexico). The flight, as planned, followed a waypoint-to-waypoint route from RQE to GUP (Gallup), Factory (buildings), Buildings, Wind Turbines, GNT (Grants-Milan), McCartys, Tower, and then to E80 (Figure 5). The pilots started the simulation flight by taking off from the Window Rock airport runway, then climbing and following the pre-planned route toward Gallup (cruising altitude of 11,500 ft.).

Because the purpose of this study was to evaluate pilot assessments of the out-the-window weather conditions, and pilot assessments of in-flight visibility, we used a scenario where pilots encounter reduced visibility along the route of flight. At the scenario start-up (while taking off from the Window Rock airport), there were VMC at all airports along the route of flight (i.e., RQE, GNT, and E80), which indicated good conditions for VFR flight. In terms of the horizontal visibility, pilots experienced +19 miles of visibility while taking off from the Window Rock airport. However, at the time pilots reached the Factory waypoint (~ 12 min into the flight) the visibility dropped below 15 miles, and at the waypoint Buildings, the visibility was below 8 sm. After the Buildings waypoint, the visibility increased and stayed just under 15 miles until pilots reach the McCarty waypoint. From there on, the visibility steadily decreased to below 5 miles (i.e. IMC) at the waypoint Tower and beyond. If pilots continued their VFR flight, despite being in IMC, the experimenter terminated the flight at approximately 43 min, or when the visibility fell to under 3 miles.

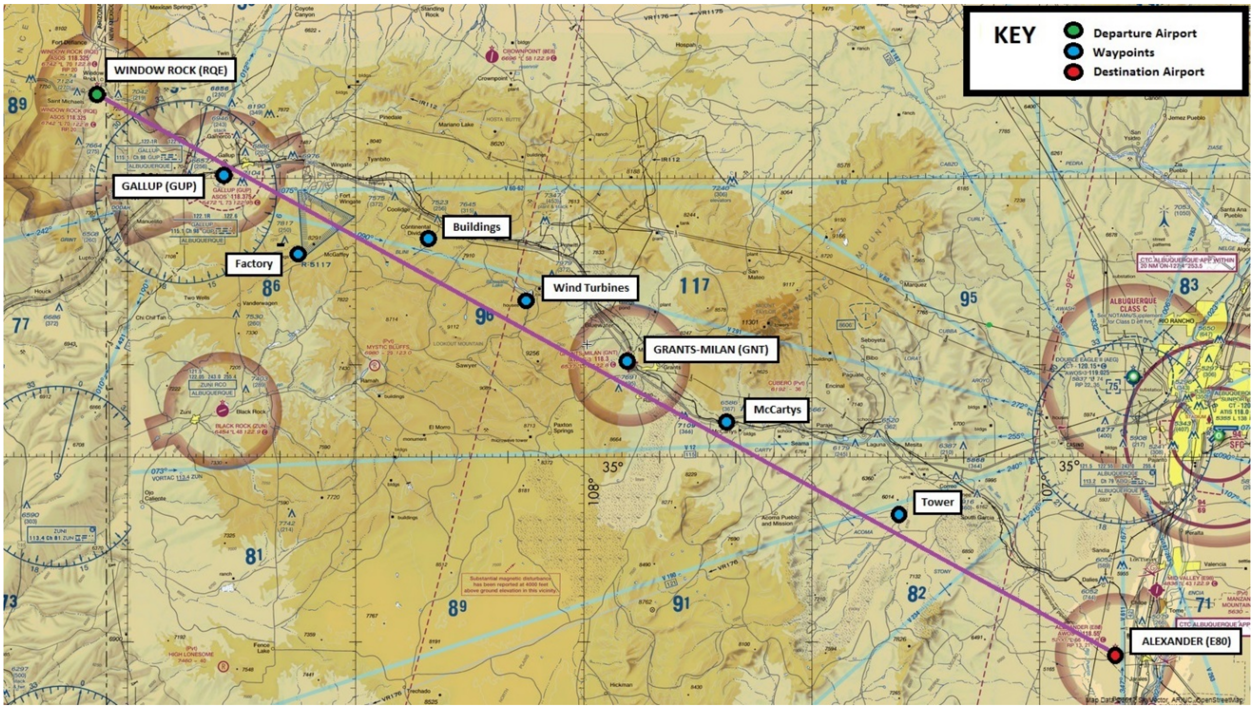


*Figure 3.* Scenario route from Window Rock (top left) to Alexander (bottom right).

### 2.10 Simulation Conditions

In a previous study (Ahlstrom et al., 2019), researchers found that pilots had great difficulty in providing accurate out-the-window visibility estimates. For large simulated visibilities (10 to 30 miles) pilots severely under-estimated the visibility. For simulated visibilities below 10 miles, there was a tendency for pilots to start overestimating the visibility (see Figure 4). Furthermore, Figure 4 also illustrates that some pilot estimates were twice as large as the simulated visibility distances or more. Thus, these visibility data illustrate the difficulty of estimating visibility distances while in flight. This study, therefore, addressed this by assessing the effect of two conditions where pilots received map training or used a tool of a ‘rule of thumb’ when providing horizontal visibility estimates.

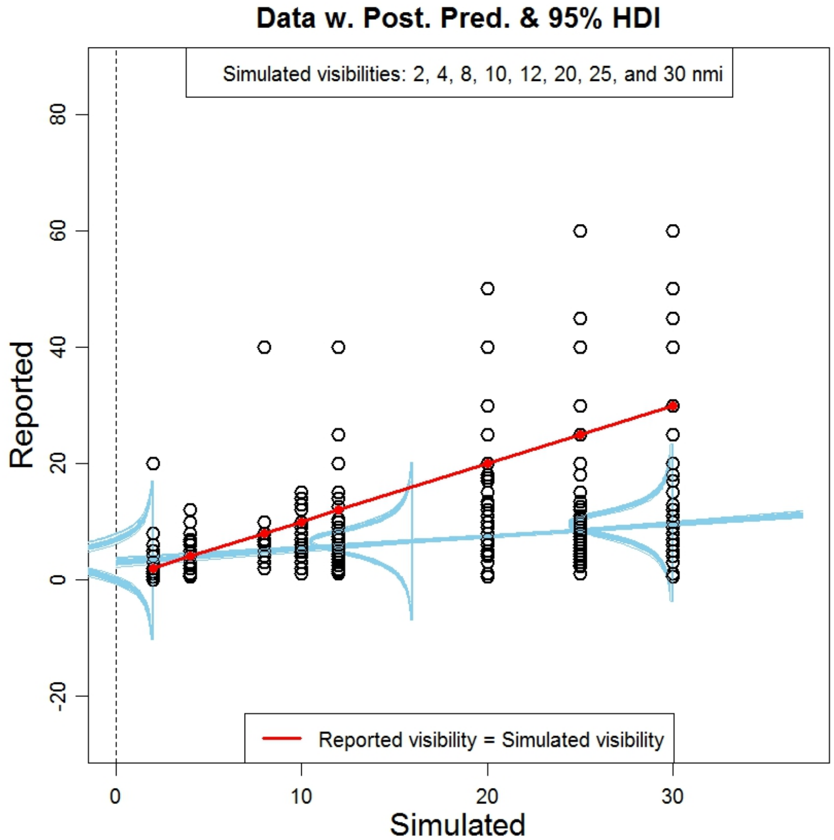


*Figure 4.* Pilot visibility estimates from Ahlstrom et al. (2019). The graph shows the outcome of a Bayesian regression with the simulated visibilities on the x-axis (Simulated) and pilots' assessments of the visibility on the y-axis (Reported). The red diagonal line illustrates the correct visibility estimates, i.e., the case where pilots' visibility estimates are the same as the simulated visibilities.

There were three different conditions during the simulation. In the first condition, Control, pilots did not receive any specific training on how to assess out-the-window weather conditions or any training on how to assess the horizontal visibility in flight. Thus, the pilots in the Control condition served as a baseline for comparison with the two other simulation groups.

In the second condition, Slant-range, pilots used a slant-range 'rule of thumb' tool while making visibility estimates (see Appendix E). To make it easier for pilots we implemented the angle and distance measures outlined in Appendix E as a continuous algorithm that displays the slant-range visibility on the G1000 display (Figure 5).


*Figure 5.* The continuous slant-range readout (lower right corner) on the G1000 display.

The Slant-range rule of thumb works as an approximate representation of visibility without the need for a calculation when the horizon is level with the nose of the airplane. For research purposes, we mounted a pencil on the dash and front/rear markers on the side of the simulator hood.  This was an attempt to assess if it was possible to extend the simple rule of thumb to situations when the horizon is above or below the nose of the airplane.  The width of the horizontal pencil was used to estimate visibility by determining how much horizon was above the nose of the airplane and adding miles to the continuous Slant-range readout (one pencil width equaled 3 miles). By aligning their eyes level with the pencil, so that it sat on the nose of the airplane, pilots could gauge whether or not the current horizon required more than one pencil width for the visibility calculation. Pilots could also use fractions of a pencil width for precise calculations (half of a pencil width equaled 1–2 miles), but whole widths provided satisfactory calculations for visibility estimates. If the horizon was below the nose of the aircraft, then the pilot, from a naturally seated position, would subtract from the continuous Slant-range readout to obtain a visibility estimate. The further the horizon fell below the nose, the greater the number of miles subtracted. A horizon between the nose and the front markers required subtracting 1–2 miles, a horizon at the front makers required subtracting 3 miles, between the front and rear markers required subtracting 4 miles, the rear markers required subtracting 5 miles, and below the rear markers required subtracting 6 or more miles – at 6 or more miles – at which point the horizon could no longer be detected.  Figure 6 is a representation of the card presented to pilots to explain how to use the slant range tool.

## Instructions for Slant Range Visibility Tool Estimation

### 1. Adding to Slant Range Visibility Figure

Align eyes level with the pencil. Horizontally held/fixed vertical pencil widths of horizon above the apex of the hood are used to add to the Slant Range Visibility figure.

Calculation:

1. 1 pencil width of horizon = 3 miles (add to S/R)
2. < 1 pencil width of horizon = 1 – 2 miles (add to S/R)

### 2. Accepting the Slant Range Visibility Figure

When the horizon is even with the apex of the hood, the Slant Range Visibility figure is generally accurate.

### 3. Subtracting From Slant Range Visibility Figure

From a naturally seated position, when the horizon is below the apex of the hood, various calculations are used to subtract from the Slant Range Visibility figure. The further the horizon is below the hood, the greater the number of miles is subtracted.

Calculation:

1. Horizon below apex of hood to above front strip = 1-2 miles (subtract from S/R)
2. Horizon reaches top of front strip = 3 miles (subtract from S/R)
3. Horizon falls between the two strips = 4 miles (subtract from S/R)
4. Horizon reaches top of back strip = 5 miles (subtract from S/R)
5. Horizon falls below back strip = 6 – 6+ miles (subtract from S/R)

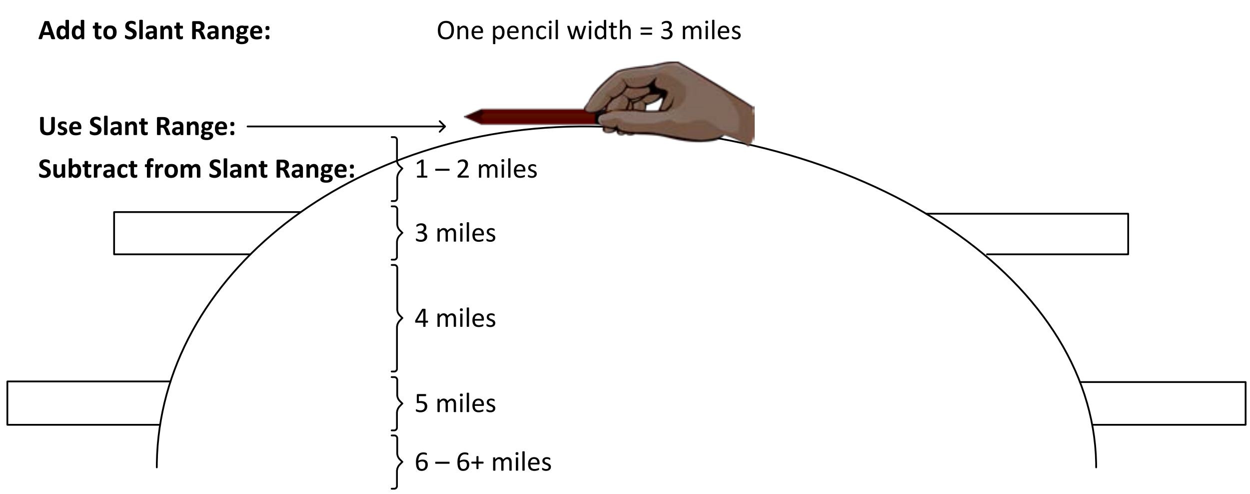


*Figure 6.* Slant range instruction card.

In the third condition, Map Training, pilots went through an exercise where they had to measure the distances between the start and destination and all the waypoints along the route of flight. Furthermore, we asked them to assess the elevation for high points (ridge tops etc.) along the route. The purpose of this exercise was to get pilots familiar with the route and distances between various waypoints, which in theory would help them make more accurate visibility estimates. For example, if you were flying from one waypoint to another, and you knew the distance between these two waypoints, you can use this distance as a 'mental ruler' and estimate how much of this distance you would need to take you to the end of the visibility.

### 2.11 Independent Variable

The independent variable in this study was *simulation condition* (Control, Slant-range, and Map Training). The independent variable simulation condition was a between-subjects variable (i.e., there are different groups in each of the three simulation conditions).

### 2.12 Dependent Variables

During this study, we recorded key dependent variables to evaluate pilot weather situation awareness and pilot decision-making.

The dependent variables captured the following categories: System performance measures (simulator data), communications (pilot/ATC PTT), weather situation awareness (pilot visibility estimates and the use of AWOS/Automatic Terminal Information Service (ATIS) stations), and decision making (e.g., whether the pilot continued flight, turned around, or deviated to an alternate airport). In Table 2, we provide a list of the dependent variables and a short description.

**Table 2. Dependent Variable List**

| Number | Dependent variable | Description |
|---|---|---|
| 1 | System performance measures | Data from the cockpit simulator (e.g., altitude, heading, lat/long position). |
| 2 | Pilot/ATC communications | The number and content of pilot/ATC communications. |
| 3 | Weather situation awareness | Pilot visibility reports (ATC will query pilots about their location, altitude, and their estimated out-the-window visibility seven times during the scenario).<br><br>The use of automated weather observing system stations (AWOS/ATIS). |
| 4 | Decision-making | Pilot decision to continue flight, turn around, or to land at an alternate airport. |

## 2.13 Part-Task: Visibility Evaluation

During the study, pilots participated in one simulation flight. Half of the participants then performed a part task static out-the-window visibility evaluation. The purpose of the out-the-window visibility evaluation task was to compare/validate the out-the-window visibility estimates recorded in this study and in Ahlstrom et al., (2019) using an off-the-shelf X-Plane 10 weather model, with pilot visibility estimates from a high-end weather-software platform by Rockwell Collins. There was a need to evaluate how pilot visibility assessments compared between the two simulation platforms, because they differ in the weather-generating algorithms. An example of two cockpit out-the-window visibilities are illustrated in Figure 7.

*Figure 7*. Illustration of two out-the-window visibilities from the Boeing 737 cockpit (left: 25 miles, right: 4 miles).

During this evaluation, pilots made out-the-window visibility estimates from static displays inside a Boeing B737 simulator (i.e., they were not flying). The pilot was instructed that for each out-the-window display, the task was to estimate the visibility straight ahead of the aircraft and to report the visibility in miles (e.g., with numbers like 5, 10 or 25.5 etc.). The pilot was also informed that the session comprised 16 out-the-window displays in total, and that all out-the-window scenes are different. In half of the static displays, the aircraft was at ~7000 feet (10000 feet ceiling) and 2500 feet (5000 feet ceiling) in the remaining displays.

The top row in Table 3 shows the eight visibilities with ceiling and altitude parameters as used in Ahlstrom et al. (2019). The bottom part of the table shows the same eight visibilities, but with a different ceiling (lower) and altitude (lower). Each pilot received a presentation of the 16 scenes in random order.

**Table 3. Ceiling, Altitude, and Visibility Parameters for the Out-the-Window Visibility Evaluation**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ceiling | 10,000ft | 10,000ft | 10,000ft | 10,000ft | 10,000ft | 10,000ft | 10,000ft | 10,000ft |
| Altitude | 8348 ft. | 8136 ft. | 7924 ft. | 7712 ft. | 7501 ft. | 7289 ft. | 7077 ft. | 6825 ft. |
| Visibility | 30 miles | 25 miles | 20 miles | 12 miles | 10 miles | 8 miles | 4 miles | 2 miles |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ceiling | 5,000 ft. | 5,000 ft. | 5,000 ft. | 5,000 ft. | 5,000 ft. | 5,000 ft. | 5,000 ft. | 5,000 ft. |
| Altitude | 2,500 ft. | 2,500 ft. | 2,500 ft. | 2,500 ft. | 2,500 ft. | 2,500 ft. | 2,500 ft. | 2,500 ft. |
| Visibility | 30 miles | 25 miles | 20 miles | 12 miles | 10 miles | 8 miles | 4 miles | 2 miles |

# 3. RESULTS

We analyzed data from the present study using Bayesian estimation, as used in Ahlstrom and Suss (2014), Ahlstrom et al. (2015a; 2015b), and Ahlstrom et al. (2019). During the analysis we used JAGS ("Just Another

Gibbs Sampler":Plummer, 2003, 2011) that we called from R (R Development Core Team, 2011) via the package rjags. All software for the analysis and figure generation was adapted program code from Kruschke (2014).

The Bayesian analysis generates a posterior distribution, which is a distribution of credible parameter values. We can use this large distribution of representative parameter values to evaluate certain parameters, or to compare differences between parameters. Here, we used a separate decision rule to convert our posterior distributions to a specific conclusion about a parameter value. When plotting the posterior distribution, we included a black horizontal bar that represents the 95% high density interval (HDI). The HDI had a higher probability density compared to values that fall outside the HDI.

When we compared conditions (i.e., perform contrasts), we computed differences at each step in the Markov Chain Monte Carlo chain and present the result in a histogram along with the HDI. These histograms show both credible differences and the uncertainty of the outcome. The width of the black 95% HDI line directly reflects the uncertainty in the estimate – wider HDIs have more uncertainty than narrower HDIs. If the value 0 (implying zero difference) is not located within a 95% HDI, we say that the difference is credible. If the 95% HDI includes the value 0 the difference is not credible as it means that a difference of 0 is a possible outcome.

For difference comparisons, effect sizes, and regression slope estimates we also used a Region of Practical Equivalence (ROPE). The ROPE contains values that, for all practical purposes, are the same as a null effect (i.e., no meaningful difference). If the 95% HDI falls completely within the ROPE margins for an effect size we can declare the presence of a null effect, and unlike traditional analyses, we can accept the null outcome. If, on the other hand, the entire ROPE falls outside the 95% HDI, we can reject the presence of a null effect.

To derive the posterior distributions we used 200,000 samples (regardless of model). For all analyses, we used priors that were vague and noncommittal on the scale of the data.

### 3.1 Flight Profile Measures

To assess pilot flight behavior when avoiding reduced visibility, we analyzed the vertical and horizontal flight profiles. In addition, we analyzed pilot deviations from the pre-planned route. We captured the vertical flight profile from the aircraft altitude at the seven waypoints along the route. We captured the horizontal flight profile from the aircraft heading at the seven waypoints. Similarly, we captured pilot deviations from the route by analyzing a metric that measured (in miles) how far off the aircraft was from the route line.

#### 3.1.1 Vertical Profile - Altitude Analysis

Figure 8 shows the altitudes for the three groups captured at the seven waypoints. As is clear from the figure, the groups are similar with regards to the central tendency, although there are some differences in dispersion. The mean altitude for the Control group was 11,462 ft with a 95% HDI from 11,431 to 11,490 ft. The mean altitude for the Map Training group was 11,435 ft with a 95% HDI from 11,388 to 11,479 ft. The Slant-range group had a mean altitude of 11,482 ft and a 95% HDI from 11,466 to 11,496 ft. To analyze the data, we used a model from Kruschke (2014) for a metric predicted variable (i.e., altitude) with one nominal predictor (i.e., group). In the model, the group data was modeled as a random variation around an overall central tendency (baseline). The group data characteristics, like the group central tendency, were analyzed as a deflection from the baseline with the requirement that deflections sum to zero. None of the group differences were credibly different although it is interesting to note the large variability in altitudes for the Map Training group.

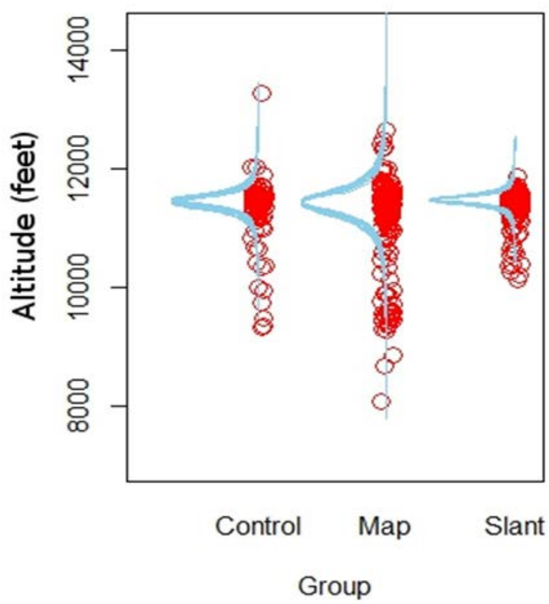


*Figure 8.* The altitudes (ft) at the seven waypoints for the Control (left), Map training (middle), and the Slant-range (right) groups.

### 3.1.2 Horizontal Profile – Aircraft Heading

Figure 9 shows the aircraft heading (in degrees) for each of the three groups (recorded at each of the seven waypoints). The heading is similar between groups with a mean heading of 122.46 for the Control group (95% HDI from 121.67 to 123.32 deg), a mean heading of 122.19 for the Map group (95% HDI from 121.50 to 122.88), and a mean heading of 122.33 for the Slant-range group (95% HDI from 121.75 to 122.89 deg). Using the same model from Kruschke (2014) for a metric predicted variable (i.e., heading) with one nominal predictor (i.e., group), we found no credible differences between the three groups.

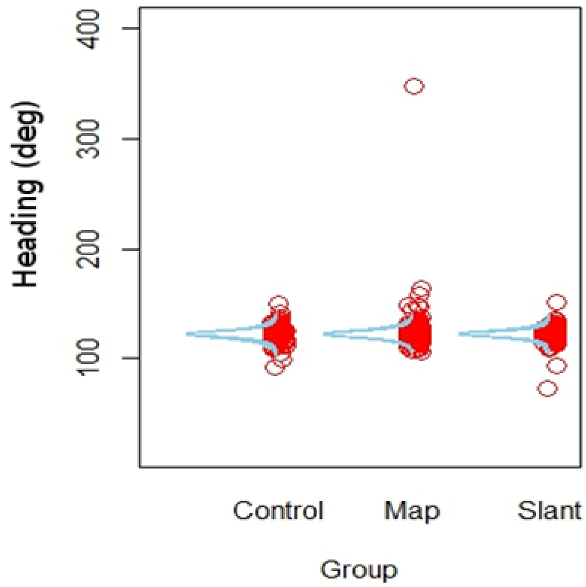


*Figure 9*. The aircraft heading (deg) at the seven waypoints for the Control (left), Map (middle), and the Slant-range (right) groups.

### 3.1.3 Horizontal Profile – Deviations from the Route

Figure 10 shows the distance to the route data (in miles). For the Control group, the mean distance to the route was 0.32 miles with a 95% HDI from 0.26 to 0.39 miles. For the Map Training group, the mean distance was 0.24 miles with a 95% HDI from 0.20 to 0.29 miles. For the Slant-range group, the mean distance to the route was 0.29 miles with a 95% HDI from 0.25 to 0.33 miles. For the analysis, we used the same model from Kruschke (2014) for a metric predicted variable (i.e., distance to route) with one nominal predictor (i.e., group). None of the contrasts between the groups were credible, implying that the distance to the route was similar for all three groups (i.e., pilots in all three groups performed equally well with regards to following the pre-planned route).

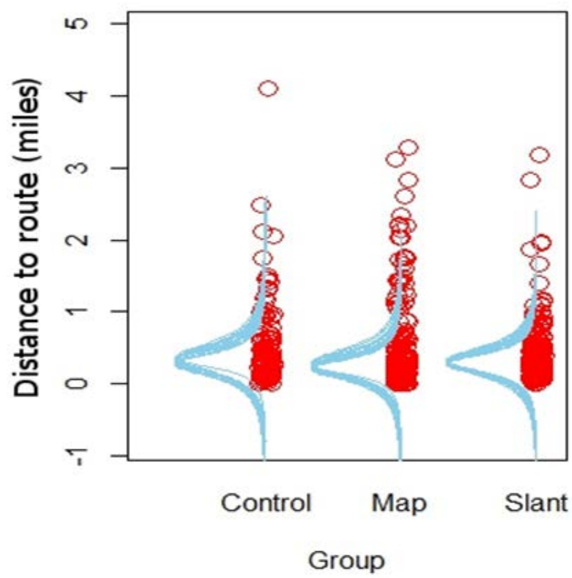


*Figure 10.* The distance to the route (miles) at the seven waypoints for the Control (left), Map (middle), and the Slant-range (right) groups.

The flight profile analysis showed that pilots had similar altitude, heading, and distances to the route at the seven waypoints. This indicates that pilot flight behavior was similar across the three groups.

### 3.2 ATC Communications

During the simulation we automatically recorded all pilot/ATC PTT communications. Figure 11 shows each pilot communication for the three groups. For the analysis we used the same model from Kruschke (2014) for a metric predicted variable (i.e., PTT communications) with one nominal predictor (i.e., group). The number and range of communications were very similar among the groups with no credible or meaningful differences. This is not surprising since the ATC/pilot communications were very structured with pilot position/visibility probes at each of the seven waypoints.

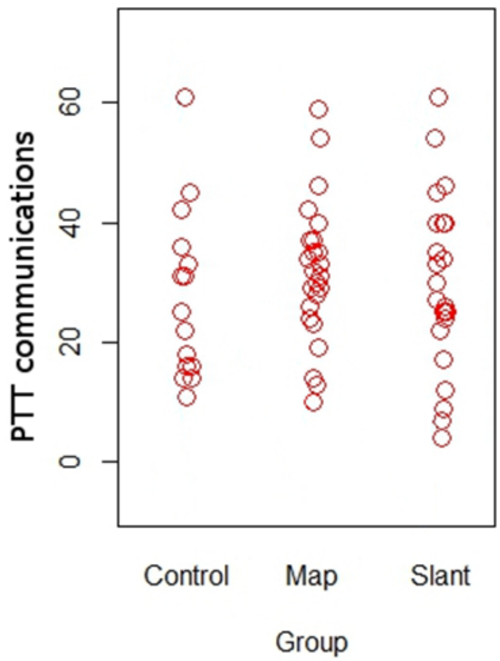


*Figure 11.* Summary of pilot communications for the Control (left), Map training (middle; Map), and Slant-range (right; Slant) groups.

### 3.3 Weather Situation Awareness (WSA)

In the present study, we used two different measures for WSA; pilot use of the AWOS / ATIS stations and pilot visibility reports.

#### 3.3.1 AWOS/ATIS Usage

Figure 12 shows the AWOS/ATIS usage for the three groups. As we can see in the figure, the usage pattern is different with a total of 53 inquiries for the Control group (posterior mean = 3.02, 95% HDI from 2 to 4), 87 inquiries for the Map Training group (posterior mean = 3.41, 95% HDI from 2.4 to 4.4), and 61 inquiries for the Slant-range group (posterior mean = 2.5, 95% HDI from 1.6 to 3.4). Most pilots only tuned in to the system twice, with a few pilots tuning in to the system seven to nine times during the flight. Figure 13 shows the outcome of a contingency table analysis where the Map training group had a credibly higher AWOS/ATIS usage than the Control group (left) and the Slant-range group (right), but with no differences in AWOS/ATIS usage between the Control and Slant-range groups (middle).

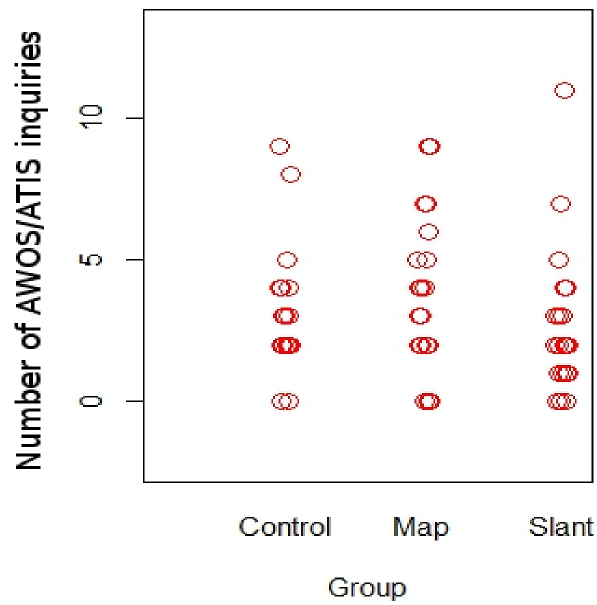


*Figure 12*. Summary of pilot AWOS/ATIS inquiries for the three groups.

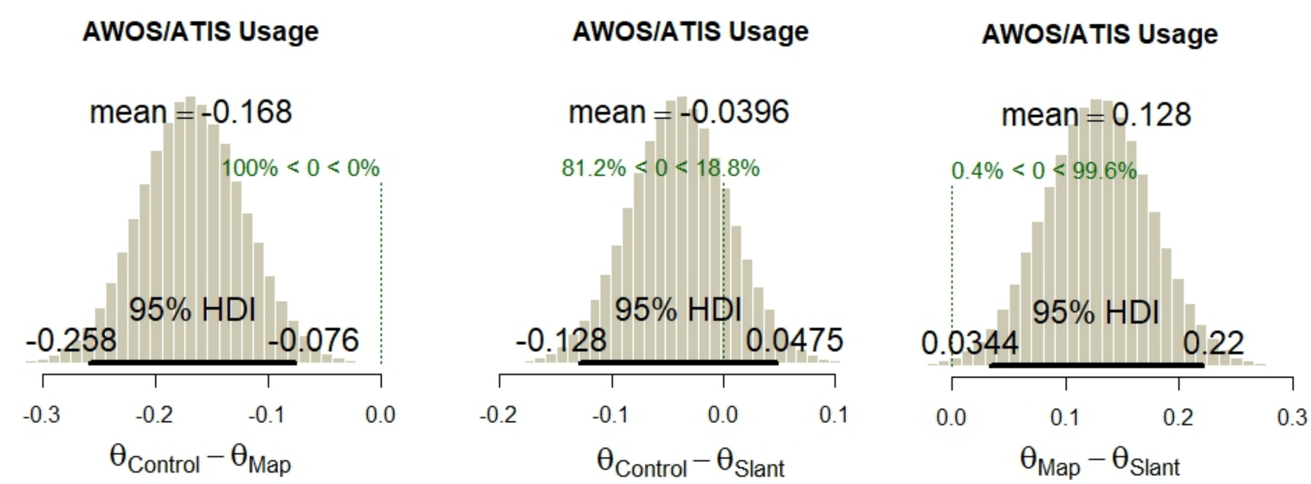


*Figure 13*. Posterior contrasts of the AWOS/ATIS usage between the three groups (Left: Control vs. Map training, Middle: Control vs. Slant-range, Right: Map training vs. Slant-range).

### 3.3.2 Pilot Visibility Reports

During the simulation flight, ATC queried pilots about their location, altitude, and their estimated out-the-window visibility. Each of these queries occurred in relation to a waypoint, at seven times during the scenario.

#### 3.3.2.1 Pilot Visibility Estimate Errors

In a first analysis we assessed pilot visibility estimate errors. That is, how far off pilot estimates were from the visibility values reported by X-Plane. To derive the error values we took the absolute value of the difference between a pilot visibility estimate and the visibility reported by X-Plane. This means that for this analysis, we were only interested in the magnitude of the estimate errors, and not whether a given estimate was below or above the simulated visibility value (we will assess this in a subsequent analysis).

Figure 14 shows the error values for each visibility estimate provided by the pilots. As is shown in the figure, the Slant-range group had lower estimate errors than the Control and Map Training groups. The mean visibility estimate error for the Control group was 3.63 miles (95% HDI from 3.21 miles to 4.06 miles). The mean visibility estimate error for the Map Training group was 3.74 miles (95% HDI from 3.33 miles to 4.17 miles). For the Slant-range group, the mean error was 1.93 miles with a 95% HDI from 1.67 miles to 2.19 miles. This means that the Control and Map Training groups had twice as high mean estimate errors as the Slant-range group.

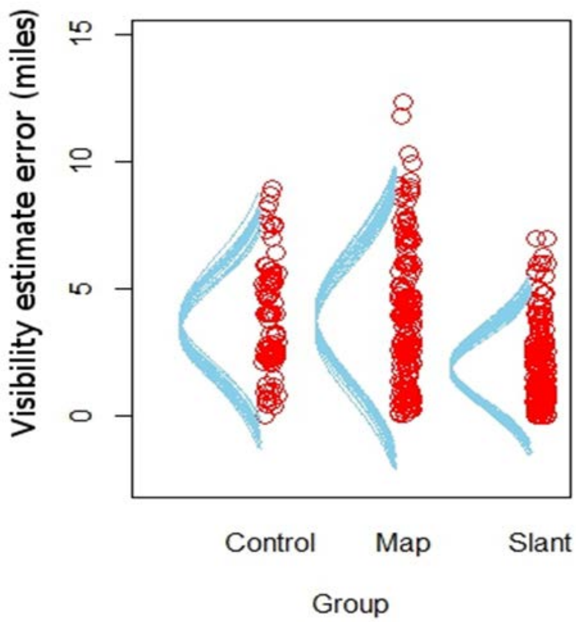


*Figure 14.* Summary of pilot visibility estimate errors (estimated visibility - simulated visibility) for the three groups. Each data point is the absolute error value (in miles) for each visibility estimate.

When assessing the error differences between groups we also computed difference contrasts and effect sizes. For the analysis, we used the same model from Kruschke (2014) for a metric predicted variable (i.e., visibility estimate error) with one nominal predictor (i.e., group). Figure 15 shows the differences between groups in the top row and the effect size in the bottom row.

The left column in Figure 15 shows the difference and effect size for the Control versus Map comparison. As we can see from the posterior distributions, there is no credible difference for the Control versus Map Training comparison. Both the difference distribution and the effect size distribution have the value 0 located in the middle of the 95% HDI, and the mean differences and effect sizes have a mode that is essentially 0.

The middle column in Figure 175 shows the contrast for the difference and the effect size for the Control versus Slant-range comparison. Here, there is a credible difference with the Control group having credibly larger visibility estimate errors than the Slant-range group. The difference distribution has a mode of 1.69 and the effect size is 0.92.

Finally, the right side of Figure 15 shows the Map Training versus Slant-range comparison. As we can see in the figure, there is a credible difference with the Map Training group having larger estimate errors than the Slant-range group. The mode of the difference distribution is 1.81 and the effect size is 0.85.

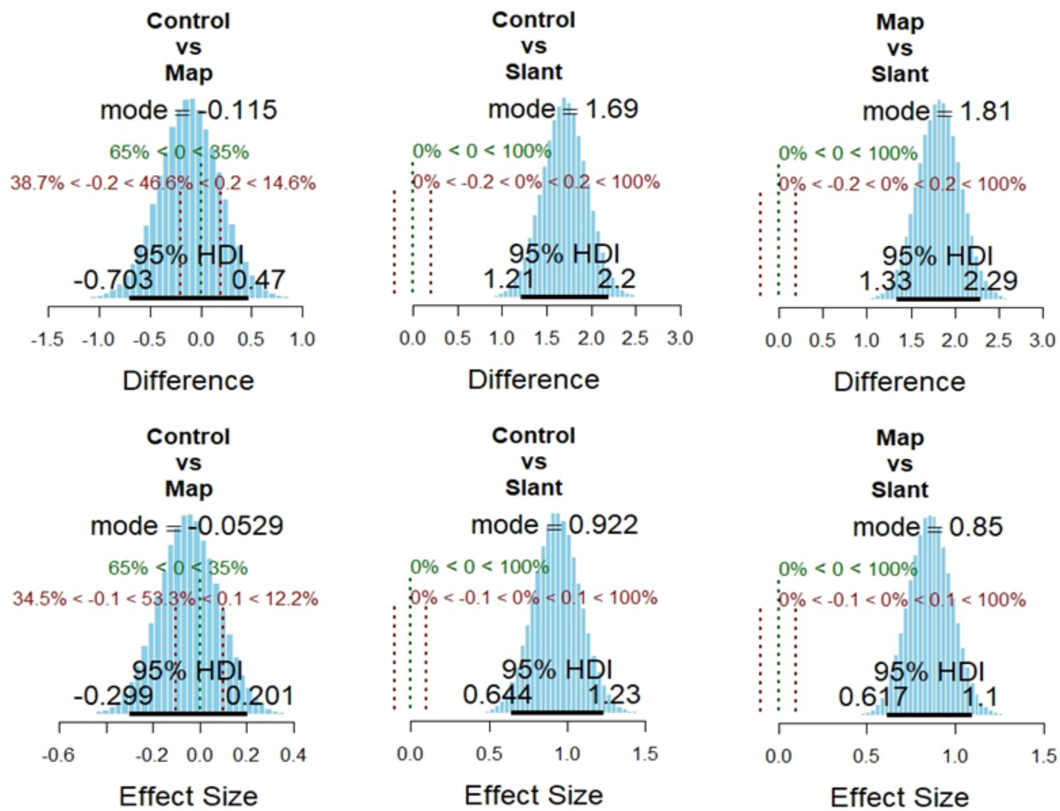


*Figure 15.* Difference contrasts and effect sizes for the comparison of visibility estimate errors for the Control, Map training, and the Slant-range groups.

Besides assessing the overall visibility estimate errors (using absolute values), we also assessed whether pilots were over- or under-estimating the forward visibility during flight. For this analysis, we used linear regression on the actual visibility estimates provided by pilots. For the analysis, we used the visibility reported by X-Plane (x) and corresponding visibility estimates (y) in a robust linear regression model by Kruschke (2014). In the model, each predicted $y$ value is computed as $y = \beta_0 + \beta_1 x$ where $\beta_0$ is the y-intercept (where the regression lines intersect the y-axis when $x$=0) and $\beta_1$ is the slope (indicates how much $y$ increases when we increase $x$ by 1). To be robust against outliers, the model uses a *t*-distribution for the noise distribution instead of a normal distribution (i.e., Gaussian distribution). At the lowest level of the model, each datum comes from a *t*-distribution with a mean $\mu$, a scale parameter (i.e., standard deviation) $\sigma$, and a normality parameter $v$. The prior on the scale parameter is a broad uniform distribution, and the normality parameter v has a broad exponential prior. Both $\beta_0$ and $\beta_1$ have broad normal priors that are noncommittal and vague on the scale of the data.

Figure 16 shows the linear regression outcome for the Control (top), Map Training (middle), and Slant-range (bottom) groups. In the graphs, pilot visibility estimates (y axis) are regressed on the simulated X-Plane visibilities (x axis). Each black circle is a visibility estimate, and the five blue vertical distributions are model estimates. The wider the distribution is, the larger the variability in the data. As we can see in the figure, there is larger variability in the Control and Map Training group data compared to the Slant-range data. The standard deviation (SD) for the Control was 2.66, for the Map it was 3.63, and 2.27 for the Slant-range group. The blue horizontal lines are the credible regression lines. There is a steeper slope on the credible regression lines for the Slant-range group (0.72) than the Control (0.51) and the Map Training (0.59) groups. This means that pilots in the Slant-range group were more accurate in estimating a range of simulated visibilities encountered during flight.

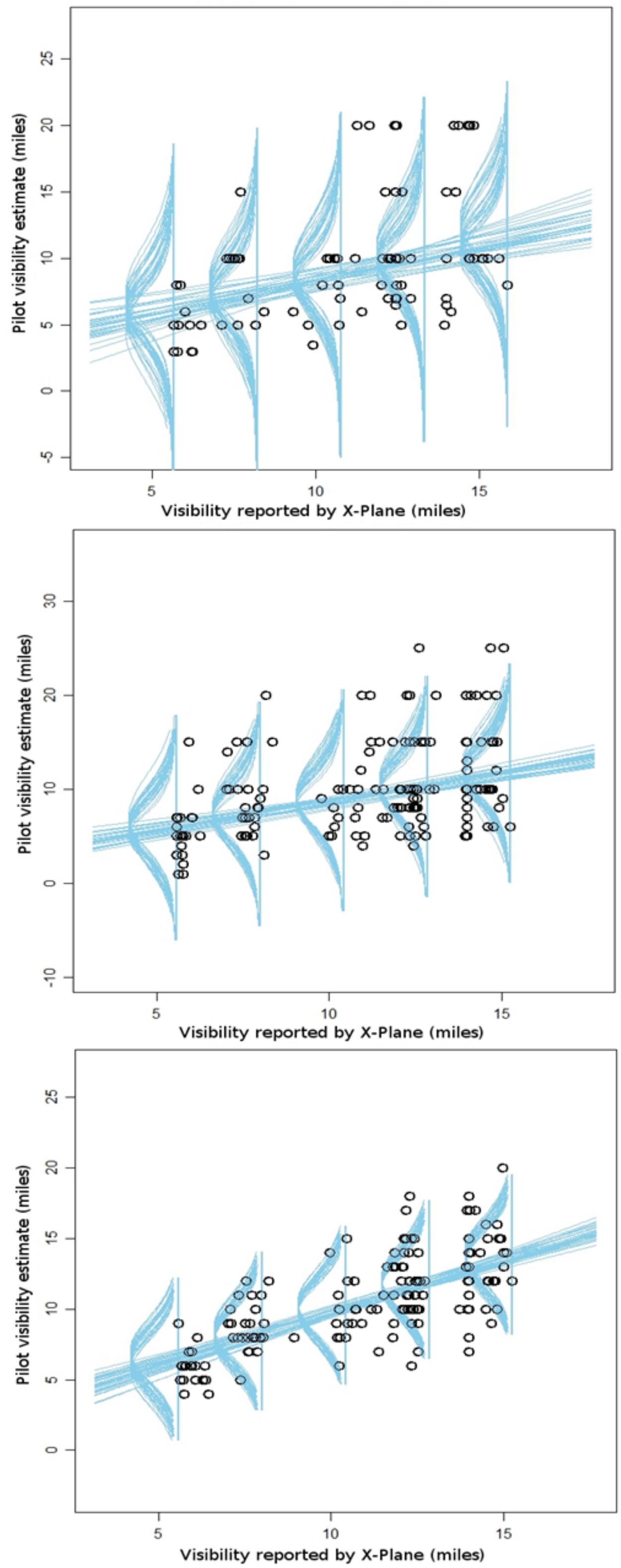


*Figure 16.* Linear regression on pilot visibility estimates for the Control (top), Map (middle), and Slant-range (bottom) groups.

Figure 17 shows that there was a tendency for all pilots to under-estimate the forward visibility for simulated visibilities above 10 miles.  However, we can also see from the prediction of the credible regression lines that pilots should start to over-estimate the forward visibility when the simulated visibility reaches 5 miles or less.  To assess this possibility, we first performed a simple regression analysis on the combined data (i.e., the aggregated visibility estimate data from all three groups) using a robust linear regression model by Kruschke (2014).  The reason for aggregating the data is that we have quite few data points for each group which will yield a large uncertainty in the regression analysis if performed on each group separately.  Second, we also used the model to predict pilots' visibility estimates (y) for discrete visibility values produced by X-Plane (x).  In essence, if we present pilots with a given out-the-window visibility value of *x* (e.g., 7 miles), what is the posterior distribution of predicted visibility values for *y* (i.e., on average, what will pilots' visibility estimates be like)?

Figure 17 shows the outcome of the regression analysis (422 visibility estimates).  On the x-axis we have the out-the-window visibilities generated by X-Plane, and on the y-axis we have pilots' reported visibility.

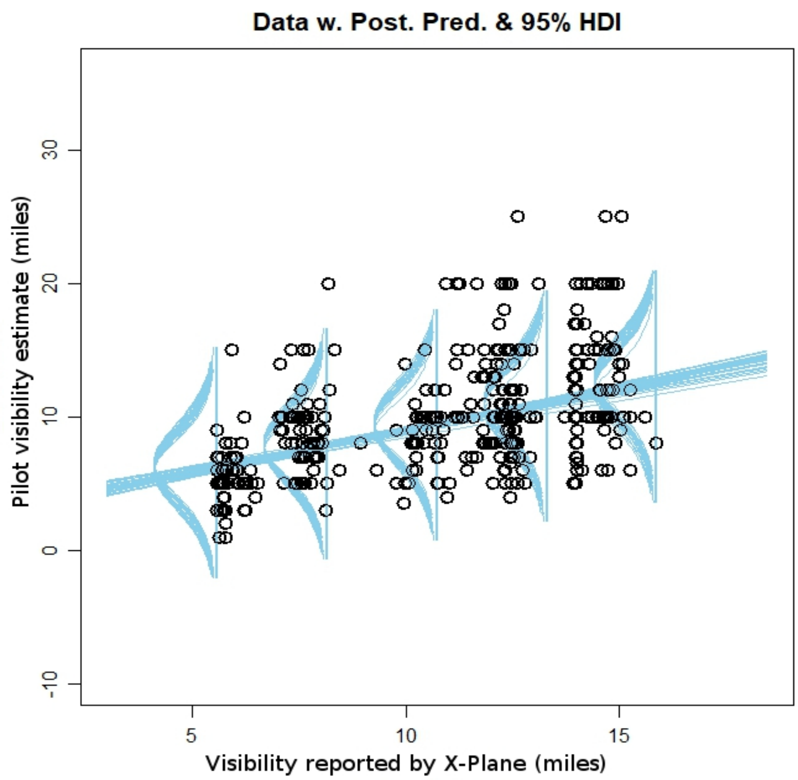


*Figure 17.* Linear regression on pilot visibility estimates for the combined Control, Map, and Slant-range data.

Figure 18 shows the mean posterior outcome for $\beta_0$ (intercept), $\beta_1$ (slope), and the scale parameter $\sigma$ (i.e., standard deviation).  The intercept has a mode of 2.67 which is the predicted value of *y* (i.e., visibility estimate) when *x* (simulated visibility) = 0 miles.  The credible slope has a posterior mode of 0.62 and a standard deviation of 2.9.  This means that as we increase the simulated visibility by 1 mile, pilot visibility estimates will increase by the value of $\beta_1$ (i.e., 0.62 miles).

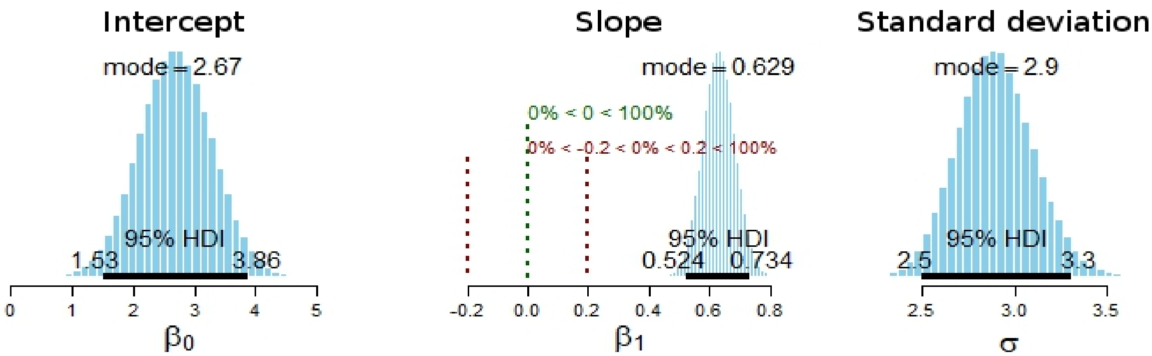


*Figure 18.* The posterior intercept ($\beta_0$), slope ($\beta_1$), and scale ($\sigma$) parameters from the robust linear regression analysis.

Figure 19 shows the posterior predicted visibility estimates (y; i.e., what pilots will report) for simulated visibilities (x) of 10, 5, 3, and 1 miles.

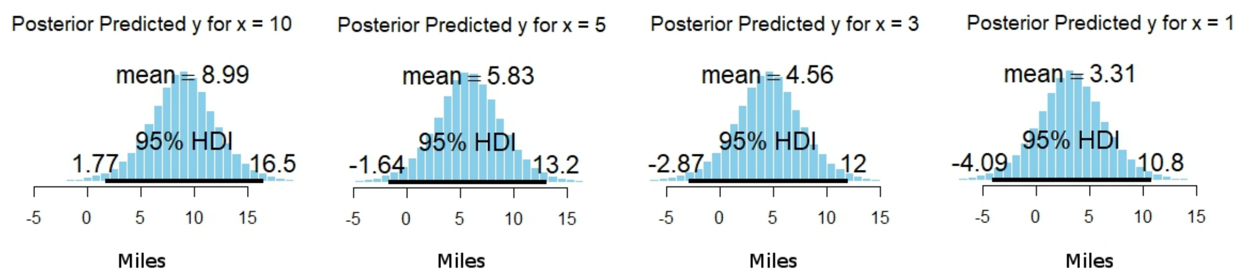


*Figure 19.* The posterior predicted visibility estimates (pilot visibility estimates) for simulated visibilities of 10, 5, 3, and 1 miles.

As we can see in Figure 19, the robust regression model predicts that pilots will under-estimate the forward visibility for simulated visibilities of 10 miles. If X-Plane simulates a forward visibility of 10 miles, pilots, on average, will estimate the visibility to be 9 miles. If the simulated visibility is 5 miles, however, pilots will on average over-estimate the visibility and report a visibility of 5.8 miles. Similarly, if the simulated visibility is 3 miles, pilots, on average, will estimate the visibility to be 4.6 miles. If the simulated visibility is only 1 mile, pilots, on average, will report an estimated visibility of 3.3 miles. This is clear evidence that our regression model, using the combined visibility estimate data, predicts that pilots will *under-estimate* the forward visibility for simulated visibilities of 10 miles or more. What is even more interesting, however, is that the same model predicts that pilots will *over-estimate* the forward visibility when the simulated visibility is 5 miles or less. This of course is a potential factor behind VFR into IMC flights.

Even though the regression analysis yielded credible estimates (narrow 95% HDIs) for the intercept and slope, the posterior predicted visibility estimates for the 10, 5, 3, and 1 mile visibilities have a high degree of uncertainty. For example, the predicted y for the simulated visibility of 10 miles have a 95% HDI that goes from 1.8 miles to 16.5 miles (the left-most distribution in Figure 21). This is a very wide HDI which implies that we have a fairly uncertain estimate.

Therefore, we ran a second regression analysis where we incorporated visibility estimates from Ahlstrom et al. (2017). During the Ahlstrom et al. simulation pilots flew an Alaska and a Pennsylvania scenario in reducing visibility and provided three visibility estimates at 10 and 12 miles simulated visibility.

Figure 20 shows the regression outcome for the combined visibility data (566 visibility estimates).

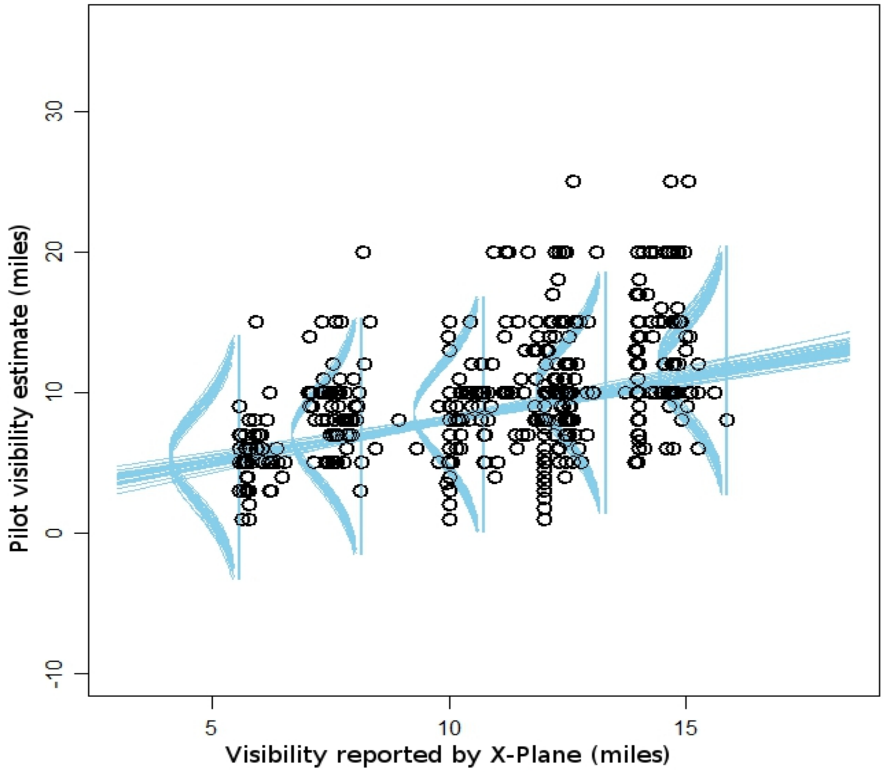


*Figure 20.* Linear regression on pilot visibility estimates for the combined data (additional data from Ahlstrom et al., 2019).

Figure 21 shows the mean posterior outcome for $\beta_0$ (intercept), $\beta_1$ (slope), and the scale parameter $\sigma$ (i.e., standard deviation). The intercept has a mode of 2.07 which is the predicted value of *y* (i.e., visibility estimate) when *x* (simulated visibility) = 0 miles. The credible slope has a posterior mode of 0.6 and a standard deviation of 3.41. This means that as we increase the simulated visibility by 1 mile, pilot visibility estimates will increase by the value of $\beta_1$ (i.e., 0.6 miles).

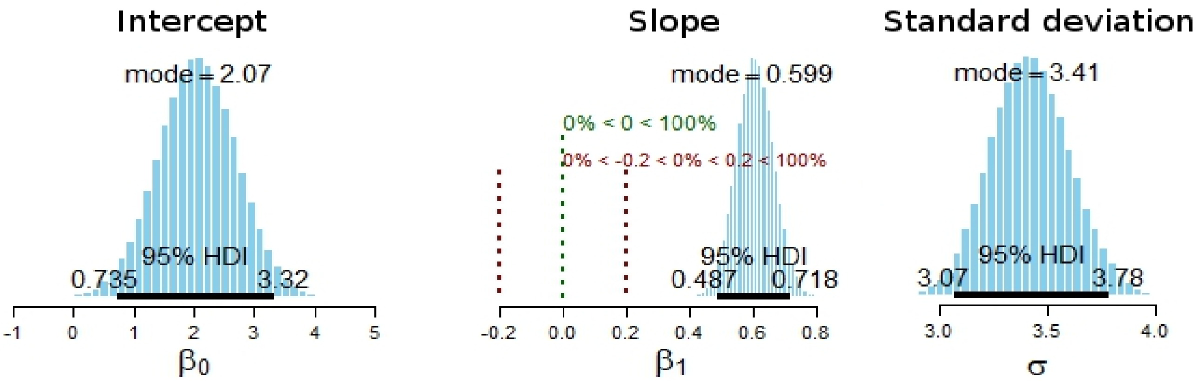


*Figure 21.* The posterior intercept ($\beta_0$), slope ($\beta_1$), and scale ($\sigma$) parameters from the robust linear regression analysis using the combined data.

Figure 22 shows the posterior predicted visibility estimates (y; i.e., what pilots will report) for simulated visibilities (x) of 10, 5, 3, and 1 miles using the combined data.

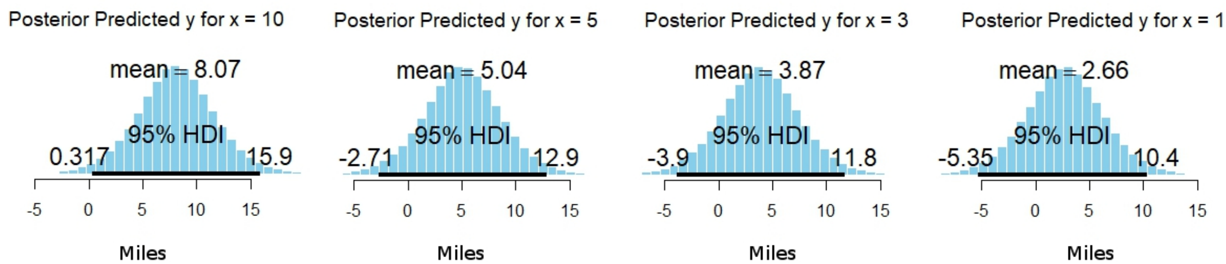


*Figure 22.* The posterior predicted visibility estimates (pilot visibility estimates) for simulated visibilities of 10, 5, 3, and 1 miles using combined data (additional data from Ahlstrom et al., 2017).

As we can see in Figure 22, the posterior predicted estimates for the combined data set are very similar to the estimates in Figure 21. The substantive conclusions have not changed; the model still predicts that pilots will under-estimate the forward visibility for simulated visibilities of 10 miles and over-estimate the visibilities for simulated visibilities of 5 miles or less.

### 3.3.2.2 Slant Range Group and Level Flight

So far, our analysis has shown that the visibility estimate errors for the Slant-range group is on average half the size compared to the estimate errors of the Control and Map training groups. However, as we can see in the regression graph (Figure 18 bottom), the visibility estimates for the Slant-range group are not perfectly correlated with the simulated visibilities. One reason for this is that the aircraft has to be 'level' when estimating the forward visibility. If the aircraft is not 'level', the visibility estimate will be off and the larger the discrepancy the larger the estimate error.

To assess how 'level' the Slant-range pilots were when providing the visibility estimates, we analyzed the pitch and roll parameters for each estimate. During the simulation, the pitch and roll parameters were recorded once a second. In the simulator, a pitch range of +2.5 to +2.8 and a roll range of +0.0 to +1.7 constituted level flight. Of a total of 161 visibility estimates, only 10 estimates were exactly within these limits. This means that although the Slant-range group visibility estimates were more accurate than the visibility estimates for the Control and Map groups, they could have been even more accurate had the estimates been given when the aircraft was perfectly level.

### 3.3.2.3 Comparison of Visibility Estimate Errors Among Pilot Age Groups

We also assessed whether there were any differences in the visibility estimates between the four age groups (i.e., pilot ages up to 34, 35 to 49, 50 to 59, and pilots age 60 and over). Figure 23 shows the visibility estimate errors (absolute values) for the four age groups. The mean visibility estimate error for the ≤ 34 age group was 2.8 miles (95% HDI from 2.3 to 3.2 miles), for the 35-49 age group it was 2.65 miles (95% HDI from 2.2 to 3.0 miles), for the 50-59 age group it was 3.6 miles (95% HDI from 3.0 to 4.1 miles), and finally for the ≥ 60 age group it was 2.8 miles (95% HDI from 2.4 to 3.1 miles).

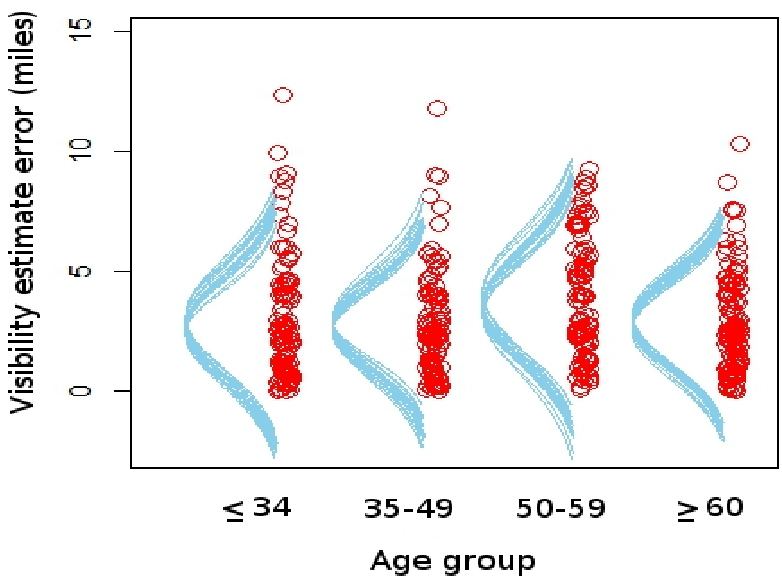


*Figure 23*. Visibility estimate errors for the four pilot age groups. From left to right: up to 34 years of age, 35 to 49 years, 50 to 59 years, and 60 years of age and older.

The estimate error data in Figure 253 shows that the 50-59 age group had higher visibility estimate errors than the other three groups. We therefore performed contrast analyses to see if these differences were credible. Figure 26 shows the comparisons between the ≤ 34 age group and the 50-59 age group (left), the 35-49 group and the 50-59 group (middle), and the 50-59 group and the ≥ 60 group (right). As we can see in the figure, all difference contrasts (top row) and their effect sizes (bottom row) are credible in that the value 0 is not included in any of the 95% HDIs. No other contrasts were credible. This means that the 50-59 year age group had credibly higher visibility estimate errors than the ≤ 34 age group, the 50-59 age group, and the ≥ 60 age group.

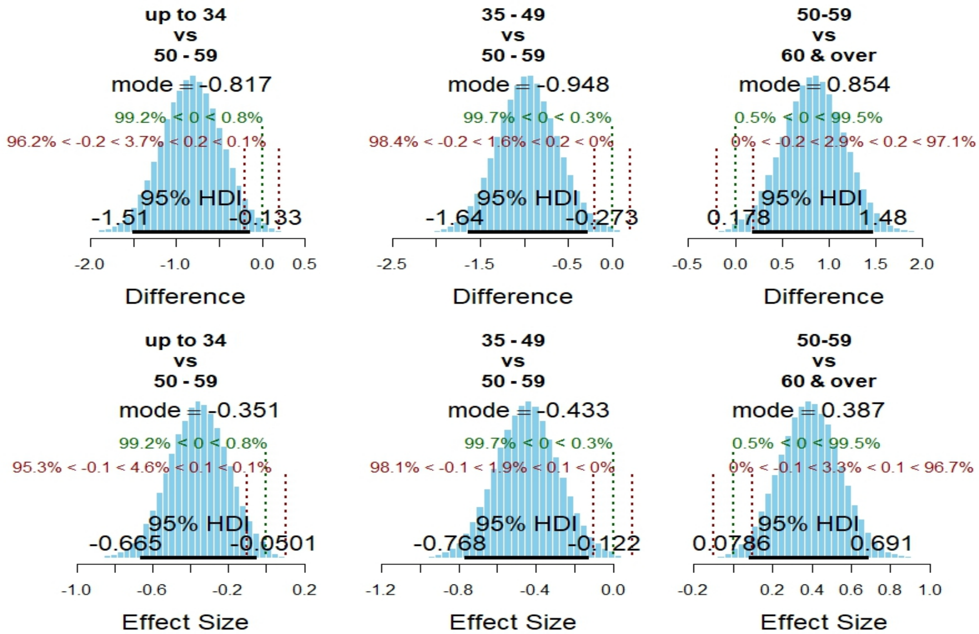


*Figure 24.* Difference contrasts (top row) and their effect sizes (bottom row) for visibility estimate errors contrasts between the four pilot age groups.

Looking at the mean differences (Figure 24, top row) in visibility estimate errors we can see that the mode of the mean differences range between 0.81 and 0.94 miles. The effect sizes range between 0.35 and 0.43. These are not large differences; however, they are consistent and credible.

The question is why the 50-59 age group consistently performed worse on the visibility estimates than the other groups. Analyzing the biographical data we see two variables that could imply that the 50-59 age group, on average, had less weather knowledge than the other three groups. First, only one out of twelve pilots (8%) in the 50-59 age group had any weather interpretation training beyond the basic pilot training. This is less than the ≤ 34 age group (50%), the 35-49 age group (33%), and the ≥ 60 age group (25%). Similarly, the 50-59 age group only had one pilot with a commercial license (8%) whereas the ≤ 34 age group (25%), the 35-49 age group (47%), the ≥ 60 age group (30%) had more than three times as many pilots with commercial licenses beyond the private pilot license.

### *3.3.2.4* Comparison of Visibility Estimate Errors Between VFR and IFR Pilots

In a final assessment, we analyzed whether there were any important differences in visibility estimate errors between VFR-only and IFR-rated pilots. Potentially, there could be differences in how these two pilot groups perceive visibility. This is due to the fact that IFR-rated pilots have experience in flying towards and penetrating areas of low visibility whereas VFR-only pilots do not. For this analysis we used one data value (i.e., the total visibility estimate error) per pilot and a Bayesian model (Kruschke, 2014) for a metric-predicted variable (i.e., visibility estimate error) for two groups (i.e., VFR-only and IFR-rated). In the model, the data are described by *t* distributions rather than normal distributions. Each group has different parameters for the means with broad normal distribution priors. Each group also has separate parameters for the standard deviations, with broad uniform distribution priors. However, both groups share a common normality parameter ($v$) which controls the height of the $t$ distribution tails. The prior on $v$ has an exponential distribution which gives equal opportunity to small values of $v$ and larger values of $v$. The common normality parameter means that both groups' data can inform the estimate of $v$. For the current analysis, we set $v$ to a small value which means that the $t$ distributions have heavy tails and can therefore accommodate outliers in the data (i.e., robust estimation).

The mean visibility estimate error was 2.91 miles for the IFR group (95% HDI from 2.6 to 3.2 miles) and 3.0 miles for the VFR group (95% HDI from 2.7 to 3.3 miles). This difference was not credible as the difference of means was 0.1 miles with the value 0 located in the middle of the 95% HDI. Neither was there a credible difference in the spread of the data (SD) between groups. The mean SD for the IFR group had a mode of 2.31 (95% HDI from 2.0 to 2.6) and the mean SD for the VFR group had a mode of 2.1 (95% HDI from 1.9 to 2.3). This means that the visibility estimate errors were essentially the same for IFR-rated and VFR-only pilots.

### 3.4 Decision-making

In this section, we analyze pilot decision-making, i.e., pilot decisions to continue flight (in decreasing visibility) or to turn around (including decisions to deviate and land at alternate airports). We first provide a summary of how many pilots continued flight or turned around. Next, we analyze the scenario time when pilots decided to turn around and what the forward visibility was at the decision point.

During the scenario, pilots encountered two phases of decreasing visibility and one phase of increasing visibility. Figure 25 shows the visibility data (recorded once a second by X-Plane) over the course of the flight for each of the 64 pilots. At the scenario start up (scenario time = 0, pilot taking off from the runway) the forward visibility was 19-20 miles. Over the next 16-17 minutes the visibility decreased from 19-20 miles to ~7 miles. Thereafter, the visibility increased from ~7 miles to ~14 miles at the 25 minute mark. During the last phase of flight, the visibility monotonically decreased from ~14 miles to 0 miles. However, we terminated the scenario when pilots continued flight and encountered a forward visibility of less than 3 miles. The figure shows that all pilots experienced very similar visibility throughout their flightpaths.

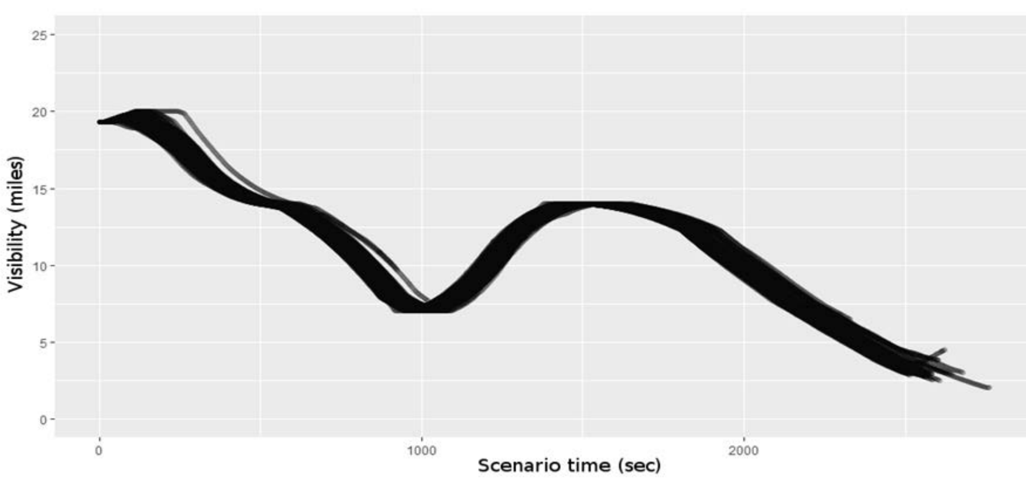


*Figure 25*. Scenario visibility as a function of scenario time. The plot consists of visibility/time data for each of the 64 pilots.

During the scenario, there were more pilots who decided to turn around than to continue flight towards the destination airport. Table 4 shows the number of pilots per group who decided to continue flight (until terminated when encountering less than 3 miles visibility) and the number who decided to turn around.

**Table 4. The Number of Pilots who Continued Flight or Turned Around**

| Number of pilots per group | Continued flight | Turned around |
|---|---|---|
| Control - 16 | 4 (25%, 1 VFR, 3 IFR) | 12 (75%, 6 VFR, 6 IFR) |
| Map training - 24 | 10 (42%, 5 VFR. 5 IFR) | 14 (58%, 8 VFR, 6 IFR) |
| Slant-range - 24 | 10 (42%, 5 VFR, 5 IFR) | 14 (58%, 6 VFR, 8 IFR) |

Although there were more than twice as many pilots in the Map Training (9) and Slant-range (10) groups than the Control (4) group that decided to continue flight towards the destination airport, none of the contingency table comparisons showed a credible difference (due to the small numbers). For pilot decisions to turn around, there were roughly an equal number of pilots in each group. Furthermore, there was no effect of pilot certification on the decision to continue flight or to turn around. That is, the number of pilots per group that decided to continue flight or to turn around were evenly split between VFR-only and IFR-rated pilots.

The time when pilots decided to turn around was also similar between groups. Figure 26 shows the decision time (in sec) when pilots communicated their intent to turn around.

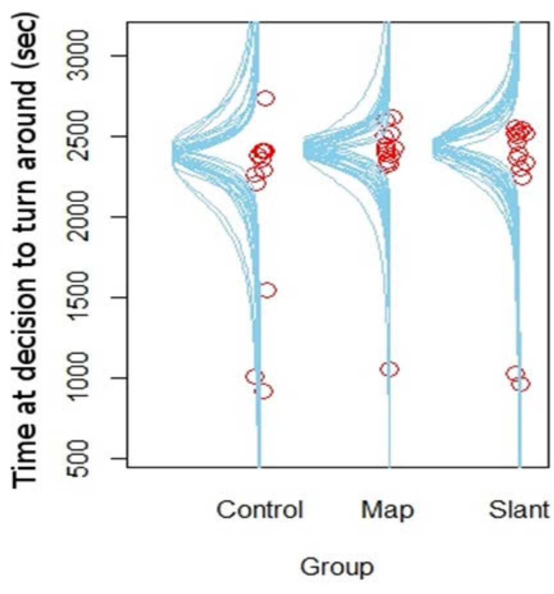


*Figure 26.* Group comparison of the scenario time (sec) when pilots decided to turn around.

The mean decision time to turn around for the Control group was 2365 sec (95% HDI from 2257 to 2466 sec), for the Map group it was 2423 sec (95% HDI from 2364 to 2483 sec), and for the

Slant-range group it was 2445 sec (95% HDI from 2357 to 2530 sec). Decision time contrasts showed that none of the group decision times were credibly different. This means that pilot decisions to turn around happened roughly at the same time for all three groups.

The visibilities at the decision times to turn around were also similar across groups. Figure 27 shows the visibility at the decision time for the Control, Map, and Slant-range groups.

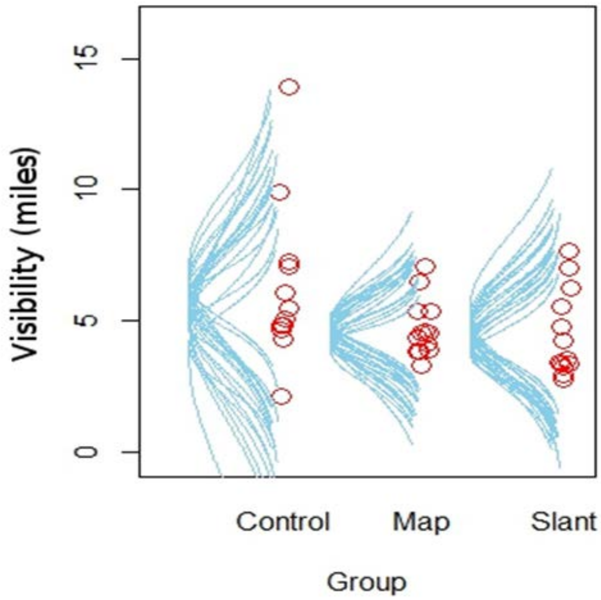


*Figure 27.* The forward visibility at pilot decision to turn around for the Control (left), Map (middle), and Slant-range (right) groups.

The mean visibility for pilot turn-around decisions for the Control group was 5.4 miles (95% HDI from 4 to 7 miles), for the Map Training group it was 4.6 miles (95% HDI from 3.9 to 5.2 miles), and for the Slant-range group it was 4.5 miles (95% HDI from 3.6 to 5.3 miles). Although there were more variation (larger dispersion) in the visibility data for the Control group than the Map and Slant-rage groups, group contrasts showed no credible differences for the visibility data. This means that pilots in all three groups made the decision to turn around at roughly the same forward visibility.

During the simulation, pilots took off from the Window Rock airport and then climbed and followed the pre-planned route at a cruising altitude of 11,500 ft. However, as pilots approached the area near the Tower waypoint many pilots decided to turn around due to decreasing visibility (see Figure 29).

## 4. CONCLUSION

One of the causes behind VFR into IMC flights is GA pilot difficulty to correctly assess the out-the-window visibility. Simulation studies frequently find that pilots fly into areas with rapidly decreasing visibility or fly into areas of IMC where VFR-only pilots are not permitted to fly (Ahlstrom, Racine, Caddigan, Schulz, & Hallman, 2017). This means that pilots have difficulty assessing weather conditions and determining if their flight is compatible with VFR requirements.

In the present study, we investigated pilot weather assessment and pilot ability to assess the out-the-window visibility. We provided two pilot groups (i.e., the Map distance training group and the Slant-range group) with specific training and compared their visibility assessment outcomes with a third pilot group that did not receive any training (the Control group). Specifically, we assessed if sectional map distance training or the use of a slant-range rule of thumb could improve pilot visibility assessments. During flight, VFR pilots can use known distances between waypoints or landmarks to help estimate the forward visibility. Similarly, using the rule of thumb: "When surface is just visible over nose of aircraft the forward visibility will be approximately 1 mile for each 1000 feet altitude" (see Appendix E) could also serve as an aid to pilots when assessing the forward visibility.

The result from this simulation showed that the visibility estimate errors for the Slant-range group were on average half the size compared to the visibility estimate errors for the Control and the Map distance training groups. This clearly shows a benefit of using the Slant-range rule of thumb when estimating in-flight visibility. The result also demonstrates the difficulty of using map distances when estimating forward visibility as the visibility estimates for the Map distance training group were not credibly better than the visibility estimates of the Control group.

For research purposes, we extended the simple slant-range rule of thumb with a continuous slant-range readout, a dash-mounted pencil, and front/rear markers on the aircraft hood. For real-world operations, however, we do believe the simple slant-range rule of thumb would suffice to aid pilots when making visibility assessments. However, a continuous slant-range readout would be easy to implement with current cockpit and portable device technology. Similarly, the dash-mounted pencil and the front/rear hood markers could be implemented in some other more permanent fashion. Regardless, we believe it would be very beneficial if the slant-range rule of thumb becomes a part of private pilot training. It seems that very few GA pilots are aware of this simple rule of thumb. When we asked the pilots how they performed their visibility assessments, not one single pilot in the Map distance training group or the Control group described using something similar to a slant-range rule of thumb. While all Map distance training pilots used map and terrain distances to aid their assessments, 33% of the Control group pilots admitted to using techniques that amounted to simply guessing the forward visibility.

While the Slant-range group performance exceeded (i.e., more accurate visibility estimates) that of the Control and Map training groups, there are a few important topics that need to be emphasized. First, the aircraft must be level for the slant-range rule of thumb to be accurate. This was not always the case during the present simulation as some pilots had difficulty keeping the aircraft level during flight. However, we believe that pilots can accommodate this requirement when flying their own aircraft or develop the level-aircraft-skill through training. A second topic concerns the course of action as pilots perceive a decreasing forward visibility. In the present simulation, 42% of the pilots *who turned around* at the end of the scenario were in violation of the VFR rules due to insufficient forward visibility. This mainly happened because the pilot was above 10,000 ft MSL (which requires a minimum of 5 miles visibility) while the reported X-Plane forward visibility was less than 5 miles. Granted, many of the pilots in our sample had never flown at 11,500 ft MSL before. Furthermore, based on post-scenario feedback, we suspect that a large portion of the pilots used a 3 mile VFR visibility rule of thumb regardless of the altitude. Thus, we cannot ascertain that all pilots were firmly aware of the visibility requirements for VFR flights above and below 10,000 ft MSL. Among the pilots *who continued flight* until researchers stopped the simulation, a common comment was: "…I was thinking about turning around when the simulation ended...". All these pilots ended up in situations where the forward visibility was less than 3 miles.

Based on the current results and data from Ahlstrom et al. (2019), Ahlstrom et al. (2015a, 2015b), Ahlstrom and Dworsky (2012), and Boyd (2017), there is plenty of evidence that pilots have difficulty judging distances to weather events. Once common example is the difficulty to keep the recommended separation minima from thunderstorms. Another example, as examined in the present paper, is the difficulty in accurately assessing the forward visibility to ensure the safety of flight and adherence to VFR rules. Pilot use of the Slant-range rule of thumb can support pilots to make a more accurate assessment of the visibility during flights in deteriorating conditions. However, pilot visibility assessments are not equally accurate at all visibility levels. At greater visibilities (> 10 miles), pilots, on average, under-estimate the forward visibility. Although this foreshortening reflects a faulty assessment, the operational impact is likely negligible as it makes pilot visibility assessments more conservative. For lesser visibilities (≤ 5 miles), however, it seems like pilots are over-estimating the forward visibility. This is not desirable as it is causes VFR flight into IMC (Wiegmann, Goh, and O'Hare, 2002). What is lacking in pilot decision-making seems to be a rule of thumb for action when the pilot perceives the visibility as deteriorating: "...if you assess the forward visibility (taking altitude into account) to be deteriorating and currently somewhere between 5 and 3 miles; turn around...deviate...go to alternate airport..."

Based on the lack of weather training in the current pilot sample (9%), we believe there is a need for training in both how to correctly interpret weather conditions and how to translate these interpretations into flight decisions. We believe that with training on the Slant-range rule of thumb, coupled with a set of decision-making rules, pilots would be in a much better position to correctly assess the out-the-window visibility and make more informed flight decisions rather than continue flight into IMC.

## 5. RECOMMENDATION

From the outcome of this study, we have three recommendations that should be addressed by future pilot training and research:

1. Incorporate the simple Slant-range rule of thumb into basic pilot training.

2. Incorporate weather interpretation training into basic pilot training.

3. Future research should assess the effect of the Slant-range rule of thumb in combination with developed actions rules on pilot visibility assessments and decision-making.

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## Acronyms

| | |
|---|---|
| ADS-B | Automatic Dependent Surveillance-Broadcast |
| AOPA | Aircraft Owners and Pilots Association |
| ATC | Air Traffic Control |
| ATIS | Automatic Terminal Information Service |
| AWOS | Automated Weather Observing System |
| CSF | Cockpit Simulation Facility |
| FAA | Federal Aviation Administration |
| GA | General Aviation |
| GNT | Grants-Milan |
| GUP | Gallup |
| HDI | High Density Interval |
| IFR | Instrument Flight Rules |
| IMC | Instrument Meteorological Conditions |
| NAS | National Airspace System |
| PII | Personally Identifiable Information |
| PIREP | Pilot Report |
| PTT | Push-to-Talk |
| ROPE | Region of Practical Equivalence |
| RQE | Window Rock, New Mexico |
| VFR | Visual Flight Rules |
| VMC | Visual Meteorological Conditions |
| WJHTC | William J Hughes Technical Center |
| WKQ | Weather Knowledge Questionnaire |
| WTIC | Weather Technology in the Cockpit |

# Appendix A: Informed Consent

## Informed Consent

I, ______________________________, understand that this study, entitled "weather information and weather-related decision making", is sponsored by the Federal Aviation Administration (FAA) and directed by Ulf Ahlstrom.

### Nature and Purpose:

I volunteered as a participant in this study that encompasses one cockpit simulation flight and one part-task. The overall purpose of the cockpit simulation and the part-task is to improve General Aviation (GA) weather presentations for the cockpit. During the simulation, participants will fly a single-engine GA simulator during Visual Flight Rules (VFR) conditions in New Mexico. During the part-task, participants will evaluate static images of weather conditions.

### Research Procedures:

Sixty-four GA pilots will participate as volunteers during a half-day (4 hours) session that covers one simulation flight and one part-task. The participants will be engaged from 8:00 AM to 12:00 PM (or from 12:00 PM to 16:00 PM) with short breaks.

The first part of the session will encompass a briefing to review project objectives and participant rights and responsibilities. This briefing will also include initial familiarization with the cockpit simulator and weather presentation. Half of the participants will perform the simulation flight before completing the part-task (and vice versa). At the end of this briefing, participants will complete a brief biographical background questionnaire and a weather questionnaire.

Before flying the simulator, participants will complete a practice flight scenario. After the practice scenario, the participant will fly a designated route during a simulator flight (approximate duration: 40-45 minutes). During the simulator flight, an automated data-collection system will record a set of standard cockpit simulation measures (i.e., altitude, heading, lat/long. etc.).

All simulation flights will also be video and sound recorded. For the video recordings, researchers will use three cockpit-mounted cameras (top view from a dome camera, front view from a bullet camera, and a side view from a fisheye camera). During simulation runs, the front view camera will record the torso and face of participants. Therefore, the camera recordings will only be tagged with the coded identifier, not the name or any other personal identifying information of the participants. The camera files will be securely stored on an external hard drive and locked up in a cabinet.

The main purpose of the video recordings is to capture participant behavior (e.g., interaction with the cockpit controls/displays) during flight and to record the display of the G1000 glass cockpit display and the auxiliary weather display. In addition, the video recordings can be used for verification (if necessary) of the accuracy of system-generated events that occur at certain pre-determined times during flight. The sound recordings will come from a two-way Windows voice communication system consisting of a push-to-talk (PTT) button mounted on the control yoke and a headset worn by the participant.

After the simulation flight, the participants will complete a questionnaire that provides questions on the cockpit system and the simulation test conditions.

After completing the simulation flight, participants will conduct a short part-task (approximately 15-20 min). During this task, participants will evaluate the horizontal visibility in static weather images as seen by pilots from the 'out-the-window' view.

**Anonymity and Confidentiality:**

The information that I provide as a participant is strictly confidential and I shall remain anonymous. I understand that no Personally Identifiable Information [PII] will be disclosed or released, except as may be required by statute. I understand that situations when PII may be disclosed are discussed in detail in FAA Order 1280.1B "Protecting Personally Identifiable Information [PII]." A copy of the FAA Order 1280.1B will be available during the Consent briefing.

**Benefits:**

Participating pilots may benefit from participation in this research in the form of improved flight skills and weather assessments, by flying the scenarios. The information obtained from the study may suggest ways to improve pre-flight and cockpit weather information for GA pilots.

**Participant Responsibilities:**

I am aware that to participate in this study I must be a GA pilot.
I will (a) fly the designated route in the cockpit simulations and (b) perform the part-task evaluation, and (c) answer questions asked during the study to the best of my abilities. I will not discuss the content of the cockpit simulation with other potential participants until the study is completed.

**Participant Assurances:**

I understand that my participation in this study is voluntary and I can withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they believe this to be in my best interest. I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed. I have not given up any of my legal rights or released any individual or institution from liability for negligence.

The research team has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Ulf Ahlstrom or another member of the research team will be available to answer any questions concerning procedures throughout this study. If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Ulf Ahlstrom at (609) 485-8642.

**Discomfort and Risks:**

Risks encountered in this study will be minimal. However, a small potential for developing simulator sickness (e.g., temporary disorientation and mild nausea) and eye strain/fatigue exists. In order to minimize the potential of these adverse effects rests between simulator practice and data collection flights are required. I agree to report immediately any injury or suspected adverse effect to Ulf Ahlstrom at (609) 485-8642.

**Signature Lines:**

I have read this informed consent form. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, I may request a copy of this form.

Research Participant:________________________________________ Date:__________

Investigator:_______________________________________________ Date:__________

Witness:__________________________________________________ Date:__________

# Appendix B: Biographical Questionnaire

**Participant # ___________** **Date ___________**

# Biographical Questionnaire

This questionnaire is designed to obtain information about your background and experience as a pilot. Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

Demographic Information and Experience

| | |
|---|---|
| 1. What pilot certificate and ratings do you hold? (circle as many as apply) | Private Commercial ATP Glider<br>SEL SEA MEL<br>Airship Instrument CFI CFII<br>MEI Helicopter A&P IA |

| | |
|---|---|
| 2. What is your age? | _____ Years |
| 3. Approximately, what is your total time? | _____ Hours |
| 4. Approximately how many actual instrument hours do you have? | _____ Hours |
| 5. Approximately how many instrument hours have you logged in the last 6 months (simulated and actual)? | _____ Hours |

1. List all (if any) in-flight weather presentation systems you have used during a flight to make actual weather judgments (not including onboard radar or Stormscope).

   ______________________________________________________________

   ______________________________________________________________

2. Have you had any training in weather interpretation other than basic pilot training (for example, courses in meteorology)? If so, to what extent?

   ______________________________________________________________

   ______________________________________________________________

3. How often *do you provide/did you provide* pilot reports (PIREPs) during actual GA flights?

   ______________________________________________________________

   ______________________________________________________________

*Thank you very much for participating in our study, we appreciate your help.*

Appendix C: Weather Knowledge Questionnaire

## Weather Knowledge Questionnaire

Each question consists of 2 parts, a and b. Part a is a question on weather and part b is a question related to your answer in part a. Please base your response to part b on the scale below.

**How confident are you that your answer above is correct?**

| Completely Guessing | | | | | | | Completely Certain |
|---|---|---|---|---|---|---|---|
| 33% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |

(It starts at 33% because there are three options (A, B, and C) for each question.)

**1a. What are characteristics of unstable air?**

A) Turbulence and good surface visibility.

B) Turbulence and poor surface visibility.

C) Nimbostratus clouds and good surface visibility.

**1b. How confident are you that your answer above is correct?**

**2a. A temperature inversion would most likely result in which weather condition?**

A) Clouds with extensive vertical development above an inversion aloft.

B) Good visibility in the lower levels of the atmosphere and poor visibility above an inversion aloft.

C) An increase in temperature as altitude is increased.

**2b. How confident are you that your answer above is correct?**

**3a. The amount of water vapor which air can hold depends on the…**

A) dewpoint.

B) air temperature.

C) stability of the air.

**3b. How confident are you that your answer above is correct**?

**4a. What clouds have the greatest turbulence?**

A) Towering cumulus.

B) Cumulonimbus.

C) Nimbostratus.

**4b. How confident are you that your answer above is correct?**

**5a. In which meteorological environment is aircraft structural icing most likely to have the highest rate of accumulation?**

A) Cumulonimbus clouds.

B) High humidity and freezing temperature.

C) Freezing rain.

**5b. How confident are you that your answer above is correct?**

**6a. For most effective use of the Radar Summary Chart during preflight planning, a pilot should…**

A) consult the chart to determine more accurate measurements of freezing levels, cloud cover, and wind conditions between reporting stations.

B) compare it with the charts, reports, and forecasts to form a mental three-dimensional picture of clouds and precipitation.

C) utilize the chart as the only source of information regarding storms and hazardous conditions existing between reporting stations.

**6b. How confident are you that your answer above is correct?**

**7a. What relationship exists between the winds at 2,000 feet above the surface and the surface winds?**

A) The winds at 2,000 feet and the surface winds flow in the same direction, but the surface winds are weaker due to friction.

B) The winds at 2,000 feet tend to parallel the isobars, while the surface winds cross the isobars at an angle toward lower pressure, and are weaker.

C) The surface winds tend to veer to the right of the winds at 2,000 feet, and are usually weaker.

**7b. How confident are you that your answer above is correct?**

**8a. While flying a 3-degree glide slope, a headwind shears to a tailwind.  Which conditions should the pilot expect while attempting to maintain the glide slope?**

A)  Airspeed and pitch attitude decrease, and there is a tendency to go below glide slope.

B)  Airspeed and pitch attitude increase, and there is a tendency to go above glide slope.

C)  Airspeed and pitch attitude decrease, and there is a tendency to remain on the glide slope.

**8b. How confident are you that your answer above is correct?**

**9a. The Hazardous Inflight Weather Advisory Service (HIWAS) is a continuous broadcast over selected VORS of…**

A)  SIGMETs, CONVECTIVE SIGMETs, AIRMETs, Severe Weather Forecast Alerts (AWW), and Center Weather Advisories (CWA).

B)  SIGMETs, CONVECTIVE SIGMETs, AIRMETs, Wind Shear Advisories, and Severe Weather Forecast Alerts (AWW).

C)  Wind Shear Advisories, Radar Weather Reports, SIGMETs, CONVECTIVE SIGMETs, AIRMETs, and Center Weather Advisories (CWA).

**9b. How confident are you that your answer above is correct?**

**10a. If you fly into severe turbulence, which flight condition should you attempt to maintain?**

A)  Constant airspeed (VA).

B)  Level flight attitude.

C)  Constant altitude and constant airspeed.

**10b. How confident are you that your answer above is correct?**

**11a. A pilot can expect a wind-shear zone in a temperature inversion whenever the windspeed at 2,000 to 4,000 feet above the surface is at least…**

A)  10 knots.

B)  15 knots.

C)  25 knots.

**11b. How confident are you that your answer above is correct?**

**12a. A high cloud is composed mostly of…**

A)  ozone.

B)  condensation nuclei.

C)  ice crystals.

**12b. How confident are you that your answer above is correct?**

**13a. Where can wind shear associated with a thunderstorm be found? Choose the most complete answer.**

A) In front of the thunderstorm cell (anvil side) and on the right side of the cell.

B) In front of the thunderstorm cell and directly under the cell.

C) On all sides of the thunderstorm cell and directly under the cell.

**13b. How confident are you that your answer above is correct?**

**14a. Maximum downdrafts in a microburst encounter may be as strong as…**

A) 8,000 feet per minute.

B) 7,000 feet per minute.

C) 6,000 feet per minute.

**14b. How confident are you that your answer above is correct?**

**15a. Which family of clouds is least likely to contribute to structural icing on an aircraft?**

A) Low clouds.

B) High clouds.

C) Clouds with extensive vertical development.

**15b. How confident are you that your answer above is correct?**

**16a. The surface Analysis Chart depicts…**

A) actual pressure systems, frontal locations, cloud tops, and precipitation at the time shown on the chart.

B) frontal locations and expected movement, pressure centers, cloud coverage, and obstructions to vision at the time of chart transmission.

C) actual frontal positions, pressure patterns, temperature, dewpoint, wind, weather, and obstructions to vision at the valid time of the chart.

**16b. How confident are you that your answer above is correct?**

**17a. One weather phenomenon which will always occur when flying across a front is a change in the…**

A) wind direction.

B) type of precipitation.

C) stability of the air mass.

**17b. How confident are you that your answer above is correct?**

**18a. Which weather phenomenon signals the beginning of the mature stage of a thunderstorm?**

A) The appearance of an anvil top.

B) Precipitation beginning to fall.

C) Maximum growth rate of the clouds.

**18b. How confident are you that your answer above is correct?**

**19a. What is an important characteristic of wind shear?**

A) It is primarily associated with the lateral vortices generated by thunderstorms.

B) It usually exists only in the vicinity of thunderstorms, but may be found near a strong temperature inversion.

C) It may be associated with either a wind shift or a windspeed gradient at any level in the atmosphere.

**19b. How confident are you that your answer above is correct?**

**20a. Thrust is managed to maintain IAS, and glide slope is being flown. What characteristics should be observed when a headwind shears to be a constant tailwind?**

A) PITCH ATTITUDE: Increases; REQUIRED THRUST: Increased, then reduced; VERTICAL SPEED: Increases; IAS: Increases, then decreases to approach speed.

B) PITCH ATTITUDE: Decreases; REQUIRED THRUST: Increased, then reduced; VERTICAL SPEED: Increases; IAS: Decreases, then increases to approach speed.

C) PITCH ATTITUDE: Increases; REQUIRED THRUST: Reduced, then increased; VERTICAL SPEED: Decreases; IAS: Decreases, then increases to approach speed.

**20b. How confident are you that your answer above is correct?**

**Answer key**: 1 A, 2 C, 3 B, 4 B, 5 C, 6 B, 7 B, 8 A, 9 A, 10 B, 11 C, 12 C, 13 C, 14 C, 15 B, 16 C, 17 A, 18 B, 19 C, 20 B.

# Appendix D: Post-Scenario Questionnaire

**Participant #** ___________ **Date** ___________

## Post-Scenario Questionnaire

### Participant:

1. What flight decisions did you make related to weather/visibility during the scenario?
(*Please mark your alternative below and use "Other" for comments*.)

| I turned around | I deviated to an alternate airport | I descended to a lower altitude | I climbed to a higher altitude | I did not make any decisions related to weather |
|---|---|---|---|---|
| Other (please specify): | | | | |

2. If you selected that you made a decision in Question 1a above: What information did you use to make those decisions?

| From what I could see "out-the-window" | Information from the ATIS/AWOS/ASOS information | I used the information from my pre-flight weather briefing | I contacted ATC and requested weather information | I did not use any information |
|---|---|---|---|---|
| Other (please specify): | | | | |

3. Do you feel that you had enough weather information to make sound and confident judgments during flight?

| Yes | No |
|---|---|
| If Yes, what weather information did you have?<br><br>If No, what additional weather information would have been helpful? | |

4. Do you feel that you had enough time, in flight, to gather all the information that you needed?

| Yes | No |
|---|---|
| If No, how much time would you have needed to gather the necessary information? | |

5. Was there any information that you lacked – that you would have liked to use along the route?

| Yes | No |
|---|---|
| If Yes, what additional information would you have liked to have available? | |

**Participant # ___________** **Date ___________**

6. When you are operating your own aircraft, what do you consider as your personal minimum "out-the-window" visibility?

| | | | | |
|---|---|---|---|---|
| 1-3 miles visibility | 3-5 miles visibility | 5 miles visibility | 5-10 miles visibility | More than 10 miles visibility |
| Other (please specify): | | | | |

7. During the simulation flight, what was the lowest horizontal visibility you encountered?

| | | | | |
|---|---|---|---|---|
| 1-3 miles visibility | 3-5 miles visibility | 5 miles visibility | 5-10 miles visibility | More than 10 miles visibility |
| Other (please specify): | | | | |

8. Did the "out-the-window" visibility change (increase or decrease) during your flight? If so, where/when along the route did you first notice that change?

| | |
|---|---|
| Yes | No |
| Location/time into flight where you first noticed a visibility change (please specify): | |

9. Was it easy for you to perceive changes in the "out-the-window" visibility along the route?

| | |
|---|---|
| Yes | No |
| If No, why was it difficult? | |

10. Did you use any techniques for estimating in-flight visibility along the route?

| | |
|---|---|
| Yes | No |
| If "Yes" above, please specify and describe: | |

11. If you selected "Yes" on the question above, how well did your "technique" work? In your opinion, how effective was it for estimating the "out-the-window" visibility?

| | | | | |
|---|---|---|---|---|
| Very Effective | Effective | Somewhat Effective | Not Very Effective | Unsatisfactory |
| Comments (please describe your response in detail): | | | | |

12. If you had to fly the scenario again - would you conduct the flight the same way?

| Yes | No |
|---|---|

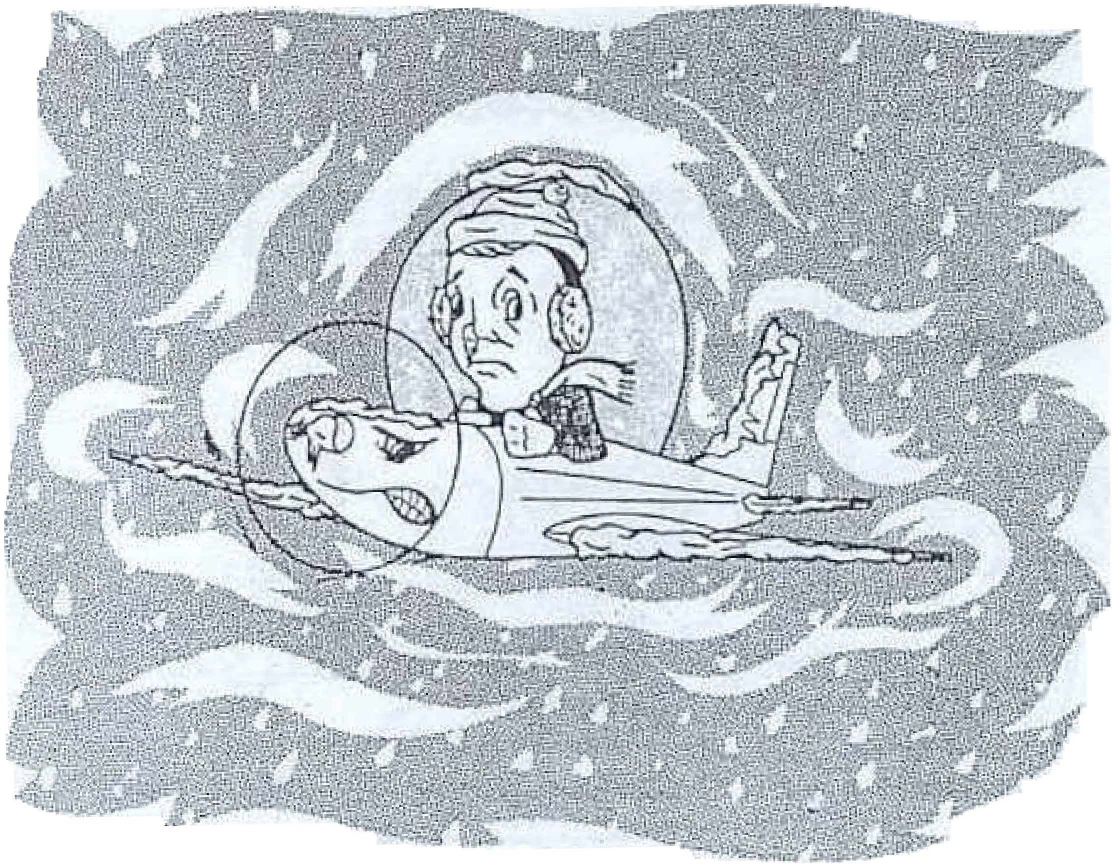
| |
|---|
| If No, please describe in detail what you would do differently regarding your visibility assessment and decision(s). |

13. Given the cockpit weather information/tools available to you during the scenario, did that information and those tools provide you sufficient time to make a timely and safe decision?

| Yes | No |
|---|---|

| |
|---|
| If No, how much lead-time prior to encountering adverse conditions do you feel you personally need as a pilot? |

# Appendix E: Estimating Inflight Visibility



**"CONTINUED FLIGHT INTO INSTRUMENT WEATHER CONDITIONS"**

**All too often this phrase is contained in the completed fatal accident report because the pilot did not have a "rule of thumb" to assist him in estimating in-flight visibility.**

**The material presented here is intended to provide the pilot with a "rule of-thumb" guide only, to assist him in making his decision to land or continue, and does not reflect official FAA policy.**

**Remember! No words in any book can replace good judgment!**

# RULE OF THUMB

when surface is just visible over nose of aircraft the forward visibility will be approximately 1 mile for each 1000 feet altitude.

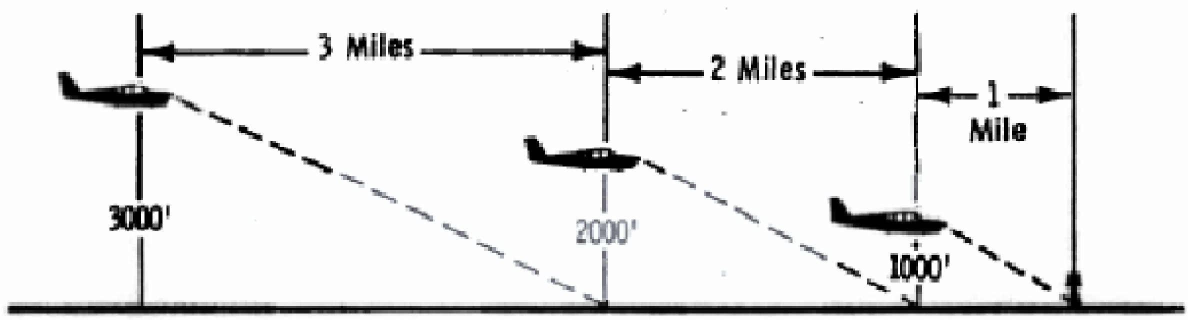



Figure 1. *Rule of thumb*

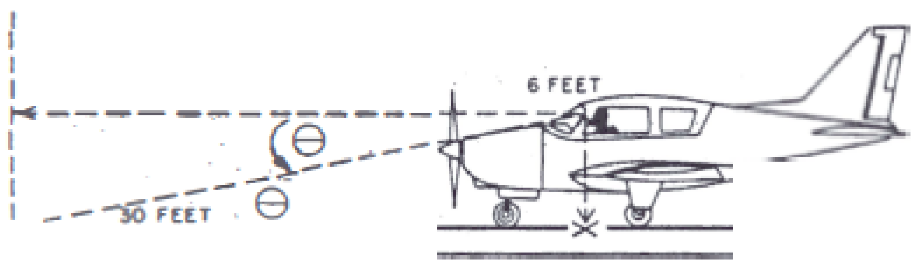
***The Cockpit Cut-Off Angle and In-Flight Visibility.*** All too often, adequate visibility at the surface becomes marginal, or even below minimums at altitude, yet the VFR pilot may continue on his way simply because surface visibilities are reported at values comfortably above minimums. Some method of determining in-flight visibility with reasonable accuracy is, therefore, important. A rule of thumb (figure 1) which will not be equally accurate for all airplanes, but which is usually better than guessing is as follows:

***The approximate visibility in miles will equal the number of thousands of feet above the surface when the surface is just visible over the nose of the airplane.*** In other words, at that point where the surface first appears over the nose of the airplane, your slant-range visibility will be approximately 2 miles if you are flying at 2,000 ft. ***above the surface.*** This rule of thumb is based on the cockpit cut-off angle. All airplanes do not have the same cut-off angle, therefore, the rule of thumb will not be equally accurate for all airplanes. As will be subsequently explained, the cockpit cut-off angle for any airplane can be determined rather easily. Once it is determined for a given airplane, it will remain constant as long as the eye level of the pilot is not changed. The steps in determining this cut-off angle on the ground are as follows (see figure 2).

## HOW TO DETERMINE COCKPIT CUTOFF ANGLE AND ESTIMATE IN-FLIGHT VISIBILITY

1. Adjust the aircraft attitude as close as possible to the normal cruise pitch attitude.
2. Get in the pilot's seat and adjust it to the same position you would use in flight. Use your normal posture.
3. Measure the distance between the ground and your eye level. (Example 6 feet)
4. Look over the nose of the aircraft (cockpit cutoff angle) at the point where the ground surface is just visible. Measure this distance from directly under your eye position along the surface. (Example 30 feet)
5. EXAMPLE: Six (6) foot eye height, and thirty (30) foot distance.
   $\frac{6}{30} = .20$; .20 is the tangent value.
6. Look on the list below for the nearest tangent value you computed and you will find the corresponding angle, which will be the cockpit cutoff angle for your aircraft.

Figure 2




| TANGENT VALUE | ANGLE | APPROXIMATE VISIBILITY AT 1000' AGL. |
|---|---|---|
| .052 | 3 degrees | 19,200 feet |
| .070 | 4 | 14,280 |
| .087 | 5 | 11,500 |
| .105 | 6 | 9,530 |
| .123 | 7 | 8,130 |
| .141 | 8 | 7,090 |
| .158 | 9 | 6,330 |
| .176 | 10 | 5,750 |
| .194 | 11 | 5,150 |
| .213 | 12 | 4,710 |
| .231 | 13 | 4,320 |
| .249 | 14 | 4,010 |
| .268 | 15 | 3,730 |
| .287 | 16 | 3,480 |
| .306 | 17 | 3,270 |
| .325 | 18 | 3,070 |
| .344 | 19 | 2,910 |
| .364 | 20 | 2,750 |

NOTE: For 500' AGL visibility in feet would be approximately half of the 1000' value.

NOTE: Values in one mile.
¼ equals 1,320 feet
½ equals 2,640 feet
¾ equals 3,960 feet
1 equals 5,280 feet