INDIVIDUAL PILOT FACTORS PREDICT DIVERSION MANAGEMENT DURING A SIMULATED CROSS- COUNTRY VFR FLIGHT

Kathleen Van Benthem, Ph.D.
ACE Lab, Carleton University
Ottawa, ON, Canada
Chris M. Herdman, Ph.D.
ACE Lab, Carleton University
Ottawa, ON, Canada

The risk of an accident during general aviation (GA) flight increases when pilots are required to make unexpected diversions. Specifically, a diversion may result in loss of situation awareness (SA). Loss of SA is associated with controlled flight into terrain, incorrect trajectory for orbiting or landing, or becoming lost en route. In the present study, 44 GA pilots (aged 41 to 74 years) flew a cross-country route in a Cessna 172 simulator and encountered an unexpected diversion to an alternate aerodrome. The outcome measure consisted of a diversion management score. Significant predictors of diversion management were pilot age and license, a measure of prospective memory in the cockpit, and response times from an executive cognitive function subtest of the CogScreen-AE. A model of performance derived from a "best subsets" linear modeling algorithm included pilot license, prospective memory, and executive function. Importantly, less skill in managing the diversion also predicted a greater likelihood of critical incidents during the cross-country flight. Understanding the role of pilot factors in identifying those most at risk when flying an unexpected diversion can better prepare pilots for these rare events, and inform customized learning opportunities during check rides and flight instruction.

General aviation continues to show higher rates of accidents per mile flown when compared to scheduled operations (AOPA, 2015). Thus, identifying high risk aspects of general aviation operations, and the factors associated with these risks is in the best interest of pilots and the public. Managing unplanned diversions, such as rerouting to an alternate aerodrome due to weather, relies on a sequence of cognitive factors, including rapid situation awareness updating and accurate and speedy decision-making, while safely navigating, communicating, and piloting the aircraft (Wright, 2013). Thus, pilot characteristics, which are known to predict situation awareness and decision-making, might also show associations with diversion management.

Situation awareness has received considerable attention in the aviation literature. Van Benthem, Herdman, Brown and Barr (2011) found that objective measures of situation awareness (knowledge of ownship and details and location of other aircraft) predicted the occurrence of critical incidents during simulated general aviation flight. Case analyses of actual accidents suggest that loss of situation awareness is associated with over 70% of pilot-caused general aviation accidents (Endsley, 1999). The construct of situation awareness has been described as a mechanistic model, and this model provides a framework for identifying predictors of situation awareness. Per Endsley (1988; 1995) situation awareness relies on three general cognitive mechanisms. The first is the perception and integration of stimuli into meaningful units of information. A second mechanism binds relevant information into a comprehensive model of the environment. The third process projects the current model into a likely future model of the environment. By this characterization, situation awareness is reliant on several cognitive functions that work in tandem to produce accurate and frequently updated representations of relevant aspects of the world. Situation awareness is responsive to top-down direction such as pilot attention and goals. At the same time, some aspects of situation awareness are affected by foundational cognitive factors such as working memory and processing speed, which support the production of situation awareness in a bottom-up fashion (Bolstad, 2001; Gugerty & Tirre, 2000; Gutzwiller & Clegg, 2013). Van Benthem et al. (2011) found that a cluster of pilot characteristics, including age, experience, perceptual-motor response times, and a situational judgement test for drivers predicted the second and third mechanisms of situation awareness (the current and future comprehensive model, as per Endsley's descriptions above). Perceptual motor speed and recent flight hours were the only two factors to predict situation awareness level one.

Decision-making during flight is also logically associated with outcomes of unplanned diversions, though few flight simulation studies have examined the predictors or outcomes of diversion-related decision-making. Along this line however, Goh and Wiegmann (2001) found that poor decisions to fly visual flight rules into instrument meteorological conditions were associated with an overconfidence in personal ability and an inaccurate diagnosis of visibility conditions. Causse, Dehais, Arexis, and Pastor (2011) examined the predictors of a landing decision task (due to wind factors on approach) and report that executive cognitive functions significantly predicted the landing decision. In the landing study, the wrong landing decision was associated with less accuracy in visual working memory updating and greater errors in detecting rule-shifts during the card sort task (Causse et al., 2011). Similarly, Kennedy, Taylor, Reade and Yesavage (2010) found that while flying simulated approaches older general aviation pilots showed a less conservative response bias in comparison to younger pilots, and were more likely to decide to land when visibility was poor. It appears that relevant predictors of decision-making during flight may be associated with individual pilot factors such as age, basic aviator competencies, executive cognitive abilities, and personality factors.

There appears to be considerable overlap between predictors of situation awareness and decision-making. This overlap also supports the notion that predictive models of unplanned diversion management will benefit from a range of factors that include cognitive functions, pilot characteristics, and aviator competencies. In the present study, general aviation pilots flew a cross-country route in a Cessna 172 simulator and encountered (and managed) an unexpected diversion to an alternate aerodrome. Considering that pilot personality and basic aviator competencies have been linked to situation awareness and decision-making we hypothesized that a broad range of predictors would be required to account for a reasonable amount of variance in diversion management scores. Using a "best subsets" technique for linear regression we compared simple to more complex models of diversion management.

Methods

The present study is part of an ongoing research agenda examining general aviation, aging and cognitive health. The sample was comprised of 44 volunteer pilots (all male) recruited from local flying clubs and schools. Inclusion criteria included age 40 years and older, having flown within the last year with a valid pilot's license and medical certification. Table 1 provides a description of the range of pilot age and experience. The study had approval from the university ethics review board, and all study participants provided informed consent after a description of the study activities was provided. Pilots attended two sessions: the first session was comprised of cognitive testing and practice flights in the simulator, and the second session consisted of three practice patterns followed by a cross-country route and diversion scenario.

Table 1.
Pilot Characteristics

	Age	Licence/Rating	Total Hours Flown	Total Years Licensed
Mean	54.80	2.455	556.3	12.83
Standard Deviation	9.065	1.044	1281	13.42
Minimum	41.00	1.000	1.000	1.000
Maximum	74.00	4.000	8000	50.00

Notes. License/Rating was based on a four-point scale where 1 = students, 2= visual flight rules (no additional ratings), 3 = visual flight rules with additional ratings, and 4 = instrument rated pilots, commercial pilots, and instructors.

Simulation Environment

The simulator structure was a converted Cessna 172 partial fuselage with a cockpit outfitted with instruments and controls specialized for flight simulation linked with Microsoft Flight Simulator X software (FSX) (Microsoft Game Systems, 2006). Projection graphics were produced by FSX "on the fly" and were not pre-rendered. Locations were geo specific in that they produced terrain modeled on actual aerodromes in Canada. The graphics architecture incorporated a broad-angle display system utilizing eight theater-quality 1080p projectors and a 14-foot tall, 180-degree curved screen to create a highly immersive visual environment. The data application computer logged the time and the pilot's location, airspeed, heading, bank, pitch, and altitude at one Hertz.

Figure 1. Cessna 172 simulator in situ with Broad-Angle Display System.

Flight Plan and Unexpected Diversion

Before entering the aircraft, pilots were briefed on a predetermined visual flight rules flight plan. Pilots were instructed to communicate with air traffic control or ground services as per the aerodrome. The weather experienced by the pilots was clear with no winds. The flight plan included a short leg from a large airport to a nearby general aviation aerodrome for two touch and gos. After departure from the small aerodrome pilots thought they were to follow a broad river to another large airport, where they were to complete their flight. After the final touch and go and departure from the aerodrome an unexpected instruction from ATC required pilots to divert from their plan and fly to an alternate aerodrome, and orbit at a prescribed altitude until further instructions were provided. A possible ground stop due to weather was the reason provided by ATC for the diversion. The cockpit was outfitted with visual flight rules navigation charts, a flight supplement document, and all non-electronic materials necessary for locating the new airfield. Pilots were expected to locate the alternate airfield on the map(s) provided and to determine an appropriate heading without assistance from ATC. Tasks also included changing radio frequencies as necessary. Throughout the flight, pilots heard other aircraft communicating with ATC or ground services. Listening to other pilot communication was the primary method of determining the location and intentions of other relevant aircraft.

Two unexpected pauses of the flight scenario occurred after the initial instructions from ATC to fly to the alternate airfield and provided the data for the diversion management metric. The diversion management score was comprised, in part, of key elements directly associated with the diversion and captured five minutes after the diversion message: speediness of response (0 or 1), acknowledgement of the alternate aerodrome (0 or 1), ability to locate the alternate aerodrome on a map (0 to 2), and accuracy in noting ownship on the map (0 to 2). An awareness of other key elements of the diversion were captured at a pause approximately 15 minutes after the diversion message (before the pilot returned to a final aerodrome as per ATC instruction), which included ownship, altitude, airspeed, and heading, and location, call sign, type, and altitude of other aircraft following similar ATC instructions (each element scored at 0 to 2 points). Pilots were also expected to make several radio calls while orbiting the alternate airfield (0-8). All elements of the diversion management score were equally weighted and summed to possible maximum score of 30. In sum, the diversion metric was based on the ability determine new flight plans in a speedy manner and maintain accurate situation awareness, while continuing to aviate, navigate, and communicate.

Prospective Memory

Pilots were expected to make radio calls at prescribed times during the scenario. Previous work in this flight simulation laboratory (Van Benthem, Herdman, Tolton & LeFevre, 2015) has found that pilot prospective memory for radio calls in the cockpit were sensitive to pilot experience, workload, age, and cognitive factors. Prospective memory for cockpit tasks have also been associated with critical incidents in the real world (Dismukes & Berman, 2010). Due to the particular sensitivity of prospective memory for infrequent radio calls in high workload situations (Van Benthem et al., 2015) only the calls for the mid-downwind position in pattern flight during higher traffic volume occasions were used to create the prospective memory metric in this analysis.

Critical Incidents

All critical events related to piloting behaviour were recorded during the flight simulation. Critical incidents included dangerous landings, incorrect response to ATC instructions, mis-dialing radio frequencies without detection etc. To avoid the inflation of a possible relationship, critical events occurring during the diversion management portion of the scenario were not counted in this performance metric.

Executive Cognitive Function

CogScreen-Aeromedical (AE) is a computerized cognitive screening tool designed to assess cognitive processes deemed relevant to the complex tasks of an aviator (Kay, 1995). CogScreen-AE measures attention, immediate and short-term memory, working memory, visual-perceptual functions, sequencing functions, logical problem solving, calculation skills, reaction time, and dual-task processing. CogScreen-AE testing was conducted using a Windows XP computer with Elo -Touch systems 2216 AccuTouch USB Touch monitor (Elo Touch Solutions). Eleven subtests of the CogScreen-AE were administered: Backward Digit Span, Math, Visual Sequence Comparison, Symbol Digit Coding, Matching to Sample, Manikin, Divided Attention, Auditory Sequence Comparison, Pathfinder, Shifting Attention, and Dual Task. The CogScreen-AE was administered to all the pilots in their first session. Only the Shifting Attention subtest was used in the present analysis because of its strong association with executive functions (Kay, 1995). In the Shifting Attention subtest participants determine and then update a repeatedly changing rule, which relates to the direction and colour of arrows and governs correct selection of arrow stimuli.

Results

A best subsets linear regression analysis was undertaken to determine the relative importance of each predictor. Despite the strong bivariate correlation found for age and the diversion score (see Table 2), age was not a significant predictor in the final model. The best combination of factors included pilot license, executive function, and prospective memory, r^2=.42. As shown in Table 2, the executive function factor (a response time metric) was strongly correlated with pilot age. Replacing executive function with age in the final model resulted in a drop of 11% of accounted variance, thus executive function was a more informative variable than age alone. In order of importance the variables were executive function, license, prospective memory, and age.

Table 2.
Correlations between Diversion Scores and Predictors

	Age	Licence	Executive Function	PM
Diversion Score	-0.457 **	0.336	-0.527 **	0.537 **
Age	—	-0.007	0.496 ***	-0.265
Licence		—	0.025	0.132
Executive Function			—	-0.426 *

* p < .05, ** p < .01, *** p < .001. *N*=34 due to random missing data. The relationship of executive function and diversion management is negative because the cognitive metric is based on participant response times.

A linear regression using Bayesian statistical analysis was also completed to confirm the order of importance of each variable, as the final linear regression results were quite different from the pattern of bivariate correlations. Bayes Factors (BF) also demonstrated that the combination of executive function, prospective memory, and pilot license best predicted diversion performance (total BF= 131.8). Although, when the factors were examined individually, age (BF= 6.9) was a stronger predictor than license (BF= 1.5).

Finally, the relationship of diversion management to critical incidents was examined using a Pearson correlation analysis. A significant negative relationship was shown, such that more a higher number of critical incidents were associated with lower diversion management scores, r= 0.343, p=.047.

Conclusion

The present findings suggest that pilots with poorer executive functions (perhaps associated with older age), lower levels of expertise, and difficulty with prospective memory in high workload situations may be at risk for poor outcomes from unplanned diversions. Low scores for diversion management were associated with a greater likelihood of critical incidents, suggesting that diversion management assessment may also provide an indication of general risk during flight. Corroboration for these results are found in a study of self-reported incidents and accidents: O'Hare (2006) found that pilots who had experienced critical incidents, in contrast to those pilots with no history of incidents or accidents, were also significantly more likely to have experienced weather-related diversions. Either choosing not to, or showing an inability to follow ATC instructions, and quickly locating ownship and alternate airfields on a well-known aviation chart may be a warning sign to any pilot who flies cross-country.

A key finding in the present work was that cognitive factors were shown to be more informative than pilot age and experience in relation to diversion management. This superiority of cognitive assessment over pilot age was also shown in similar work examining predictors of pilot deviations during pattern flight (Van Benthem & Herdman, 2016). Thus, pilot screening for cognitive factors, such as executive functions and prospective memory for cockpit tasks may be promising methods for reliable identification of at-risk pilots. Understanding the role of pilot factors in identifying those most at risk when flying an unexpected diversion can better prepare pilots for these rare events, and inform customized learning opportunities during check rides and flight instruction.

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