8-2011

THE EFFECTS OF WEATHER RECOGNITION TRAINING ON GENERAL AVIATION PILOT SITUATION ASSESSMENT AND TACTICAL DECISION MAKING WHEN CONFRONTED WITH ADVERSE WEATHER CONDITIONS

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Recommended Citation

Kim, Chansik, "THE EFFECTS OF WEATHER RECOGNITION TRAINING ON GENERAL AVIATION PILOT SITUATION ASSESSMENT AND TACTICAL DECISION MAKING WHEN CONFRONTED WITH ADVERSE WEATHER CONDITIONS" (2011). *All Dissertations*. 754.
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THE EFFECTS OF WEATHER RECOGNITION TRAINING ON GENERAL AVIATION PILOT SITUATION ASSESSMENT AND TACTICAL DECISION MAKING WHEN CONFRONTED WITH ADVERSE WEATHER CONDITIONS

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Industrial Engineering

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by
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August 2011

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ABSTRACT

Previous general aviation (GA) accident studies showed that decision errors were more associated with fatal GA accidents than other kinds of human errors, and weather-related accidents, especially continued visual flight rules (VFR) flight into instrument meteorological conditions (IMC), remained the major cause of fatal GA accidents. Thus, finding the underlying causes of GA pilots' decision errors and continued VFR flight into adverse weather conditions are needed to reduce weather-related GA accidents as well as fatal GA accidents.

Causal factors and hypotheses of weather-related GA accidents show that knowledge, experience, motivation, and weather information frequently have been referred as causal factors of weather-related GA accidents. Among causal hypotheses, situation assessment and risk assessment hypotheses have been cited frequently as the causes of weather-related GA accidents.

The purpose of this study is to evaluate the effects of weather recognition training on GA pilots' situation assessment and tactical decision making under gradually aggravating weather conditions. To meet this purpose, WeatherWise and an X-Plane 9 flight simulation program has been used. WeatherWise is a computer-based weather training program developed by Wiggins et al. (2000) to improve GA pilot weather-related decision making, and was approved by the Federal Aviation Administration (FAA) for free public use.

Pilot situation assessment is a pilot's understanding of a current flight state, and was evaluated in terms of weather assessment and risk assessment. Weather assessment is

the pilot’s ability to recognize or estimate the changes in visibility, ceiling, and weather condition. Risk assessment is the understanding of the risks associated with flying in adverse weather conditions, and was measured in terms of risk perception and risk tolerance using the Hazardous Event Scale, personal weather minimums, and the Aviation Safety Attitude Scale. Pilot situation assessment was measured by a post-experiment questionnaire.

Pilot tactical decision making is in-flight judgment, and was evaluated in terms of decision accuracy and decision confidence. Decision accuracy was evaluated by measuring the distance that a pilot has flown from an optimal divert point to an actual divert point, and the distance a pilot has flown into adverse weather conditions. Decision confidence is the pilot’s confidence level in making diverting decisions when the pilot encounters adverse weather, and was measured by subjective rating method.

Findings of the study indicated that the WeatherWise training group exhibited significantly higher weather assessment as measured by ceiling estimation ability and decision accuracy as measured by flown distance into adverse weather condition than the control group, but no significant differences were found in their risk assessment and decision confidence. Although the effects of weather training on the risk assessment were not significantly different between the two groups, participants in the WeatherWise training group was more conservative toward flying into adverse weather condition than the control group.

It was hypothesized to find a positive relationship between pilots’ situation assessments and their tactical decision-making because situation assessment forms a basis

for decision making; however, positive relationship was found only between pilots' ceiling estimation and flown distances into adverse weather in this study. Thus, it can be concluded that the weather training was effective at least in part to pilot situation assessment and tactical decision making. In addition, considering the weather training was just one-time 30 minute training, long-term effects of weather training should be conducted to find further relationship between pilot situation assessment and tactical decision making.

The results of this study can be expanded not only to GA pilots but also to commercial airline pilots and military pilots for various reasons. First, all pilots are expected to acquire weather recognition skills and knowledge to ensure a safe flight regardless of their flight types because the nature of weather condition changes is dynamic and hard to predict during the flight. Second, although those aircrafts are well equipped with navigation aid systems and weather display radar, they do not provide real-time weather information, and they sometimes malfunction.

In conclusion, it is expected that this study will be helpful for GA pilots to understand the effects of weather recognition training on weather decision-making, and eventually help them assess a situation correctly and make a timely in-flight decision. It is believed that this study will help to establish a sound foundation for weather training program and has the potential to reduce weather-related GA accidents by implementing weather training during flight training.

ACKNOWLEDGMENTS

First, and foremost, this work would not have been possible without God's will. Many obstacles were overcome by the gifts of excellent mentors and the encouragement of my family and friends at the right time and place I needed those gifts most.

My sincere gratitude goes to my advisor, Dr. Scott Shappell, for his guidance, encouragement, and support throughout this work. I may not have finished my work in a limited time period without his understanding of my situation and devotional support. I am very grateful to other committee members, Drs. Anand Gramopadhye, Cho, and Wiegmann for their expertise, time, and advice.

I would like to thank the general aviation pilots who participated in this study. Especially, I would like to give special thanks to Jongchul (Alex) Park, manager of the Mint Air, for participating in the experiment as well as helping me recruit additional general aviation pilots.

Lastly, but not least, I would like to thank my family in Korea for their continuous support and love. My utmost appreciation and thanks goes to my lovely wife, Jung-a, who waited and supported me in various ways throughout the completion of my dissertation. I thank to my children, Jihoo, Hwanhee and Heeyul, for making me happy and proud as their father. My sincere thanks also go to Yuan-Han, my sincere friend, for his help and encouragement from Buffalo to Clemson.

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CHAPTER ONE

INTRODUCTION

Overview of General Aviation (GA) Accidents

General aviation (GA) accidents represented 70 to 90% of all aviation accidents (ATSB, 2007; Lenne et al., 2008; Li & Baker, 2007), as well as 73% of the fatal accidents that occurred in 2007 (AOPA, 2008). However, little attention has been paid to GA accidents as compared to commercial aviation accidents and military aviation accidents (Shappell & Wiegmann, 2003b), because the majority of the world's air traffic fall into the GA category, and most GA operations were for personal flight (39.4%).

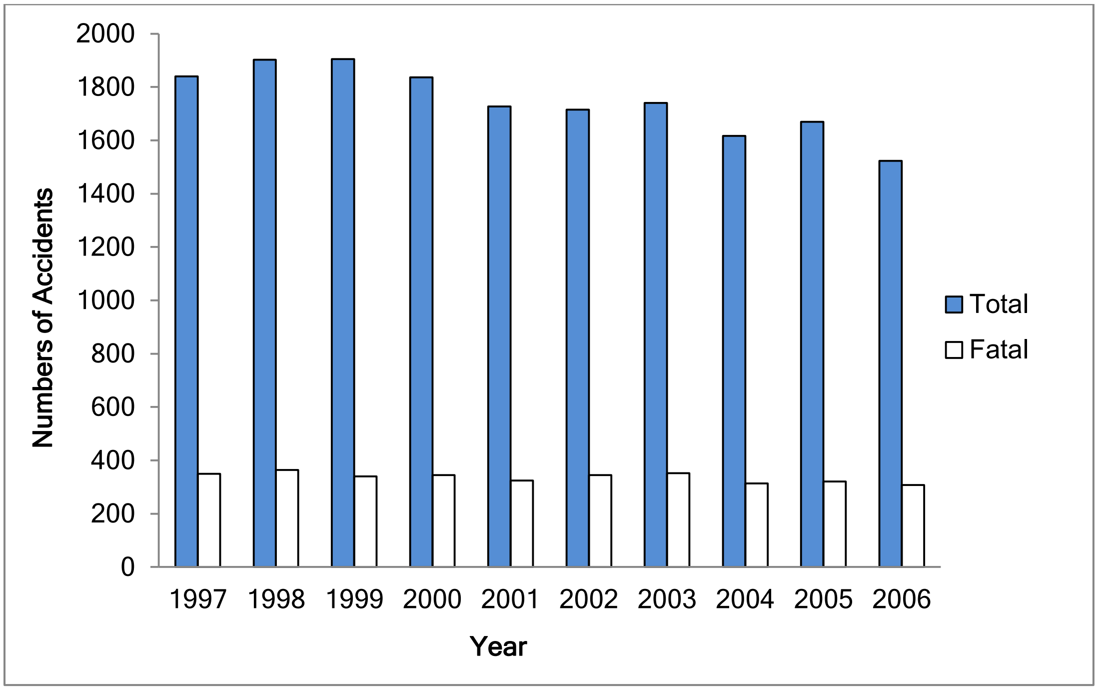


Figure 1.1 Annual Numbers of General Aviation Accidents (NTSB, 2010)

The development of aviation industry technology and navigational aid systems enabled pilots to fly safer when compared with pilots who flew 50 years ago, and the portion of GA accidents has decreased slightly during the last 10 years. However, the rate of fatal GA accidents is almost the same (Figure 1.1; AOPA, 2008; NTSB, 2010).

According to the National Transportation Safety Board (NTSB) report (2005), 6% of all GA accidents were weather-related, and 70% of them were fatal accidents that led to approximately 25% of all GA pilot fatalities (Ball, 2008). This finding was similar to what Li and Baker (2007) found, as they showed that even though the portion of adverse weather conditions caused only 9% of GA accidents, it claimed 28% of pilot fatalities. Most often, these weather-related fatal GA accidents resulted from pilots' decision to continue visual flight rules (VFR) flight into instrument meteorological conditions (IMC) (Figure 1.2; AOPA, 2009). Thus, the causes of GA accidents as well as weather-related GA accidents need to be understood clearly to reduce GA pilot fatalities.

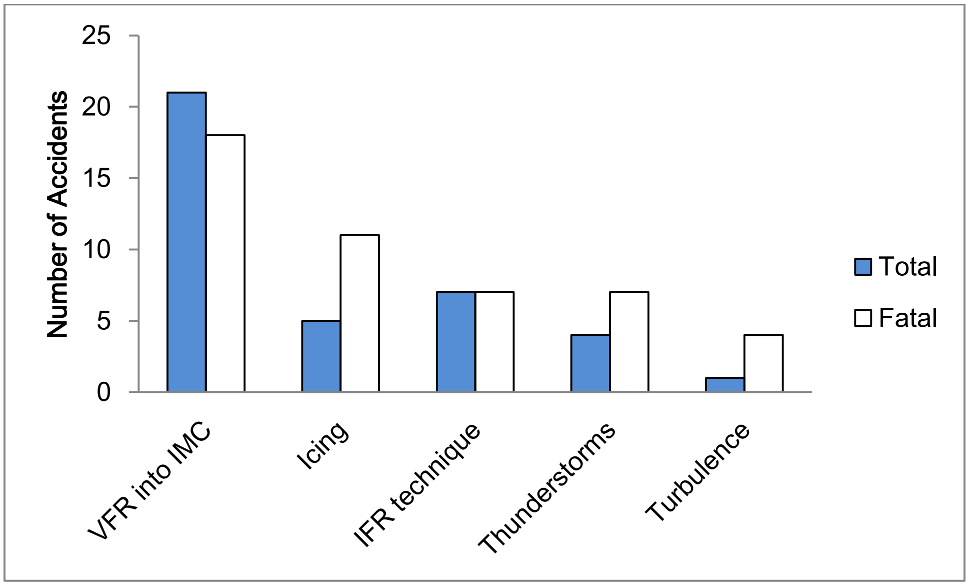


Figure 1.2 Types of Weather Accidents in 2008 (AOPA, 2009)

Causes of GA Accidents

Previous GA accident studies were focused mostly on either human error or the causal factor approaches. Human errors have been deemed to be contributing factors to 70-80% of all aviation accidents (Adams & Thompson, 1987; Dinges, 1995; Nagel, 1988; Wiegmann & Shappell, 2007), as well as 70-85% of the GA crashes (Sawyer & Shappell, 2009; Li et al., 2001; Li and Baker, 2007; Shappell & Wiegmann, 2003b), and can be classified into skill-based errors, decision errors, perception errors, and violations.

Shappell and Wiegmann (2003b) analyzed 14,571 GA accidents that occurred between 1990 and 1999 in the United States, and found that skill-based errors (80%) were the most prevalent, followed by decision errors (36%), violations (32%), and perceptual errors (less than 10%) (Figure 1.3). Although the portion of skill-based errors were the highest, decision errors were related more to fatal GA accidents (Adams & Thompson, 1987; Jensen & Benel, 1977; O’Hare, 1990).

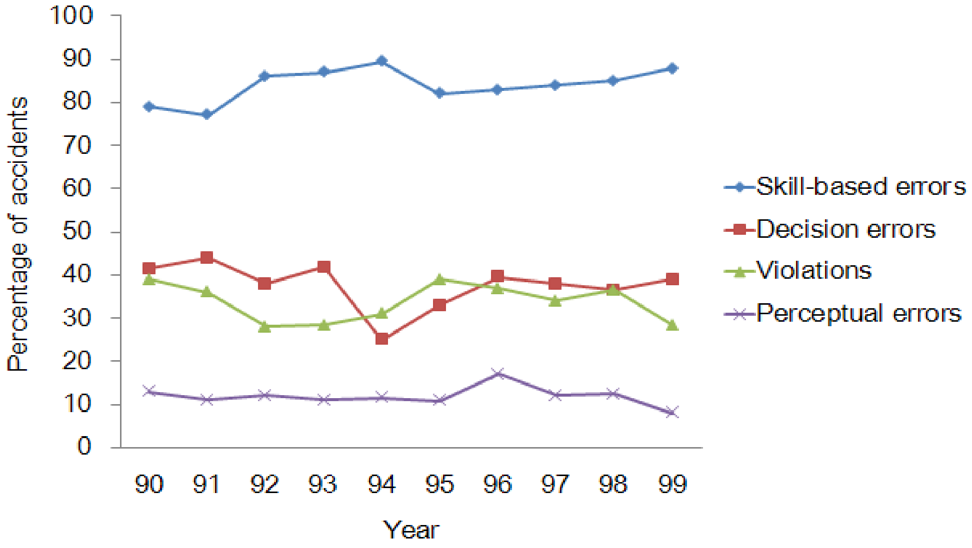


Figure 1.3 Percentages of GA Accidents by Each Unsafe Act

The Australian Transportation Safety Bureau (ATSB) accident data analysis (2007) from 1993 to 2002 showed similar results. The portions of the aviation accidents were the highest in skill-based errors (87%), followed by decision errors (30%), violations (6%) and perception errors (5%). However, the portion of decision errors and violations in the fatal accidents were much higher than that of non-fatal accidents. Overall, reducing skill-based errors might be the most effective way to reduce the entire accident rate; however, decision errors and violations appeared to be more related to the fatal aviation accidents and continued VFR flight IMC (Giffin & Rockwell, 1987). Thus, it can be assumed that pilot's good decision making and judgment is crucial to reducing fatal aviation accidents (Barnett et al., 1987; O'Hare, 1992).

Besides the human error approaches, there have been causal factor approaches to understand GA accident studies. Giffin and Rockwell (1987) asserted that pilots' continued VFR into adverse weather conditions ranked as the highest cause for all GA accidents, and often led to spatial disorientation, which is the second major cause of the fatal accidents. Surveys of GA pilots (Hunter, 1995; O'Hare & Chalmers, 1999) also showed that VFR flight into IMC is a major safety concern in GA, and revealed that approximately one out of four GA pilots experienced VFR into IMC, with 4% having done so multiple times (Pauley et al., 2008).

Using NTSB statistics from the timeframe of 1982 to 1999, Craig (2001) found 12 frequent causes of GA accidents, three of which coincided with studies done by other researchers. The three factors are: continued VFR flight into IMC (AOPA, 2008; Coyne et al., 2005; Crognale & Krebs, 2008; Goh & Wiegmann, 2001a; Knecht et al., 2003;

O'Hare & Smitheram, 1995; Pauley et al., 2008; Wiggins & O'Hare, 2003a), loss of situation awareness (SA) (Adams & Thompson, 1987; Endsley & Garland, 2000; Molesworth et al., 2006), and pilot health and physiology (Higdon, 2009; Salazar, 2007; Taneja & Wiegmann, 2002).

Beard and Geven (2005) assessed 68 Aviation Safety Reporting System (ASRS) reports between 1995 and 2005, and found that poor weather assessment, distraction, and overestimation of piloting capabilities were the major factors to aircraft upset. Among them, poor weather assessment was the major causal factor that led to GA ASRS reports.

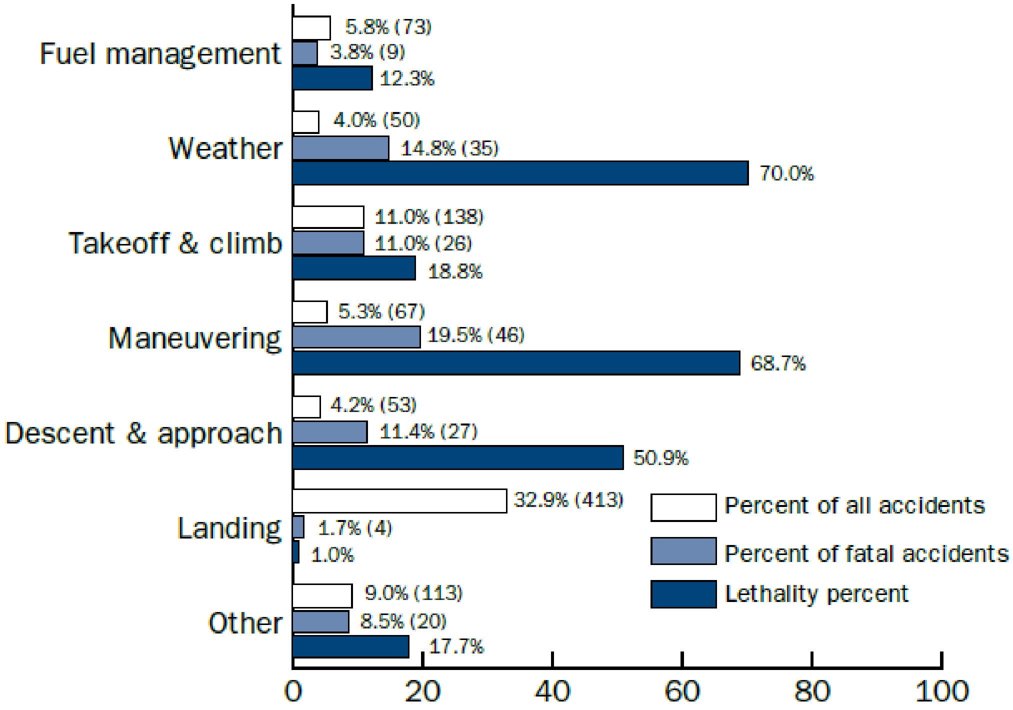


Figure 1.4 Types of Pilot-Related GA Accidents (AOPA, 2008)

The Aircraft Owners and Pilots Association (AOPA) accident trends and factors (2008) also showed that weather caused the highest portion of the fatality in GA accidents (Figure 1.4), and continued VFR flight into IMC was the main cause of fatalities among weather-related accidents (Batt & O'Hare, 2005; Coyne et al., 2008; Craig, 2001; Li & Baker, 2007; Wiggins, 1999).

In summary, previous GA accident studies showed that decision errors were associated more with fatal GA accidents than other kinds of human errors, and weather-related accidents, especially continued VFR flight into IMC, remained the major cause of fatal GA accidents (Figure 1.5). Thus, finding the underlying causes of GA pilots' decision errors and continued VFR flight into adverse weather conditions are needed to reduce weather-related GA accidents as well as fatal GA accidents.

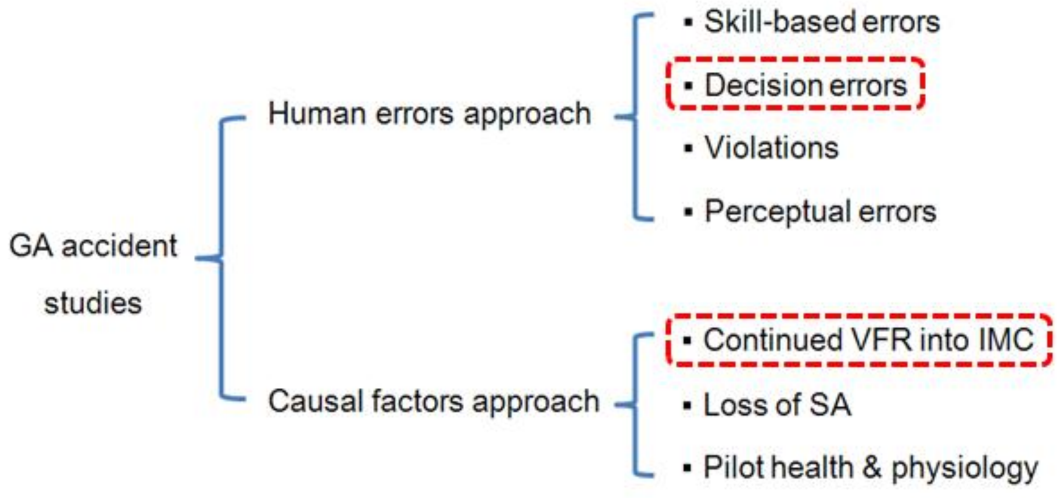


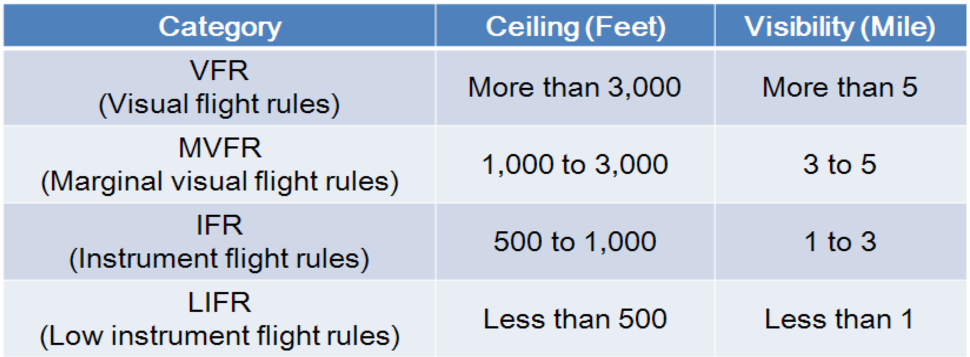
Figure 1.5 GA Accident Studies

Weather-Related GA Accidents

Previous human error studies and causal factor studies of GA accidents showed that decision errors and weather-related accidents were the two main causes of fatal GA accidents. Therefore, it is important to learn why GA pilots commit such frequent weather-related accidents. Specifically, do pilots' decision errors affect weather-related accidents?

Pilots need to follow flight rules to fly an aircraft in a certain weather condition. The Federal Aviation Regulations (FARs) established guidelines for pilots about what the predominant flight visibility should be, and how far the airplane should remain away from the ceiling. The ceiling is the lowest layer of clouds, and is reported as above ground level (AGL) (Coyne et al., 2008). Visibility is the greatest distance at which an object can be seen and is reported as status mile (SM) (International Civil Aviation Organization , 2002). Cloud ceiling and visibility minimums vary, depending on the airspace in which the pilots are flying. In general, if the ceiling is more than 1,000 feet AGL, and the visibility is three miles or more, the weather is VFR. However, if the ceiling is less than 1,000 feet AGL, and the visibility are less than three miles, the weather is instrument flight rules (IFR). This classification can be further categorized into marginal visual flight rules (MVFR) and low instrument flight rules (LIFR), according to the weather minimums. Table 1.1 shows the weather minimums by flight category (FAA, 2006).

Table 1.1 Ceiling and Visibility Minimums by Flight Category



Category	Ceiling (Feet)	Visibility (Mile)
VFR (Visual flight rules)	More than 3,000	More than 5
MVFR (Marginal visual flight rules)	1,000 to 3,000	3 to 5
IFR (Instrument flight rules)	500 to 1,000	1 to 3
LIFR (Low instrument flight rules)	Less than 500	Less than 1

However, because of the limitations of time and money required to get the IFR qualification, many GA pilots are only VFR qualified. Thus, when VFR-only qualified GA pilots encounter IMC, they are not allowed to fly into IMC. Still, many GA pilots continue VFR flight into instrument flying weather condition for various reasons, and 75% of pilots who were involved with VFR into IMC accidents were not qualified for IFR flight (AOPA Air Safety Foundation, 1996). Many factors and hypotheses have been suggested to explain such pilots' behaviors.

Burian et al. (2000) analyzed 276 ASRS incident reports involving in-flight encounters with weather, and asserted that even though pilots notice deteriorating weather cues early, they tend to stick to their original flight plan. These authors termed such behaviors as plan continuation events (PCE), and suggested four factors that could cause such actions as lack of weather knowledge and experience, lack of correct weather information, time pressure, and organizational or social pressure.

Capobianco and Lee (2001) examined 1,520 GA accidents' data from 1995 to 1998, and found that "VFR into IMC" and "flight into adverse weather" were two common causes of weather-related GA accidents. They also found that the weather-related causal factors associated with the fatal accidents were low ceiling, fog, wind, and night.

O'Hare and Owen (2002) examined the GA air crash data in New Zealand between 1988 and 2000, and proposed over-confidence, faulty risk perception, lack of awareness, and sunk costs as the causes of fatal GA crashes. The sunk cost hypothesis predicts that pilots who encounter adverse weather late in the flight are more likely to continue flying than pilots who encounter adverse weather early in the flight, because the former might have spent more time, money, and effort. Thus, the greater the sunk cost, the further pilots will fly through adverse weather (Knecht et al., 2005). In their study, pilots who were involved in weather-related GA crashes flew closer to the destination airport as compared with pilots who were involved in non-weather-related crashes, which indicated that the sunk cost hypothesis can be more explanatory of weather-related GA accidents.

Weather-related GA accidents were not only associated with an individual causal factor, but multiple causal factors and their interaction effects. Knecht et al. (2003) investigated the effects of ground visibility (three levels), cloud ceiling (two levels), and financial incentive (two levels) on GA pilots' voluntary takeoff into adverse weather. Sixty participants were instructed to fly under VFR weather conditions, but there were no statistically significant main effects between the three factors. Instead, there were significant interaction effects between the three factors, which indicated that combinations of these factors might drive a pilot to make a decision. Knecht et al. (2005) tested 60 GA pilots' willingness to takeoff into adverse weather conditions using a high-fidelity flight simulator. These authors classified the causal factors of weather-related decision errors into interior factors and exterior factors. Interior factors were related to the pilot's perceptual and cognitive factors, such as knowledge, risk perception, overconfidence, and the sunk cost effect. Exterior factors included environmental factors such as visibility, ceiling, and financial incentive. The results indicated that a pilot's takeoff in adverse weather conditions was more predictable when the interactive effect of visibility and ceiling was considered together than when the linear effect of each factor was considered separately.

Wiegmann et al. (2008) also asserted that many accidents were not associated with a single factor alone, but with a combination of factors. They analyzed previous aviation accidents and incidents involving VFR into IMC, and found that weather-related causal factors were involved with a lack of weather knowledge and experience to fly safely in adverse weather, failure to complete pre-flight planning, limited weather evaluation skills, poor risk assessment, overconfidence, and poor in-flight planning.

Some researchers suggested hypotheses to explain the causes of weather-related GA accidents. Goh and Wiegmann (2001b; 2002a) conducted a comprehensive review of the NTSB GA accident statistic data between 1990 and 1997, and suggested four hypotheses to explain a pilot’s continued VFR flight into IMC: situation assessment, risk perception, decision framing, and social pressure. They also found the top 10 causal factors of VFR flight into IMC, three of which were weather conditions (70%), terrain conditions (25%), and spatial disorientation (24%).

Beard and Geven (2005) suggested three reasons for the pilot’s risky behavior of taking off in adverse weather conditions: underestimation of the risk level, lack of experience, and frequency gambling. Frequency gambling refers to one’s expectant attitude of success in a risky situation. In aviation, pilots sometimes are motivated to fly in an adverse weather after seeing other pilots’ success in taking off, although one pilot’s successes do not guarantee another’s success in takeoff.

Sawyer and Shappell (2009) divided 60 participants into three equal groups of 20 based on their flight experience: non-pilots (no flight experience), low-time pilots (less than 500 flight hours), and high-time pilots (greater than 500 flight hours). They assessed how experience and training affect pilot weather decision-making accuracy, response bias, and visual scan paths. To meet this purpose, the authors showed all participants 10 randomly-chosen weather pictures taken in the sky, and asked them whether they would continue to fly, or divert the flight if they encountered the weather condition in the pictures. Participants then completed the WeatherWise training program, and measured visual scan paths using an eye tracker while seeing another 10 randomly-selected weather pictures. Finally, all participants viewed the first 10 weather pictures again, and were asked the same questions. The findings showed that weather training did not improve participants' decision accuracy, but there was significant shifts of conservation bias towards not continue flying into adverse weather.

In summary, many causal factors and hypotheses of weather-related GA accidents have been suggested in previous studies (Table 1.2). It can be seen that interior factors, such as knowledge, experience, and motivation, and exterior factors, including weather information, frequently have been referred as causal factors of weather-related GA accidents.

Among causal hypotheses, situation assessment and risk assessment hypotheses have been cited frequently as the causes of weather-related GA accidents. This classification is in line with Coyne et al.'s (2008) study, which presented situation assessment and improper motivation as the major causes of GA accidents. Improper motivation or misplaced motivation can be classified as the lack of risk assessment of pilots, in that pilots sometimes are overconfident in their abilities and do not fully consider the associated risks of flying in bad weather conditions. Most of the causal factors and hypotheses mentioned were suggested from accident analysis studies, and only a few were suggested from empirical studies.

Table 1.2 Causes of Weather-Related GA Accidents

Causes / Authors	Factors							Hypotheses			
	Knowledge	Skills	Experience	Motivation	Personality	Flight Planning	Weather Information	Situation assessment	Risk assessment	Decision framing	Sunk cost
O’Hare (1990)	O	O						O	O		
Burian et al. (2000)	O		O	O			O	O			
Latorella & Chamberlain (2001)			O		O		O	O			
Goh & Wiegmann (2002a)				O				O	O	O	
O’Hare & Owen (2002)								O	O		O
Adams et al. (2002)	O			O				O	O		
Wiggins & O’Hare (2003b)		O	O	O						O	
Beard & Geven (2005)	O	O	O	O			O	O	O		
Coyne et al. (2005)			O					O	O	O	
Knecht et al. (2005)	O			O					O		O
Ball (2008)			O	O			O	O	O		
Wiegmann et al. (2008)	O	O				O	O	O	O		
Sawyer & Shappell (2009)	O		O	O		O	O	O	O		O

Purpose

This study addresses issues concerning the effects of weather recognition training on GA pilots’ situation assessment and tactical decision making when encountered adverse weather conditions. For this purpose, WeatherWise was used as a weather training program and the X-Plane 9 flight simulation program was used to measure the pilots’ situation assessment and in-flight judgment in a dynamic and uncertain flight environment.

WeatherWise is a computer-based weather decision-making training program developed Wiggins et al. (2000), and the program was approved for free public use by the Federal Aviation Administration (FAA). The validity of WeatherWise was examined by Wiggins and O’Hare’s empirical study (2003b), in which the authors found that those who received training with the WeatherWise program could improve timely weather-related decision making during VFR flight.

However, previous studies dealing with the WeatherWise training program had several limitations. First, the weather conditions used in WeatherWise were clearly different from each stage, and quite easy for a pilot to find the optimal divert point. Thus, it is not clear whether WeatherWise is effective in a gradually aggravating weather condition. Second, pilots did not actually control the flight, but just saw the weather conditions, and chose an optimal divert point. This might lack the reality of flying, and truly may not represent the workload imposed on pilots. Including Wiggins and O’Hare’s (2003b) study, previous studies using the WeatherWise program showed participants short video clips (Coyne et al., 2008) or static images (Ball, 2008; Sawyer & Shappell, 2009; Wiggins & O'Hare, 2003a) to simulate flight environment, and participants were asked to choose either to continue or to divert the flight at seeing the video clips or static images. Third, the concept of situation assessment was not defined clearly, and was used interchangeably with situation awareness (Fracker, 1988), decision accuracy (Sawyer & Shappell, 2009), self-assessment of hazard attitude (Wiggins et al., 1995), or estimation of the weather conditions (Wiggins & O'Hare, 2003b; Wiegmann et al., 2002). To solve the above-mentioned limitations and simulate one step close to the real flight environment, pilots' situation assessment and tactical decision making were measured using a questionnaire and the flight simulation program in a gradually aggravating weather condition. Table 1.3 shows detailed measurement methods of situation assessment and tactical decision making.

Table 1.3 Situation Assessment and Tactical Decision Making

	Categories	Explanation	Method
Situation Assessment	Weather Assessment	Estimation of visibility, ceiling, and weather condition	Questionnaire
	Risk Assessment	Risk perception and risk tolerance	
Tactical Decision Making	Decision Accuracy	Distance from an optimal divert point to an actual divert point	Flight simulation program
		Distance flying into adverse weather condition	
	Decision Confidence	Confidence level in making divert decision	Questionnaire

Pilot situation assessment is the pilot's understanding of a current state, and was measured in terms of weather assessment (Coyne et al., 2008; Goh & Wiegmann, 2001a;

Sawyer & Shappell, 2009) and risk assessment (Coleman & Marks, 1999; Hunter, 1995; 2002b; Latorella & Prabhu, 2000).

Weather assessment is the pilot's ability to recognize or estimate the changes in visibility, ceiling, and weather condition, and was considered to measure pilots' situation assessment because pilots may not fly into adverse weather if they have read the weather conditions correctly. Risk assessment is the understanding of the risks associated with flying in adverse weather conditions, and was measured in terms of risk perception and risk tolerance. Risk assessment was included in the pilot situation assessment categories because poor risk assessment may lead pilots to press on into adverse weather (Jensen & Benel, 1977; O'Hare, 1990). Risk assessment was measured using the Hazardous Event Scale (HES; Hunter, 1995), personal weather minimums, and the Aviation Safety Attitude Scale (ASAS; Hunter, 1995). Situation assessment and tactical decision making were measured by a post-experiment questionnaire.

Pilot tactical decision making is associated with pilot's in-flight decision to continue flight (Coyne et al., 2008), and was evaluated in terms of decision accuracy and decision confidence (Bliss et al., 2005; Wiggins & O'Hare, 2003). Decision accuracy was evaluated by measuring the distance that a pilot has flown from an actual divert point to an optimal divert point, and the distance a pilot has flown into adverse weather condition. Decision confidence is the pilot's confidence level in making diverting decision when he encounters adverse weather. Decision confidence was considered because pilots' situation assessment and decision confidence are required to improve pilot decision making (Lichacz & Farrell, 2005). Decision confidence was evaluated using subjective rating method after the experiment. It was expected that the pilots' confidence level in making the decision to divert in adverse weather conditions will be high if they receive weather recognition training and correctly recognize the deteriorating weather condition.

Whereas strategic decision making is forward thinking made on the ground in pre-flight planning, tactical decision making is real-time judgment made in-flight. It was assumed that this study will find a positive relationship between a pilot's situation assessment and his tactical decision making.

In this study, using the flight simulation program, GA pilots made a simulated cross-country flight from the North Central West Virginia Airport (KCKB) in West Virginia to the Louisa County/ Freeman Field Airport (KLKU) in Virginia as long as they assumed that they did not violate VFR conditions in gradually deteriorating weather conditions. When pilots encountered IMC, they were not allowed to continue the flights, and should divert to the alternative airports that they think optimal. The experiment was terminated when a pilot began to divert to an alternative airport, lost control of the aircraft, or crashed on the terrain.

CHAPTER TWO

LITERATURE REVIEW

General Aviation (GA)

GA Classification

The Federal Aviation Administration (FAA) classifies civil aviation into three groups (Figure 2.1): GA, major airlines, and commuter air carriers and air taxis. The GA classification includes all non-commercial aircraft flying under Title 14, Code of Federal Regulations Part 91 (14 CFR Part 91). The major airlines include commercial aircraft operating under 14 CFR Part 121, and the commuter air carriers and air taxis consist of scheduled and on-demand commercial flights of aircraft with 30 or fewer seats operated under 14 CFR Part 135 (Li et al., 2003; Shappell & Wiegmann, 2003b).

The NTSB (2006, p.2) defined GA as, "any civil aircraft operation that is not covered under 14 CFR Parts 121, 129 (foreign air carriers and foreign operators of U.S registered aircraft), and 135, commonly referred to as commercial air carrier operations."

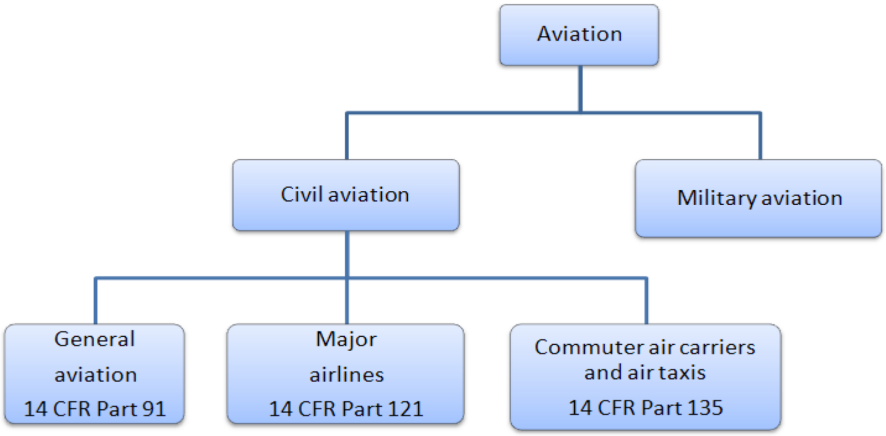


Figure 2.1 Aviation Classification

In short, GA refers to all flight other than military and scheduled airline flights, both private and commercial (AOPA, 2008). The GA flights range from gliders and helicopters to non-scheduled cargo jet flights, and comprise the largest part of aviation activities (Li & Baker, 2007).

Phases of Flight

Phases of flight can vary according to the mission of the airplane. Roskam (1998) and the FAA (1999) categorized flight phases of GA flight into takeoff, climb, cruise, descent, and landing. Detwiler et al. (2006) categorized GA flight phases into taxi, takeoff, climb, cruise, descent, approach, and landing. The AOPA (2008) categorized the flight phases into takeoff, climb, cruise, maneuvering, descent/approach, and landing. Table 2.1 shows the previous categorization of GA flight phases.

Table 2.1 Categorization of GA Flight Phases

Authors	Categorization
AOPA (2008)	Takeoff, climb, cruise, maneuvering, descent/approach, landing
Detwiler et al. (2006)	Taxi, takeoff, climb, cruise, descent, approach, landing
Schvaneveldt et al. (2001)	Takeoff, climb, cruise, transition to cruise, descent, approach, landing
FAA (1999)	Takeoff, climb, cruise, descent, landing
Roskam (1998)	Takeoff, climb, cruise, descent, landing

Summarizing previous studies, GA flight phases can be broken down into five sequential phases, which are takeoff, climb, cruise/maneuvering, descent/approach, and landing (Figure 2.2).

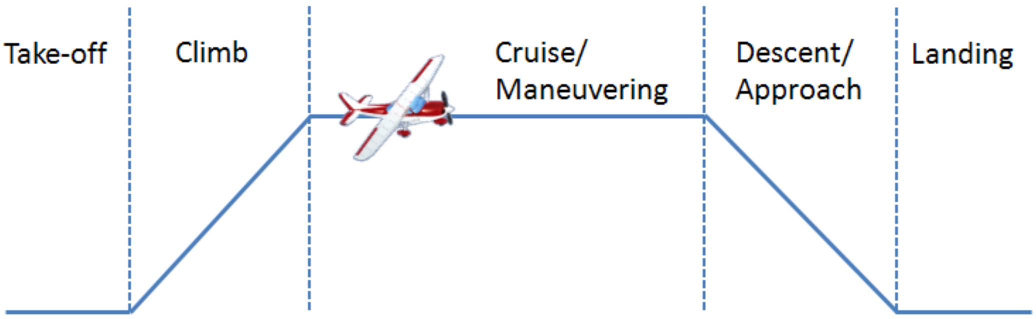


Figure 2.2 Flight Phases for General Aviation

Previous aircraft accident studies mostly focused on the takeoff and landing phases because a pilot's mental workload is the highest during them, and accordingly, many aircraft accidents happen (Dambier & Hinkelbein, 2006; Detwiler et al., 2006; Di Nocera, 2007; Wilson, 2002). However, GA accident data (Adams & Thompson, 1987; Benbassat et al., 2005; O'Hare, 1999) showed that cruise and maneuvering phases took most of the fatal aircraft accidents, and should be regarded as more important than other flight phases (Figure 2.3).

Cruise phase is a condition of flight in which pilots maintain constant heading, altitude, and speed (FAA, 1999). The GA pilots' attention might decrease as they fly in cruise phase for a long time while hearing loud and monotonous engine noise. Also, GA pilots generally spend most of the time in the cruise flight phase checking navigation information, and weather information, and accordingly, the cruise flight phase has a high chance of aircraft accidents for GA pilots (Coyne, 2004).

The vulnerability of the cruise phase in GA was shown in GA accident analysis studies. Capobianco and Lee (2001) analyzed 1,520 instances of GA accidents from 1995 to 1998 and found that 63% of fatal weather accidents occurred during the cruise phase.

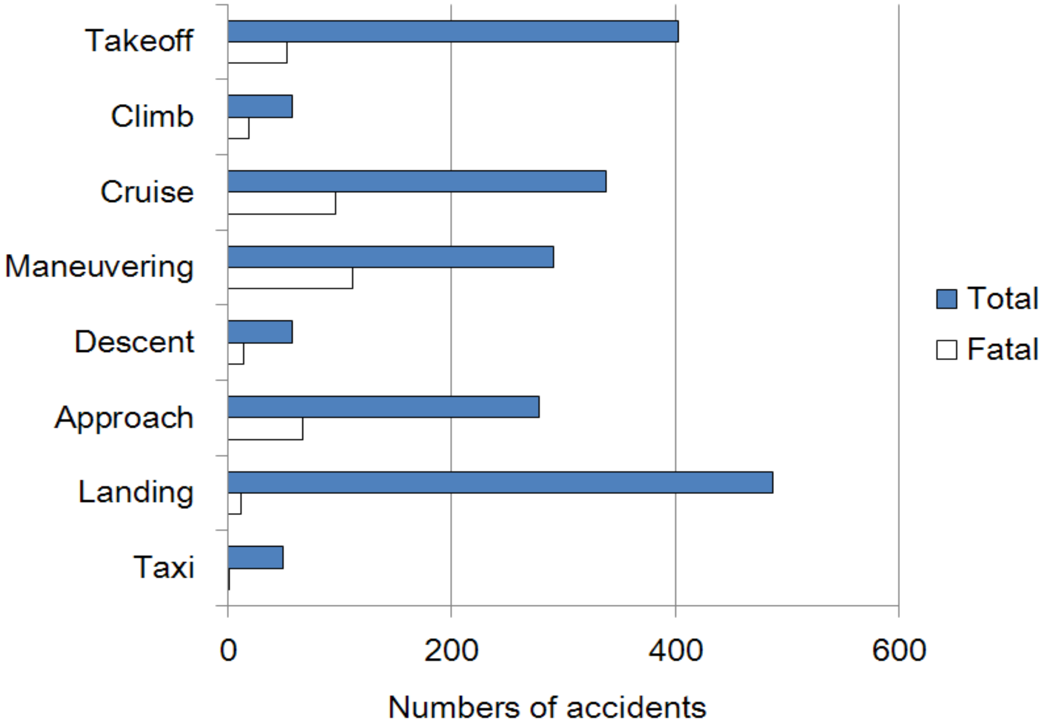


Figure 2.3 Mean Total and Fatal GA Accidents during 1995 to 1998

Similarly, Taneja and Wiegmann (2001) analyzed 70 civil aviation mid-air collision accidents that occurred between 1994 and 1999, and they found that the maximum damages of mid-air collisions occurred during cruise phase. The AOPA (2008) data also showed that cruise and maneuvering phases were among the highest safety-critical flight phases.

This was not different in questionnaire studies. O’Hare and Wiggins (2004) defined critical flight event as any situation in which unplanned action is needed to prevent incidents or accidents. They analyzed 162 surveys from Australia, New Zealand, and the United States, and found that pilots reported the cruise phase as the most frequent flight phase (45.6%) in which incidents or accidents occurred during critical flight event. Previous weather-related empirical studies found that weather also began to deteriorate in the cruise phase to simulate the real-world flying environment (Ball, 2008; Baron, 2011; O’Hare & Owen, 2002; Wiegmann et al., 2002).

GA Accident Studies

In general, GA accident rates are higher than commercial aviation accident rates or military aviation accident rates, because GA pilots have more exposure to risk. The GA pilots flew in and out of airports that are less equipped with navigation aids and emergency equipment (Craig, 2001), and they generally are less experienced than commercial airline pilots or military pilots. The causes of GA accidents have been examined by accident data analysis studies, empirical studies, and questionnaire studies.

Data Analysis Studies

Goh and Wiegmann (2001b) analyzed the data from 409 VFR into IMC GA accidents between 1990 and 1997, and found 10 contributing factors that were associated with GA pilots’ continued VFR flights into adverse weather. They categorized the GA causes into aircraft, facility, environment, flight crew, and other person. The analysis showed that the top three causes were weather conditions, terrain conditions (environment category), and spatial disorientation (flight crew category).

Li et al. (2001) examined around 30,000 aviation accidents that occurred between 1983 and 1996, and found that the IMC were associated more with pilot error regardless of operation type (commercial aviation, commuter/air taxi, and GA). These authors asserted that external factors such as weather or terrain are more associated with pilot error than internal factors such as experience.

Shappell and Wiegmann (2003a) analyzed 16,510 GA accidents that occurred between 1990 and 1998 using the Human Factors Analysis and Classification System (HFACS), and found that skill-based errors (73.5%) encompassed the highest portion of human errors in controlled flight into terrain accidents followed by decision errors (35%), violations (14.3%), and perception errors (7.7%). Wiegmann et al. (2005) analyzed 14,436 GA accidents that occurred between 1990 and 2000, and found similar results. These authors found that the odds ratio of violations associated with fatal accidents was four times higher than that of nonfatal accidents (Wiegmann et al., 2005). The results are quite consistent with Goh and Wiegmann's (2002a) study, which showed that 76% of VFR flight into IMC accidents involved pilots' intentional violations to continue flights into adverse weather.

Empirical Studies

Goh and Wiegmann (2001a) conducted an empirical study to find factors that lead to pilots' continued VFR flights into IMC. Based on Jensen's judgment model (1995), they examined factors including situation assessment, risk perception, motivation, and decision framing. These authors divided the participants into two groups (continue/divert VFR flight into IMC), and compared the possible contributing factors of continued VFR flight into IMC. The results showed that visibility estimate, risk-taking behavior frequency, skill, and judgment ratings were the most important factors in predicting pilots' continued VFR flights into IMC. Pilots who continued flying showed higher ratings of their skill and judgment, and they were more willing to take risks than those who diverted in IMC.

Wiggins and O'Hare (2003b) recruited 66 GA pilots and divided them into two groups. One group took a cue-based decision-making training called WeatherWise, and the other group did not. The authors assessed the self-reported ratings of the perceived importance of weather cues and the performance in terms of timely decision making after the experiment. The results showed that both the perceived importance of critical weather cues and the performance level were higher for the WeatherWise training group than the control group, which indicated that WeatherWise could improve pilots' timely decision-making ability during simulated cross-country flights.

Wiggins (2006) assessed GA pilots' performance on various dimensions in a simulated cross-country flight. Thirty-four pilots flew five legs of flight in visual meteorological conditions (VMC). Pilot performance was measured in terms of pilot self-report, experimenter observation, and flight simulator data. Performance dimensions were composed of aircraft control, track, altitude, fatigue management, and communication. The results suggested that performance differences between pilots were not due to recent flight experience, nor qualifications, but due to the stages (leg 1 to 5) of flight. In this study, pilot performance was lowest in the fifth leg of flight, which indicated that the combination of fatigue and mental demands may affect the pilots’ capacity to precisely control the aircrafts.

Inadvertent VFR flight into IMC was not just a major problem of fixed-wing GA. Crognale and Krebs (2008) investigated 20 civilian helicopter pilots’ flight performance using a flight simulator in an inadvertent VFR flight into IMC. In their scenario, the visibility rapidly decreased near zero, with ceilings less than 100 feet, and participants were allowed to take whatever actions they needed to cope with the changing weather conditions. Each participant flew six missions at given speeds and altitudes, and performance data were collected regarding aircraft attitude, flight performance, and pilot efforts. The findings showed that there were significant differences in pilots’ performance when flying in VMC and IMC.

Questionnaire Studies

O’Hare (1990) developed the Aeronautical Risk Judgment Questionnaire (ARJQ) to assess GA pilots’ perceptions of their abilities, willingness to take a risk, hazard awareness, and risk judgment. Forty-four licensed pilots flew a VFR flight into a marginal VFR weather condition. The ARJQ showed that young and currently active pilots showed a higher likelihood of accident involvement when compared with other pilots. The results implied that age and experience are associated with high risk and personal invulnerability.

Hunter (2002b) developed two instruments to measure pilots' risk-taking behavior: risk perception and risk tolerance. Each instrument consisted of a series of short scenario descriptions that represent risky situations and activities. In his study, 402 pilots completed the study exercises on the FAA-sponsored website. The findings showed that higher levels of experience and qualifications are related to lower levels of risk perception. These results support the zero risk theory (Summala, 1988), which suggested that as self-confidence increases, perceived risk diminishes to the point of zero. In other words, experienced pilots may feel that there is no risk at all.

Frequent Causes of GA Accidents

Weather-related

According to the NTSB report (2009), there were 4,159 weather-related accidents (21.3%) out of the 19,562 accidents between 1996 and 2005, and 3,617 of them (86.6%) were GA operations. The NASA ASRS report (2007) analysis showed that the major weather factors related to the GA accidents were ceiling lowering ceiling, reduced visibility, and deteriorating weather conditions (Figure 2.4).

Latorella and Chamberlain (2001) classified GA pilots into three groups according to their cross-country experience, and presented them with three weather cues, respectively: VMC, IMC, and Graphical Weather Information System (GWIS)-augmented IMC. The results showed that the GA pilots who were faced with VMC and GWIS-augmented IMC had better confidence ratings, perceived performance, and information sufficiency than those who were faced with IMC. Overall, this study emphasized the benefits of the GWIS to improve pilots' SA. However, there were some limitations to their study. First, the numbers of participants were too small. The authors classified six GA pilots into three groups, and only two pilots were assigned to each group. This small number of participants could lower the power of the data, and may lack representativeness for each group. Second, the participants did not perform flights by themselves; a NASA test pilot served as the pilot in command (PIC). Considering the fact that flying is complex and dynamic task, assessing pilots' decision making and SA while they are seated in passenger's seat could weaken the reality of flying environment.

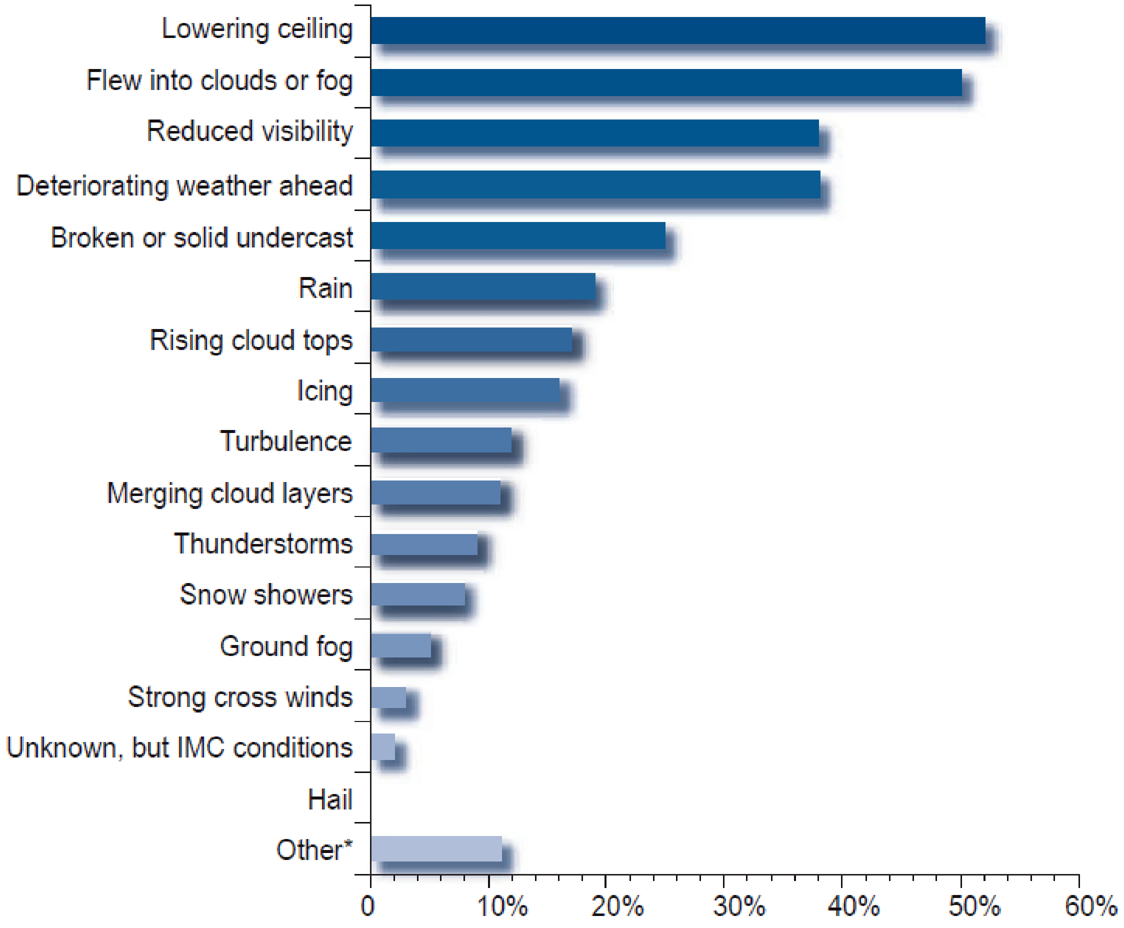


Figure 2.4 Types of GA Weather Encountered (NASA ASRS, 2007)

Adams (2002) developed a Decision Making Styles (DMS) instrument, a next-generation aeronautical decision-making training material, to identify the characteristic of high-risk pilots. The DMS is a simplified five-variable model that is composed of information resource management, influence of somatic or negative inner signals, reliance on gut reaction, less military training, and strong feeling of time pressure. The author analyzed 4,000 pilots' surveys, and found that high-risk pilots are more likely to feel time pressure, expose themselves to unsafe flying situations, misdiagnose their abilities, and not review alternative options. Adams et al. (2002) also suggested that the aforementioned variables should be used to do an initial screening test for high-risk pilots.

Wiegmann et al. (2002) studied the relationship between GA pilots' situation assessment and flight experience, and measured the time and distance a pilot traveled before diverting to an alternative airport. The GA pilot encountered IMC either early or late in the flight, and the authors studied how the location at which the pilot encounters adverse weather could affect the pilot's decision to continue the flight into adverse weather. The authors found no significant correlations between pilots' flight experience and their situation assessments in terms of estimates of visibility and cloud ceilings. Although the authors wanted to adopt the situation assessment hypothesis, they could not reveal the exact role that experience played in affecting a pilot's weather decision, and failed to examine the situation assessment hypothesis.

Wiggins and O'Hare (2003b) examined the validity of the WeatherWise program by using both a self-report assessment and a performance assessment. Participants were allowed to see short video clips and choose an optimal divert stage to an alternative airport. For the self-report assessment, pilots were asked to choose as many weather cues as they thought affected the continuation of the flight. For the flight performance assessment, pilots selected either to continue or divert the flight within ten seconds after seeing a short video clip. The findings showed that participants who were trained with the WeatherWise made better, timelier decisions when compared with control group.

Coyne et al. (2008) focused on pilot weather assessment study, because pilots' assessments of weather conditions are related to their decisions to continue flight or not. The authors conducted weather assessment in terms of estimation of the ceiling (height AGL), visibility (statute miles), and distance to the airport, using the short video clip. They showed participants five seconds of out-the window video using an overhead projector. The findings indicated that there were interaction effects between a pilot's estimate of ceiling and visibility in making a decision to continue flight.

Ball (2008) assessed the impact of training and graphical weather display on GA pilots' weather-related decisions. The author measured the time to the initial/final decision for a pilot to encounter a storm, the proximity to the storm, the number of weather inquiries, and the post-experiment ratings. He classified the participants into tactical users and strategic users (Beringer & Ball, 2004). Tactical users were those who attempted to fly to the destination, and strategic users were those who navigated at a safe distance. The results showed that both training and graphical weather display enabled pilots to make a decision sooner and maintain a safe distance from the storm.

Sawyer and Shappell (2009) conducted a study to understand the effects of experience and training on pilots' ability to identify adverse weather conditions using eye tracking method. The authors divided pilots into three groups: non-pilots, low-time pilots, and high-time pilots, and showed participants static pictures, and asked them whether they would continue the VFR flight when they encountered the weather in the picture. The authors assessed pilots' weather identification accuracy, response bias, and visual scan paths. The results showed that the WeatherWise training group showed a significant conservative response bias toward not to continue flying when they were confronted with adverse weather after being trained with the WeatherWise program, which indicated that the weather training program is related positively with weather decision making.

However, the role of experience on weather decision making was not clear in their study. Although eye tracking data showed a decrease in the number of fixations and fixation durations as expertise increased, the authors did not find a significant effect between flight experience and weather identification accuracy. Overall, WeatherWise was deemed useful in preventing pilots from flying into adverse weather conditions. However, what is required of GA pilots to assess weather conditions is to earn the skills to perceive and distinguish VFR conditions from IMC precisely, rather than to divert upon encountering the adverse weather.

Loss of Situation Awareness (SA)

Pilots may fly into an adverse weather because they may not perceive the deteriorating weather condition precisely (Batt & O'Hare, 2005). The SA of a pilot helps him to know and understand the current situation as well as predict how things will change in the future. Situation awareness was first introduced in the aviation domain, which is involved in the operation and control of a complicated system in a dynamic environment (Uhlarik, 2002), and has been extended to other domains, such as air traffic control (Endsley, 1998), driving (Kass et al., 2007, Ma & Kaber, 2005), command and control (Salmon et al., 2006), and the health care system (Gaba et al., 1995; Wright et al., 2004). Although SA is a difficult concept to define, there have been studies defining SA in aviation domains (Table 2.2; Adams et al., 1995; Gaba et al., 1995; Sarter & Woods, 1991; Vidulich, 1995).

Table 2.2 Definition of Pilot Situation Awareness

Authors	**Definition**
Adams & Thompson (1987)	The accurate perception of the factors and conditions that affect the aircraft and the flight crew during a specific period of time
Regal et al. (1988)	An integrated understanding of factors that will contribute to the safe flying of the aircraft under normal or abnormal conditions
Sarter & Woods (1991)	All accessible knowledge which can be integrated into a coherent picture, and if required, assess and cope with a situation
Endsley (1995a)	The perception of the elements in the environment within a volume of time and space, the comprehension of their training, and the projection of their status in the near future
ICAO (2002)	One’s ability to accurately perceive what is in the cockpit and outside the aircraft

Adams and Thompson (1987) defined SA as, “the accurate perception of the factors and conditions that affect the aircraft and the flight crew during a specific period of time,” and asserted that pilots who have a high level of SA are safer than those who have a low level of SA (p.11). Similarly, the International Civil Aviation Organization

(ICAO) (2002) defined SA as, “one’s ability to accurately perceive what is in the cockpit and outside the aircraft” (p.9). Regal et al. (1988) asserted that SA means that a pilot has an integrated understanding of factors that will contribute to the safe flying of the aircraft under normal or abnormal conditions. Sarter & Woods (1991) emphasized the significance of temporal dimension of SA, and defined SA as, “all accessible knowledge which can be integrated into a coherent picture, and if required, assess and cope with a situation” (p.55).

Endsley (1995a) conducted a comprehensive study on SA, and defined SA as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” which is by far the most widely-cited definition of SA (p.36). According to her SA model (1995b; Figure 2.5), there are three hierarchical levels for achieving SA: perception of the element (Level 1), comprehension of the current situation (Level 2), and projection of future status (Level 3). Level 3 SA can be achieved through Levels 1 and 2. To achieve SA, an individual must rely on perception and pattern recognition abilities (Durso & Gronlund, 1999; Kass et al. 1991), attention and working memory (Gugerty, 1997), and long-term memory (Endsley, 1995b).

Perception of element (Level 1 SA) is fundamental. Basic perception of important information increases the chances of forming a picture of the situation. For example, a pilot should perceive weather cues correctly to understand what those weather cues mean. Comprehension of the current situation (Level 2 SA) involves more than perception, and includes multiple pieces of information and the determination of their relevance to the goal. For a GA pilot, his goal might be a timely and safe arrival to the destination. Projection of future status (Level 3 SA) is the highest level of understanding of the situation. This ability allows for timely decision making, something on which experienced operators heavily rely. When a pilot suddenly encounters severe weather, he should decide whether to divert or to continue into the adverse weather to meet the goal.

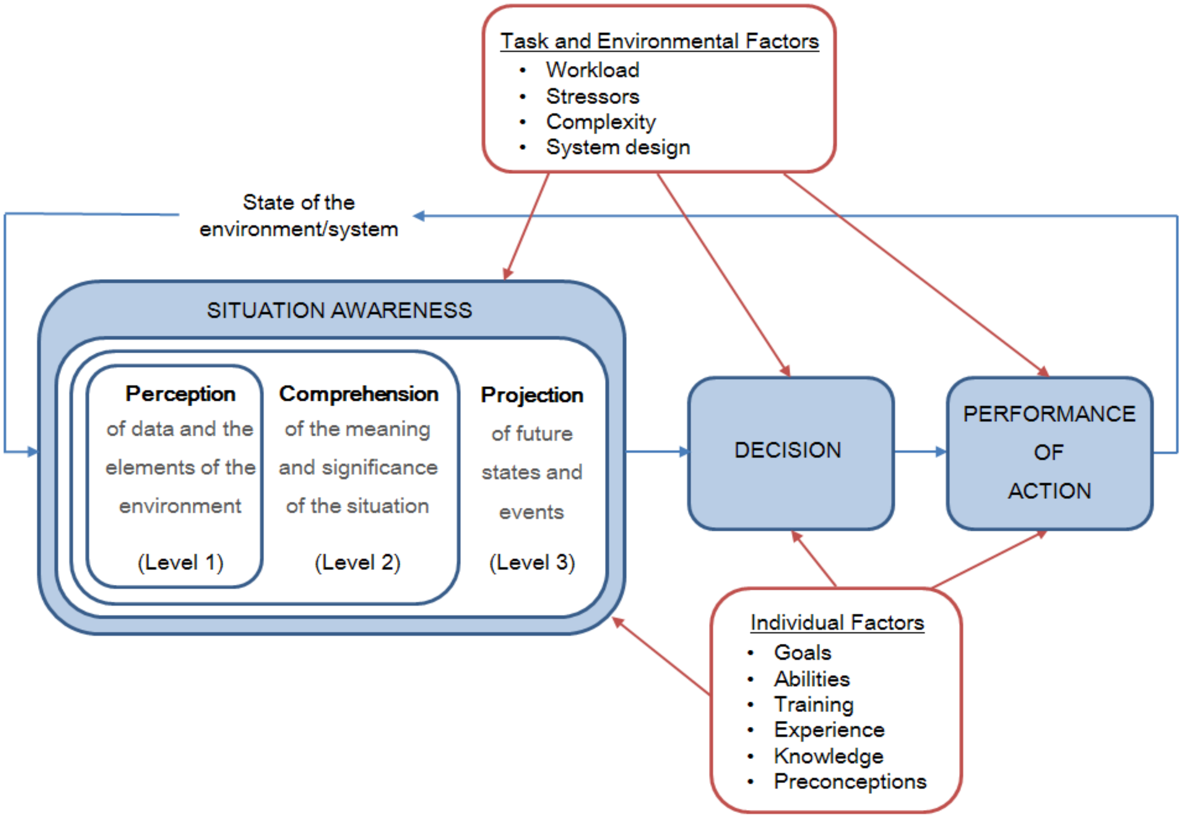


Figure 2.5 SA Model in Dynamic Decision Making (Endsley, 1995b)

In general, previous SA studies in the aviation domain have shown that pilots who have high level of SA showed better decision making and higher performance (Doane et al., 2004) than pilots who have low level of SA. Bustamante et al. (2005) examined pilots' workload, SA, and trust, in weather systems during critical weather events. The authors used the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988) to measure the workload, and the Situation Awareness Rating Technique (SART; Jones, 2000) to measure the SA. The results showed that the pilots' workload increased significantly and SA decreased as they flew closer to the weather event. Overall, previous SA studies tried to enhance pilots' SA to improve pilots' decision making.

Pilot Health and Physiology

Most causal factors studies related to pilot health and physiology entailed fatigue, alcohol or drug use, and pilot incapacitation (Craig, 2001). Among them, fatigue was regarded as the most influential physiological factor of aviation accident. Fatigue is an expected and ubiquitous aspect of life, and can be resolved with a nap or by stopping the activity that caused the fatigue. However, if the person is involved in critical safety activities such as operating a motor vehicle, piloting an aircraft, performing surgery, or running a nuclear reactor, the consequences of fatigue can be disastrous.

Fatigue was defined as, "a condition characterized by increased discomfort with lessened capacity to respond to stimulation, and is usually accompanied by a feeling of weariness and tiredness" (Salazar, 2007, p.1). Causes of fatigue range from boredom to circadian rhythm disruption to heavy physical exertion (Caldwell & LeDuc, 1988; Caldwell, 2004). Symptoms of fatigue include irritability, impatience, impaired communication and decision making, forgetfulness, increased reaction times, reduced attention, diminished memory, and withdrawn mood (Dinges, 1995; Taneja, 2007).

Akerstedt (2000) indicated that fatigue is the largest identifiable and preventable cause of accidents in transport operations. A review of data from mishaps and hazard reports between 1990 and 2008 showed that fatigue was the highest aeromedical causal factor in naval aviation (Figure 2.6; Davenport & Lee, 2007; Davenport, 2009). The NTSB also has cited fatigue as a significant contributing factor in aviation accidents, and has included it on their "Most Wanted List" of actions needed by federal agencies (Galloway & Hanks, 2008). Accident statistics, reports from the pilots themselves, and operational flight studies all showed that fatigue is a growing concern within aviation operations (Caldwell, 2005).

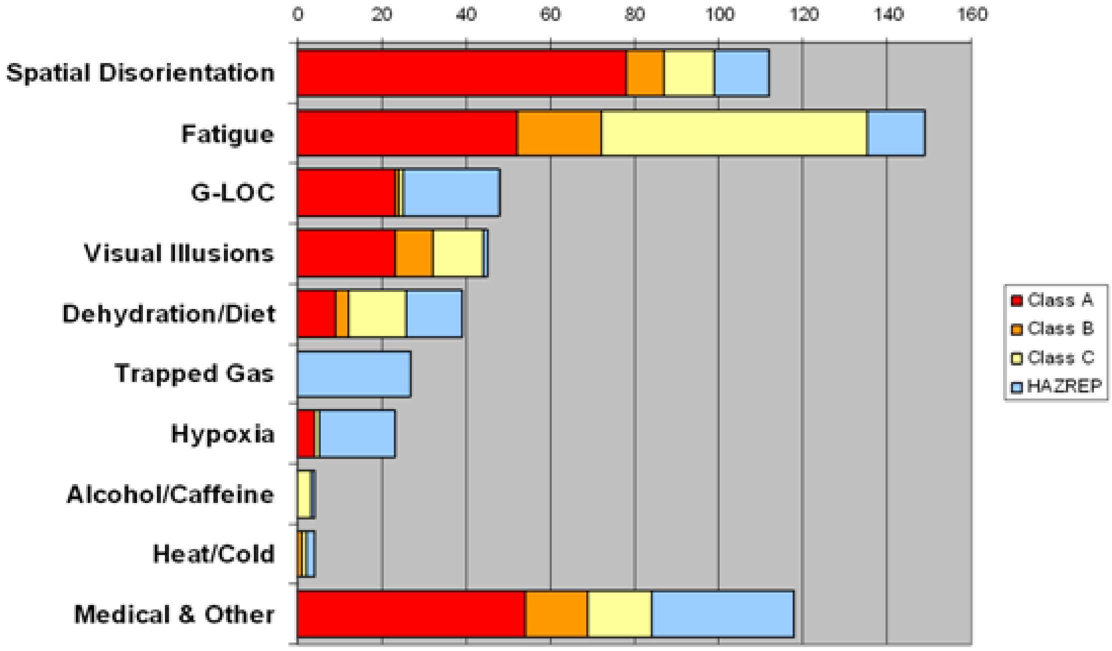


Figure 2.6 Aeromedical Causal Factors (Davenport, 2009)

Decision Making Models

People make decisions every day. Those decisions could be related to routine tasks, such as eating breakfast, or complex tasks, such as a pilot choosing an alternative airport when confronted with adverse weather conditions. Medin and Ross (1992) asserted that decision making involves risk, and a good decision maker effectively assesses the risks associated with each option. In other words, decision making is to select one option from a number of alternatives while considering the risks involved with them. In making a decision, people use multiple strategies that depend on a wide variety of task demands (Castellan, Jr., 1993).

The decision-making process generally can be represented in three phases: acquiring and perceiving relevant cues, generating and selecting situation assessments about the meaning of the cues, and planning and selecting choices based on the costs and values of different outcomes (Goh & Wiegmann, 2002b; Wickens et al., 2004). These three phases are similar to Endsley's (1995a) dynamic decision-making process, in which the three phases are awareness of the situation, making the decision, and performance of the action (Figure 2.5). However, in each phase, limited human cognitive resources can bring out biases.

In the first phase, primary cue and anchoring bias can occur. In general, pilots put more weight on the first cues they receive than cues that they receive later. This often leads pilots to anchor on situation assessment. In short, information processed early could be the most influential to pilots' decision making.

In the second phase, overconfidence can take place. Pilots tend to believe that they are correct more than they actually are, and they make decisions quickly. As a result, pilots might be less likely to prepare for the alternative choices in pre-flight planning and in-flight planning.

Finally, framing bias can happen in the action selection phase. Framing bias explains that a pilot makes a decision depending on, “how the problem is represented and what frame is used to interpret the situation” (Goh & Wiegmann, 2002a, p. 818). A well-known framing bias is sunk cost bias (Arkes & Hutzel, 2000). Sunk cost bias predicts that pilots who encounter adverse weather late in their flights will be more likely to continue flying than pilots who encounter adverse weather early, because people tend to incur greater risk when losses are involved; this is why sunk cost bias is also called escalated commitment bias (Bailey, III, et al., 2007).

The decision making model can be categorized into the classical decision making model, the naturalistic decision making model, the information processing model, and the recognition-primed decision making model, which is a kind of naturalistic decision making model.

Classical Decision Making Model

The traditional approach to understanding individual decision making is the classical decision making model, which is also known as the rational economic model (Huczynski & Buchanan, 2001). This model assumes that a decision maker is completely rational and has available all the information needed, as well as all of the alternatives, and both are considered when making a decision. A decision maker will select the optimum choice through the following strictly-defined sequence of steps in the classical decision making model: problem identification, identification of objectives with respect to problem, identification of alternative course of action, evaluation of alternatives, selection of the best alternative, and implementation (Figure 2.7; Heracleous, 1994).

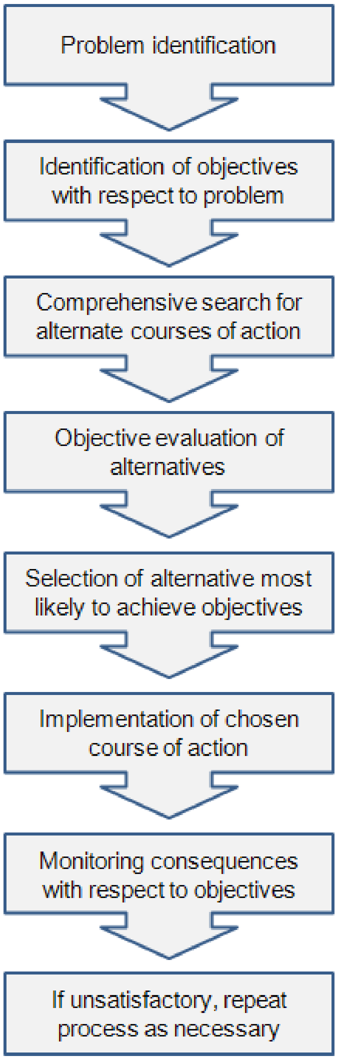


Figure 2.7 Classical Decision Making Model

However, this model has several limitations to its use in the field. First, the classical decision making model is based on the assumptions that decision makers are objective and consider all the possible alternatives, which is quite unrealistic in practice (Li, 2008), because it may take too much time to consider all the alternatives.

Additionally, a decision maker's emotions also may influence his behavior and choices (Barnes & Thagard, 1996). Second, this model does not consider the contextual factors, such as domain knowledge or experience in the decision-making process (Bailey, III, et al., 2007), which have been regarded as important human competence factors that can be acquired through training.

Information Processing Model

Wickens and Flach (1988) proposed an information processing model to explain the flow of information within the human brain (Figure 2.8). This four-stage model (Parasuraman et al., 2000) consists of short-term sensory store (STSS), perception, decision and response selection, and response execution stages.

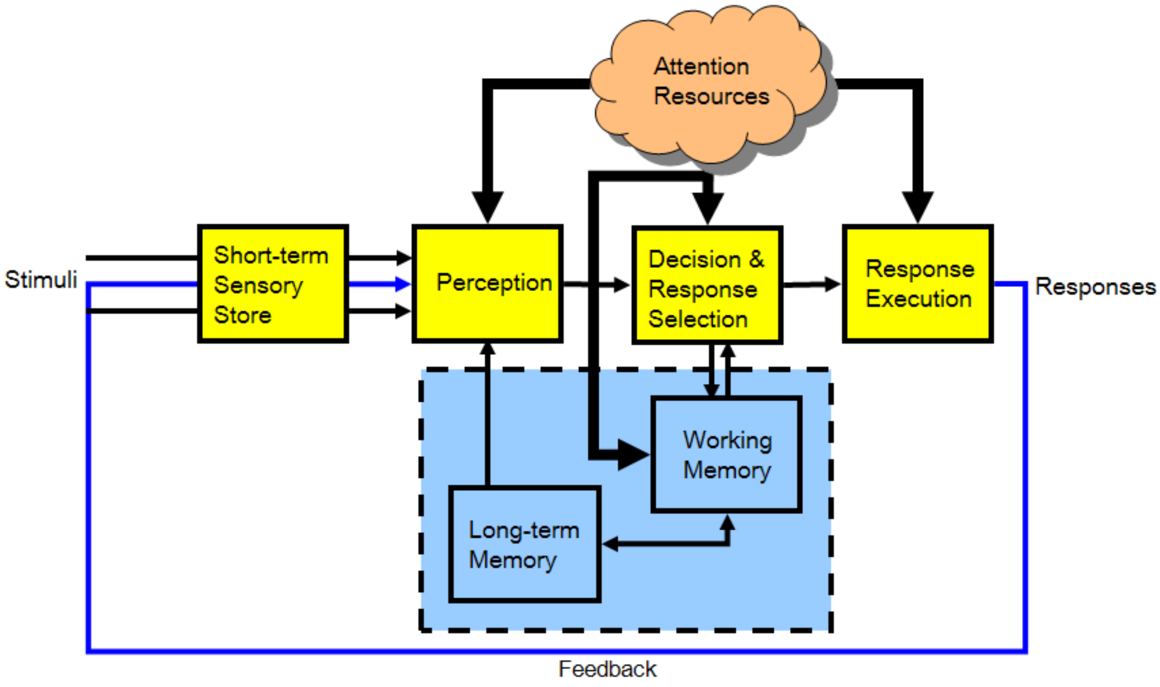


Figure 2.8 Information Processing Model (Wickens & Flach, 1988).

The STSS is a temporary mechanism for prolonging the representation of the raw stimulus evidence for a short period of time after the stimulus has terminated physically. It is pre-attentive stage and decays rapidly. Raw STSS relayed to the brain is then interpreted through the perception stage. Perception is the awareness of the elements through physical sensation, and includes the stimulus of the sensory organs through the identification of that stimulus. The decision and response selection stage is also known as the cognitive stage, and this determines the appropriate action. This stage generally requires greater time and attention when compared to the perception stage, because cognitive operations are carried out by working memory and long-term memory. Working memory is a system that must maintain information until its translation into action. Long-term memory is our storehouse of facts about the world and about how to do things. In the cognitive stage, processes begin to operate with the goal of determining the appropriate action. Finally, the response execution stage requires the coordination of the muscles for controlling motion to assure that the chosen goal is obtained correctly (Wickens & Hollands, 2000).

Naturalistic Decision Making (NDM) Model

The NDM model was first introduced in 1989, when researchers began to wonder how experienced people make decisions in natural environments or in simulations (Zsambok, 1997). Unlike the classical decision making model, the NDM model considered real-world settings that often are uncertain in regard to time constraints. For example, natural flight environments are mostly dynamic in their characteristics and aeronautical decisions are made under time pressures and uncertain situations (Orasanu & Connolly, 1993). The NDM model asserts that decision makers rely on their experience to rapidly assess the situation, and generally do not consider all the alternatives and make their responses accordingly (Bailey, III, et al., 2007). This aspect makes the NDM model different from the classical decision making model. Kaempf and Orasanu (1997) concluded that situation assessment is important to make correct and timely decisions, and needs to be supported through decision aids and training.

Recognition-primed Decision Making (RPD) Model

Similar to the NDM model, Klein (1995) suggested a recognition-primed decision making (RPD) model to know how people, especially experts, make quick and effective decisions when faced with complex situations. In this model, the decision maker is assumed to generate a possible course of action, compare it to the constraints imposed by the situation, and select the first course of action that is not rejected (Klein, 1998). The RPD model highlights three aspects of operation settings: the quality of the decision maker’s situation assessment, his/her experience level, and the use of recognition rather than an analytical decision process (Mosier & Fischer, 2010). Thus, the RPD model explains that experts do not go through an exhaustive evaluation of all the possible solutions, but rather focus on shortcuts or workable options that produce fast results using their domain knowledge. Thus, according to the RPD model, the options that experts choose may not necessarily be the best option (Klein, 1995).

Experts also draw on a vast background of experience to avoid typical decision-making bias (Wickens et al., 2004). On the contrary, non-experts rely on more deliberate decision-making processes, and go through exhaustive searches and comparisons of alternatives (Orasanu, 1997). For these reasons, the RPD model functions well under time pressure and when there is only partial information, and goals are poorly defined.

Klein (1995) asserted that the RPD model, focused on situation assessment rather than deciding on one option, is superior to other decision making models. He also asserted that people use situation assessment to generate a possible course of action, and they use mental simulation to evaluate that course of action.

The RPD model assumes that time pressure does not affect performance, because experts can use rapid pattern matching induced from past experience (Wickens et al., 2004). Thus, the RPD model is used to explain expert pilots' decision-making processes in naturalistic environments, and could be adopted to explain pilots' weather-related decision making when considering the uncertainty and dynamic weather changes of flying environments.

Decision Errors

Pilot Decision Errors

Aviation accident analysis showed that about half of the civil aviation accidents were attributed to pilots' faulty decision making (Jensen, 1982). Driskill et al.'s (1997) study also suggested that pilots' decision errors are one of the two most frequently cited causes of GA accidents. Pilots' decision errors result from a variety of breakdowns, biases, or tendencies in human information processing (i.e., faulty aerial situation assessments, aircraft status assessments, environment assessments), and they are more likely to produce fatalities in aviation (Wickens et al., 2005).

Pilots’ decision making should be considered different from general decision making, because most pilots’ decisions are made in three-dimensional space under uncertainty and with time-constraints. To reduce pilots’ decision error, decision aid devices, such as GPS or navigation systems, have been developed and widely utilized among pilots.

It can be assumed that a single-pilot operated GA flight might be more dangerous than a multi-crew operated GA flight. Considering most GA pilots flew without the presence of a co-pilot, it is important to know which factors cause a GA pilot’s decision errors, especially under adverse weather conditions.

Weather-Related Decision Errors

Weather decisions involve judgmental decisions, which are a knowledge-based activity as opposed to skill or rule-based activity (Giffin & Rockwell, 1987). Beringer and Ball (2004) conducted a study on how varied Next-Generation Radar (NEXRAD) weather display data resolution could affect a pilot’s visual performance data (how long he assessed the data), and the flight performance data (the distance to the severe weather, and the deferred decision time to continue the flight). The findings indicated that the high-resolution NEXRAD images are more likely to encourage pilots to navigate between adverse weather areas than the low-resolution NEXRAD images, which left pilots with the expectation that they could fly around or between heavy precipitation areas.

Ball (2008) assessed the impact of training and graphical weather display on GA pilots' weather-related decisions. The training consisted of 38 pages of guidance of the proper usage of the Flight Information Systems Data Link. The weather display was presented with NEXRAD systems and the Meteorological Aerodrome Report (METAR). The NEXRAD is a network of Doppler weather radar systems and is provided by the National Weather Service (NWS), and METAR is the international standard code format for hourly surface weather observations. The author classified participants into tactical users and strategic users. Tactical users were those who attempted to fly to destinations through small holes in the storm, and strategic users were those who avoided hazardous weather by navigating at a safe distance. He measured a time to the initial/final decision at encountering the storm, the proximity to the storm, the number of weather inquiries, and the post-experiment ratings. The results implied that both training and graphical weather displays would enable pilots to make decisions sooner and maintain safe distances.

Causal Factors

Previous studies on the causes of weather-related GA accidents showed that frequently-cited individual causal factors are interior factors, such as knowledge, skills, experience, motivation, and personality, and exterior factors, such as flight planning and weather information (Table 1.2). Foushee and Helmreich (1988) also listed knowledge, skill, attitude, personality characteristics, and physical states as individual factors that affect performance.

Group causal factors of weather-related GA accidents have been studied by researchers as well. Baron (2011) conducted an empirical study on the effects of social pressure and team communication on GA pilots' decision making to determine the group factors. However, only individual factors were considered in this study, because this study is focused on a single-pilot controlled cross-country GA.

Knowledge

To accurately diagnose the salient weather cues in the operational environment, weather knowledge is important (Wiggins & O'Hare, 2003b), and a lack of weather knowledge frequently has been cited as the cause of weather-related GA accidents. According to the situation assessment hypothesis, a lack of knowledge about weather conditions might cause GA pilots to risk entering into adverse weather conditions.

Giffin and Rockwell (1987) conducted an empirical study using a computer aided weather test (CAWT), and found that the poor decision making group had low quiz scores in weather knowledge items.

Wiggins and O'Hare (2003b) investigated the effect of cue-based weather training on the GA pilots' perceived importance of weather cues and flight performance. The results showed that those who received weather training initiated a diversion at or before the optimal decision point during the flight when they encountered IMC.

Skills

Although recently built airplanes are equipped with weather display radar such as NEXRAD, it does not provide real-time weather information (Bailey, III, et al., 2007) and sometimes may not function correctly. Additionally, pilots are expected to acquire weather recognition skills through weather decision-making training, to ensure a safe flight regardless of the flight type, because weather condition changes so dynamic and hard to predict during in-flight. Decision skills can be trained (Kaempf & Orasanu, 1997), and Hunter et al. (2000) developed a computer-based training program to improve pilots' cue recognition skills in weather-related decision making.

Experience

Experience long has been known to have a positive relationship with pilots' SA (Doanne et al., 2004; Endsley, 1999) and decision making (Beringer & Ball, 2004; Chamberlain & Latorella, 2001; Wiggins et al., 2002). In previous empirical studies, pilots were classified either experts or novices based on their total flight hours (Table 2.3; or cross-country flight hours (Table 2.3).

In empirical studies, dealing with pilot weather decision making, however, classifying pilots based on cross-country flight experience was regarded more as representative of evaluating experience in decision-making tasks (O'Hare & Wiggins, 2004; Wiggins et al., 2002), because pilots who flew only the local area may not have had many chances to make decisions when they encountered adverse weather, despite that their overall flight time may have been high.

Table 2.3 Classification of Pilots Based on Flight Experience

Authors	**Classification**	**Criteria**
Latorella & Chamberlain (2001)	Low (135) – Medium (379) – High (738)	Cross-Country Flight Hours
Wiggins et al. (2002)	Novice (less than 100) – Intermediate (100 to 1000) – Expert (more than 1000)	
Wiggins & O'Hare (2003a)	Novice (less than 1000) – Expert (more than 1000)	
Coyne et al. (2008)	Novice (less than 1000) – Expert (more than 1000)	
Wiggins & Henley (1997)	Inexperienced (less than 300) – Experienced (more than 300)	Overall Flight Hours
Beringer & Schvaneldt (2002)	Novice (less than 500) – Experienced (more than 500)	
Sawyer & Shappell (2009)	Low(less than 500) – High (more than 500)	

In Wiggins and Henley's (1997) study, notable differences in pre-flight decision making were found between experienced and inexperienced flight instructors as to whether to authorize a student pilot to conduct an initial, solo, and/or cross-country flight. The findings showed that the inexperienced flight instructors were more cautious than experienced instructors in decision making. Whereas the experienced flight instructors changed their decisions according to the accessibility of weather information, there were no changes among the inexperienced flight instructors. Goh and Wiegmann (2001a) also found that pilots with lower amounts of flying time made more VFR into IMC accidents.

However, some studies did not show a positive relationship between pilots' experience and their decision making. Sawyer and Shappell (2009) measured a pilot's decision accuracy and eye tracking data to learn the effects of experience and training on a pilot's ability to identify adverse weather. Pilot situation assessment was measured in terms of an estimation of visibility, cloud ceilings, and decision accuracy, and the authors did not find a significant relationship between pilot experience and situation assessment.

Beringer and Schvaneldt (2002) categorized expert and novice pilots using 1,000 hours of overall flight experience as the criterion, and made them rate the important weather factors along phases of flight. Although there were no significant differences between their weather ratings, expert pilots tended to rate the majority of weather factors as more important than did the novice pilots.

Motivation

In general, motivation is related to behavior changes and the factors that direct the changes (Cantor et al., 1986). In aviation, the motivational approach asserts that a pilot continues the VFR flight into IMC because of misplaced motivation (Wiggins & O'Hare, 2003b), such as social pressure or Get-home-itis. Thus, social pressure and time pressure can be included in the motivation category in Table 1.2.

Social pressure has been shown to affect a pilot's decision making (Goh & Wiegmann, 2001b). In their retrospective study, Goh and Wiegmann (2002a) found that around 55% of VFR into IMC GA accidents had passengers whereas the other 45% of GA accidents did not. Although the exact effect of passenger presence on a GA pilot's decision making is not clear, it is assumed that pilots may feel pressure to continue VFR flight into IMC so as not to disappoint the passengers aboard.

The effect of time pressure on decision making is well known, too (Adams et al., 2002; Beard & Given, 2005; Craig, 1998). Under severe time pressure, people tended to accelerate their processing (e.g., less time was spent per item of information acquired), selectively focus on a subset of the more important information, and change their patterns of processing in the direction of relatively more attribute-based processing. This general pattern of results is consistent with the simulator results, which suggested that an efficient strategy under severe time pressure would involve selective and attribute-based processing (Wickens et al., 1993).

It is also possible that pilots are motivated to fly into adverse weather by seeing other pilots' successes in taking off in adverse weather conditions. Beard and Geven (2005) termed this behavior as frequency gambling, and suggested it is one of a pilot's frequent risky behaviors, to takeoff in adverse weather conditions. Frequency gambling refers to one's expectant attitude of success in a risky situation.

Personality

One's personality is relatively stable over time and consistent across situations (Chidester et al., 1991), and this could affect a pilot's decision making (Loewenstein et al., 2001). McGrath (1964) suggested that individual factors such as skill, knowledge, and personality could affect group performance. Additionally, Helmreich (1986) explored the structure of men's and women's personality and found that personality is a valid performance determinant in a variety of environments.

Thus, personality has been regarded to affect pilots' behavior, although the concept of accident proneness as a personality type has not been accepted widely (Hunter, 2005; McKenna, 1988). However, together with motivation, personality is difficult to measure objectively. Knecht et al. (2005) measured the effects of visibility, cloud ceiling, incentive, and personality on a pilot's willingness to takeoff in adverse weather. However, the findings showed that personality could not predict whether a pilot would fly into adverse weather or not.

To assess how personality affects pilots' risk-taking behavior, Holt et al. (1991) developed a new Hazard Attitude Scale (New-HAS), and Hunter (1995) developed the Aviation Safety Attitude Scale (ASAS). Hunter (2005) also compared several kinds of hazardous assessment tools (e.g., the ASAS, the Old Hazardous Attitude Scale [Old-HAS], the New Hazardous Attitude Scale [New-HAS], the Situational Judgment Test [SJT], the Thrill and Adventure Seeking Scale, the Locus of Control [LOC], the Risk Perception and Tolerance, and the Hazardous Event Scale [HES]), and found that the Likert-scale assessment tools (New-HAS) showed superiority to the previous ipsative scale (Old-HAS).

Flight Planning

Previous aviation accident analysis studies revealed that a lack of pre-flight procedures have been related to the VFR into IMC GA accidents (Sawyer & Shappell, 2009; Wiegmann et al., 2008). Knecht (2008a) conducted interviews with 221 GA pilots across five states in the United States, and investigated the pilots' weather information usage patterns. The author measured the time that participants spent in pre-flight planning, and found that many GA pilots preferred convenient, simple, and comprehensive forms of weather information (e.g., METARS) to understand and acquire needed weather information in their pre-flight briefing stage.

Weather Information

There have been studies conducted as to how the type and format of weather information display would affect pilots' situation assessment, but they did not show how the displayed information actually reduced pilot's willingness to continue VFR flight into IMC.

Latorella and Chamberlain (2001) classified GA pilots into three groups according to their cross-country flight experience, and presented them with three weather cues separately: VMC, IMC, and Graphical Weather Information System (GWIS)-augmented IMC. They found that participants who were faced with the VMC and GWIS-augmented IMC display had better confidence ratings, perceived performance, and information sufficiency than those who were faced with the IMC display. This study emphasized the benefits of the graphical weather information display to improve pilots' situation awareness.

Bustamante et al. (2005) examined the relationship between pilots' SA and trust in weather systems when they fly in adverse weather. The authors showed participants static images of the onboard weather radar and static images of NEXRAD. As expected, participants' trust significantly increased when the weather information in the two sources coincided.

Bliss et al. (2005)'s study showed similar results. The authors conducted a simulated study with 24 pilots to examine how weather display agreements affect a flight crew's weather deviation decision accuracy. These authors combined a captain and a first officer as one team, and showed them the onboard weather display and NEXRAD. Using a questionnaire, the authors measured the team's deviation accuracy, deviation confidence, and overall decision confidence. The results showed that a team's confidence level and deviation decisions were highest when both weather display systems were in agreement, which indicated the importance of flight display redundancy (Selcon et al., 1995) and agreement.

Bailey, III, et al. (2007) conducted an empirical study to assess pilots' decision confidence as a function of distance, display agreement, communication, leadership, and experience. Participants were presented with a real-time on-board weather system and a delayed NEXRAD weather system. The results showed that pilots' decision confidence was high when there were display agreements between the weather display systems. Also, pilots tended to commit sunk cost bias when the outcome was uncertain or the weather update was not outstanding.

Thus, the weather information display might be better to provide real-time weather information in an integrated and redundant way if there are additional weather displays to support the pilot's decision. Also, providing an auditory display when the weather severity reaches a certain level might be a good way to prevent VFR only qualified pilots from continuing flying in IMC. Finally, the weather information might be better displayed in a simple and comprehensive form to reduce pilot workload, because pilots may make decisions in an uncertain and time-constrained flying environment.

Causal Hypotheses

Situation Assessment

Together with pilots' situation awareness (SA) studies, studies have been conducted regarding pilots' situation assessment (Fracker, 1988; Gaba et al., 1995; Wiegmann et al., 2002) and weather assessment (Coyne et al., 2008; Wiggins et al., 1995). Although SA and situation assessment concepts are different, those concepts often have been used interchangeably. Whereas SA refers to an operator's understanding of a situation as a whole, which forms a basis for decision making (Endsley, 1995), situation assessment is referred to as problem recognition in the cognitive process model (Gaba et al., 1995; Patterson, 2009), and emphasizes the operator's understanding of a current state.

According to the situation assessment hypothesis, pilots fly into adverse weather because they do not know they are doing so, or fail to recognize the severity of the weather (Coyne et al., 2008; Goh & Wiegmann, 2002a; Pauley et al., 2008). The situation assessment hypothesis also proposes experience as a key factor in diagnosing adverse weather. This is in accordance with Klein's (1995) RPD model, which asserts that experienced decision makers can find and identify good options better than those less-experienced decision makers when under time pressure and ambiguous conditions (Burian et al., 2000). Previous weather-related pilot decision error studies were successful in correlating pilot experience with the NDM model or the RPD model (Bailey et al., 2007).

Wiggins et al. (1995) examined the relationship between pilot self-assessment and performance. They divided forty one participants into three groups according to their total cross-country flight hours (Table 2.2), and used a self-assessment questionnaire to measure pilots' skill, judgment rating, and willingness to take risks. The findings indicated that the inexperienced pilots were influenced by a combination of both their self-perceived ability and their risk taking behavior. Goh and Wiegmann (2002a) analyzed accident data from between 1990 and 1997, and found that there is a significant relationship between the type of aviation accidents and pilot certifications. About 70% of pilots who committed VFR-IMC accidents had only a private license, whereas 42% of pilots who were involved in other GA accidents had commercial certifications. However, not all studies showed a positive relationship between pilot experience and situation assessment.

Unlike the previous accident analysis study (Goh & Wiegmann, 2002a), Wiegmann et al.'s (2002) empirical study did not find a positive relationship between pilots' experience and their situation assessments (estimates of visibility and cloud ceilings) for the short-flying group, and negative correlations were found between the pilots' experience and the time and distance that the pilots flew into adverse weather for the long-flying group. The authors examined the relationship between pilots' situation assessment and flight experience, and studied how the location at which a pilot encounters adverse weather could affect the pilot's decision to continue the VFR flight into IMC. The results showed that there was no significant relationship between the pilot's situation assessment (estimation of visibility and cloud ceiling) and flight experience for the short-flying group, but negative correlations were found for the long-flying group. Thus, the exact role that experience plays in a pilot's decision to continue or divert the flight was not revealed. Instead, they found that the location at which a pilot encountered adverse weather could affect the pilot's decision to continue the flight or not.

Coyne et al.'s (2008) study showed similar results. The authors investigated a pilot's ability to estimate the ceiling and visibility in a VFR flight into IMC. The results showed that instrument-rated pilots did not estimate the ceiling and visibility better than non-instrument-rated pilots. On the contrary, non-instrument-rated pilots outperformed instrument-rated pilots in estimating the visibility, and there were no significant differences between the two groups in estimating the ceiling. Although these authors tried to adopt the situation assessment hypothesis, they failed to examine the hypothesis.

While the same situation assessment hypothesis was considered, it can be seen that the results from accident analysis studies and empirical studies were different. Part of this result might be that the concept of situation assessment was not defined clearly in the previous studies. Situation assessment is knowing the current situation, and does not include a prediction of the future situation. In adverse weather conditions, pilots' situation assessments may include weather assessments and risk assessments.

Orasanu and Fischer (1997) measured GA pilots' situation assessment in a similar manner. The authors measured a commercial pilot's three major decisions while he was conducting a missed approach due to bad weather. The three decisions were: a go-no go decision, the selection of an alternate airport, and a coordination of the flap and gear extension procedures due to hydraulic failure during the final approach.

The best way to increase situation assessment or situation awareness is training (Gaba et al., 1995), and the salient cue is related to high level of SA (Endsley, 1999). Thus, Wiggins and O'Hare (2003b) developed the cue-based training program, WeatherWise, to enhance pilots' weather-decision making. The validity of the program proved helpful in timely decision making to divert when pilots were confronted with adverse weather.

Risk Assessment

Pilots may correctly assess the weather conditions, but incorrectly determine the potential risks associated with the weather conditions. Risk assessment is defined as a structured process to estimate the likelihood and severity of all risks (Coleman & Marks, 1999; Latorella & Prabhu, 2000), and poor risk assessment is a leading factor that causes poor decision making (Hunter, 2002b; Molesworth et al., 2006). In the aviation domain, risk assessment means an understanding of the risks associated with flying in adverse weather conditions. Risk assessment includes the processes of risk perception and risk tolerance, and can be measured by the Hazardous Event Scale (HES; Hunter, 2002a), personal weather minimums (Hunter, 1995), and the Aviation Safety Attitude Scale (ASAS; Hunter, 2002a; Pauley et al., 2008).

Risk perception involves the ability to detect, perceive, and assess the risk associated with a situation or a traffic hazard (Hunter, 2002b), and can be influenced by personal experience and ability (Goh and Wiegmann, 2001b). Risk perception can be measured by the number of incidents and hazardous events a pilot reports using the HES.

Risk tolerance relates to the amount of risk an individual is willing to accept in a situation (Hunter, 2002b), and can be measured using personal minimums and attitudes toward flying (Hunter, 1995). Other factors that area associated with risk assessment are overconfidence and violation. Violation is a willful disregard of established rules, and can increase the probability or error and the likelihood that the error results in a negative error (Reason et al., 1998). Pilots occasionally violate flight rules because they are overconfident and think they have less of a chance of encountering bad weather, and they do not fully assess the associated risks when continuing VFR flights into IMC. Goh and Wiegmann (2002a) examined the causes of GA accidents associated with VFR flights into IMC using the NTSB statistic data, and found that around 76% of the VFR flights into IMC accidents were involved with the pilot’s intentional flight into adverse weather.

O’Hare (1990) conducted a questionnaire study with 44 licensed pilots using Aeronautical Risk Judgment Questionnaire (ARJQ), and found that young and currently-active GA pilots were most likely to take the marginal VFR flight. He also found that they showed a low level of risk awareness as well as high optimistic self-appraisals of their abilities and judgment (Hunter, 2002b; Goh & Wiegmann, 2001b). Similarly, Hunter (2006) measured 630 GA pilots’ risk perceptions using a response scale of one (low risk) to 100 (high risk), and found that participants who rated higher self-confidence and risky behavior tended to assess their situations as less risky.

Wiggins et al. (1995) examined the relationship between three levels of experience (inexperienced, intermediate, and experienced pilots) and pilot self-perceived risk-taking behavior, pilot judgment, and aeronautical ability. Participants rated their own skills and judgment in comparison to other pilots of similar experience. Although the authors failed to find main effects across the three factors, they found significant interaction effects from inexperienced pilots between self-perceived abilities and their risk-taking behaviors. The results also indicated that inexperienced pilots are more likely to be influenced by their risk-taking behaviors than their abilities.

Decision Framing

Minsky (1975, p.246) defined a frame as, a “collection of questions for representing a stereotyped situation.” and asserted that there are some kinds of information related to each frame. He explained that some information is related to how to use the frame, while other information is about what one can expect to happen next, and still other information is related to what to do if expectations are not confirmed.

In summary, pilots’ decision making depends on how the problem is represented, and what frame is used to interpret the situation (Goh & Wiegmann, 2002a). For example, if pilots frame their decisions in terms of gains in a continued VFR flight into IMC, they are prone to continue flying to the adverse weather. Similarly, when pilots frame their decisions in terms of losses or put priority in safety, they are more likely to divert early in an adverse weather condition. Prospective theory (Kahneman & Tversky, 1984), one of the risky decision making models, also asserts that a person chooses either a risky or safe action depending on how he/she frames an option (as a gain or loss), and also on “the norms, habits, and personal characteristics of the decision maker" (p. 341). A well-known decision framing bias is sunk cost bias /effect (Arkes & Hutzel, 2000).

Sunk Cost Effect

Sunk cost explains that pilots who have flown further are motivated to continue flying to the destination, despite adverse weather conditions, because they might have spent more time and money to get there. Batt and O'Hare (2005) examined 491 weather-related GA occurrences from data drawn from the Australian aviation accidents and incidents of the Australian Transport Safety Bureau (ATSB), and divided occurrences into VFR into IMC, precautionary landing, and weather avoidance groups. The authors found that the VFR into IMC occurrences group showed an increasing tendency to continue flying as they flew closer to the destination. This result was in contrast with the weather avoidance group, whose portion of weather-related GA occurrences was highest in the early flight.

Decision Confidence

Good situation assessment is important to make good decisions. However, good situation assessment itself is not sufficient for making a good decision (Artman, 2000). Decision confidence plays an important role in the decision-making processes that guide our everyday activities (Griffin & Tversky, 1992; Lichacz & Farrell, 2005), and is found to be a valid predictor of recognition (Costermans et al., 1992).

Wiggins and O'Hare (2003a) showed 577 pilots 10 randomly-selected weather pictures taken in the air, and then asked them to choose whether they would continue the

VFR flight or not. Pilots accessed the questionnaire through the Internet, and expert pilots showed higher confidence levels than novice pilots.

However, Goh and Wiegmann (2002b) found different results. Using pre-experimental questionnaires, the authors asked pilots to rate how good they were at monitoring, recognizing, diagnosing, generating, and implementing solutions when compared with average GA pilots. The results showed that experienced pilots rated themselves better at recognizing problems and implementing solutions than average GA pilots, but they did not feel more confident in diagnosing the underlying causes of the problems. Experienced pilots also were conservative in their self-perceptions of their diagnostic skills, which suggest that confidence in diagnosing situations does not necessarily come with more flight experience, and should be enhanced within flight training curricula.

O'Hare (1989)'s study showed similar results. The author recruited 18 licensed pilots and asked them to conduct a cross-country flight task while referring to weather information. Participants rated their risk-taking behaviors, skill, and judgment after the experiment. The author found that the more confident pilots were willing to accept higher risk levels than the less confident pilots.

Pilot Decision Making Training

Aeronautical Decision Making (ADM) Training

Telfer (1986) conducted an empirical study with 20 student pilots using the Australian Pilot Judgment Training (PJT) materials. He divided participants into three groups: experimental (trained with manual and special instruction), academic (trained with manual), and control groups (no training). Participants conducted pre and post-written tests of manuals, followed by a flight simulation test. The written test results showed that there were no significant differences in knowledge among each group. However, in the flight simulation test, the experimental and academic groups outperformed the control group in overcoming hazards and interferences. Overall, the use of the Australian PJT materials from the beginning of the flight training was regarded as essential for pilot judgment training. Nevertheless, there are some limitations in Australian PJT study (Telfer, 1989). First, there was a delay in completing the material between each group. Because participants were not divided into each group randomly, participants' motivation to finish the materials was different in each group. Such differences in motivation caused a performance difference among groups. Second, the validity of the PJT program was not examined, because no construction testing had been done to examine the effectiveness of this training program.

Adams and Thompson (1987) asserted that judgment errors are the major causal factors of aircraft mishaps, and developed an ADM manual to improve helicopter pilots' decision making. The authors found that pilots who received ADM training showed better performance than control groups. However, the ADM manual had never been tested for its effectiveness on reducing pilots' decision errors. Jensen et al. (1987) found that instrument pilots who receiving aeronautical decision making training showed reduced pilot error rates.

WeatherWise

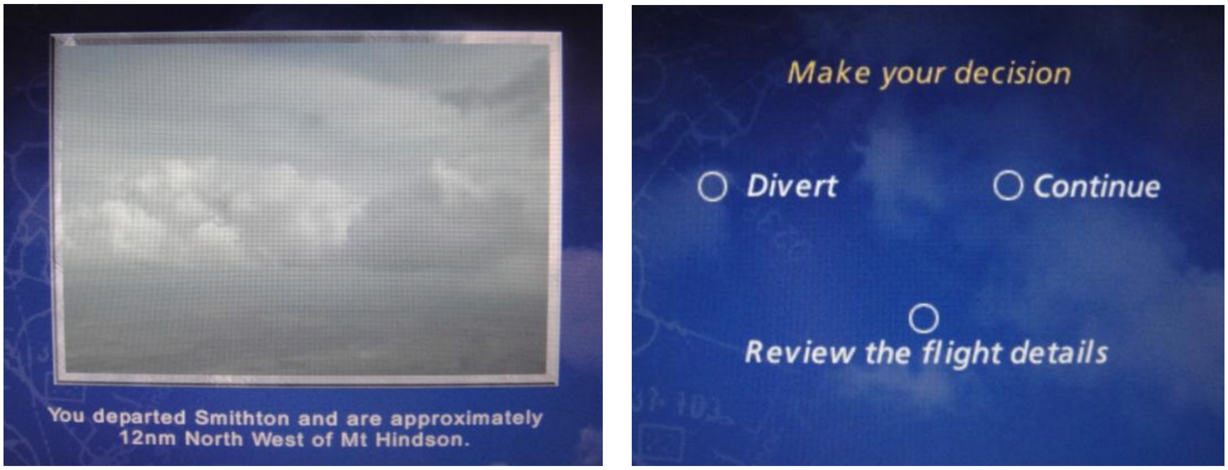
Previous aviation accident analysis studies revealed that weather comprised the highest portion of fatalities in GA accidents (AOPA, 2008), and continued VFR flight into IMC was the main cause of fatalities among weather-related GA accidents (Batt & O'Hare, 2005; Wiggins, 1999). Currently, the FAA has 17 documents that cover weather-related topics, but VFR into IMC is dealt with in only a few of these documents (Wiegmann et al., 2008). Thus, there has been an increasing need to develop a GA pilot weather decision-making training program to reduce weather-related accidents.

Various stressors (i.e., time pressure, noise, ambiguity, etc.) during the flight can narrow a pilot's attention field by systematically reducing the cue utilization range (Hiel & Mervielde, 2007). Thus, recognizing a weather cue appropriately is vital in order for a pilot to make a correct decision. For this purpose, Drs. Hunter, Wiggins, and O'Hare (2000) developed WeatherWise, a computer-based training program, to improve pilot weather cue recognition skills. WeatherWise was produced by the Federal Aviation Administration (FAA) and the Office of Aerospace Medicine for the Aviation Safety Program of the Flight Standards Service with the assistance of the Ohio State University, the University of Western Sydney, the University of Otago, and King Schools (Sawyer, 2009). WeatherWise was approved by the FAA for free public use. As WeatherWise was produced and distributed in the form of a CD, pilots can acquire weather cue recognition skills without the help of an instructor. WeatherWise is easy to install and does not require a flight simulator to use.

WeatherWise is composed of three parts: the WEATHER TO FLY, the DECIDE TO FLY, and the TAKE A FLIGHT. In the WEATHER TO FLY section, a user is asked to rate the given weather condition as either above or below the minimum requirements for VFR flight. This test is to alert a user as to how he/she is not clearly aware of the differences between VFR and IFR conditions. At the end of the section, the program shows the score for the total correct answers, but does not show which answers were correct. Then, WeatherWise provides a list of weather cues, such as cloud base, visibility, cloud coloring, cloud density, terrain clearance, rain showers, and cloud type, and briefly explains how each cue can be recognized in a given image. After that, the program asks a user to find weather cues that are present in the image. Once answers are submitted, the program provides feedback as to the actual features present and the correct decision to make.

The DECIDE TO FLY is composed of accident investigation, diverting during flight, and a summary. The program asks a user to identify factors that might lead to the aircraft's accident in the scenario. Then, WeatherWise asks a user to choose one alternative airport to divert to among three alternative airports, and asks why the user chose that airport. It aims to tell a user how difficult it is for a pilot to make a weather-related decision during flight. Once the answers are submitted, the program provides feedback about the correct alternative airport and reasons for that selection.

Finally, in the TAKE A FLIGHT section, a user completes a flight with the given flight scenario by seeing short video clips simulating a series of flights from a departing airport to the destination airport in Australia. The weather was VFR on departure, and a user is expected a smooth flight. Among the five flight stages, a user is asked to choose one stage in which to divert, and one alternative airport (Figure 2.9). Once a decision to divert has been made, the user will land at the alternative airport, and feedback about divert decision to divert is provided. At the end of the program, WeatherWise provides the total points for decision timing out of 100, and for the decision option of the alternative airport out of 100. Thus, a user can learn his score after the training. The GA pilots are required to score at least 80 out of 100 in each category, and it takes around 20 minutes to finish the training program.



You departed Smithton and are approximately 12nm North West of Mt Hindson.

Figure 2.9 Screenshot of WeatherWise

Wiggins and O'Hare (2003b) examined the validity of the WeatherWise program through self-report assessments and performance assessments. These authors categorized the decision points into five stages, and asked participants to fly VFR into IMC and divert at the optimal decision point. The participants were composed of 66 licensed pilots who had accumulated less than 150 hours of cross-country flight experience. The result showed that those who were trained with the WeatherWise training program recognized more weather cues, and tended to use those weather cues during flight. They also showed better performance in finding the divert stage than the control group. The results indicated that the WeatherWise can be helpful for novice pilots to build up weather cue recognition skills. However, there was no significant increase of an expert pilot's flight performance, which indicated that WeatherWise may not be so helpful for the expert pilot.

Computer-Aided Weather Test (CAWT)

The CAWT is a computer-aided weather testing software developed from a process model (Rockwell & Giffin, 1987). It is composed of four elements: the pilot's biographical questionnaire, a simulated flight involving weather information acquisition and decision making, a computer-aided debriefing, and a computer-presented quiz about pilot knowledge and judgment of weather (Giffin & Rockwell, 1984). Quiz questions were generated from publications such as *How to Obtain a Good Weather Briefing* (FAA-P-87840-30A), *Aviation Weather* (FAA and NWS AC-00-6), and *Weather Flying* (Buck, 1970).

Giffin and Rockwell (1987) conducted an empirical study with 454 pilots about the value of computer aided testing, CAWT, and found that pilots who had fewer cross-country hours, fewer IFR ratings, fewer average number of weather inquiries, and lower quiz scores had poor weather information-seeking strategies. The authors suggested the use of different weather scenarios to examine the validity of the software, and the development of a training module to improve the pilot's weather information search and decision behavior.

Human Competency Model

Many factors have been suggested as causes of weather-related GA accidents in Table 1.2. Among them, knowledge, skills, and attitudes are components of human competencies and have been known to be important components in training (Salas et al., 2000). However, a focus on some factors does not necessarily affect pilots' overall decision making. Previous studies showed that knowledge and skills do not necessarily change people's behavior (Feuerstein et al., 2004). McClellend (1971) asserted that knowledge and skills generally are easy to train because they are located in the outer layer of the human competence model. Inner competence factors, such as personality traits, attitude, and motivation are hard to train, because they are hard to measure and are affected easily by specific situations and environments (Figure 2.10). However, they also have been known to be the causal factors of weather-related GA accidents (Table 1.2).

The WeatherWise program focused on developing weather knowledge and the weather cue-recognition skills of pilots to improve their weather decision-making abilities, but do not consider overall human competence factors that affect performance. Cantor et al. (1986) asserted the effect of motivation, and suggested that motivation cannot be fully understood without considering the self-concept: people's understanding on themselves. Thus, future weather decision-making training programs might do better to consider all human competence factors to maximize their training effects.

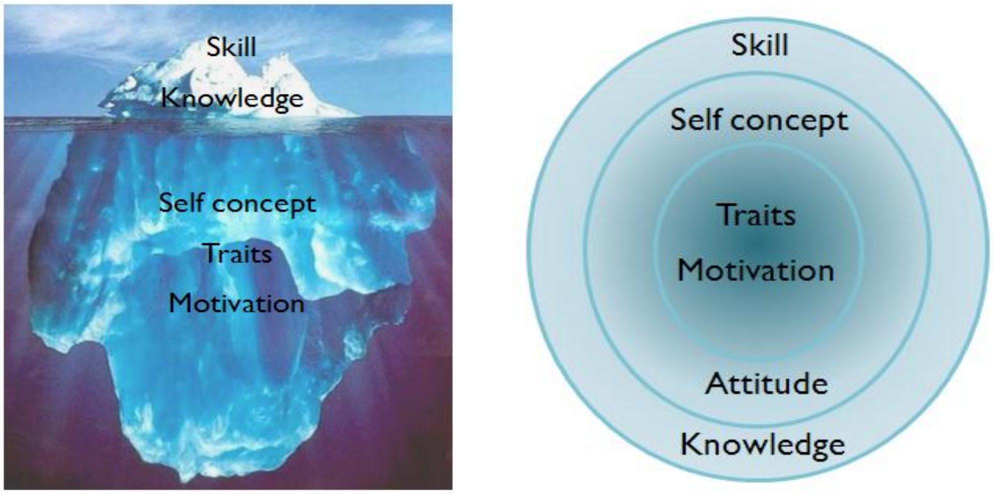


Figure 2.10 Structure of Human Competence Model (Kim, 2002)

Flight Simulator

Benefits of Simulation Studies

Human factors engineers analyze and interact with people, the work environment, and technology systems. Simulation is a commonly deployed method for the study and analysis of human behavior (Drury, 2005; Laughery, 2005) in complex environments such as aviation (Dahlstrom et al., 2009; Sarter et al., 2007), driving (Lee et al., 2007), and healthcare (Gardiner et al., 1998; Thompson et al., 2004), to name a few. Simulations allow all participants to experience the same set of controlled tasks and conditions, and make it possible to collect performance data in simulated environments that may be occur only rarely in the real world. Thus, a flight simulator has been used to train pilots and to measure their performance and workloads because it can provide high degrees of realism in the environment with no more than minimal risk (Bradley & Abelson, 1995).

However, simulation studies have their limitations as well. For example, a desk top flight simulator provides sufficient visual cues, but auditory cues and motion cues are not sufficient to influence the vestibular system. Additionally, delayed visual feedback and a lack of aerodynamic force transmission lower the reality of flying compared to an in-cockpit study. Simulation fidelity also may influence pilots' decision-making training, although previous studies asserted that there are no significant differences between using a high-fidelity simulation and a low-fidelity simulation. Nevertheless, there are more strengths than limitations in simulations, and many studies have been conducted using a simulator.

Applications of Flight Simulator to Assess Pilot Behavior

Flight simulator has been used for pilot training because it can provide high degrees of realism in the environment (Bradley & Abelson, 1995) as well as experimental control (Chidester et al., 1991).

Molesworth et al. (2006) suggested that interactions with hazards during simulated flight training could increase pilots' situation assessments and eventually develop decision making. In either immersive high-fidelity simulations or lower-fidelity simulations, flight simulators provide methodological benefits for research and training.

Dahlstrom and Nahlinder (2009) investigated the mental workloads of civil aviation pilots using physiological measures, including heart rates and eye movements, and subjective measures. The results showed that there were no significant differences in heart rates and mental workloads between the simulator flights and aircraft flights. This would hold true in this study, as the type of aircraft used will be GA. The motion cues, which were regarded as critical factors in military aircrafts, almost can be overcome by providing frequent visuals of moving environments (Bradley & Abelson, 1995).

However, in weather decision-making training, the fidelity of simulation is not negligible, in that pilots clearly should recognize weather cues such as the visibility, ceiling, and cloud movement upon seeing the display. If the displayed weather information does not provide a moderate level of fidelity, a pilot may have difficulty in correctly assessing the weather and making a decision in a gradually aggravating weather conditions.

CHAPTER THREE

METHODS

Participants

A total of 40 GA pilots participated in this study. They were recruited from local flight club, flight schools, and airports in Upstate South Carolina throughout advertisement (Appendix A). They were divided randomly into one of two groups of 20: a WeatherWise training group, and a control group. The control group received fatigue training as a non-weather-related training. Table 3.1 provides the details of 40 participants' demographic and flight experience information.

Table 3.1 Participants' Demographic and Flight Experience Information

	Age		Total flight hours		Last 90 days flight hours		Total cross country flight hours		Last 90 days cross country flight hours	
	M	SD	M	SD	M	SD	M	SD	M	SD
WeatherWise group	41.8	14.9	1708.5	3144.2	27.7	31.8	866.5	2191.9	13.8	15.6
Control group	45.7	17.0	2537.2	3260.6	20.3	26.8	1474.8	2789.2	12.4	19.8
Total	43.8	15.9	2122.9	3189.3	24.0	29.3	1170.7	2495.1	13.1	17.6

Thirty eight pilots were male, and two were female pilots. Twenty six pilots got married, and 14 were single. Pilots' ages ranged from 20 to 78 years, with an average of 17 years of flight experience. Pilots' total flight time ranged from 53 to 13,000 hours (Mean: 2123, SD: 3189). Thirty of them were IFR-qualified, and 10 were VFR-only qualified pilots. Pilots were classified to either experienced or inexperienced pilots based on their total cross-country flight hours (Table 2.2; cut-off 500 hours), and 15 were experienced pilots and 25 were inexperienced pilots. On average, the control group was slightly older and had slightly less recent flight experience than the WeatherWise training group although the mean of the control group's total flight hours and total cross-country flight hours were higher than the WeatherWise training group (Table 3.1). There were no significant differences in age (F (1, 38) = 0.58, p = 0.45), and flight experiences (F (1, 38) = 1.19, p = 0.29) between the two groups.

Apparatus

All experimental data were collected in the Human Factors Laboratory on the Clemson University campus (Figure 3.1). A desktop computer with a flat-panel display and a projector were used to run the experiment. The desktop computer is a Dell OptiPlex 745, with a 2.4 GHz Intel dual-core processor and 3,072 MB RAM. The addition of extra RAM and an updated video card, the GeForce 8500, were added to support the high-resolution settings used in the X-Plane 9 flight simulation program developed by Laminar Research Inc. A 17" Dell monitor was used to view the instrument panel. A Panasonic PT-FW300 projector was used to project a large image of the cockpit view in front of the pilot, and the size of the projected image will be 98.5" * 62", with a resolution of 1,280*2,048 pixels.

Figure 3.1 Human Factors Laboratory Flight Simulator

The X-Plane program has add-ons that can be adapted for either home use for the PC-gamer, or as a high-tech training tool for pilot certification. In this study, the home version was used, with the addition of a yoke equipped with a throttle, mixture controls, and rudder pedals to interact with the flight simulation program. The X-Plane has advanced capabilities to design and manipulate flight scenarios, and used widely throughout flight simulation studies. The program allowed for the collection of flight parameters (e.g., altitude, time traveled, distance traveled, airspeed, etc.), and programmed weather conditions were plugged in to ensure that the weather specifications of the scenario could be enacted as designed.

The specifications used in the weather scenario in this study (Table 3.2) were created with the assistance of meteorologists, and the weather was gradually aggravated as participant approaches to the destination airport (KLKU).

WeatherWise, the CD-ROM weather-training product sponsored by the FAA, was used as the weather-training program, and Garmin GPS (GNS 430) was installed to the flight simulator to help pilots navigate to the destination airport.

Table 3.2 Airport and Weather Information

Airport ID	Wind	Visibility	Ceiling	Weather Category	Distance	ETA
KCKB	180/10 KT	10 SM	SCT 10.0 M’	VFR	----	----
KEKN	180/20 KT	6 SM	SCT 8.0 M’	VFR	31 NM	:17
W99	180/20 KT	5 SM	BKN 6.0 M’	MVFR	54 NM	:30
KVBW	180/20 KT	4 SM	BKN 5.0 M’	MVFR	82 NM	:45
KCHO	180/20 KT	2 SM	BKN 4.0 M’	IFR	109 NM	1:00
KLKU	180/15 KT	1 SM	BKN 3.0 M’ OVC 1.0 M’	LIFR	132 NM	1:12

Hypotheses

Although Wiggins and O’Hare (2003b) and Saywer and Shappell (2009) investigated the effects of weather training on pilots’ decision making, their studies were not conducted using flight simulators, nor were there any significant differences in decision accuracy between expert and novice pilots. However, according to the situation assessment hypothesis, expert pilots showed higher situation assessment abilities than novice pilots, and training was regarded as the best method to increase their situation assessments. Thus, it is expected that the WeatherWise training would improve pilots' situation assessments (i.e., weather assessments, risk assessments), and eventually their tactical decision making (i.e., decision accuracy, decision confidence) in gradually aggravating weather conditions. To meet the purposes, the following hypotheses were tested by this study:

Hypothesis 1: The WeatherWise training group will estimate the visibility better than the control group.

Hypothesis 2: The WeatherWise training group will estimate the ceiling better than the control group.

Hypothesis 3: The WeatherWise training group will estimate the weather condition better than the control group.

Hypothesis 4: The WeatherWise training group will assess risks better than the control group.

Hypothesis 5: The WeatherWise training group will be more confident in their decisions to divert than the control group.

Hypothesis 6: The WeatherWise training group will divert at or before the IMC more often than the control group.

Hypothesis 7: There will be a positive relationship between pilots' situation assessments and tactical decision making.

Experimental Design

This study used a single factor between-subjects design. The independent variables were two levels of weather decision-making training (i.e., the WeatherWise training and the fatigue training). The dependent variables were pilot's situation assessment and tactical decision making. Pilot situation assessments were composed of weather assessment and risk assessment, and were measured using the post-experiment questionnaire. The post-experiment questionnaire was designed by modifying previous studies (Hunter, 1995; Knecht, 2008b; Shappell et al., 2010) to increase study validity.

Weather assessment questions were composed of participants' estimations of the visibility, ceiling, and weather condition (e.g., VFR, MVFR, IFR, and LIFR). Weather assessment was measured by calculating the visibility proportional error (VPE; Coyne et al., 2008), ceiling proportional error (CPE; Coyne et al., 2008), and weather condition estimation frequency. The CPE was computed as [(Estimated ceiling-Actual ceiling)/Actual ceiling]. Similarly, the VPE was computed as [(Estimated visibility-Actual visibility)/Actual visibility]. Negative values of CPE and VPE indicate that a ceiling estimation is below the actual depicted ceiling, and visibility estimation is below the actual depicted visibility. The CPE and VPE data were analyzed using a single factor analysis of variance (ANOVA).

Risk assessment was conducted in terms of risk perception and risk tolerance using the Hazardous Event Scale (HES; Hunter, 1995), personal minimums, and the Aviation Safety Attitude Scale (ASAS; Hunter, 1995). The validity of these questionnaires was examined by Hunter in 2006. Risk assessment questions are composed of previous hazard accidents or events, personal weather minimums for VFR local and cross-country flights, and pilots' attitudes toward flying.

Using the flight simulation program and post-experiment questionnaire, tactical decision making was evaluated in terms of decision accuracy and decision confidence. Decision accuracy was evaluated by measuring the proximity from an actual divert point to an optimal divert point. Decision confidence question represented participants' confidence levels in making divert decision, and was measured by the subjective rating method by asking participants assess themselves on a scale ranging from zero (not at all confident) to 100 (extremely confident). Subjective rating scales have been frequently used to measure participants' workload or decision making because they are easy to administer, and have high face validity (Bustamante et al., 2005; Weirwille & Eggemeier, 1993).

Procedures

Participants were briefed on the study upon arrival in the laboratory. They were told that the purpose of the study was to understand GA pilot behavior during cross-country flight. They signed a consent form (Appendix B), and filled out a background questionnaire (Appendix C). The questionnaire included demographic information and flight experience such as total flight time, recent three month flight time, cross-country flight time, certificate, license, etc. Then, participants were divided randomly into two groups: the WeatherWise training group and the control group. The WeatherWise training group went through the WeatherWise program using the desktop computer in the lab. The control group did not receive any weather-related training, but watched an aviation-related video file from the Internet (Physiology of Flight: fatigue in aviation, 2010) using the desktop computer in the lab. In both groups, the training session lasted approximately 20 minutes.

Prior to the real experiment, participants flew a short practice flight to familiarize themselves with the flight controls and dynamics of the simulator, and the cockpit displays they would use during the cross-country flight. There was no time limitation in practice flight.

Participants were provided with a weather briefing (Appendix D), sectional chart, the Cessna 172 owner's manual, the Cessna flight computer, a navigation log, and the relevant weather information (Terminal Aerodrome Forecasts (TAFs), METARS, and Temporary Flight Restrictions (TFRs)).

Then, participants were given instruction about the detail flight procedures. They were told that the aircraft (Cessna 172) was not certified for instrument flight, and they were the pilot in command and had to be aware of possible aircraft mechanical failures, weather changes, rising terrains, and other aircraft throughout the flight. When participants were ready to fly, they flew a simulated VFR solo cross-country flight from the North Central West Virginia Airport (KCKB) to the Louisa County/ Freeman Field Airport (KLKU), as long as they deemed they did not violate the VFR in a gradually deteriorating weather condition.

The flight path distance was around 132 nautical miles, and consisted of a route with six points along it (KCKB, KEKN, W99, KVBW, KCHO, and KLKU) where weather deteriorated. This deterioration included decreased visibility, cloud ceiling, and a terrain that crossed over several points of higher elevation (Figure 3.2).

Figure 3.2 Screenshot of Simulated Cross-Country Flight

As shown in Figure 3.3, the rising terrain occurred early into the flight (around 30NM), and continued until marginal conditions encountered.

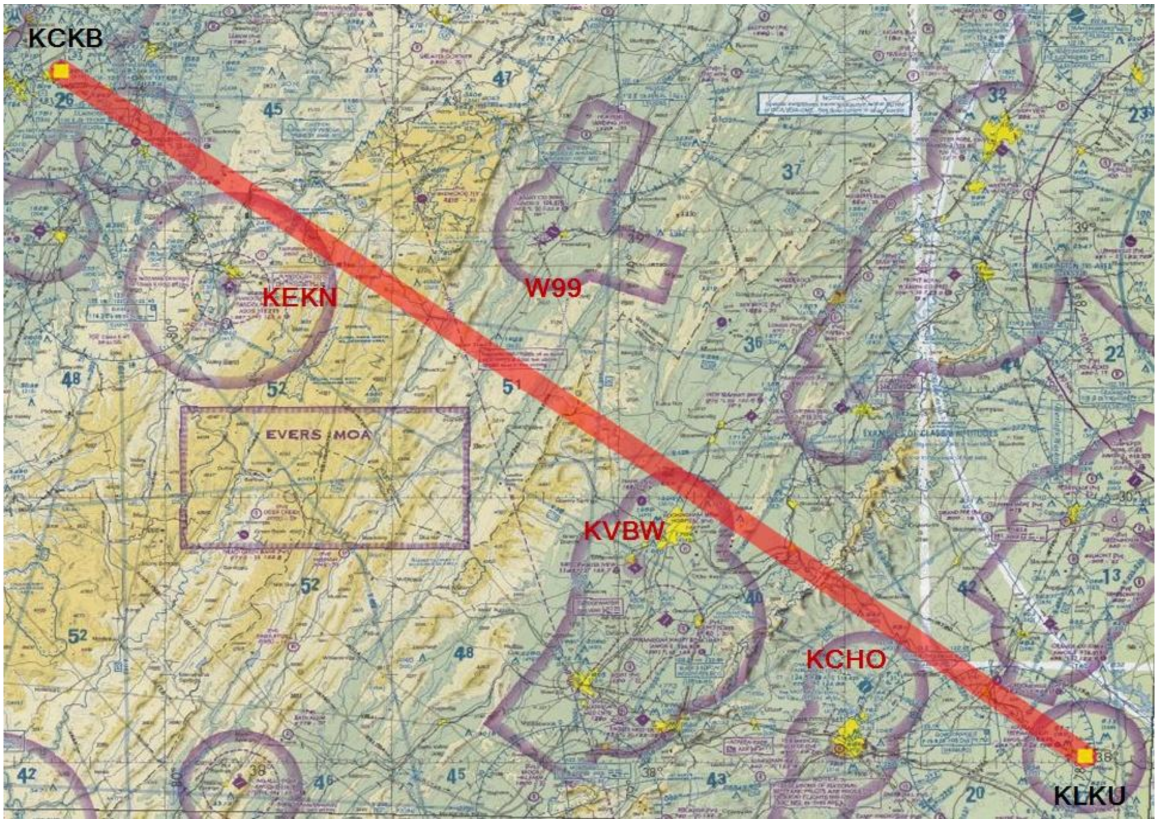


Figure 3.3 Sectional Chart of Flight Path (fltplan.com)

The visibility and cloud ceiling specifications of six points along the flight path can be found in Table 3.2, which details the progression from visually clear to instrument conditions. The weather conditions around the departing airport, KCKB, indicated high visibility and cloud ceiling, in contrast to the area around the destination airport, KLKU, which exhibited severely deteriorated visibility and a lowered cloud ceiling.

The cross-country flight is either an IFR or VFR flight, for which the distance to the nearest airport is more than 20 nautical miles (Wiggins et al., 1995). Participants were allowed to maintain a cruise speed of 110 knots indicated air speed (KIAS) and altitude range between 6,000’ mean sea level (MSL) and 8,000’ MSL. It took approximately twenty minutes to get in MVMC, and forty minutes to get in IMC, and this period allowed for ample time for the pilot to become accustomed to the aircraft prior to experiencing any adverse weather.

When participants encountered IMC, they were allowed to make a divert turn to an alternative airport. The study was terminated immediately when the pilot either began to divert to an alternative airport, lost control of the aircraft, or crashed on the terrain. Then, participants went through the post-experiment questionnaire (Appendix F), received compensation of 50 dollars for their participation, and were debriefed. The amount of time required for the study was about 90 minutes, and the study results were saved for later analysis of situation assessment and tactical decision making.

CHAPTER FOUR
RESULTS

To evaluate the effects of weather training on pilots' situation assessments and tactical decision making in gradually aggravating weather conditions, the following hypotheses were tested by this study:

Hypothesis 1: The WeatherWise training group will estimate the visibility better than the control group.

Hypothesis 2: The WeatherWise training group will estimate the ceiling better than the control group.

Hypothesis 3: The WeatherWise training group will estimate the weather condition better than the control group.

Hypothesis 4: The WeatherWise training group will assess risks better than the control group.

Hypothesis 5: The WeatherWise training group will be more confident in their decisions to divert than the control group.

Hypothesis 6: The WeatherWise training group will divert at or before the IMC more often than the control group.

Hypothesis 7: There will be a positive relationship between pilots' situation assessments and tactical decision making.

Situation Assessment

Weather Assessment

Estimation of Visibility

Participants were asked to estimate the visibility when they were confronted with adverse weather conditions. The visibility is the greatest distance at which an object can be seen, and is reported as status mile (SM) (ICAO, 2002). The visibility proportional error (VPE) was computed as [(Estimated visibility - Actual visibility) / Actual visibility] and analyzed using a single factor ANOVA (Coyne et al., 2008). The results showed that there were no significant differences in the estimation of visibility between the two groups, $F(1, 38) = 0.79$, $p = 0.38$ (Figure 4.1). Interestingly, the VPEs of 36 participants out of 40 were negative, which indicated that most participants underestimated the visibility (visibility was higher than participants estimated).

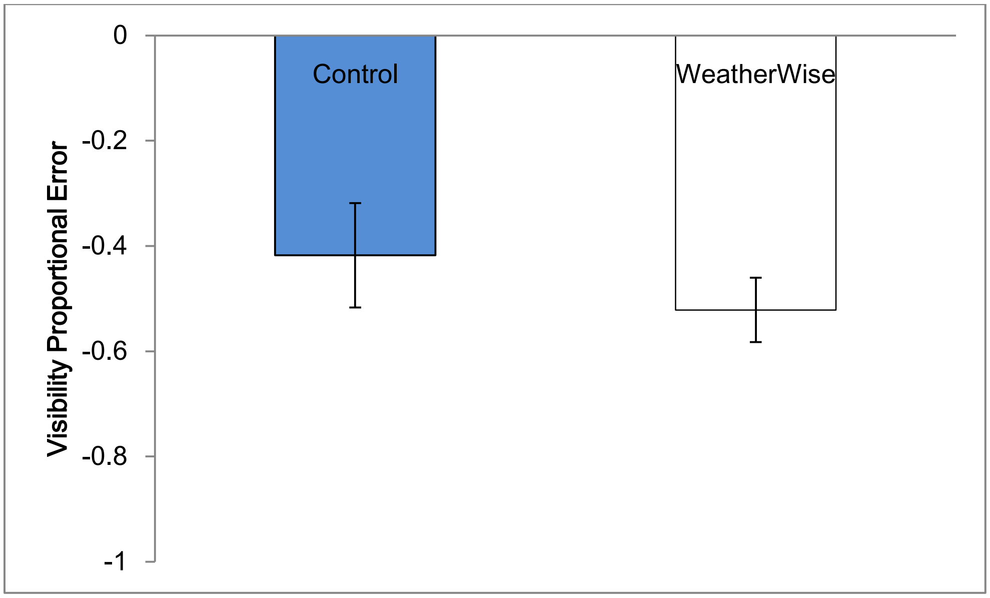


Figure 4.1 Main Effect of Training on Visibility Estimation

Note: Negative values of VPE indicate that visibility was higher than participants estimated. Error bars reflect the standard error of the mean.

Estimation of Ceiling

Participants were also asked to estimate the ceiling when they would like to discontinue the flight. The ceiling is the lowest layer of clouds and is reported as above ground level (AGL). Similarly, the ceiling proportional error (CPE) was computed as [(Estimated ceiling - Actual ceiling) / Actual ceiling] and analyzed using a single factor ANOVA (Coyne et al., 2008). Actual ceiling was computed as [programmed ceiling height – terrain height] to calculate in AGL. Unlike the negative values of the VPE, the CPE of 32 participants out of 40 was positive, which indicated that most participants overestimated the ceiling (ceiling was lower than participants estimated). In addition, the WeatherWise training group showed better ceiling estimation accuracy than the control group, and there were significant effects of training on the estimation of ceiling between the two groups, *F* (1, 38) = 4.65, *p* = 0.03 (Figure 4.2).

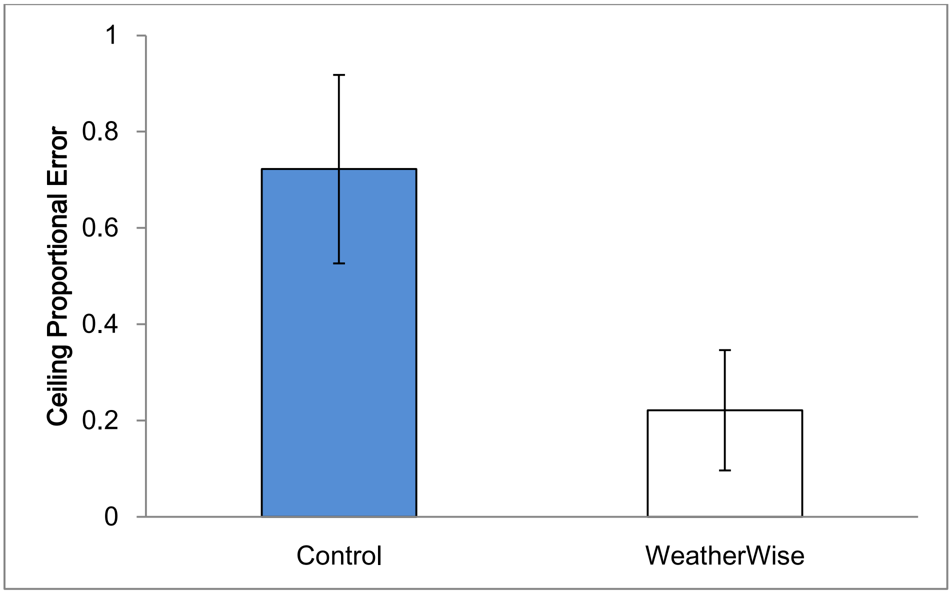


Figure 4.2 Main Effect of Training on Ceiling Estimation

Note: Positive values of CPE indicate that ceiling was lower than participants estimated. Error bars reflect the standard error of the mean.

Estimation of Weather Condition

Finally, participants were asked to estimate the weather conditions (e.g., VFR, MVFR, IFR, LIFR) when they were confronted with adverse weather conditions. The Mann-Whitney *U* test was used as a nonparametric method because participants' weather condition estimations were ordinal (rank-ordering) data. The purpose of this test was to examine whether there were significant differences in the medians of weather condition estimation between the control group and the WeatherWise training group. The findings indicated that there were no significant differences in the medians of weather condition estimation between the two groups (the Mann-Whitney $U_{0.05}$ = 161.5, nonsignificant, see Appendix G for calculation). Frequency analysis on the weather condition estimation of the control group and the WeatherWise training group are presented in Figure 4.3.

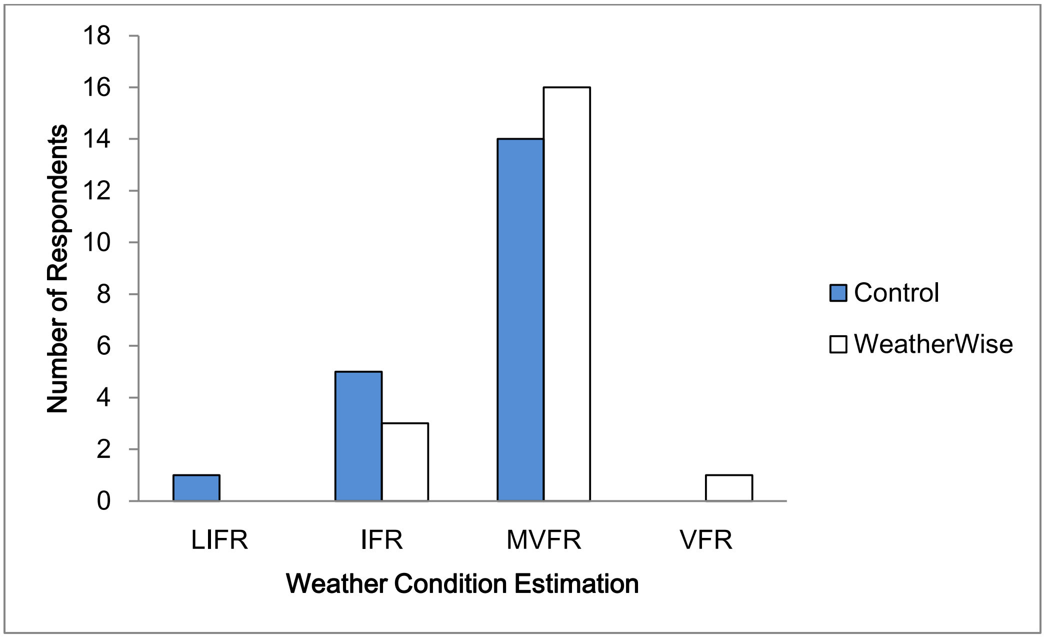


Figure 4.3 Frequency Analysis on Weather Condition Estimation

Note: There was no response for LIFR among the WeatherWise training group, and no response for VFR among the control group.

The weather assessments of the seven outlier participants in each group (Figure 4.4) were compared to see whether there were distinct differences in the estimation of visibility, ceiling, and weather conditions due to weather training. The findings again showed that here were no significant differences in the estimation of visibility (F (1, 12) = 1.19, p = 0.29) and estimation of weather conditions (the Mann-Whitney $U_{0.05}$ = 10.5, nonsignificant, see Appendix G for calculation), but there were significant differences in the estimation of ceiling (F (1, 12) = 9.22, p = 0.01) between the two groups.

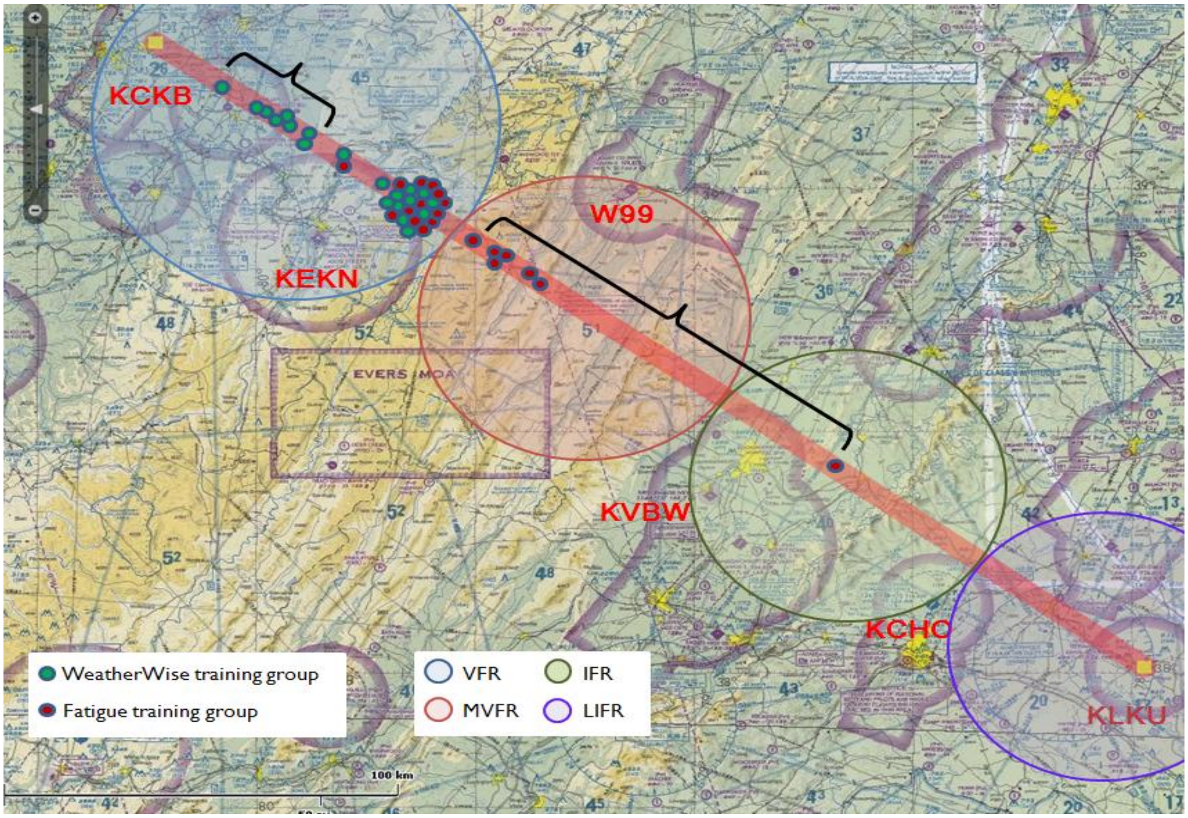


Figure 4.4 Outlier Participants' Divert Points

In summary, the WeatherWise training group and the control group were not significantly different in the estimation of visibility and weather conditions. However, there were significant differences in the estimation of ceiling between the two groups. Furthermore, the comparison of seven outlier participants in each group clearly showed that the control group tended to overestimate the ceiling whereas the WeatherWise training group tended to underestimate the ceiling (Figure 4.5). It can also be seen that the WeatherWise training group showed higher ceiling estimation accuracy than the control group.

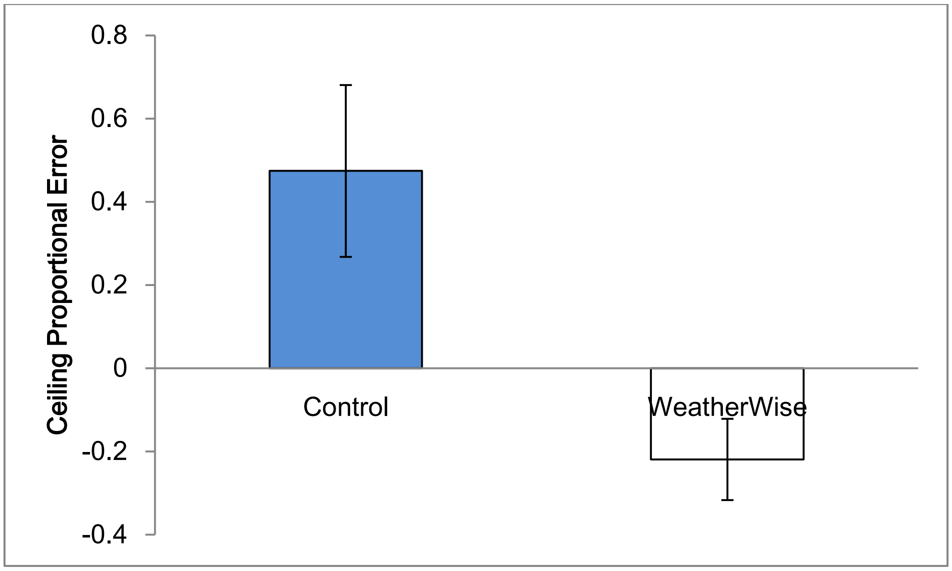


Figure 4.5 Main Effect of Training on Ceiling Estimation of Outlier Participants

Note: Positive values of CPE indicated that ceiling was lower than participants estimated, and negative values of CPE indicated that ceiling was higher than participants estimated.

Risk Assessment

Risk Perception

Participants’ risk assessment was measured in terms of risk perception and risk tolerance. Risk perception is the ability to detect, perceive, and assess the risk associated with a situation or a traffic hazard (Hunter, 2002b), and was measured by the number of incidents and hazardous events a pilot reported (Hazardous Event Scale: Hunter, 2002a). The HES is a ten-item scale, and has a possible range of 0 to 21. Higher scores indicated that the participants had experienced more hazardous events (Hunter, 2005).

There were no significant differences in the risk perception between the control group (Mean: 7.65, SD: 4.27) and the WeatherWise training group (Mean: 7.85, SD: 6.60), *F* (1, 38) = 0.01, *p* = 0.91). The mean numbers of hazardous events between the two groups are presented in Figure 4.6.

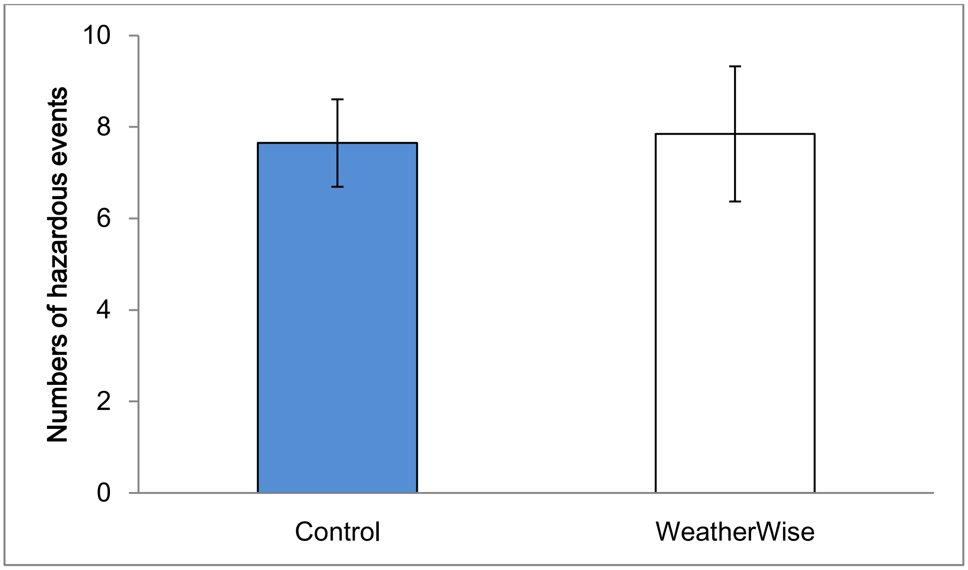


Figure 4.6 Mean Numbers of Hazardous Events

Risk Tolerance

Risk tolerance is the amount of risk an individual is willing to accept in a specific situation (Hunter, 2002b), and was measured using personal minimums and the Aviation Safety Attitude Scale (ASAS; Hunter, 1995).

Personal minimums represent participants' visibility and ceiling minimums, and the percentage of the common practices under which they would fly. Thus, when the given scenario ceiling was lower than their ceiling minimum or the visibility was less than this minimum, participants would not continue flying. The results showed that there were no significant differences in the weather minimums and common practices between the two groups (Figures 4.7 to 4.10; see Appendix H for calculation). Table 4.1 summarizes the details of personal minimums of the control group and the WeatherWise training group.

Table 4.1 Personal Minimums

	Personal Minimums		
	Visibility (SM)	Ceiling (Feet)	Common Practices (%)
Control group	7.14	3487.5	74.21
	2.23	772.1	23.89
WeatherWise training group	7.10	3437.5	80.33
	2.012	912.3	24.75

Note: Upper values represent mean, and lower values represent standard deviation.

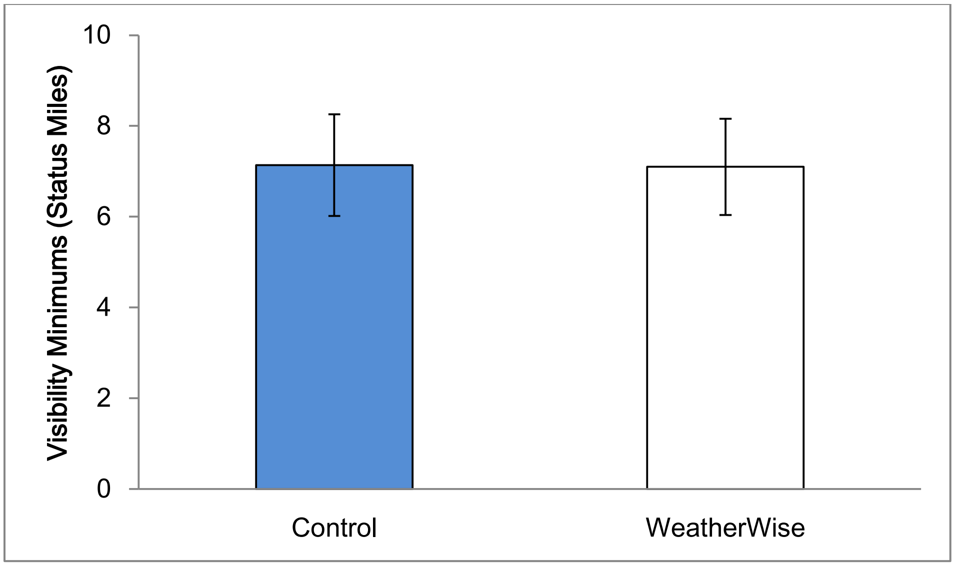


Figure 4.7 Personal Visibility Minimums

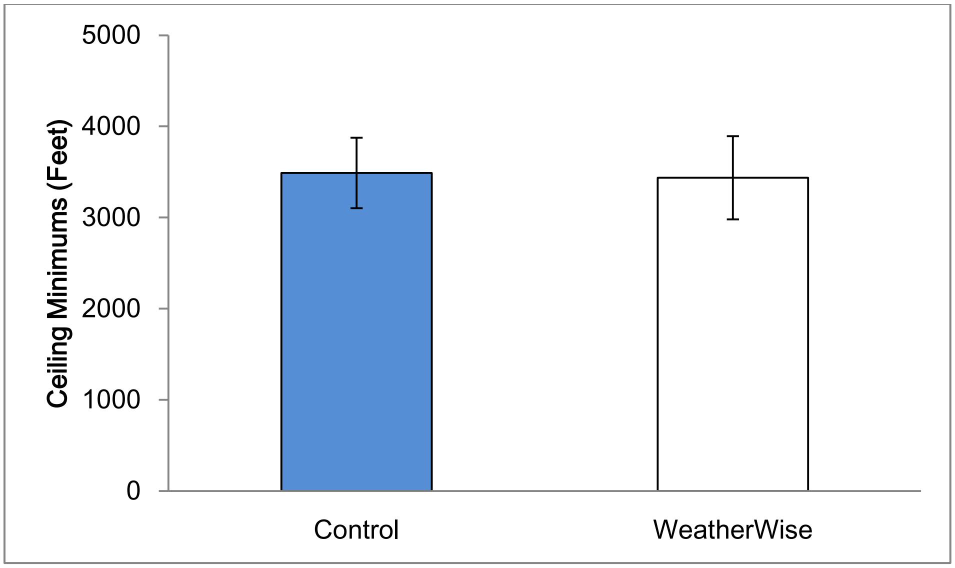


Figure 4.8 Personal Ceiling Minimums

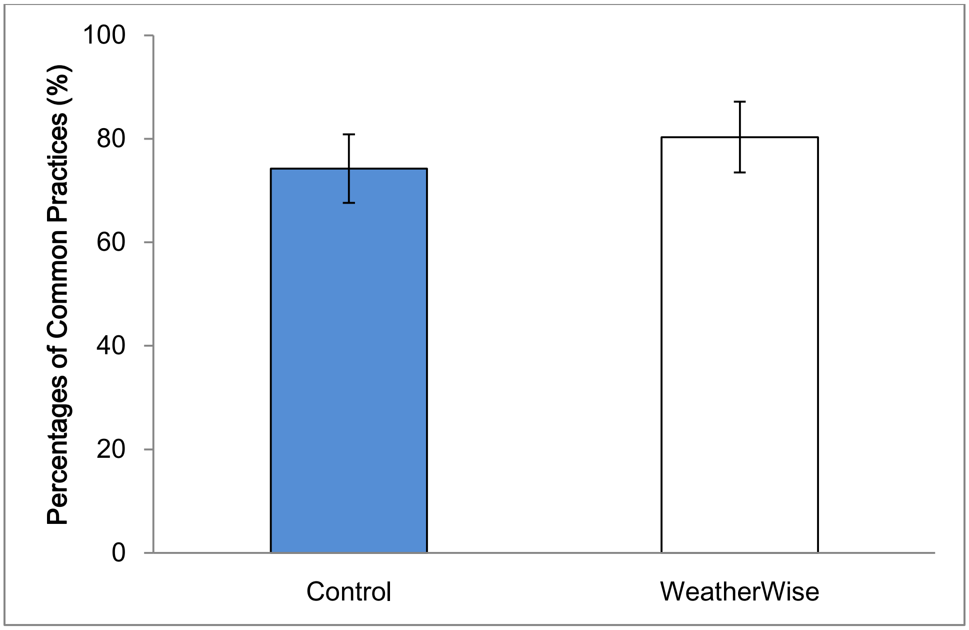


Figure 4.9 Percentages of Common Practices in a VFR Local Flight

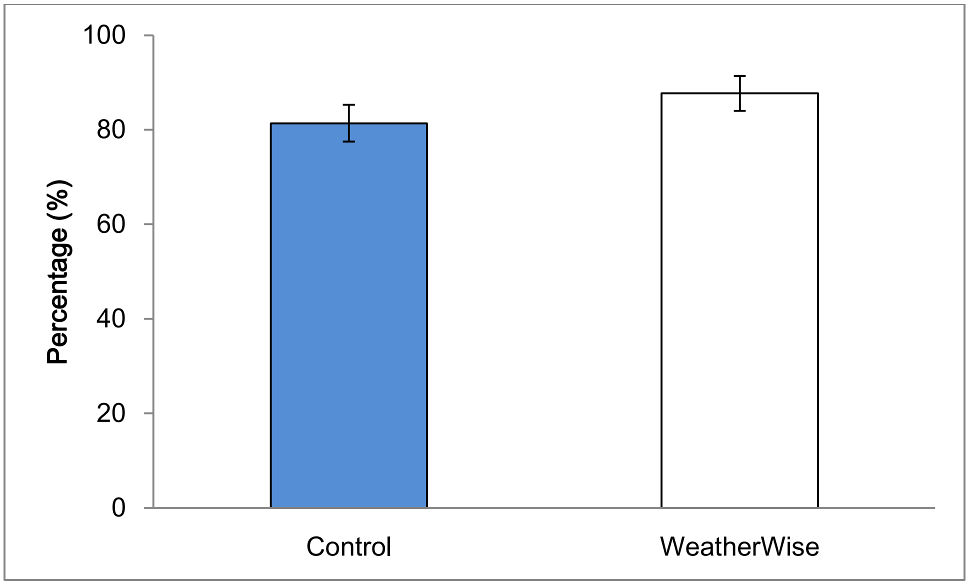


Figure 4.10 Percentages of Common Practices in a Cross-Country Local Flight

ASAS represents pilots' attitudes about flying and consists of questions regarding weather, the risks encountered in aviation, the likelihood of experiencing an accident, and self-perceived skill (Hunter, 2005). The ASAS is a 27-item scale, and response choices range from 1(strongly disagree) to 5 (strongly agree). Higher scores indicated that the participants had safer attitudes toward flight.

The findings showed that there were no significant differences in the ASAS response between the control group (Mean: 2.86, SD: 0.94) and the WeatherWise training group (Mean: 2.91, SD: 0.94), *F* (1, 52) = 0.04, *p* = 0.85 (Figure 4.11).

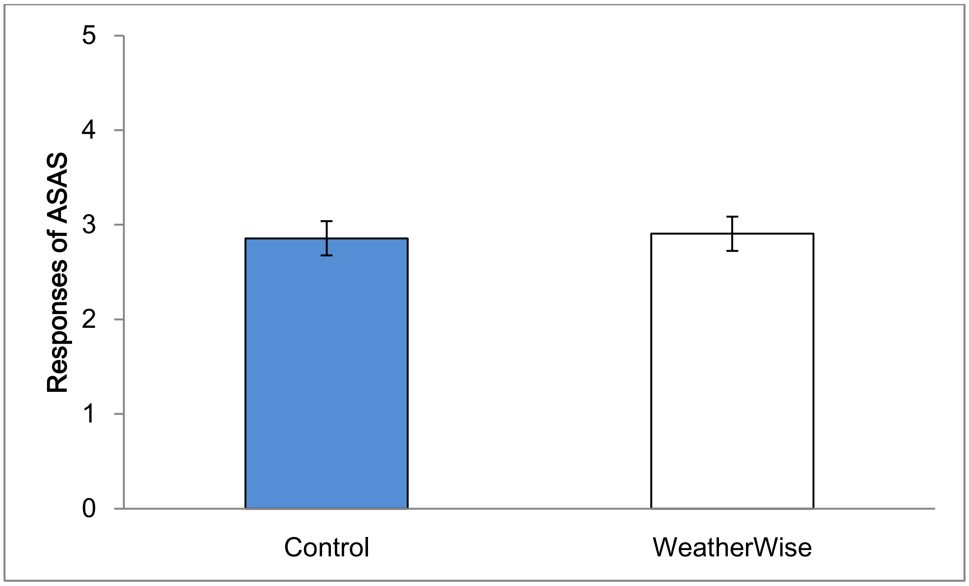


Figure 4.11 Mean Responses of Aviation Safety Attitude Scale

Overall, the personal minimum and ASAS analyses showed that there were no significant differences in the risk tolerance between the control group and the WeatherWise training group although the WeatherWise training group was more conservative toward flying into adverse weather conditions than the control group.

Tactical Decision Making

Decision Accuracy

In this study, four weather conditions were deployed along the flight path, which passed by six airports (KCKB, KEKN, W99, KVBW, KCHO, and KLKU) (Figure 4.12). The weather conditions were chosen in order to simulate gradually worsening weather conditions: VFR (blue circled area), MVFR (red circled area), IFR (green circled area), and LIFR (purple circled area).

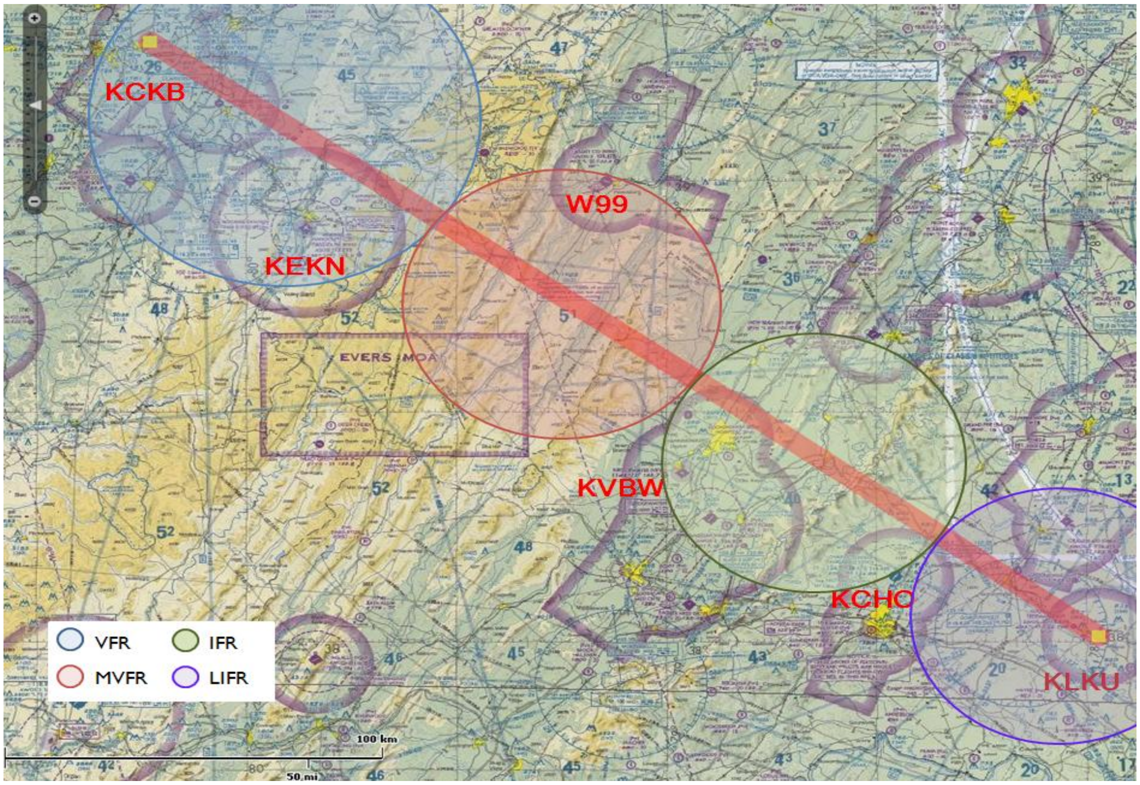


Figure 4.12 Weather Conditions along the Flight Path

Pilot tactical decision making is in-flight judgment and was evaluated in terms of decision accuracy and decision confidence. Decision accuracy was evaluated by measuring the distance that a pilot has flown from an optimal divert point to an actual divert point, and the distance that a pilot has flown into adverse weather conditions. A coordinate distance calculator was used to measure the distance. An optimal divert point was judged by three expert pilots, who chose stage #10 out of 15 screenshots of divert points along the flight path (Figure 4.13; see Appendix I for 15 screenshots of divert points along the flight path).

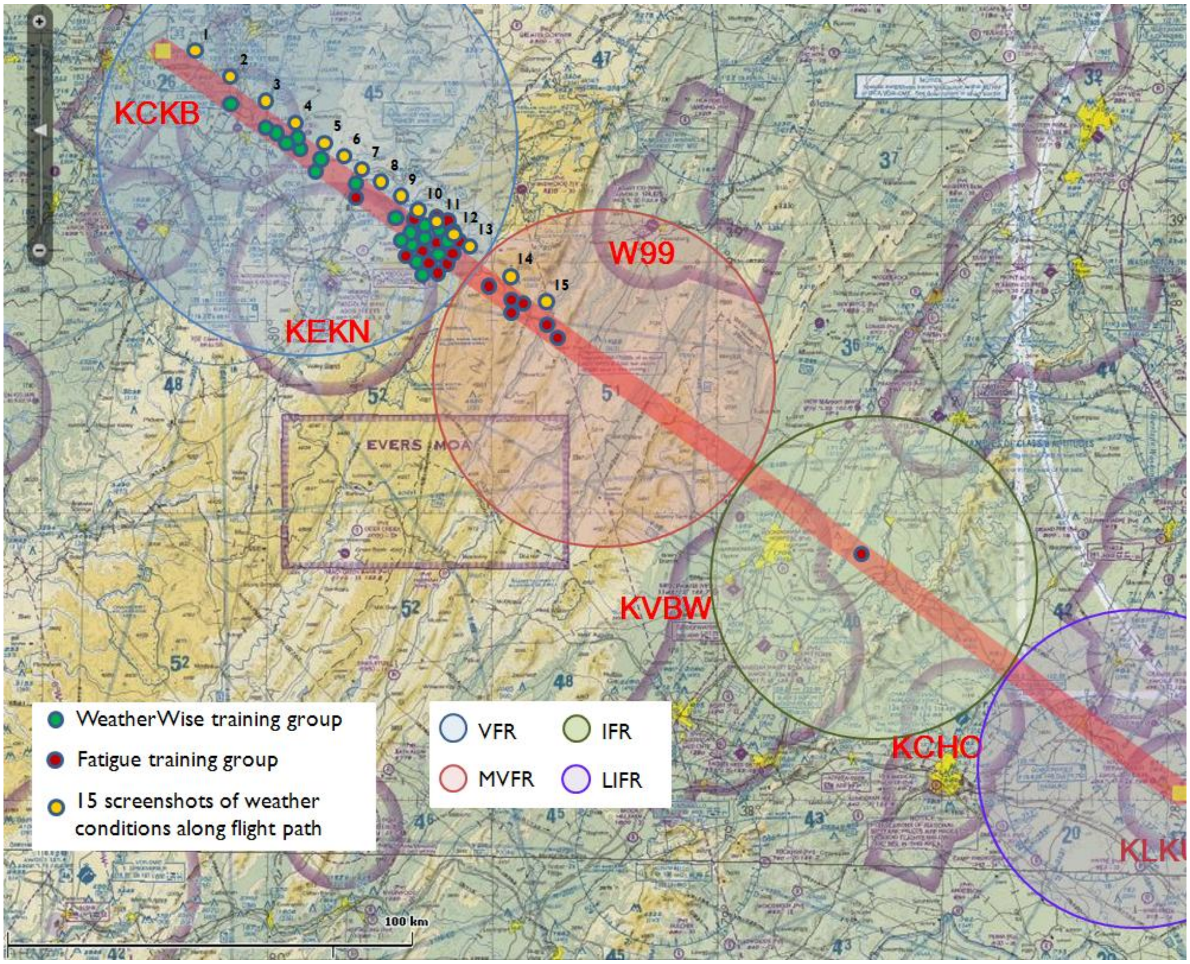


Figure 4.13 Participants' Divert Points

In Figure 4.13, green dots represent divert points of the WeatherWise training group, red dots represent divert points of the control group, and yellow dots represent 15 screenshots of weather conditions along the flight path.

The distances between the optimal divert point and the actual divert point were not statistically significant, but approached significance, *F* (1, 38) = 3.43, *p* = 0.07 (Figure 4.14).

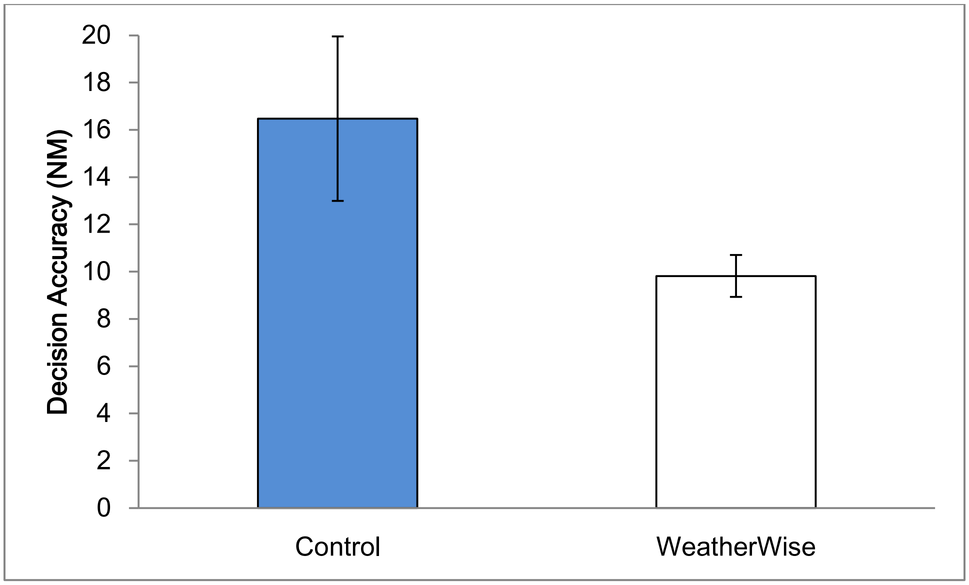


Figure 4.14 Main Effects of Training on Decision Accuracy

Note: Decision accuracy represents the distance between an optimal divert point and an actual divert point.

When compared in terms of the distances flown into adverse weather, however, there was significant main effect of training between the WeatherWise training group and the control group, *F* (1, 38) = 13.04, *p* = 0.001. As can be seen from Figure 4.15, the control group (Mean: 41.32, SD: 15.54) generally diverted later than the WeatherWise training group (Mean: 26.62, SD: 9.47) when they encountered adverse weather conditions.

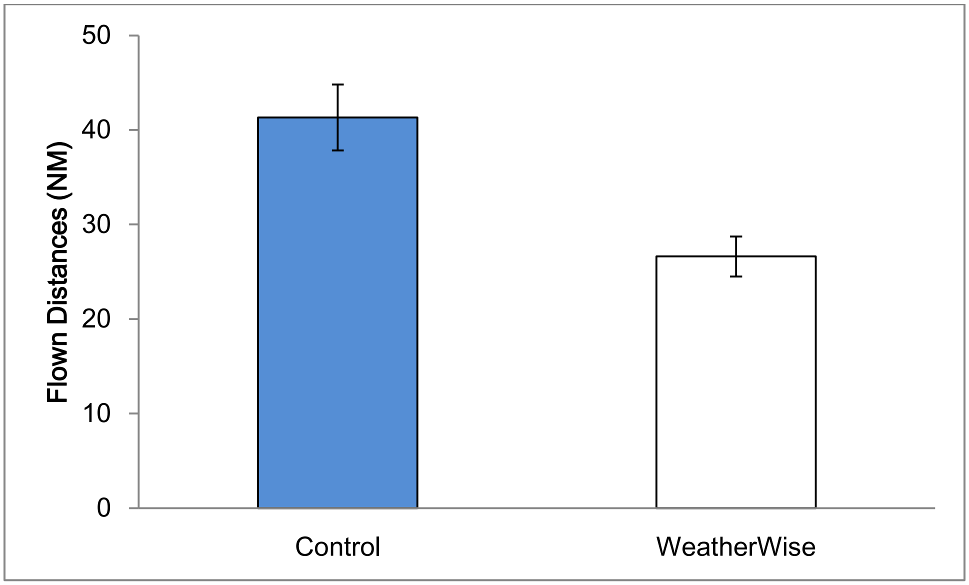


Figure 4.15 Main Effects of Training on Distances Flying into Adverse Weather

Decision Confidence

The decision confidence represents participants' confidence levels in making the divert decision. It was measured using a subjective rating method by asking participants assess themselves on a scale ranging from zero (not at all confident) to 100 (extremely confident).

The findings showed that the confidence level of the control group was higher than the WeatherWise training group. However, there was no significant difference in decision confidence between the two groups (Figure 4.16), *F* (1, 38) = 1.79, *p* = 0.19.

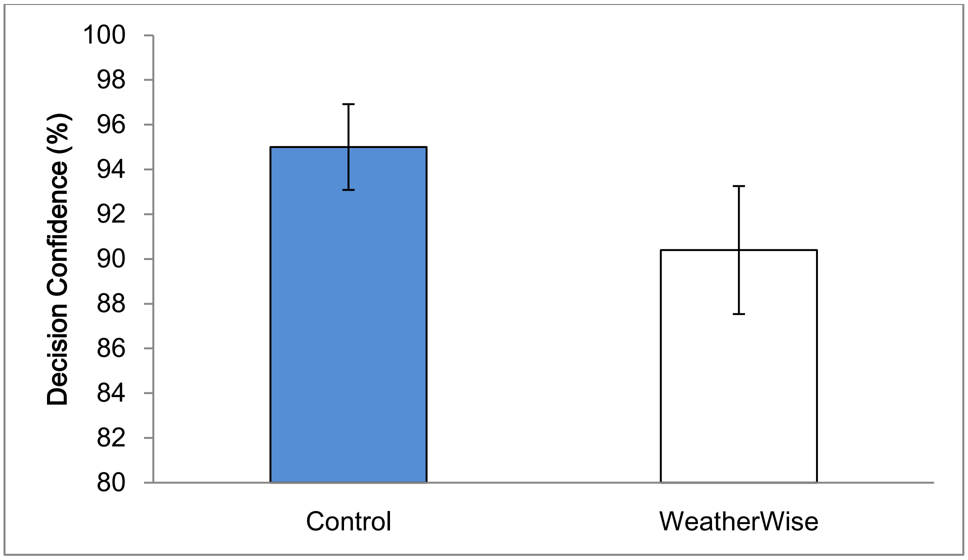


Figure 4.16 Main Effects of Training on Decision Confidence

When compared in terms of their flight experience, (Table 2.2; cut-off 500 hours of cross-country flight), however, the expert group showed significantly higher decision confidence than the novice group (Figure 4.17), *F* (1, 38) = 9.13, *p* = 0.004.

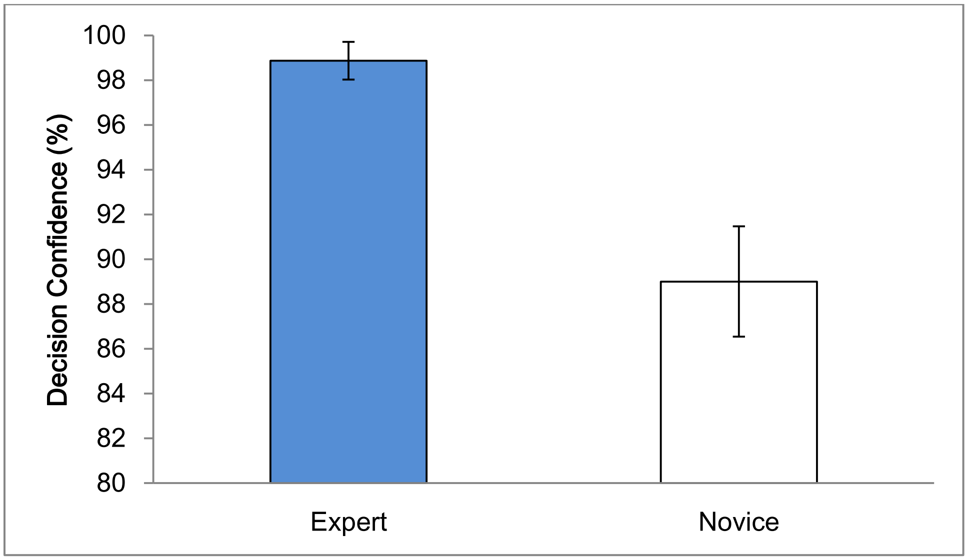


Figure 4.17 Main Effects of Flight Experience on Decision Confidence

CHAPTER FIVE

DISCUSSION

The purpose of this study is to evaluate the effects of weather recognition training on GA pilots' situation assessment and tactical decision making under gradually worsening weather conditions. The discussions are composed of pilot situation assessment, tactical decision making, significance and academic contribution of the study. The tests for seven hypotheses are also discussed.

Situation Assessment

Pilot situation assessment is a pilot's understanding of a current flight state and was evaluated in this study in terms of weather assessment and risk assessment. Participants' weather assessment was measured in terms of the estimation of visibility, ceiling, and weather conditions. One of the hypotheses was that the WeatherWise training group would estimate the visibility, ceiling, and weather conditions better than the control group. Tests of the hypotheses showed that the estimation of visibility and weather conditions of the WeatherWise training group was not better statistically than the control group; however, there was a significant main effect of training on the ceiling estimation between the two groups. Overall, there were no statistical differences in the weather assessment abilities between the WeatherWise training group and the control group.

The results indicated that pilots may have difficulties in estimating weather conditions correctly, and that they often consider multiple factors when estimating weather conditions. This finding is consistent with Knecht et al.'s (2003) results. The authors investigated the effects of visibility, ceiling, and financial incentives on pilots' decisions to take off in marginal weather conditions. There were no significant differences for the separate main effect (i.e., visibility, ceiling, and financial incentive), but there were significant differences in the interaction effect between visibility and ceiling, which implied that pilots might make weather-related decisions based on the simultaneous consideration of multiple factors. Similarly, Coyne et al. (2008) investigated pilots' ability to estimate the visibility and ceiling in a VFR into IMC scenario. They found that pilots tended to overestimate the ceiling, and this trend increased as visibility increased. The authors asserted that an interaction effect of visibility and ceiling might impact a pilot's weather condition estimation.

The weather assessment findings in this study were contrary to Wiegmann et al.'s (2002) findings. In their study, there were no differences in the ceiling assessment, but there were differences in the visibility assessment between the "continue group" (pilots who chose to continue the flight after encountering the adverse weather) and the "divert group" (pilots who chose to divert the flight after encountering the adverse weather). As expected, the continue group was less accurate in estimating visibility than the divert group.

In this study, the visibility and ceiling were initially designed as VFR conditions, but the rising terrain that occurred about 16 minutes into the flight might have influenced the participants' estimation of ceiling more than visibility. As a result, the perceived ceiling height as measured by AGL might be lowered, and this could enable participants to underestimate the weather condition as MVFR when it was actually VFR.

While pilot weather estimation as measured by visibility and weather condition revealed no difference between the two groups, the findings did suggest that the WeatherWise training might be helpful for GA pilots to enhance ceiling estimation ability when they encountered adverse weather conditions. The comparison of seven outlier participants in each group clearly showed that the WeatherWise training group showed higher ceiling estimation accuracy than the control group. Furthermore, the control group overestimated the ceiling, whereas the WeatherWise training group underestimated the ceiling. This indicates that WeatherWise was successful in enabling pilots to make safer weather-related decisions. Considering that GA-controlled flight into terrain (CFIT) accidents account for 17 percent of all GA fatalities (FAA, 2003), it should be noted that the WeatherWise training might be helpful to reduce CFIT accidents that occur when a pilot tries to continue flight beneath a low ceiling and hits an obstacle or terrain.

Risk assessment was measured in terms of risk perception and risk tolerance. As expected, there were no significant differences in the risk perception between the two groups because participants were randomly divided into the WeatherWise training group and the control group. Unlike the questionnaire studies with more than 400 participants (Hunter, 2001; 2006), it was difficult to find significant differences in the number of accidents between two groups of 20 participants in this empirical study. Specifically, accidents are relatively rare events and any differences between the groups were unlikely to have occurred because of sample size and power.

Risk tolerance was measured by personal minimums and aviation safety attitude scale. Although there was no statistical difference in the risk tolerance between the two groups, there was a tendency for the WeatherWise training group to be more conservative than the control group in terms of higher visibility minimums and percentages of common practices. Thus, the hypothesis that the WeatherWise training group would assess risks better than the control group was not supported, the WeatherWise training group was slightly more conservative.

These findings were in line with Knecht et al.'s (2005) study. The authors measured the effects of visibility, cloud ceiling, incentive, and personality on a pilot's willingness to takeoff in adverse weather. The findings indicated that personality could not predict whether a pilot would fly in adverse weather or not.

To summarize, the WeatherWise training group exhibited higher weather assessment with regard to ceiling estimation than the control group: however, there were no statistical differences in the risk assessment between the two groups.

Tactical Decision Making

Pilot tactical decision making was evaluated in terms of decision accuracy and decision confidence. The findings showed that the distance from an optimal divert point to an actual divert point, as judged by three experienced pilots, between the two groups was not statistically different. However, when compared with the flown distances into adverse weather, significant differences were found between the two groups. Given that the WeatherWise training group would divert at or before the IMC more often than the control group, this hypothesis was supported.

This result was in accordance with Sawyer and Shappell’s (2009) study. The authors showed pilot participants 10 randomly ordered weather images and asked them whether they would continue flying in the weather condition in the images. Participants then completed the WeatherWise training program and were asked the same questions again with randomly ordered weather images. There were no significant differences in the decision accuracy between pilot groups, but all groups showed a significant shift in bias, with pilots becoming more conservative (i.e., tended to view weather as more adverse and would not fly into it) after receiving training. This suggests that while weather training did not necessarily make pilots more accurate in their weather assessment, it was effective in making pilots more conservative/safer in their weather-related decision making.

In this study, the confidence level of the control group was higher than the WeatherWise training group, but the differences were not significant. Therefore, the hypothesis that the WeatherWise training group would be more confident in their decisions to divert than the control group was not supported. Notably, however, when flight experience was considered, decision confidence of the expert group was significantly higher than that of the control group.

Although the hypothesis on participants’ decision confidence between the two groups was not supported, the results indicated that the decision confidence data is still reliable because expert pilots generally show higher confidence levels than novice pilots

(Goh & Wiegmann, 2002b; Wiggins & O'Hare, 2003a). In Goh & Wiegmann's (2002b) study, for example, the authors asked pilot participants to rate how good they were at making VFR into IMC decisions during a dynamic simulation of a cross-country flight. The results suggested that the experienced pilots were more confident in recognizing problems and generating and implementing solutions than the inexperienced group.

To summarize, the WeatherWise training group demonstrated better decision accuracy as measured by the flown distance into adverse weather conditions than the control group. However, there were no significant differences in decision confidence between the two groups.

Significance and Academic Contribution

This study clarified the concept of pilot situation assessment and tactical decision making and comprehensively evaluated the effects of weather training on pilots in an empirical study. In general, situation assessment is referred to as problem recognition in the cognitive process model (Gaba et al., 1995; Patterson, 2009). In this study, pilot situation assessment was defined as a pilot's understanding of a current flight state and was evaluated in terms of weather assessment and risk assessment. In previous studies, the concept of situation assessment was used interchangeably with situation awareness (Fracker, 1988), decision accuracy (Sawyer & Shappell, 2009), and self-assessment of the weather conditions (Wiggins & O'Hare, 2003b; Wiegmann et al., 2002) and was often measured only from weather assessment. Because poor weather assessment was the major causal factor that led to the GA Aviation Safety Reporting System (ASRS) report

(Beard & Geven, 2005), there is no doubt that weather assessment must be considered. However, the risks associated with flying into adverse weather should also be considered to measure pilot situation assessment (Wiggins et al., 1995) because even though pilots correctly assess the weather conditions, they may incorrectly determine the potential risks associated with the weather conditions. In addition, although inner competence factors such as personality traits, attitude, and motivation are hard to train and measure (McClellend, 1971), they also have been known to be the causal factors of weather-related GA accidents (Table 1.2). In contrast, pilot tactical decision making is in-flight judgment, and was evaluated in terms of decision accuracy and decision confidence.

Another important finding was that pilots’ thinking and attitude might be disconnected when they encountered adverse weather. In this study, the control group flew farther into adverse weather and showed lower decision accuracy than the WeatherWise training group (Figure 4.4; Figure 4.5). This may have been because the control group overestimated the weather conditions more than the WeatherWise training group. However, in the post-experiment questionnaire, the control group tended to underestimate the weather conditions whereas the WeatherWise training group tended to overestimate the weather conditions (Figure 4.3).

The disagreement between participants’ thinking (situation assessment) and attitude (tactical decision making) is known from a previous study (Endsley, 2000). For example, it is entirely possible that a pilot thoroughly understands the weather condition, yet makes inappropriate decisions (i.e., penetrates a hole between clouds to fly the shortest path). When a pilot is exposed to a dynamic environment, this trend can be more frequently found.

Another possible reason for this disagreement might be the lack of experience or training. In this study, the WeatherWise training group received a one-time half hour computer-based training, which may not be sufficient to change their attitude because one's attitude is relatively stable and consistent across situations (Chidester et al., 1991). To measure the effects of weather training thoroughly, the WeatherWise training group would need to replicate the training for a long period (e.g., 6 month) and then investigate whether there are significant differences in their risk taking behavior and decision confidence with the control group.

It should also be noted that this study proceeded one step further to understand the effects of weather training on pilot weather decision making in a VFR into IMC. In previous studies, the weather conditions used in WeatherWise were clearly different in each stage; hence it was not clear whether the weather training program is effective in gradually worsening weather conditions (Wiggins & O'Hare, 2003b). In addition, pilots did not actually control the flight, but just saw the weather conditions presented either through static images (Ball, 2008; Sawyer & Shappell, 2009; Wiggins & O'Hare, 2003a) or short video clips (Coyne et al., 2008). Participants then chose an optimal divert point, which lacks the reality of flying, and may not represent the workload imposed on pilots. Thus, it is necessary to use a more "real-world" simulation of VFR flight to understand the underlying effects of weather recognition training on GA pilot situation assessment and tactical decision making (Goh & Wiegmann, 2001b).

In this study, participants flew to the destination airport as long as they did not violate the VFR condition using the flight simulator. This is the latest study investigating the effects of weather training on pilots' weather-related decision making.

CHAPTER SIX

CONCLUSIONS

This study explored how pilots' situation assessment and tactical decision making were affected by weather recognition training when they were confronted with adverse weather conditions. The findings showed that the WeatherWise training group exhibited better weather assessment with regard to ceiling estimation and decision accuracy, as measured by flown distance into adverse weather conditions, than the control group, but there were no significant differences in the risk assessment and decision confidence between the two groups. However, the WeatherWise training group did demonstrate a conservative tendency toward flying into adverse weather conditions.

Thus, it can be concluded that the weather training was somewhat effective in altering pilot situation assessment and tactical decision making when pilots encounter adverse weather conditions.

The findings of this study also answered the research question whether pilots' decision errors are associated with weather-related accidents. The findings of pilot tactical decision making showed a positive relationship between pilots' decision errors and continued VFR into IMC in that flown distances of the control group were significantly longer than the WeatherWise training group in gradually worsening weather conditions in this study.

This study also had limitations, the first of which was that a desktop flight simulator used in this study may not provide sufficient visual cues and simulation fidelity, which might influence pilots’ weather assessment. In previous empirical studies using low-fidelity flight simulators (Coyne et al., 2008; Crognale & Krebs, 2008), pilots had difficulty in correctly assessing weather conditions. In this study, this limitation was partially overcome by projecting a large image of the cockpit view in front of the pilot. A second limitation was the short length of weather training period. Participants received a one-time half-hour weather training due to time and budget limitations, which may not be sufficient to change pilots’ attitude toward flying into adverse weather conditions. To fully investigate the effect of weather training, its the long term effects (e.g., 6 months) should be explored in the following study.

The results of this study can be expanded not only to GA pilots but also to commercial airline pilots and military pilots for various reasons. First, all pilots are expected to acquire weather recognition skills and knowledge to ensure a safe flight, regardless of their flight types, because the nature of changing weather conditions is dynamic and hard to predict during the flight. Second, although those aircraft are generally well-equipped with weather display radar or navigation systems that include a weather map, they do not provide real-time weather information, and they sometimes malfunction. Finally, commercial airline pilots and military pilots are more prone to press into adverse weather conditions due to organizational culture, although the impact of resultant accidents is more tragic than GA accidents.

In conclusion, it is expected that this study will be helpful for GA pilots to understand the effects of weather recognition training on weather decision-making, and eventually help them to assess a situation correctly and make a timely in-flight decision when they encounter adverse weather conditions. This study described causal factors (e.g., skill, experience, and personality) and causal hypotheses (e.g., situation assessment, risk assessment) of weather-related accidents. Thus, it is believed that this study will help to establish a sound foundation for weather training programs and has the potential to reduce weather-related GA accidents by implementing weather recognition training during basic flight training courses as well as periodic qualification training courses.

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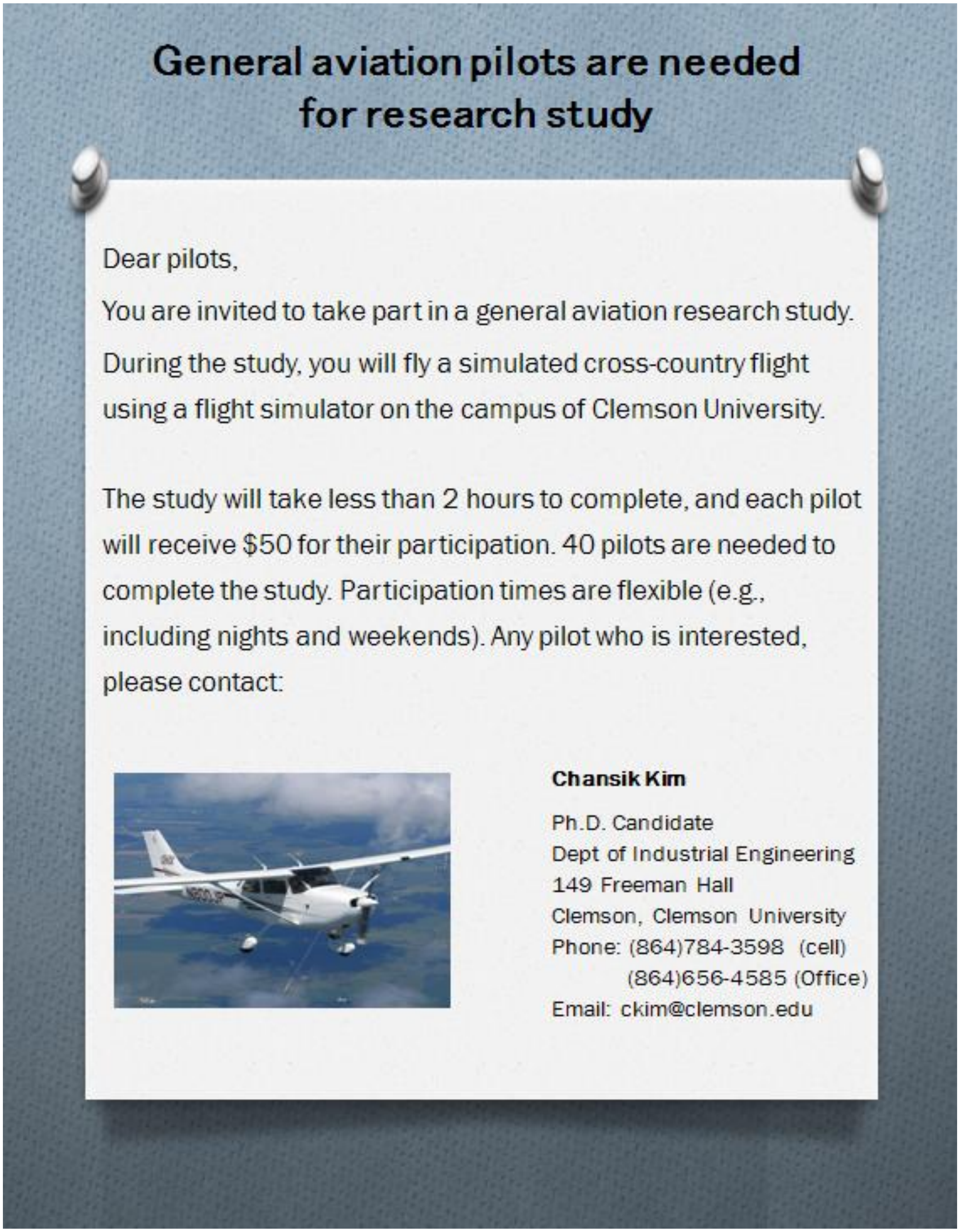
APPENDICES

Appendix A

Participant Recruitment Flyer



General aviation pilots are needed for research study

Dear pilots,

You are invited to take part in a general aviation research study. During the study, you will fly a simulated cross-country flight using a flight simulator on the campus of Clemson University.

The study will take less than 2 hours to complete, and each pilot will receive $50 for their participation. 40 pilots are needed to complete the study. Participation times are flexible (e.g., including nights and weekends). Any pilot who is interested, please contact:

Chansik Kim

Ph.D. Candidate
Dept of Industrial Engineering
149 Freeman Hall
Clemson, Clemson University
Phone: (864)784-3598 (cell)
(864)656-4585 (Office)
Email: ckim@clemson.edu

Appendix B

Informed Consent Form

Information Concerning Participation in a Research Study
Clemson University

A study on the behaviors of general aviation pilots when fly a cross-country flight using a flight simulator

Description of the Research and Your Participation

You are invited to participate in a research study conducted by Dr. Scott Shappell and Mr. Chansik Kim. The purpose of this research is to understand the decision making of general aviation pilots when they fly a cross-country flight using a flight simulator.

Experimental procedures

You will be briefed on the study upon arrival in the laboratory. You will sign a consent form and will go through a background questionnaire. The questionnaire includes information such as age, total flight time, recent flight time, cross-country flight time, certificate, license, etc.

Your will fly a Cessna 172 on a Visual flight rules (VFR) solo cross-country flight from the North Central West Virginia Airport (KCKB) to the Louisa County/ Freeman Field Airport (KLKU). You will then complete a post-experiment questionnaire, be compensated with fifty dollars for your participation, and debriefed.

The amount of time required for your participation will be about one and half hours.

Risks and Discomforts

There are no known psychological risks associated with this research. However, there is a slight risk of low level of motion sickness due to the flight simulation. To minimize the potential risk of motion sickness, you are allowed to discontinue the experiment whenever you feel discomfort without any penalty. A debriefing will follow the study to respond to any questions or concerns you might have. In addition, this time can be used to determine the effect that the study had on you, and to deal with any problem that may arise.

Potential Benefits

There are no known benefits to you that would result from your participation in this research apart from enhanced safety in overall general aviation.

Incentives

You will be compensated with fifty dollars for the participation in the study.

Protection of Confidentiality

We will do everything we can to protect your privacy. The captured data will be stored on a password-protected computer in the Industrial Engineering Department's Human Computer Systems Laboratory (Freeman Hall 147). The survey questions will be kept in a locked cabinet. The documents will be accessible only to the principal investigator and co-investigators. Your identity will not be revealed in any publication that might result from this study.

In rare cases, a research study will be evaluated by an oversight agency, such as the Clemson University Institutional Review Board or the federal Office for Human Research Protections, that would require that we share the information we collect from you. If this happens, the information would only be used to determine if we conducted this study properly and adequately protected your rights as a participant.

Voluntary Participation

Your participation in this research study is voluntary. You may choose not to participate and you may withdraw your consent to participate at any time. You will not be penalized in any way should you decide not to participate or to withdraw from this study.

Contact Information

If you have any questions or concerns about this study or if any problems arise, please contact Dr. Scott Shappell at (864)-656-4662 or Chansik Kim at (864)-784-3598 at Clemson University. If you have any questions or concerns about your rights as a research participant, please contact the Clemson University Office of Research Compliance (ORC) at 864-656-6460 or irb@clemson.edu. If you are outside of the Upstate South Carolina area, please use the ORC's toll-free number, 866-297-3071.

Consent

I have read this consent form and have been given the opportunity to ask questions. I give my consent to participate in this study.

Participant’s signature: ___________________________ Date: __________________

A copy of this consent form will be given to you.

Appendix C

Pilot Background Questionnaire

Subject ID #:

Please fill out the following information to the best of your ability. This information will only be used to analyze data in this study. Any personal, identifying information that is collected will be kept confidential. Only your subject identification number should be included on this form. Your identity will not be revealed in any publication that might result from this study.

I. Demographic Information

1. Age _________
2. Gender Male ☐ / Female ☐
3. Marital status: Married ☐ / Single ☐ / Other ☐
4. Primary occupation: ____________ Full time ☐ / Part time ☐
5. Other current occupation(s): ____________ Full time ☐ / Part time ☐
6. When was the date of your last airman medical certificate? _____________
7. What class of medical certificate do you currently hold? I / II / III / None
8. How many hours do you sleep in general? _________
9. How many hours did you sleep last night? _________
10. Did you take any kind of medicine during the last week? _____________

    If yes, specify in detail. ______________________________________

II. Flight Experience

1. Place where you learned to fly (ex: Miami, FL) ____________________
2. Which year did you receive your private pilot's license? ________
3. What certificates and ratings do you currently hold? Check all that apply.

Sport	☐	Airplane Single-Engine	☐
Recreational	☐	Airplane Multiengine	☐
Private	☐	Rotorcraft	☐
Commercial	☐	Balloon	☐
ATP	☐	Airship	☐
Instrument	☐	Glider	☐
Flight Insructor	☐	Powered Lift	☐

4. What type of aircraft do you typically fly? Please list primary and secondary aircrafts you have flown.

Primary aircraft: Make / Model ______________

Primary aircraft: Hours of time in aircraft ______________ (estimate)

Secondary aircraft: Make / model ______________

Secondary aircraft: Hours of time in aircraft ______________ (estimate)

II. Flight Experience (continued)

5. Total flight hours: _________ (estimate)

6. Total VFR flight hours: _________

7. Total IFR flight hours: _________ (if you are IFR qualified)

8. Total cross-country flight hours: _________

9. Total recent 3 months cross-country flight hours: _________

10. Total recent 3 months flight hours: _________

11. Did you have experience with flying a Cessna 172? If so, please list the approximate flight hours. __________________

12. Check which of the following categories best describe your current flying activities:

Training ☐	Self-transport ☐	Agriculture/ aerial work ☐
Recreational ☐	Commercial ☐	Flights for hire ☐

13. Did you get any weather training before? If yes, specify in detail.

____

14. Have you ever used X-Plane 9 flight simulation before? If so, how many hours?

Yes ☐ No ☐ Number of hours _______

15. Have you ever heard of the WeatherWise program before?

Yes ☐ No ☐

16. Have you viewed the WeatherWise CD or on-line training program?

Yes ☐ No ☐

Appendix D

Pre-Flight Weather Briefing

Flight Weather Briefing

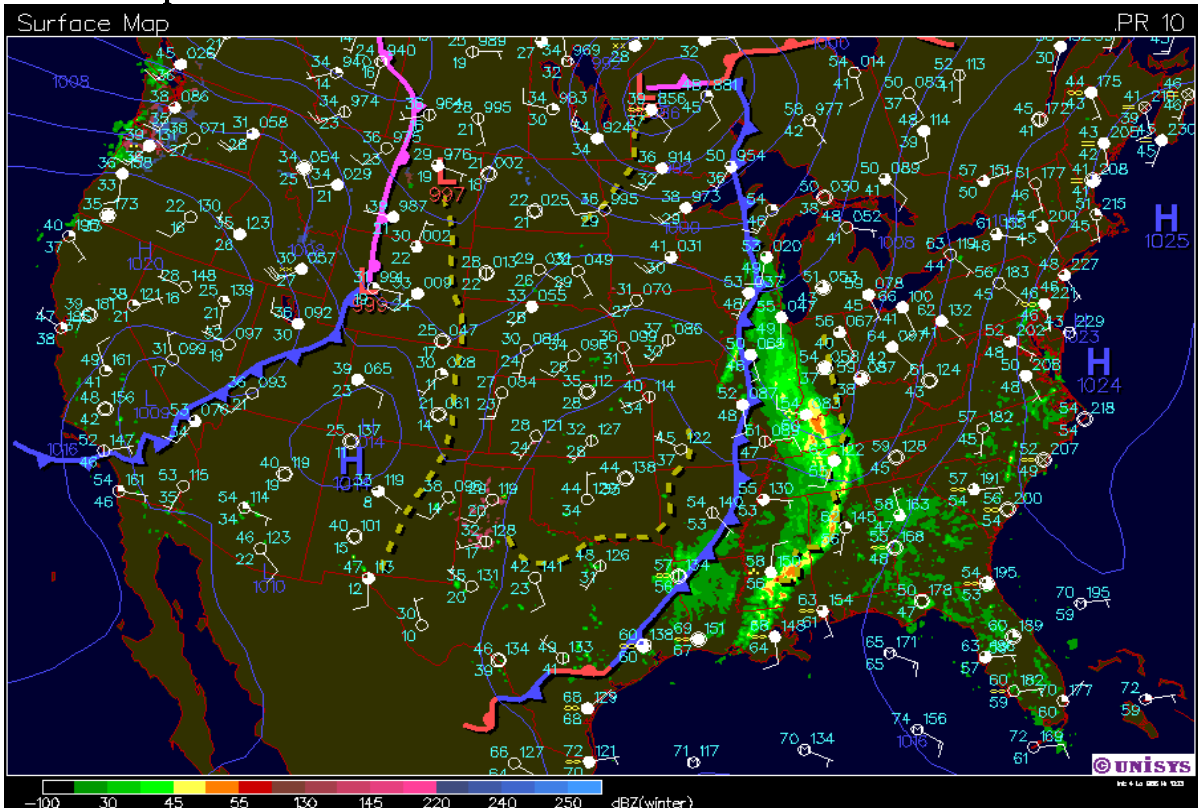
Flight Path: KCKB (North Central West Virginia) – KLKU (Louisa County/ Freeman Field)
ETD: 1:00EDT/ 1700Z
ETA: 3:00EDT/ 1900Z

Adverse Conditions:

No current SIGMET/AIRMETs, PIREPs

Synopsis:

Surface Map 1:00EDT/1700Z



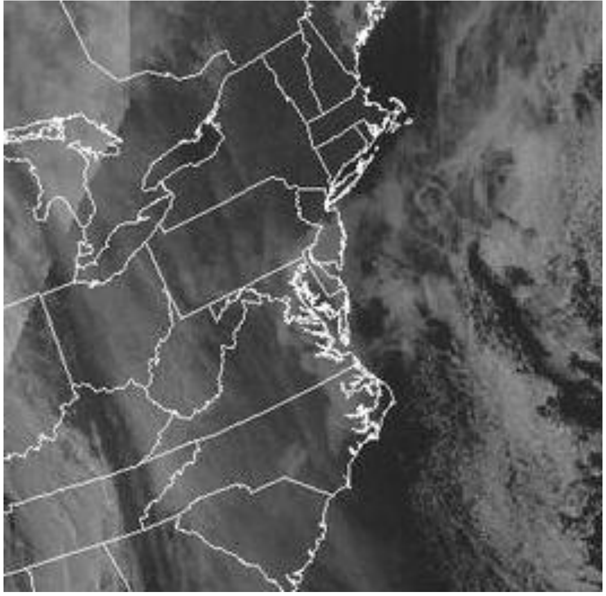
Current Conditions:

```
KCKB 081653Z 18010KT 10SM SCT100 05/M10 A2997 RMK AO2
SLP120 T00540101
```

Area Forecast (FA)

```
000
FAUS41 KKCI 081653
FA1W
BOSC FA 081653
SYNOPSIS AND VFR CLDS/WX
SYNOPSIS VALID UNTIL 091200
CLDS/WX VALID UNTIL 090600...OTLK VALID 090600-091200
.
SYNOPSIS...LOW PRES SYSTEM CNTRD OVR CNTRL CANADA COLD FRNT MVG TWD OH
VLY.  HIGH PRES SYSTEM DOMNATG ESTRN SBRD. COLD FRNT FRCST ARV 09/12Z.
.
MD DE DC WV VA
APLCNS WWD...
  NRN HLF.. SCT050-070. WND S 10KT. 02Z BKN040. TOPS 120. WND S 10G15KT.
OTLK...VFR.
  SRN.. BKN090. TOPS 100. WND S 10G15KT. 02Z SCT-BKN090. TOPS 150.
    OTLK...VFR.
E OF APLCNS...
  CSTL PLAINS..
    NRN HLF..SKC. WND S 7KT. OTLK...VFR.
    SRN HLF..SCT-BKN090. TOPS 100. SCT -RA. WND S 10G20KT. OTLK...VFR.
```

Visible Satellite Image: **12:30EDT/1630Z**

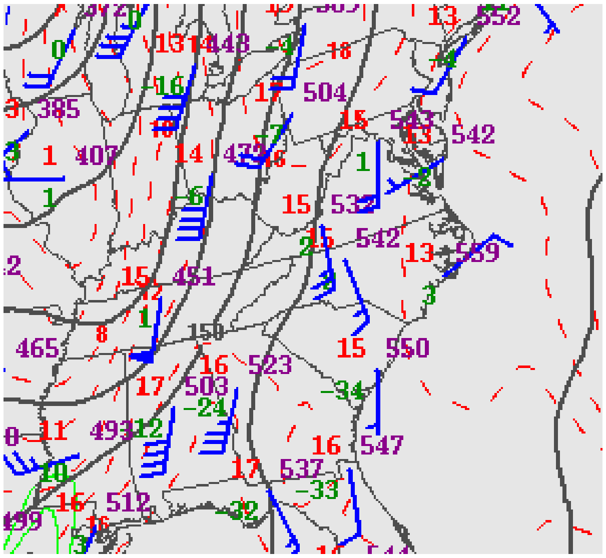


Destination Forecast:

```
KLKU 081653Z 0816/0912 18015KT P2SM BKN035
       TEMPO 0818/0820 4SM -RA OVC035
       FM091100 22025G20KT 4SM BKN035
```

Winds Aloft:

850 mb Chart:



No current NOTAMS/TFRs

Appendix E

Additional Pertinent Information to Use

Additional Pertinent Information
Permission to Use Data Collected in a Research Study
Clemson University

A study on the effects of weather recognition training on general aviation pilot situation assessment and tactical decision making when confronted with adverse weather conditions.

Thank you for participating in this study. You were told at the beginning of the study that the purpose of this research is to understand the decision making of general aviation pilots when they fly a cross-country flight using a flight simulator. Now that you have completed your participation, we want to let you know that the true purpose of this study was to measure the effects of weather recognition training on general aviation pilot situation assessment and tactical decision making when confronted with adverse weather condition using a flight simulator. We did not tell you the true purpose of this study because it might have biased your performance.

If you would like a copy of the results of the study once it is completed, you may contact Dr. Scott Shappell, the principal investigator, at hfes@clemson.edu or Mr. Chansik Kim, a co-investigator, at ckim@clemson.edu.

Because we did not tell you the truth at the beginning of this study, you now have the option to have us destroy the data we just collected or you can give permission for us to keep your data and use it for research purposes. Please **initial** below to indicate your choice.

_______ You may not use the data collected from me. Please destroy all data collected from me immediately.

_______ I give permission to have my data used in this research project.

Please remember that some of your acquainted pilots also may be signed up for this study. If they knew this study is about weather decision making, that could negatively affect the results of this study, thereby wasting your time and ours. Therefore, we would appreciate it if you would not share this additional information with others who may be participating in this study.

Thank you again for your participation in this study!

Appendix F

Pilot Post-Experiment Questionnaire

Subject ID #:

Please fill out the following information to the best of your ability. This information will only be used to analyze data in this study. Any personal, identifying information that is collected will be kept confidential. Only your subject identification number should be included on this form. Your identity will not be revealed in any publication that might result from this study.

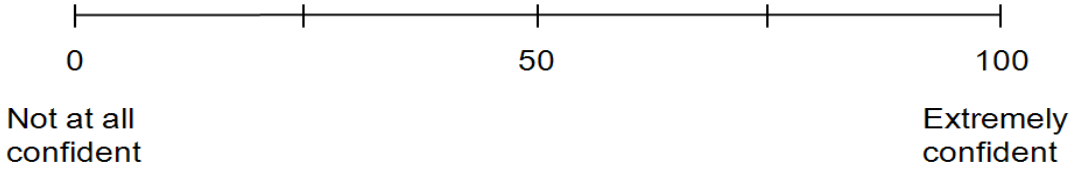
I. Weather Assessment

1. What do you estimate the visibility was when you made a divert decision? ______
2. What do you estimate the ceiling was when you made a divert decision? ______
3. What do you estimate the weather condition was when the program ended?

VFR ☐ MVFR ☐ IFR ☐ MVFR ☐

II. Decision Confidence

1. How confident were you in making your divert decision? Mark on the scale.



2. Risk Assessment

This part is composed of critical aviation accidents (10), your personal minimums (34), and attitudes about flying (27). Please respond to below questions based on your previous flight experience.

1. Critical Aviation Incidents

	0	1	2	3	4	5	6+
1. How many aircraft accidents have you been in (as a flightcrew member)?	☐	☐	☐	☐	☐	☐	☐
2. How many times have you run so low on fuel (NOT because of equipment failures) that you were seriously concerned about making it to an airport before you ran out?	☐	☐	☐	☐	☐	☐	☐
3. How many times have you made a precautionary or forced landing as an airport other than your original destination?	☐	☐	☐	☐	☐	☐	☐
4. How many times have you made a precautionary or forced landing away from an airfield?	☐	☐	☐	☐	☐	☐	☐
5. How many times have you inadvertently stalled an aircraft?	☐	☐	☐	☐	☐	☐	☐
6. How many times have you become so disoriented that you had to land or call ATC for assistance in determining your location?	☐	☐	☐	☐	☐	☐	☐
7. How many times have you had a mechanical failure which jeopardized the safety of your flight? (i.e., nav failure while on a cross-country; engine quitting).	☐	☐	☐	☐	☐	☐	☐

1. Critical Aviation Incidents (continued)							
	0	**1**	**2**	**3**	**4**	**5**	**6+**
8. How many times have you had an engine quit because of fuel starvation, either because you ran out of fuel or because of an improper pump or fuel tank selection?	☐	☐	☐	☐	☐	☐	☐
9. How many times have you flown into areas of instrument meteorological conditions, without an instrument rating or an instrument-qualified aircraft?	☐	☐	☐	☐	☐	☐	☐
10. How many times have you turned back or diverted to another airport because of bad weather while on a VFR flight?	☐	☐	☐	☐	☐	☐	☐

2. When and how do you fly?

If you wanted to make a VFR flight for some personal or business reason (not involving life or death), what are the minimum conditions under which you would begin that flight? Assume that you are flying from the airport you normally use and that these are the current conditions at the departure airport and along the route of flight for a cross-country flight and that your aircraft is not equipped for IFR operations. If the ceiling was lower than this value or the visibility was less than this value, you would not takeoff.

	Visibility (Miles)								
	1	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**15**
11. A local (30 minute) day flight.	☐	☐	☐	☐	☐	☐	☐	☐	☐
12. A local (30 minute) night flight.	☐	☐	☐	☐	☐	☐	☐	☐	☐
13. A cross-country (200 mile) day flight.	☐	☐	☐	☐	☐	☐	☐	☐	☐
14. A cross-country (200 mile) night flight.	☐	☐	☐	☐	☐	☐	☐	☐	☐

	Ceiling (Feet)					
	1000	**1500**	**2000**	**3000**	**4000**	**5000**
15. A local (30 minute) day flight.	☐	☐	☐	☐	☐	☐
16. A local (30 minute) night flight.	☐	☐	☐	☐	☐	☐
17. A cross-country (200 mile) day flight.	☐	☐	☐	☐	☐	☐
18. A cross-country (200 mile) night flight.	☐	☐	☐	☐	☐	☐

2. When and how do you fly? (Continued)

If you are making a VFR LOCAL FLIGHT in a general aviation aircraft (e.g., Cessna 172), what percentage of the time do you do the following?

	PERCENTAGE							
	0	**10**	**25**	**50**	**75**	**90**	**100**	**N/A**
19. I get a briefing on the weather before I takeoff.	☐	☐	☐	☐	☐	☐	☐	☐
20. I top off and/or check my fuel before I takeoff.	☐	☐	☐	☐	☐	☐	☐	☐
21. I compute my weight and balance before I takeoff.	☐	☐	☐	☐	☐	☐	☐	☐
22. I perform a complete pre-flight inspection.	☐	☐	☐	☐	☐	☐	☐	☐
23. I use a checklist for before-takeoff and before landing checks.	☐	☐	☐	☐	☐	☐	☐	☐
24. I compute my expected fuel consumption before I takeoff.	☐	☐	☐	☐	☐	☐	☐	☐
25. I file a flight plan.	☐	☐	☐	☐	☐	☐	☐	☐
26. I request weather updates during flight.	☐	☐	☐	☐	☐	☐	☐	☐
27. I fly under VFR above overcast cloud layers.	☐	☐	☐	☐	☐	☐	☐	☐
28. I fly at less than 1000 feet AGL to maintain cloud clearance.	☐	☐	☐	☐	☐	☐	☐	☐
29. I fly at less than 500 feet AGL to maintain cloud clearance.	☐	☐	☐	☐	☐	☐	☐	☐
30. I verify my fuel consumption rate in flight.	☐	☐	☐	☐	☐	☐	☐	☐
31. I use my shoulder harness.	☐	☐	☐	☐	☐	☐	☐	☐

2. When and how do you fly? (Continued)

If you are making a VFR CROSS-COUNTRY FLIGHT in a general aviation aircraft (e.g., Cessna 172), what percentage of the time do you do the following?

	PERCENTAGE							
	0	**10**	**25**	**50**	**75**	**90**	**100**	**N/A**
32. I get a briefing on the weather before I takeoff.	☐	☐	☐	☐	☐	☐	☐	☐
33. I top off and/or check my fuel tanks before I takeoff.	☐	☐	☐	☐	☐	☐	☐	☐
34. I compute my weight and balance before I takeoff.	☐	☐	☐	☐	☐	☐	☐	☐
35. I perform a complete pre-flight inspection.	☐	☐	☐	☐	☐	☐	☐	☐
36. I use a checklist for before-takeoff and before-landing checks.	☐	☐	☐	☐	☐	☐	☐	☐
37. I compute my expected fuel consumption before I takeoff.	☐	☐	☐	☐	☐	☐	☐	☐
38. I file a flight plan.	☐	☐	☐	☐	☐	☐	☐	☐
39. I request weather updates for my route and destination during flight.	☐	☐	☐	☐	☐	☐	☐	☐
40. I fly under VFR above overcast cloud layers.	☐	☐	☐	☐	☐	☐	☐	☐
41. I fly at less than 1,000 feet AGL to maintain cloud clearance.	☐	☐	☐	☐	☐	☐	☐	☐
42. I fly at less than 500 feet AGL to maintain cloud clearance.	☐	☐	☐	☐	☐	☐	☐	☐
43. I verify my fuel consumption rate in flight.	☐	☐	☐	☐	☐	☐	☐	☐
44. I use my shoulder harness.	☐	☐	☐	☐	☐	☐	☐	☐

3. Attitudes About Flying

1: Strongly Disagree, 2: Disagree, 3: Neither agree nor disagree, 4: Agree, 5: Strongly Agree

	1	**2**	**3**	**4**	**5**
	SA	**A**	**N**	**D**	**SD**
45. I would duck below minimums to get home.	☐	☐	☐	☐	☐
46. I am capable of instrument flight.	☐	☐	☐	☐	☐
47. I am a very careful pilot.	☐	☐	☐	☐	☐
48. I never feel stressed when flying.	☐	☐	☐	☐	☐
49. The rules controlling flying are much too strict.	☐	☐	☐	☐	☐
50. I am a very capable pilot.	☐	☐	☐	☐	☐
51. I am so careful that I will never have an accident.	☐	☐	☐	☐	☐
52. I am very skillful on controls.	☐	☐	☐	☐	☐
53. I know aviation procedures very well.	☐	☐	☐	☐	☐
54. I deal with stress very well.	☐	☐	☐	☐	☐
55. It is riskier to fly at night than during the day.	☐	☐	☐	☐	☐
56. Most of the time accidents are caused by things beyond the pilot's control.	☐	☐	☐	☐	☐
57. I have a thorough knowledge of my aircraft.	☐	☐	☐	☐	☐
58. Aviation weather forecasts are usually accurate.	☐	☐	☐	☐	☐
59. I am a very cautious pilot.	☐	☐	☐	☐	☐
60. The pilot should have more control over how he/she flies.	☐	☐	☐	☐	☐
61. Usually your first response is the best response.	☐	☐	☐	☐	☐
62. I find it easy to understand the weather information I get before flights.	☐	☐	☐	☐	☐
63. You should decide quickly and then make adjustment later.	☐	☐	☐	☐	☐

3. Attitudes About Flying (continued)					
1: Strongly Disagree, 2: Disagree, 3: Neither agree nor disagree, 4: Agree, 5: Strongly Agree					
	1	**2**	**3**	**4**	**5**
	SA	**A**	**N**	**D**	**SD**
64. It is very unlikely that a pilot of my ability would have an accident.	☐	☐	☐	☐	☐
65. I fly enough to maintain my proficiency.	☐	☐	☐	☐	☐
66. I know how to get help from ATC if I get into trouble.	☐	☐	☐	☐	☐
67. There are few situations I couldn’t get out of.	☐	☐	☐	☐	☐
68. If you don’t push yourself and the aircraft a little, you’ll never know what you could do.	☐	☐	☐	☐	☐
69. I often feel stressed when flying in or near weather.	☐	☐	☐	☐	☐
70. Sometimes you just have to depend on luck to get you through.	☐	☐	☐	☐	☐
71. Speed is more important than accuracy during an emergency.	☐	☐	☐	☐	☐

Appendix G

Weather Condition Estimation

1. All the Participants

Participant	Estimated weather condition	Assigned score	Weather training	Adjusted rank
1	MVFR	2	No	16.5
2	MVFR	2	Yes	16.5
3	MVFR	2	Yes	16.5
4	MVFR	2	No	16.5
5	MVFR	2	No	16.5
6	MVFR	2	Yes	16.5
7	MVFR	2	Yes	16.5
8	MVFR	2	No	16.5
9	IFR	3	Yes	35.5
10	MVFR	2	Yes	16.5
11	LIFR	4	No	40
12	MVFR	2	No	16.5
13	MVFR	2	Yes	16.5
14	IFR	3	No	35.5
15	IFR	3	No	35.5
16	MVFR	2	Yes	16.5
17	IFR	3	No	35.5
18	IFR	3	Yes	35.5
19	IFR	3	Yes	35.5
20	MVFR	2	Yes	16.5

Participant	Estimated weather condition	Assigned score	Weather training	Adjusted rank
21	MVFR	2	No	16.5
22	VFR	1	Yes	1
23	MVFR	2	Yes	16.5
24	MVFR	2	Yes	16.5
25	MVFR	2	No	16.5
26	MVFR	2	No	16.5
27	MVFR	2	No	16.5
28	MVFR	2	Yes	16.5
29	MVFR	2	No	16.5
30	MVFR	2	No	16.5
31	MVFR	2	Yes	16.5
32	MVFR	2	Yes	16.5
33	MVFR	2	Yes	16.5
34	MVFR	2	No	16.5
35	MVFR	2	Yes	16.5
36	MVFR	2	Yes	16.5
37	IFR	3	No	35.5
38	IFR	3	No	35.5
39	MVFR	2	No	16.5
40	MVFR	2	No	16.5

Participants' weather condition estimat2ions were calculated using the Mann-Whitney *U* test.

H_0: The median of weather condition estimation between the two groups are equal.

H_1: The median of weather condition estimation between the two groups are not equal.

Participants were assigned to a rank according to their weather condition estimation as bellow (VFR: 1, MVFR: 2, IFR: 3, LIFR: 4).

$\sum R_1$ (yes) = 16.5(16) + 35.5(3) + 1(1) = 371.5

$\sum R_2$(no) = 16.5(14) + 40(1) + 35.3(3) = 448.5

n_1= 20, n_2=20

Employing below equations, the values of U_1 and U_2 are computed.

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - \sum R_1 = 20*20 + \frac{20*21}{2} - 371.5 = 238.5$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum R_2 = 20*20 + \frac{20*21}{2} - 448.5 = 161.5$$

Critical U value for $\propto = 0.05$ is 127 in the Mann-Whitney *U* Statistic table.

Since the test statistics of *U* = 161.5 is greater than the critical *U* value of *U* = 127, H_0 is retained.

2. 14 Outlier Participants

Participant	Estimated weather condition	Assigned score	Weather training	Adjusted rank
2	MVFR	2	Yes	5.5
3	LIFR	4	Yes	5.5
6	IFR	3	Yes	5.5
8	IFR	3	No	5.5
11	IFR	3	No	14
14	MVFR	2	No	12
15	MVFR	2	No	12
16	MVFR	2	Yes	5.5
17	MVFR	2	No	12
26	MVFR	2	No	5.5
28	MVFR	2	Yes	5.5
31	MVFR	2	Yes	5.5
33	MVFR	2	No	5.5
36	MVFR	2	Yes	5.5

Participants' weather condition estimations were calculated using the Mann-Whitney *U* test.

H_0: The median of weather condition estimation between the two groups are equal.

H_1: The median of weather condition estimation between the two groups are not equal.

Participants were assigned to a rank according to their weather condition estimation as bellow (VFR: 1, MVFR: 2, IFR: 3, LIFR: 4).

$\sum R_1$ (yes) = 5.5(7) = 38.5

$\sum R_2$(no) = 5.5(3) + 12(3) + 14(11) = 66.5

n_1= 7, n_2=7

Employing below equations, the values of U_1 and U_2 are computed.

$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - \sum R_1$ = 7*7 + $\frac{7*8}{2}$ − 38.5 = 38.5

$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum R_2$ = 7*7 + $\frac{7*8}{2}$ − 66.5 = 10.5

Critical U value for $\propto = 0.05$ is 8 in the Mann-Whitney *U* Statistic table.

Since the test statistics of *U* = 10.5 is greater than the critical *U* value of *U* = 8, H_0 is retained.

Appendix H

Personal Minimums

1. Visibility (Status Miles)

	Control group	WeatherWise training group
A local (30 minutes) day flight	4.35	4.6
A local (30 minutes) night flight	6.95	7.8
A cross-country (200 mile) day flight	7.45	6.4
A cross-country (200 mile) night flight.	9.8	9.6
Mean	7.14	7.10
Standard Deviation	2.23	2.12
Standard Error	1.12	1.06

ANOVA: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	4	28.55	7.1375	4.997292
Column 2	4	28.4	7.1	4.493333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002812	1	0.002812	0.000593	0.981367	5.987378
Within Groups	28.47188	6	4.745313			
Total	28.47469	7				

F (1, 6) = 0.0006, *p* = 0.98, nonsignificant.

2. Ceiling (Feet)

	Control group	WeatherWise training group
A local (30 minutes) day flight	2475	2200
A local (30 minutes) night flight	3625	3600
A cross-country (200 mile) day flight	3500	3550
A cross-country (200 mile) night flight.	4350	4400
Mean	3487.5	3437.5
Standard Deviation	772.04	912.3
Standard Error	386.02	456.15

ANOVA: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	4	13950	3487.5	596041.7
Column 2	4	13750	3437.5	832291.7

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5000	1	5000	0.007001	0.936038	5.987378
Within Groups	4285000	6	714166.7			
Total	4290000	7				

F (1, 6) = 0.007, *p* = 0.94, nonsignificant.

3. Common Practices in a VFR Local Flight (%)

	Control group	WeatherWise training group
Get weather briefing before take off	79	87.75
Top off/check fuel tanks	98.25	100
Compute weight/balance	51.25	55.25
Perform complete pre-flight inspection	95	99.5
Use a checklist for landing & take off	85.5	92.75
Compute expected fuel consumption	84.5	94
File a flight plan	28	31
Request weather updates	32.5	32.5
Fly VFR above clouds	79	84.75
Fly below 1,000 AGL under clouds	83.75	90.25
Fly below 500 AGL under clouds	99	98.75
Verify fuel consumption in flight	59.5	77.75
Use shoulder harness	89.5	100
Mean	74.21	80.33
Standard Deviation	23.89	24.75
Standard Error	6.63	6.86

ANOVA: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	964.75	74.21154	570.613
Column 2	13	1044.25	80.32692	612.629

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	243.0865	1	243.0865	0.410882	0.527596	4.259677
Within Groups	14198.9	24	591.621			
Total	14441.99	25				

F (1, 24) = 0.41, *p* = 0.53, nonsignificant.

Common Practices in a VFR Cross-Country Flight (%)

	Control group	WeatherWise training group
Get weather briefing before take off	89.5	99.5
Top off/check fuel tanks	94.5	99.5
Compute weight/balance	65.5	90
Perform complete pre-flight inspection	95	100
Use a checklist for landing & take off	86.5	95.25
Compute expected fuel consumption	93.25	92
File a flight plan	58.5	70
Request weather updates	60	59
Fly VFR above clouds	70.75	76.5
Fly below 1,000 AGL under clouds	81.5	88.25
Fly below 500 AGL under clouds	98.75	97.5
Verify fuel consumption in flight	75.25	82.5
Use shoulder harness	89	100
Mean	81.38	87.69
Standard Deviation	13.94	13.23
Standard Error	3.87	3.67

ANOVA: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	1058	81.38462	194.4856
Column 2	13	1140	87.69231	175.137

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	258.6154	1	258.6154	1.399348	0.248419	4.259677
Within Groups	4435.471	24	184.8113			
Total	4694.087	25				

F (1, 24) = 1.40, *p* = 0.25, nonsignificant.

Appendix I

Screenshots of Weather Conditions along the Flight Path

1.

2.


PAUSED
N172SP
AIRSPEED
KNOTS
ALTIMETER
VACUUM
D.C. ELEC.
TURN COORDINATOR
2 MIN
VERTICAL SPEED
100 FEET PER MIN
FUEL
QTY
OIL
HOURS
COM 1
COM 2
FLIGHT DIR
HDG
LOC
G/S
BC
ALT

3.


PAUSED
N172SP
AIRSPEED
ALTIMETER
VACUUM
D.C. ELEC.
TURN COORDINATOR
VERTICAL SPEED
FUEL
OIL
COM 1
NAV 1
COM 2
NAV 2
ADF 1
FLIGHT DIR
HDG
LOC
G/S
BC
ALT
WARNING
HOURS

4.

5.


PAUSED
N1725P
AIRSPEED
ALTIMETER
VACUUM
TURN COORDINATOR
VERTICAL SPEED
FUEL QTY
OIL
WARNING

6.


PAUSED
N1728P
ALTIMETER
VERTICAL SPEED
TURN COORDINATOR
VACUUM
FUEL
OIL
COM 1
NAV 1
COM 2
NAV 2
HDG
LOC
G/S
BC
ALT

7.

8.


PAUSED
N1728P
VACUUM
ALTIMETER
VERTICAL SPEED
TURN COORDINATOR
D.C. ELEC.
FUEL
OIL
WARNING

9.


PAUSED
N172SP
ALTIMETER
VERTICAL SPEED
TURN COORDINATOR
FUEL
OIL

10.

11.


PAUSED
N172SP
AIRSPEED
KNOTS
VACUUM
ALTIMETER
D.C. ELEC.
TURN COORDINATOR
2 MIN
NO PITCH INFORMATION
VERTICAL SPEED
100 FEET PER MIN
FUEL QTY
OIL
RPM
HOURS
COM 1
NAV 1
COM 2
NAV 2
FLIGHT DIR
WARNING

12.


PAUSED
N1728P
AIRSPEED
KNOTS
VACUUM
ALTIMETER
D.C. ELEC.
TURN COORDINATOR
VERTICAL SPEED
100 FEET PER MIN
FUEL
QTY
OIL
RPM
HOURS
COM 1
NAV 1
COM 2
NAV 2
ADF 1
FLIGHT DIR
HDG
LOC
G/S
BC
ALT
WARNING

13.


PAUSED
N1728P
AIRSPEED
KNOTS
VACUUM
ALTIMETER
D.C. ELEC.
TURN COORDINATOR
VERTICAL SPEED
100 FEET PER MIN
FUEL
OIL
RPM
HOURS
COM 1
NAV 1
COM 2
NAV 2
ADF 1
FLIGHT DIR
HDG
LOC
G/S
BC
ALT

14.


PAUSED
N172SP
AIRSPEED
KNOTS
ALTIMETER
VACUUM
D.C. ELEC.
TURN COORDINATOR
VERTICAL SPEED
RPM
HOURS
FUEL
OIL
WARNING

15.


PAUSED
N1725P
AIRSPEED
ALTIMETER
VACUUM
D.C. ELEC.
TURN COORDINATOR
VERTICAL SPEED
FUEL
OIL
WARNING