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Predicting General Aviation Pilots' Weather-related Performance through a Scenario-based Written Assessment

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PREDICTING GENERAL AVIATION PILOTS' WEATHER-RELATED
PERFORMANCE THROUGH A SCENARIO-BASED WRITTEN ASSESSMENT

By
Jessica Cruit

A Dissertation Submitted to the
Department of Human Factors & Systems
in Partial Fulfillment of the Requirements for the Degree of Doctorate of Philosophy in
Human Factors

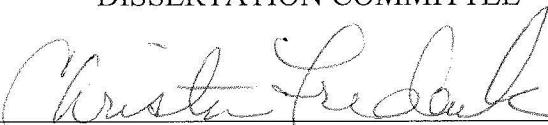
Embry-Riddle Aeronautical University
Daytona Beach, Florida
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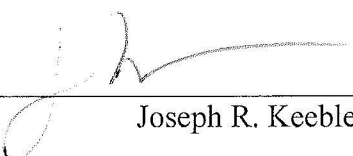
By
Jessica Cruit


This dissertation was prepared under the direction of the candidate's dissertation committee chair, Dr. Frederick. The Department of Human Factors & Systems has approved the members of this dissertation committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Doctorate of Philosophy in Human Factors.

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Abstract

Weather-related accidents continue to challenge the general aviation community and with the development of advanced weather technology, GA pilots need additional education and training on how to effectively use these weather products to ensure flight safety. Currently, the literature on aviation weather suggests that there is a gap in both training and assessment strategy for GA pilots. Furthermore, several studies suggest that there needs to be more assessment of weather-related scenario/application questions for the private pilot's written knowledge exam in order to assess a deeper level of knowledge for weather-related material. The purpose of this study is to design a scenario-based exam that assesses GA pilots' weather knowledge and then to determine whether the scenario-based exam better predicts GA pilot performance in a simulated weather scenario than a traditional weather-related exam. The results of the study could potentially help aviation officials better assess and train general aviation pilots on weather-related topics.

Chapter 1

1.1. Introduction to General Aviation Accidents

The rise of the Industrial Revolution in the eighteenth century brought many new changes in design and innovation (Hobsbawm & Wrigley, 1999). Businesses flourished, agriculture boomed, and technology exploded into the scene, changing the rural farming communities of the world into a burgeoning economic enterprise. Through the rise of technology, aviation was born and soon the aviation industry would not only change how individuals traveled from city to city but how individuals, countries, and the entire global compact defined who they were.

Today, the world of aviation draws three main types of pilots who operate aircraft for commercial, military, or recreational purposes. Those pilots who operate under commercial airline or military operations are typically referred to as career pilots while those who fly for recreational purposes fall under the category of General Aviation (GA). GA also consists of other flight operations such as agricultural operations, gliders and parachutes, and corporate and business flights. GA operations account for roughly 63% of all towered operations in the United States (Shetty and Hansman, 2012), making up the majority of flight operations. However, with the increase of GA operations over the years, there is also a continuous challenge to increase the safety of these operations.

Like many technological industries, aviation operations work to maintain a consistently high safety rate. World War I generated interest in developing safer principles for the aviation industry. At that time, for every 100 aviators killed, 90 were due to their own human error (Orlady & Orlady, 1999). While vast changes have occurred since World War I, the aviation industry continues seeking to improve safety.

The last ten years has seen an increasingly diminished rate of overall aviation accidents (Hunter, 2001). And although the accident rate of general aviation has decreased since the 1970s, General Aviation still maintains a higher accident rate than commercial or military operations. In fact, General Aviation (GA) accidents continue to retain the highest number of aviation accidents for any of the main types of aviation (i.e., GA, commercial, military) and human error accounts for 85% of all GA accidents (Hunter, 2001). Table 1 breaks down the number of GA accidents and fatalities by aircraft certificate type. As seen from the table, the private pilot and sport certificate level (General Aviation) represented the majority of accidents and fatalities (AOPA, 2010). Table 2 shows accident rates from 2001-2010 and categorizes accidents by human error and mechanical failures (2010). The table displays human error accounting for a larger percentage of accidents over mechanical failures.

Table 1

GA Accident Rate and Fatalities by Aircraft Certificate Type (2001-2010)

Certificate Level	Accidents	Fatal Accidents	Lethality
Commercial	330	65	19.7%
Private	574	110	19.2%
Sport	18	4	22.2%
Student	67	5	7.5%

Table 2

Accidents Related to Human Error (2001-2010)

	All Accidents	Fatal Accidents
Human Error	857	148
Mechanical	174	22
Other	129	44

One possibility for this high level of accident rates could be that most GA pilots fly for recreational purposes as opposed to career purposes like that of commercial and military operations (Wiegmann and Shappell, 2003; AOPA, 2010). Thus, GA pilots may lack the experience level and degree of training that career pilots receive (O'Hare and Chalmers, 1999). Pilot experience level includes educational training (e.g., flight courses, certificates, degrees, and simulator experience), flight hours, decision making ability, leadership, and communication skills (Chi et al., 1988; Klein, 2008; Jensen, 1995). One challenge in reducing the GA accident rate is determining what level and type of skills are necessary to navigate a safe flight operation and more importantly, how GA pilots can learn these skills to make accurate decisions in order to effectively reduce the current accident rate.

1.2. The Role of Weather in GA Accidents

One factor that has continued to plague GA accidents over the years is degraded weather. Although weather-related accidents account for a smaller portion of the total number of GA related accidents, they account for roughly 83% of the fatality rate (Li and Baker, 2007). Figure 1 highlights the weather-related GA accident rate from 2001-2010 and the consistency of fatalities associated with these weather-related accidents (AOPA, 2010). The Nall Report from AOPA (2010) explains that the decrease in accidents for the year, 2010 could be the delay in aircraft recovered that is needed for a thorough investigation. It is evident from Figure 1 that there is a consistent trend in weather-related GA accidents and fatalities over a ten year period (AOPA, 2010).

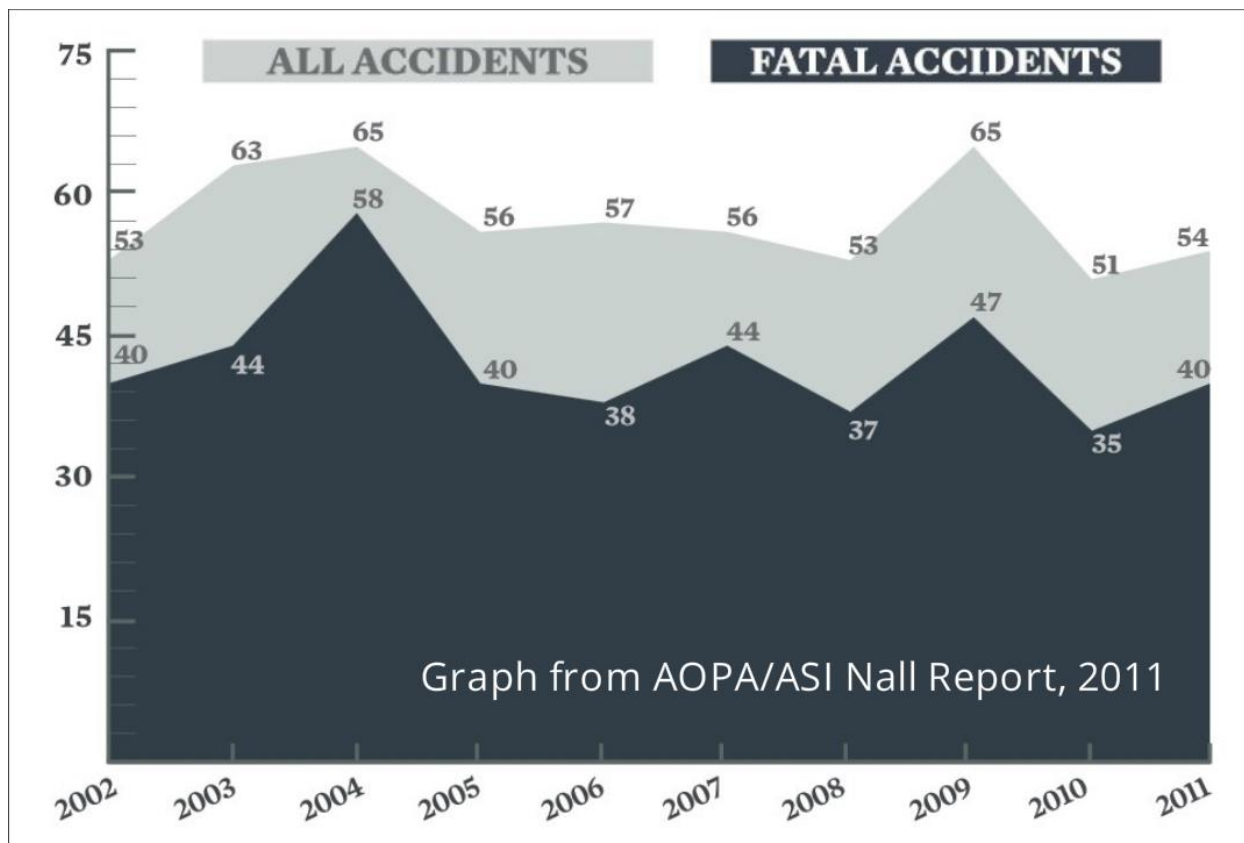


Figure 1. Weather-Related GA accidents and fatality trend (AOPA, 2011)

Additionally, this fatal trend in GA weather-related accidents is consistent over the last thirty years. Two-thirds of all weather-related accidents have resulted in fatalities, making weather-related GA fatalities three times higher than the fatality rate of all other GA accidents (NTSB, 2005).

1.3. Contributing Factors to Weather-Related GA Accidents.

Within the last several decades, research literature on those factors that contributed to weather-related GA accidents revealed two overarching categories; those factors that can be attributed to environmental phenomenon and those factors that can be

attributed to the human (NTSB, 2005; Wiegmann and Shappell, 2006; Hunter 2001; Wiggins and O’Hare, 2003). Environmental factors include weather phenomena that are routinely associated with weather-related accidents (e.g., winds, turbulence, icing, thunderstorms). AOPA (2010) categorizes environmental factors contributing to GA accidents from those most occurring to those least occurring. As seen from *Figure 2*, Visual Flight Rules to Instrument Meteorological Conditions (VFR to IMC) followed by icing are the largest contributors to GA weather-related accidents.

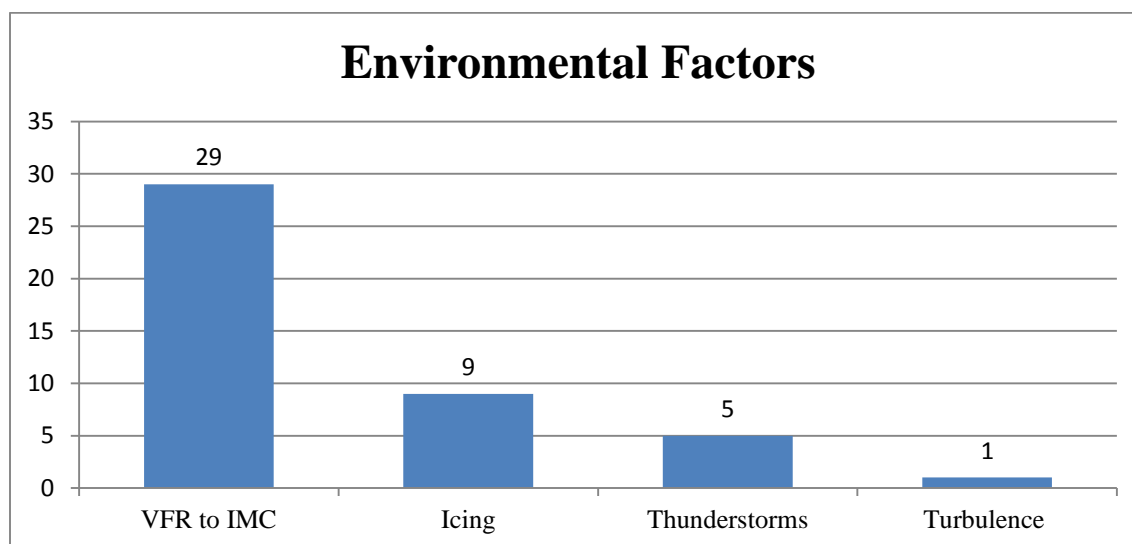


Figure 2. Environmental factors contributing to GA accidents (2001-2010).

The second category contributing to GA accidents are those factors inherent to the human. These factors include decision making errors, pilot expertise, lack of communication, poor leadership, pilot skill, and loss of situation awareness (Wiegmann and Shappell, 2001; Wiggins and O’Hare, 2005; Jensen, 1995). Wiegmann and Shappell (2001) examined GA accidents from 1990-2000 and found that the most frequent factors contributing to pilot error were technical, stick and rudder type errors (*skill-based errors*)

followed by intentional errors in decision making (*decision-making errors*). Since VFR to IMC is the most frequent environmental problem, the following sections will address the GA research on human performance during VFR to IMC operations.

VFR to IMC. General Aviation pilots, who are primarily trained in Visual Flight Rules (VFR) operations, are flying beyond their training level and knowledge of weather-related phenomena into Instrument Flight Rules (IFR) operations (NTSB, 2005; Goh & Wiegmann, 2001). This finding suggests the need for further examination into why pilots are deciding to fly into deteriorating weather conditions when they lack the skills and training.

The Federal Aviation Regulations (FARs) have categorized two meteorological conditions with corresponding flight rules (FAA, 2010). The first meteorological condition is called Visual Meteorological Conditions (VMC) and the flight rule corresponding to VMC is called VFR. VMC represents those environmental conditions for which the pilot can see without using their instruments to control the aircraft (NTSB, 2005). The pilot relies on the visual cues of the environment that are evident by looking out the window of the aircraft. The pilot can see using those visual, environmental cues in order to avoid crashing into terrain or other aircraft. VFRs are the visibility flight standards that dictate what type of visibility and cloud coverage a pilot can legally fly within a given airspace. VFR operations are filed by the pilot during the preflight phase.

The second meteorological condition categorized by the FARs is called Instrument Meteorological Conditions (IMC (FAA, 2010) and these conditions consist of weather that prevents the pilot from controlling the aircraft by only looking out the window (NTSB, 2005; AOPA; 2010). In these weather conditions, the visual cues of the

environment (e.g., terrain, other aircraft) are not visible to the human eye and the pilot must use the instruments of the aircraft to control the plane. To file an instrument flight plan under IFRs, the pilot must be instrument rated and the majority of GA pilots do not hold this instrument rating. Since many of the GA pilots fly for recreational purposes as opposed to career purposes, they are not required to be IFR certified; however, they are expected to fly under Visual Meteorological Conditions and not IMC (NTSB, 2005). However, there are exceptions to this rule when a VFR flight unexpectedly turns into instrument meteorological conditions. In this situation, pilots can no longer use the visual cues of the environment and they must request an IFR flight from air traffic controllers (ATC). This condition is called VFR to IMC.

It is not uncommon for VFR to IMC to occur and GA pilots who do not possess the knowledge, experience, training, or certification must fly under instrument meteorological conditions. Unsurprisingly, VFR to IMC represents a danger to GA flight as the fatality rate of these flights if an accident occurs is 80%. This is compared to a 19% fatality rate of other types of fatal GA accidents (Detwiler, Holcomb, Hackworth, and Shappell, 2008). Pilots who fly VFR to IMC either fly intentionally into these conditions (e.g., pilots believe they can fly through degraded weather without any risk of safety) or inadvertently (e.g., pilots misunderstood or misinterpreted forecasts). Research studies on why pilots fly VFR to IMC focus on many causal factors ranging from faulty decision making, poor situation assessment, risky behavior, and lack of experience with weather technology (Wiegmann, Goh, and O'Hare, 2001; Beard and Geven, 2005; Latorella, Lane, and Garland, 2002). A full review of all the causal factors is beyond the scope of this literature review. Instead, this paper focuses on aviation weather expertise,

aeronautical decision making errors and GA pilot training in weather technology and resources.

Chapter 2

After examining the fatal effect of degraded weather on GA accidents every year, it is evident that pilots need to understand the various weather conditions that may pose a risk to their flight. Furthermore, with the development of advanced weather technology intended to aid pilots in making safer aeronautical decisions, it is important to understand how pilots are using and interpreting this new technology to make better preflight and inflight decisions. The purpose of this chapter is to explain what aviation weather knowledge and skills are required to perform a safe flight, the lack of aviation weather training with current weather technology and resources, and how pilot knowledge and skills play a role in aeronautical decision making. Finally, this chapter describes the

importance of assessing GA pilots with a comprehensive assessment that tests GA pilots on the required weather knowledge and skills for GA flight in hopes to prevent future GA accidents.

2.1. Aviation Weather Knowledge and Skills

Throughout all phases of GA flight, pilots are required to make a number of weather-related decisions that will ultimately affect the outcome of the flight. For example, during the preflight phase, pilots need to collect weather information from a variety of weather sources and products that inform pilots about weather forecasts and conditions along their flight. The weather information that pilots collect at this time will influence aeronautical decision-making along the flight. Therefore, pilots' understanding of this type of weather-related knowledge is crucial to the overall success of the flight. Lanicci et al. (2011) examined GA pilots' education and training of weather technology in the cockpit products (WTIC) and advocated that there were three different domains of aeronautical meteorological knowledge that pilots need to know. These three required knowledge domains are *weather phenomenology*, *weather hazard products*, and *weather hazard product sources*. Within each of these domains, there is a list of the necessary knowledge and skills that pilots are required to obtain in order to understand the complexity of weather on GA flight.

The first domain, *weather phenomenology*, includes information pertaining to the knowledge of weather phenomena that can influence the flight. Weather phenomena includes the different attributes of the earth's atmosphere such as how the earth cools and heats throughout the day, the direction and strength of winds, air masses that create

fronts, pressure systems, temperature variability, and moisture. All of these weather attributes create the weather phenomena that pilots experience during a flight such as thunderstorms, icing, wind shear, and turbulence. Understanding the different components of weather phenomena should help pilots make appropriate weather-related decisions during flight. For example, during a standard preflight briefing, pilots receive information about the cloud ceilings and whether the ceiling is scattered, broken, or overcast. Pilots are asked to understand what types of clouds make up scattered, broken, and overcast ceilings and then project what type of weather phenomena they may experience from these ceilings during their flight.

The second domain that Lanicci et al. (2011) describe is called *weather hazard products*. These weather products contain either graphical or text-based weather information from FAA approved sources that are used by pilots to plan their flight. Some examples of text-based products include METARS, TAFS, and PIREPS. Pilots are required to understand the coded information within these products to interpret how the weather-related information applies to their flight. It is important for pilots to first understand the meteorological phenomena so that they can accurately interpret the information presented in the weather hazard products. For example, consider the following METAR (Aviation Routine Weather Observation) in Figure 3.

```
KAUS 092135Z 26018G25KT 8SM -TSRA BR SCT045CB BKN060 OVC080  
30/21 A2992 RMK FQT LTGICCCCG OHD-W MOVG E RAB25 TSB32 CB  
ALQDS SLP132 P0035
```

Figure 3. Example METAR

The highlighted text, “TSRA” tells the pilot that there are thunderstorms (TS) with rain (RA) that is considered light (-) within the selected vicinity. In this situation, the pilot would need to decode, “TSRA” and then understand the implication of that thunderstorm with light rain on a VFR flight. Thunderstorms may contain high winds, lightning, hail, turbulence, and low visibility which create additional challenges for VFR pilots who are not trained to use instruments. If the VFR pilot in this situation was landing at an airport that contained a thunderstorm, the pilot should consider landing at an alternate airport that contained fair weather conditions. The different types of weather products such as METARs and PIREPS are described in more detail in the sections that follow.

The third domain that Lanicci et al. (2011) describe is called, *weather hazard product sources*. These product sources are FAA approved sources that publicize weather products to pilots and can either come from the federal government (e.g., contract towers and airport operators), Enhanced Weather Information Systems (EWINS), or commercial weather information providers. Examples of weather hazard product sources include, pilot briefings from the internet (e.g., DUAT/S, ADDS) or telephone information briefings (e.g., 1800-wxbrief). Weather product sources are described in more detail in the sections that follow. Lanicci et al. (2011) describe the lack of standardization among

As previously mentioned, Lanicci et al. (2011) describe these three meteorological domains as overlapping and each influencing one another. That is, pilots need to have an understanding of weather phenomena before they understand how to read and interpret weather products. Furthermore, pilots need to know what weather product sources are FAA approved sources for disseminating weather product information. Also, pilots would need an understanding of the weather products to know which approved sources provide information from those weather products. For example, if a VFR pilot decides to check the FAA approved ADDS weather source website to gather weather information during preflight, the pilot would be faced with multiple weather products (e.g., PIREPs, SIGMETs, Radar, Satellite, METARS). The pilot needs to first understand what all of these products offer. For example, PIREPs offer weather information from other inflight pilots through radio transmission that is converted to a text-based product, whereas radar offers the pilot a graphical image of the location of precipitation, its direction of motion, and its type (e.g., rain, snow, hail). Next the pilot needs to understand how to decode the product. If the VFR pilot received the following PIREP, “RM LLWS –15 KT SFC-030 DURGC RY 22 JFK” they need to understand that hazardous elements appear first. In this example, the highlighted text, “LLWS” stands for low level wind shear. Finally, the pilot needs to understand the implications of wind shear on their flight. If a pilot is landing on an approach and faces wind shear that results from a decreasing head wind, the aircraft could potentially lose airspeed and altitude. The pilot needs to factor in enough altitude to recover from this situation or the flight could result in a crash. In summary, it is essential for the pilots to understand where to obtain FAA approved weather sources and then accurately interpret the weather products in order to

apply the weather information gathered from the products to their flight. *Figure 4* shows the overlapping aviation weather knowledge domains from Lanicci et al. (2011).

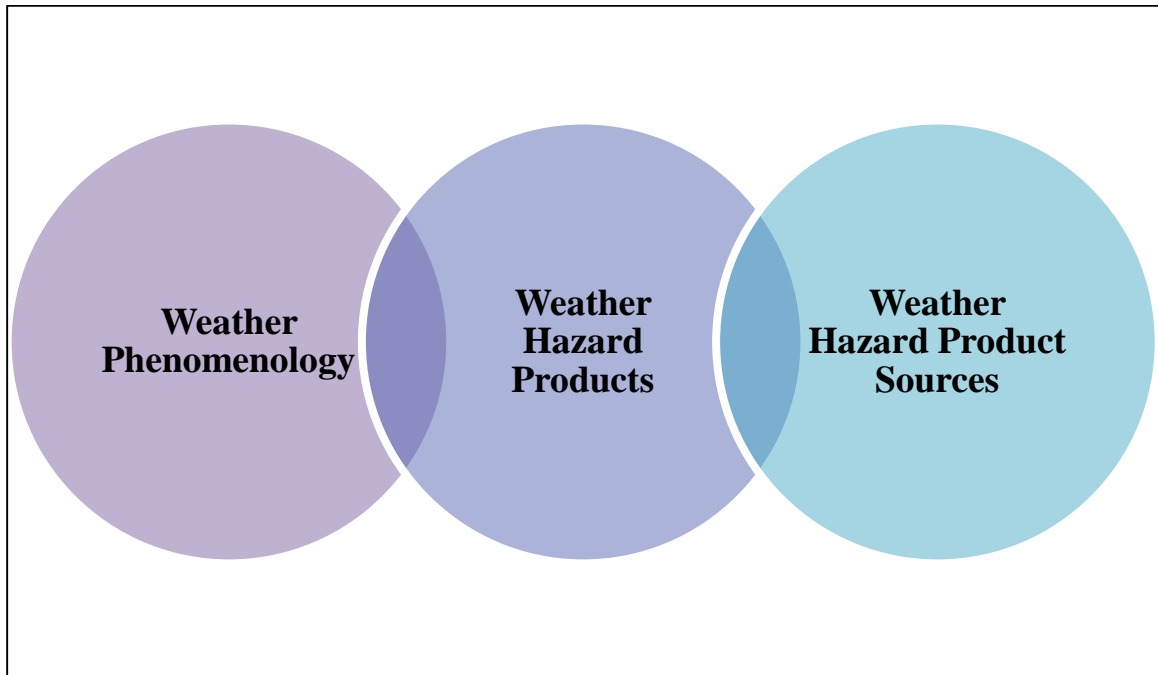


Figure 4. Lanicci et al. (2011) Domains of required GA pilots' meteorological knowledge

The three domains of meteorological aviation knowledge that Lanicci et al. (2011) describe provide a foundation for collecting insight into the specific knowledge and skills that are required of GA pilots throughout all phases of GA flight.

Cruit and Blickensderfer (2015) used a task analysis approach to determine what tasks are required for each phase of GA flight and then what type of knowledge and skills pilots need to have to effectively complete those tasks. Furthermore, Cruit and Blickensderfer (2015) categorized each task according to the Lanicci et al. (2011) domains of meteorological aviation knowledge (See Table 3). What was unique about this task analysis was that it included a comprehensive account of all phases of GA flight

(e.g., preflight, taxi, take-off, climb, cruise, descent, and landing) in order to determine what weather-related tasks GA pilots were required to be proficient in and then to illustrate either gaps in training GA pilots or gaps in assessing GA pilots' knowledge and skills of these tasks.

Table 3

GA Weather-Related Tasks, Knowledge, and Skills by Phases of Flight

Phase of Flight	Weather-Related Task	Knowledge and Skills (Domain of Meteorological Knowledge)	Example and how it Links to Domains of Meteorological Knowledge and Implications for Flight
Preflight	Obtain weather information through METARs, TAFs, and Area Forecast through weather sources like ADDS and the Flight Service Station	1. Technical knowledge of how to decode and interpret textual information from these weather products.	A. Pilot obtains METAR (Wx Hazard Product) from ADDS website (Wx Hazard Product Sources)
			B. Pilot interprets textual information in the METAR (e.g., -TSRA = Thunderstorm with light rain)
		2. Skill to look for weather trends from the different weather products and to estimate the weather along the flight path.	C. Pilot understands that thunderstorms can cause lightning, wind, hail, and low visibility (Wx Phenomenology) and influence the safety of the flight.
			A. Pilot obtains PIREPs, METARs, and Area Forecast (Wx Hazard Products) from FAA approved source (Wx Hazard Product Sources).
B. Pilot reads from a METAR that the conditions at Airport X are clear. However, PIREPs tell the pilot that there are icing conditions 20 miles from destination airport (Wx Hazard Products).			
C. Pilot understands that icing conditions can build upon the aircraft during flight and cause the aircraft to stall. Sometimes recovery becomes impossible (Weather Phenomenology).			
Taxi	Pilot should look at the sky to collect more information about the environmental conditions (e.g., rain, wind, cloud type).	1. Knowledge of different cloud types.	A. Pilot looks at the sky and identifies Altiocumulus Castellanus. Pilot knows that these types of clouds may point to a thunderstorm later in the day. Pilot needs to make arrangements on the return flight so that they do not encounter thunderstorms (Wx Phenomenology).
		2. Knowledge about what direction the wind is moving.	B. Pilot looks at the wind sock to know the direction and velocity of wind. If a crosswind is present during this phase of flight, the wing or tail could be lifted and the plane could roll over (Wx Phenomenology).
Take-off	Check Visibility	1. Knowledge that unexpected weather exists.	A. Pilot understands that weather is variable and forecasts are not always correct. If a weather product fails to report fog, but pilot sees fog upon take-off, the pilot understands that there was unforecasted weather that could affect the safety of the flight (Wx Phenomenology).
		2. Knowledge that pilots can always abort the mission.	B. Pilots need to understand that when unexpected weather is encountered during take-off, the pilot can still abort the mission to avoid deteriorating weather conditions throughout the flight (Wx Phenomenology).
Climb	Pilot may need to break one rule to avoid breaking a more dangerous rule (e.g., Pilot may violate basic VFR weather minimum without requesting IMC because the pilot does not have enough time during take-off).	1. Knowledge and skill at proper planning for take-off. 2. Skill at estimating cloud height.	A. Pilot needs to collect as many different weather products from multiple weather sources as possible to look at various weather conditions for their flight (Wx Hazard Products and Wx Hazard Product Sources).

			B. Pilot needs to have the skills to understand VFR minimums by estimating cloud height. Knowledge of cloud types give pilots understanding of how high each type of cloud builds in the sky (Wx Phenomenology).
Cruise	Pilot should Communicate with Flight Watch Enroute Flight Advisory Service.	1) Knowledge that this a 2-way communication service where the pilot can ask about the flight.	A. Pilot needs to continue to seek information from weather sources throughout the flight. EFAS can update the pilot on weather that has developed within the pilots flight path (Wx Hazard Product Source) B. Pilot needs to understand how the information from EFAS applies to their flight and whether they should continue or divert the flight path due to deteriorating weather (Weather Phenomenology).
Descent	Pilot should check AWOS or ASOS for the airport that they are landing at.	1) Knowledge that the tower will say, "do you have weather for that airport?"	A. The pilot knows that AWOS/ASOS is an FAA approved source of weather information (Wx Hazard Product Sources). B. Pilot needs to interpret the weather information from this product and apply the information to their descent. If pilot receives information from ASOS/AWOS that indicates snowy weather at destination airport, Pilot needs to think about choosing an alternate landing (Wx Phenomenology) since snowy weather can create low visibility, icing, and wind.
Landing	Pilot should check tower to see if ATC advises wind shear.	1. Pilot needs to understand how wind shear can affect their landing.	A. Pilot needs to understand the implications of wind shear on their flight. If a pilot is landing on an approach and faces wind shear that results from a decreasing head wind, the aircraft could potentially lose airspeed and altitude. The pilot needs to factor in enough altitude to recover from this situation or the flight could result in a crash (Wx. Phenomenology) B. Pilot also needs to know to check for weather information at the destination airport with ATC (Weather Hazard Product Sources).

Table 3 highlights examples from the task analysis (Cruit & Blickensderfer, 2015). For example, during the preflight phase of flight, GA pilots are required to gather information about weather conditions before take-off. Pilots need to have the knowledge of various weather products such as METARs, TAFs, and Area Forecasts to choose which one they want to use. Additionally, pilots need to know how to interpret these products as well as the skill to be able to look at the bigger picture so they can look for trends in the weather patterns. This example was categorized under all three of Lanicci et al. (2011) domains of meteorological aviation knowledge (i.e., *weather phenomenology*, *weather hazard products*, and *weather hazard product sources*). This implies that during the preflight phase of flight, pilots are required to gather information from different

weather products such as METARs and they need the knowledge and skills to interpret these products as well as knowing basic information about weather theory to be able to look at weather trends. This task analysis can be used to identify gaps in GA training and assessment to aid educators and test developers to assess GA pilots on those knowledge and skills that are required for all phases of GA flight.

2.2. Current Meteorological Training for GA Pilots

Because degraded weather poses a concern to the safety of GA, the FAA has required all pilots-regardless of certificate level-to be trained with certain knowledge and skills for avoiding weather hazards (NTSB, 2005). These knowledge and skills are as follows: 1) Pilots must be trained in the recognition and avoidance of hazardous weather, 2) Pilots must be trained in the basic preflight procedures for choosing appropriate weather products and interpreting forecasts, 3) Pilots must be trained on aeronautical decision-making and risk management. To achieve success with this training, pilots must show proficiency at controlling the aircraft while navigating around clouds if they inadvertently enter IMC. During this instrument training, the pilot must fly the aircraft straight and level with a constant airspeed with climbs and descent, they must be able to turn to a heading, recover from unusual flight attitudes, perform radio communications, and then appropriately use the navigational systems and radar services that are appropriate to instrument flight (Title 14 CFR 141 61.101 of NTSB, 2005). All of this training is required before the pilot receives their private pilot certificate. Private pilots are not required to receive recurrent instrument flight training; however, they are required to a biennial flight review that includes one hour of ground and flight instruction covering general flight knowledge, operating rules and procedures (14 CFR 61.56; NTSB, 2005).

Since the topics covered at this review are at the discretion of the flight instructor, there are many important topics (e.g., landing procedures, radio communications, fuel management, etc.) that may not include the pilot to demonstrate weather-related knowledge or skills (NTSB, 2005). The following paragraphs inform the reader about what type of weather knowledge and skills is required by the FAA during both preflight phases and inflight phases.

Preflight Training Requirements and Procedures. The Federal Aviation Regulations (FARs) Title 14 CFR section 91.103 states that during preflight procedures, pilots are responsible for becoming familiar with all of the available information that concerns the flight. This information includes weather reports, traffic delays, runway lengths, and fuel management. Under this title and section, *weather reports*, could include pilots' knowledge of a variety of weather concepts, resources, and products. To ensure that the pilot is receiving a thorough briefing, the Aviation Weather Service program issued an advisory circular that addresses how pilots can obtain an appropriate weather briefing during preflight. Pilots may choose to either collect this briefing from an approved internet source (e.g., ADDS, DUAT/DUATS) or by calling the Flight Service Station and speaking to a specialist (FAA, 2010).

If the pilot chooses to call the Flight Service Station to receive their weather briefing, they must have the knowledge to understand what type of briefing to ask for (i.e., Standard, Abbreviated, or Outlook) as well as knowledge of the information that is provided in the briefing. That is, pilots need to understand how the information given to them during a briefing could affect their flight. Examples of the type of information that the Flight Service Station specialist gives the pilot include, a synopsis, current conditions,

enroute forecast, destination forecast, winds and temperature aloft, NOTAMS, and ATC delays. The information provided in these reports gives technical information that the pilots need to understand to interpret and apply to their flight. For example, the current conditions may include radar and satellite data that the pilot must understand to be able to apply the information to their flight. The pilot must also be able to look at a variety of reports given to develop a mental picture of what the flight will and could be like. This includes developing a mental picture of the weather and understanding the implications of both the current conditions as well as the forecasted conditions. For example, as stated in the aviation weather task analysis (Cruit & Blickensderfer, 2015), if a pilot receives information from the Flight Service Station about possible icing conditions, the pilot must understand that icing conditions can build upon the aircraft during the flight and cause the aircraft to stall. At this point, recovery could be impossible. During preflight, a GA pilot will gather information from several different weather products (e.g., METARs Winds Aloft, NEXRAD) and from a variety of weather product sources (e.g., DUAT/DUATS, 1800-wx-brief) in order to consider all information from products and sources before deciding to take-off. In this example, the GA pilot may look at radar images for predicted weather conditions at various airports along the flight path in case the pilot decides to land at an alternate airport due to degraded weather conditions.

The pilot may also decide to use an FAA approved internet source to obtain preflight weather information. The FAA and National Weather Service offer a variety of internet weather sources to choose from. These services include Direct Use Access Terminal Service (Duats/Duat), Lockheed Martin Flight Services Portal, Aviation Digital Data Service (ADDS), and Telephone Information Briefing Service (TIBS). When using

each of these services, pilots will need to be familiar with the textual coded content of the information provided as well as how to read and interpret graphical weather images. For example, when receiving a weather briefing from the Aviation Digital Data Service website, a pilot can obtain a Meteorological Aviation Terminal Weather Report (METAR) that contains conditions at the current airport, winds, temperature, dew point, visibility, ceilings, and clouds. However, the representation of the information is found in *Figure 3*. As seen from the figure, the pilot first needs the knowledge to translate the METAR's abbreviated terms into actual meteorological events or concepts. Next, the pilot needs to understand the meaning of the meteorological events. Finally, the pilot needs to understand the implications of these meteorological events for flight. Recall an example of a METAR from the aviation weather task analysis (Cruit & Blickensderfer, 2015), the pilot not only needs to understand that –TSRA means thunderstorms with light rain but that thunderstorms can cause lightning, wind, hail, and low visibility along the flight. The boxes below the coded information found in the first line do not typically appear in a METAR. Those are only for the reader's understanding. In summary, the pilot is held responsible for obtaining all weather information during preflight, but the pilot has many options for using different weather products and sources for collecting this information. If the pilot lacks the training and experience for using these weather products and sources, it could be challenging to make appropriate decisions about weather information.

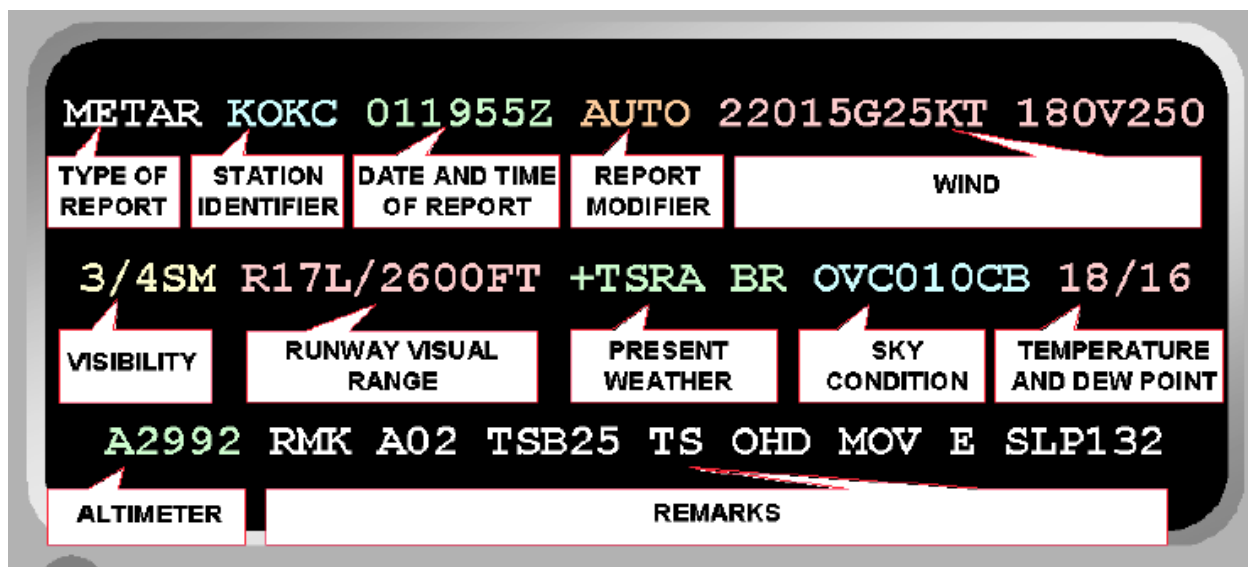


Figure 3. Example of METAR (Avionicswest.com, 2015)

Inflight Training Requirements and Procedures. While in flight, pilots who are not instrument rated have the responsibility to maintain VFR throughout the flight. To avoid IFR, these pilots must understand meteorological phenomena and how the phenomena can become weather hazards. For example, pilots must understand cloud types, ceiling height, winds and forecasts to know if a thunderstorm is near and what they need to do to avoid entering IMC. In addition, pilots are given a variety of weather information sources while inflight. Pilots need to understand which product is available to them while inflight, and then decide which one is best to use. A pilot also has the option to choose many different weather sources to collect as much information as possible. If the pilot chooses this option, the pilot must understand how to interpolate the information they gather from inflight weather sources with the information they received during preflight.

In flight, pilots are responsible for communicating with ATC directly through radio transmission to obtain weather information or contacting Hazardous Inflight Weather Advisory Service (HIWAS) if they begin to experience degraded weather. Both of these services can aid the pilot through various weather conditions. HIWAS provides the pilot with information about convective weather, icing conditions, turbulence, and possible wind shear. Although the information that HIWAS provides is comprehensive, the pilot still needs to have the skill to comprehend and possibly interpret the information given. For example, HIWAS provides the pilot with PIREPS, SIGMETS, and AIRMETS, but if the pilot lacks the knowledge of what these products are and the implication for their flight, then it doesn't put much value on the information that the pilot is receiving. As illustrated in the aviation weather task analysis (Cruit & Blickensderfer, 2015), pilots need to understand the implications of wind shear on their flight. If a pilot is landing on an approach and faces wind shear that results from a decreasing head wind, the aircraft could potentially lose airspeed and altitude. The pilot needs to factor in enough altitude to recover from this situation or the flight could result in a crash. Additionally, newer aircraft may be equipped with advanced technology that allows the pilot to visually see weather information inflight through ground-based or satellite radar displays. The Flight Information Service-Broadcast (FIS-B) is one example of this type of ground-based technology. If aircraft has the capability of using FIS-B, pilots can view graphical displays of METARS, PIREPS, SIGMETs, AIRMETS, and NEXRAD products throughout the flight. Yet again, the pilot needs the knowledge and skills to understand these products and with newer technology like NEXRAD, pilots need training on the

specific complexities of the product (e.g., latency issues of when the product is issued vs when the pilot receives the information).

To illustrate some of the complexities of newer weather technology, Latorella and Chamberlain (2002) examined pilots' assumptions with NEXRAD mosaics. NEXRAD is graphical weather forecasting product that can be used during preflight or inflight to make decisions pertaining to the flight path. This type of technology provides the pilot with graphical information on thunderstorms, convective weather, winds, and precipitation. If used correctly, it can allow pilots to make effective decisions with respect to their flight. However, one of the limitations of NEXRAD is information latency. Specifically, it takes time for the NEXRAD system to collect the weather data, synthesize it, and then transmit it to the aircraft. Although the display includes a time stamp in the top right corner of the screen that captures the time of when the image was produced, pilots may have difficulty comprehending the implication of that delay. When pilots receive a radar image, they could be looking at an image that is 15 minutes old. When Latorella and Chamberlain (2002) examined limitations with pilots' use of NEXRAD, they found that 50% of the participants did not consider the latency issue. The implications could indicate that pilots do not fully understand the complexities and limitations of weather technology; *pilots do not realize the storm is no longer in the same position as depicted by NEXRAD.*

2.3. Lack of Training with Weather Technology and Resources

With the vast research over the years supporting weather as being a significant contributor to the number of GA accidents and fatalities, large organizations supporting aviation safety such as the FAA, NTSB, and AOPA seek to understand how

meteorological training affects pilots' weather-related decision-making. With advances in weather technology and resources, pilots are required to understand a large variety of weather products and resources (Lanicci et al., 2012; Shappell et al., 2012). Recall from the Cruik & Blickensderfer (2010) weather-related task analysis and Lanicci et al. (2011) research on required GA meteorological knowledge that during preflight, pilots can gather weather product information (e.g., METARs, TAFs, Winds Aloft, Area Forecast) from a variety of sources (DUATS/DUAT, Flight Service Station, HIWAS).

Understanding these products is only the beginning. Once the pilot obtains the knowledge of these weather products and sources, the pilot must then be able to choose an appropriate weather product from the large pool of weather products and sources. Those pilots with more experience with making decisions in various weather conditions are able to draw information from their memory to make efficient and effective decisions.

However, pilots who lack the training and expertise with weather technology may be challenged with making timely and appropriate decisions in the face of weather conditions. Several research studies illustrate examples of how GA pilots lack the general understanding and appreciation of weather-related concepts, products, and sources (Cobbett, Blickensderfer, & Lanicci, 2014; Shappell et al., 2012; Lanicci et al., 2012; NTSB, 2005). Furthermore, these studies address the concerns with the lack of education and training for these weather-related concepts, products, and sources and the implications for the safety of GA flight.

To investigate the concerns with GA safety during degraded weather encounters, Cobbett, Blickensderfer, & Lanicci (2014) approached these concerns from an education and training perspective with a specific concentration on pilots' understanding and use of

Next Generation Radar (NEXRAD) products. After prior research indicating that GA pilots need and want to understand how to use NEXRAD products more effectively (Lanicci et al. 2011; Lanicci, Roberts, & Blickensderfer, 2011), Cobbett, Blickensderfer, & Lanicci (2014) implemented a training program that was designed to train GA pilots on how to use and interpret NEXRAD products. The results of the study showed that GA pilots who experienced the NEXRAD training module performed better on a radar knowledge test than those GA pilots who received no training. The results of this study revealed that with an effective, well-designed training course that targets a particular area of aviation weather, GA pilots can learn the meteorological concepts/products that are needed for making weather-related decisions during flight.

Shappell et al. (2012) and Lanicci et al. (2012) examined GA inflight decision-making regarding weather-related encounters. Prior research in the area of GA accident analysis concerning weather-related events indicated that GA pilots were intentionally flying into degraded weather because they had a willful disregard for the rules. However, the results of the accident analysis failed to include the perspective of the accident from the GA pilot and instead only relied on the accident investigator's subjective understanding of the accident. To gain a deeper understanding of why GA pilots decide to enter degraded weather, Shappell et al. (2012) interviewed 25 GA pilots about their experience with near-miss weather encounters during flight. The goal of the study was to gather more information about why these GA pilots were making decisions to fly into degraded weather. The results of the study revealed that pilots were entering adverse weather situations because they lacked the understanding of the hazards associated with bad weather. *Therefore, the lack of knowledge of weather phenomena did not allow the*

pilots to fully appreciate or comprehend the severity of the weather hazards encountered during flight.

Additionally, Shappell et al. (2012) found that the pilots often experienced conflicting weather information from the weather products and weather product sources they were using. For example, pilots reported that during flight, the on-board weather radar displayed a gap in convective activity; however, after calling the Flight Service Station, the dispatcher reported the same area as shown on the on-board radar display as having instrument meteorological conditions. The inconsistency between weather products can be problematic when pilots are not utilizing several sources of weather information and they fail to see the actual picture of developing weather. Lastly, Shappell et al. (2012) discovered that some GA pilots did not receive a complete report of weather information from one source. When pilots do not have the knowledge or experience to understand that they are missing critical information within a weather report, pilots will neglect to consider searching for more information from other resources (2012).

To further investigate the interview data collected from the previous GA study with 25 GA pilots (Shappell et Al., 2012), Lanicci et al. (2012) found that the weather products that pilots were collecting weather information from during preflight lacked consistency with what the different products reported. For example, pilots could receive information from METARs reporting fair weather, but TAFs was reporting IMC. In addition to the inconsistency, Lanicci et al. (2012) discovered that while in flight, GA pilots did not utilize all available weather products and sources. With the inconsistency in the information disseminated from the weather products, pilots need to gather as much

information as possible from several products. With more knowledge of all possible weather conditions, pilots can make informed decisions during flight.

The literature also addresses the aviation weather knowledge gap that GA pilots experience with respect to their education and training. Lanicci et al. (2012) point out that GA pilots are only required to complete the necessary training to complete ground school or a home-based training course. Currently, there are no regulations that require the amount of time GA pilots should record meteorological training hours. In addition, other research addresses the inconsistencies of flight instructors' requirements for general aviation pilots passing practical flight exams (NTSB, 2005; Burian & Felman). In fact, the NTSB (2005) noted that during a GA pilot's biennial flight review, it is under the subjective discretion of the flight instructor to choose which weather concepts to include during the review and how many questions. Also, Burian and Felman (2009) found that flight instructors typically only spend 10 to 12 hours of total instruction time on general aviation weather education.

Lanicci et al. (2012) address the concern of whether GA pilots-in-training are only taught the minimal amount of weather concepts to pass the written exam that grants them a private pilot's certificate. Moreover, Lanicci et al. (2012) explain that if pilots are only learning weather-related material to pass the exam, they may not be learning any additional weather-related information after they have passed the exam. Since the pilots do not fully understand the weather concepts and weather products, they may feel hesitant to consult these products and their sources for weather information. However, it is important for pilots to check as many weather products as possible to get a comprehensive outlook on the weather for the flight. The information from the literature

on the lack of aviation weather training and education that GA pilots receive suggests that more research is needed to examine this apparent lack of weather-related knowledge and skills.

2.4 Weather-Related Pilot Expertise and Decision Making Errors

To investigate further into the question of whether pilots lack aviation meteorological training several studies have looked at pilots' decision making during preflight and inflight procedures (Goh and Wiegmann, 2001; Detwiler et al., 2005; Knecht, 2006; Wiegmann, Talleur, and Johnson, 2008). The goals of these studies were to examine pilots' basic weather knowledge and skills, preflight planning procedures, how pilots assess risk during weather related incidents, and how pilots assess different weather scenarios inflight and interpret changing environmental cues (Wiegmann, Talleur, and Johnson, 2008).

Wiggins and O'Hare (1995) define weather-related decision making skills as those skills that pilots need to obtain in order to avoid deteriorating weather conditions during a flight. Weather-related decision making involves pilots having the ability to recognize environmental cues that warn them of dangerous weather phenomena throughout the flight. When addressing decision making, there are many different theories of decision making such as classical decision making, the information processing model of decision making, naturalistic decision making and decision making using heuristics and biases. This paper solely focuses on the Naturalistic Decision Making Theory, which examines experienced individuals in their natural environment when making decisions quickly under time pressure. This theory is appropriate for examining

decision making skills with GA pilots, given the complex nature of a typical GA flight (Blickensderfer, Strally, & Doherty, 2012).

The Naturalistic Decision Making Theory focuses on how each individual uses their experience to make decisions in a complex and dynamic environment under the real aspects of time pressure (Klein, 2008). Naturalistic Decision Making involves asking how experts solve problems in complex situations and to identify risks in order to make decisions that avoid the least amount of consequences. From an aviation perspective, pilots are often faced with making decisions when flying through various meteorological conditions such as degraded weather. As mentioned in previous sections, pilots often fly VFR to IMC because they do not have the experience to recognize the environmental cues of deteriorating weather (Burian, Orasanu, and Hitt, 2000). Wiggins and O'Hare (1995) suggest that weather-related decision making is a difficult skill to learn during training and instead, explain that it is learned through practical, real world experience. Furthermore, Wiggins and O'Hare (1995) explain that since there are no standard guidelines for inexperienced pilots who are making clear decisions during various weather phenomena, there is a need for a detailed identification of the skills needed for effective weather-related decision making during pilot training.

One particular decision making error that pilots continually make is called a planned continuation error (Orasanu, Martin, & Davidson, 2001), which entails a pilot failing to revise or adjust a flight plan despite the evidence of deteriorating conditions. An example of a planned continuation error is when a pilot is faced with deteriorated meteorological conditions, the pilot does not choose to divert to an alternate airport or go around the storm; instead, the pilot continues on the planned flight path. Pilots often

make these planned continuation decisions because they lack the knowledge of the local flight area, lack overall flying expertise, or lack the knowledge and understanding of various weather-related products and resources (Goh and Wiegmann, 2002; NTSB, 2005). Goh and Wiegmann (2002) state that novice pilots lack the experience of identifying weather hazards and correctly assessing a risky situation that expert pilots have.

2.5 Limitations with GA Assessment Strategy

Despite the evidence that GA pilots do not understand the meteorological concepts, products, and sources to obtain those products in order to avoid hazardous weather encounters in flight, student pilots are still passing their certification exam (FAA Airmen's Knowledge Exam) to obtain a private pilot certificate. Wiegmann, Talleur, and Johnson (2008) investigated the relationship between pilots' lack of meteorological knowledge and skills and the pass rate of the FAA written exam that grants student pilots a private pilot certificate. The study examined both the FAA approved weather training material used as a study guide for pilot taking the written exam and the weather-related content of the written exam. The results of the study concluded several different issues that could imply that the current FAA Airmen's Knowledge Exam is not predictive of GA pilots' actual weather knowledge and skills and possibly not predictive of GA flight performance.

The first issue that Wiegmann, Talleur, and Johnson (2008) found was that there were many FAA weather-related source documents that pilots could use as a study guide for taking the Airmen's Knowledge Exam but that these documents contained scattered

weather information across each of the documents as opposed to a comprehensive manual that contained all weather information in one document. Furthermore, the study revealed that these weather-related source materials were outdated. That is, some of the advisory circulars that are FAA approved study materials for the written exam are from the 1970s and contain general meteorological phenomena but fail to include information about radar products and datalink weather technology.

The second concern that Wiegmann, Talleur, and Johnson (2008) address is the pass rate of the student pilots taking the Airmen's Knowledge exam. According to the FAA (2011), the current pass rate for student's taking the Airmen's Knowledge exam is 91.93% and the average score is 85%. In order for students to pass the exam, they must score a 70% or above. A typical knowledge exam contains a total of 60 questions but only 5-8 questions are weather-related. It only requires simple math to determine a pilot-in-training can fail all weather questions yet still pass the written exam. In fact, Wiegmann, Talleur, and Johnson (2008) analyzed score reports of 106 private pilot applicants who had passed the written exam, and sure enough they found that students could pass the exam, yet answer all of the weather questions incorrectly. This finding is consistent with the NTSB (2005) report that advocates for a restructured FAA written exam for private pilots. The NTSB (2005) suggests that students should not be able to pass the entire exam if failing one portion of the exam (e.g., weather). Ultimately, Wiegmann, Talleur, and Johnson (2008) found that those 106 students who passed the Airmen's Knowledge Exam performed well on non-weather-related exam questions. This indicates that those students do retain adequate aviation knowledge, but are knowledge deficient with respect to aviation weather (2008).

The third and final issue that Wiegmann, Talleur, and Johnson (2008) addressed is the type of learning that is assessed on the Airmen's knowledge exam. The Airmen's Knowledge Exam contains only multiple choice questions that mostly assess rote level learning. This means that students are not required to conceptualize, apply, and correlate their weather knowledge and skills to new scenarios. Furthermore, the multiple choice questions on the written exam are randomized and do not follow a particular pattern that correlates chronologically with the tasks of a typical flight from preflight to landing. Because GA flight planning requires the pilot to conceptualize and assimilate weather information in a complex environment, the artificiality of the question arrangement seems particularly mismatched with the actual tasks of flight (2008).

The FAA continues to assess private pilots taking the Airmen's Knowledge exam with a hierarchy of learning outcomes. Before 1999, these learning outcomes consisted of four different levels of learning. The first level of learning, *rote*, assesses pilots' ability to memorize and recall factual data. For example, pilots could be asked to memorize the different layers of the atmosphere and then to recall those layers on the assessment. This level of learning does not require any type of understanding of the earth's atmosphere. The second level of learning is called, *understanding*, and this involves the student to compare and contrast different concepts that relate to the concept in question. For example, a question aimed at the level of *understanding* may ask students to explain the differences between the troposphere and the mesosphere. This question requires the student to understand the different components of both parts of the atmosphere. The third level of learning is called, *application*. The application level of learning requires the student to use what has been learned and apply it to the complex environment that they

would be working in. For example, a question at the application level of learning might ask the student to apply what they know about icing conditions, and apply it to their particular flight. The final level of learning assesses the student's ability to *correlate* information that has been learned and applied to subsequent information. For example, a student is able to recognize the cues of deteriorating weather because of their experience with a previous flight, and they can apply those cues to their current flight situation. Both the application and correlation level of learning is difficult to assess in a decontextualized environment such as a traditional multiple choice test.

While it is clear that GA pilots need various levels of weather-related knowledge, it is unclear how much weather-related knowledge is needed to be an effective GA pilot. More importantly, more clarity is needed on how to accurately assess various levels and degrees of weather-related knowledge and whether the amount and type of weather-related knowledge predicts GA pilot performance.

3.1 What is Expertise

Within any domain, there are individuals that perform at a higher, superior level than others. Experts are distinguished from novices by their superior knowledge, skill, or opinion within a specific area (Ericsson and Lehmann, 1996; Hoffman, 1998). The vast research on experienced performers reveals that their expertise in a given field does not transfer to other domains (Ericsson and Lehmann, 1996; Bedard, 1992). That is, expert musicians may not be expert dancers, expert runners may not be expert golfers, and expert pilots may not be experts at flying through various weather situations. One's expertise has limits (Ericsson, 1993) and one of those limits is that the experience an individual possesses is contained to a specific area (Chase and Simon, 1973; Klein, 1998). This limitation however, sets the stage for standardization requirements when assessing individual expertise within a given domain.

3.2 Assessing Expertise

When labeling individuals as experts, different domains have different requirements on what they consider as expert performance in a particular skill. When assessing individual expertise through standardized assessment, it is important to define these requirements through measurable objectives (Ericsson and Smith, 1991). Ericsson and Lehmann (1996) expound how in de Groot's (1978) study of expertise, expertise in typing was measured by asking typists to type as many words as possible during a 3-minute period. Expert typists were able to type a passage faster and more accurately within a specific period of time than non-expert typists. Furthermore, expert musicians were measured by having pianists play a specific piece of music and then asked to

replicate that same piece of music the exact same way they played it the first time. The expert pianists were able to reproduce their musical piece with better skill and accuracy than non-experts. Within each of these examples, there were requirements that the expert had to meet in order to be deemed as containing superior performance. Original research on expertise by de Groot (1978) and Chase and Simon (1973) explain how expert performance can be reproduced in a laboratory setting as long as there are standardized methods within the domain for measuring performance. Additionally, Ericsson and Smith (1991) stress the importance of identifying standardized tasks within a particular domain to allow the individual to reproduce their superior performance in the laboratory.

The literature on expertise suggests that experts can be generalized as holding certain characteristics that distinguish them from non-experts. These generalizations can be narrowed down into two common themes: 1) Experts have the ability to perceive, recognize, and retrieve informational cues faster than non-experts (de Groot, 1978; Ericsson and Smith, 1991; Ericsson and Lehmann, 1996; Wiggins et al., 2002). 2) Experts are capable of linking complex and elaborate information together in order to apply later concepts (Meterissian, 2006; Chi and Glaser, 1988; Ross and Spalding, 1991).

The first theme that emerges within the literature on expertise is that experts have the ability to perceive, recognize, and retrieve informational cues faster than non-experts. With his study of expert chess players, de Groot (1978) found that these experts had acquired an extensive amount of informational knowledge over the years pertaining to the game of chess. This allowed these experts to exhibit superior performance over their opponents because they were able to recognize strategic chess moves, play out a string of possible chess moves in their mind, and then execute the best strategy upon their

opponent. When an individual has the ability to perceive and recognize patterns of information quickly, it allows those individuals to make decisions more rapidly (Kahneman and Klein, 2009). This skill can be especially beneficial for pilots needing to make quick decisions to solve immediate problems during deteriorating weather events. One reason thought to explain experts' ability to recognize patterns more effectively than non-experts is their superiority in domain-specific memory retrieval (Ericsson and Smith, 1991; Ericsson and Lehmann, 1996). Since experts contain an extensive amount of domain-specific knowledge, they are able to retrieve that knowledge from long-term memory as opposed to short-term memory. When non-experts rely on using their short-term memory to encode information, it takes longer to assess and interpret the situation than experts (Ericsson and Kintsch, 1995). One disadvantage of short-term memory is that only a limited amount of information can be processed at one time (Baddely, 1992). Alternatively, experts are able to chunk large amounts of information together that results in a faster retrieval time (Ericsson and Staszewski, 1989).

The second theme that the expertise literature reveals is that experts are capable of linking complex and elaborate information together in order to apply that information to later concepts. Experts are able to organize and conceptualize information into different categories and then form patterns. This helps experts draw from their extensive knowledge bank and discriminate between typical and atypical situations when faced with new information. Einhorn and Hogarth (1981) support this idea by explaining the concept of mental simulations. Experts use mental simulations by imagining various formations of situations that they know to be true or might be true and then project these formations into a new situation. Experts are able to use their complex knowledge system

to assess their understanding of the current situation and then construct mental simulations to predict future situations (Phillips, Klein, Sieck, 2004). Klein's (1998) study on firefighters revealed that expert firefighting commanders understood how a building was burning just by observing the burning building from the outside. Because these experts created mental simulations of how the fire was affecting the stairwells, elevators, and roof supports, they were able to predict how the fire would continue burning (Klein and Crandall, 1995). After discussing common characteristics of expertise in order to study and assess expertise, the next section will explain how a scenario-based exam can be used to capture expertise from an assessment standpoint.

3.3 Scenario-Based Assessment to Capture Expertise

The purpose of this section is to describe and discuss how a scenario-based written assessment can better predict expertise over a non-scenario assessment; and therefore, better predict superior pilot performance from a written scenario-based test over a traditional, written non-scenario test. This section illustrates three main ideas: 1) It compares the underlying differences between scenario-based assessment and traditional assessment; 2) It will explain existing research on the use of scenario-based assessment; 3) It describes how theories of expertise drives the motivation for using a scenario-based assessment to predict GA pilot performance over a non-scenario assessment.

Comparing Scenario-based Assessment with Traditional assessment. A traditional written test usually contains multiple choice or true or false questions which assess the learner on low-level cognitive skills. Simon, Ercikan and Rousseau, (2012) argue that traditional multiple choice tests often assess one's test-taking skills as opposed

to the actual knowledge and skills of a given domain that the test intends to measure. Traditional written assessments typically assess memorized data, facts, or a decontextualized application of knowledge (Linn, Baker, and Dunbar, 1991; Frederiksen, 1984). These types of tests measure information gathered from books or lectures, memorizing protocols or understanding concepts from checklists (Kaner and Padmanabhan, 2007). That is, traditional written assessments capture basic, lower-level thinking as opposed to the higher-level cognitive complexities. Herman (1992) states that traditional written assessments require the tester to *choose* as opposed to *generate* a response. This supports the claim that traditional assessments only measure rote level learning as opposed to measuring critical thinking and problem solving skills (Simon, Ercikan and Rousseau, 2012).

As opposed to the lower level thinking traditional tests measure, a scenario-based assessment measures both higher-level cognitive skills (i.e., decision making, situation awareness, problem solving, metacognitive processes, critical reasoning and risk assessment) and interpersonal skills (i.e., communication, leadership, and teamwork (Kang, McDermott, Roediger, 2007; Meterissian, 2006)). A scenario-based assessment tests the learner from a hypothetical story that requires the tester to work through a complex problem or system and allows the tester to be immersed in the mindset of the situation that they are working through (Miller, 1990). Scenario-based assessment provides the test taker with understanding, remembering from experience, and motivation. For example, a scenario-based assessment testing clinical diagnostic skills in nursing could provide the nurse with a case study about a patient from the time the patient walks through the hospital until the nurse diagnoses the patient. The case study

description supplies the rich, detailed complexity of the clinical situation that allows the nurse to be immersed into the mindset of the situation. Since the scenario in the case study draws information from previous questions, the nurse can remember through situational cues on how to perform tasks and make decisions regarding the patient's treatment plan. Furthermore, the scenario motivates the nurse to think carefully and to make accurate assessments since the scenario setting is familiar to the nurse's training.

Existing Research on the use of Scenario-Based Assessment. Existing literature supports the argument that scenario-based assessment captures a wider range of student knowledge when measuring students' knowledge and skills. Through the review of the literature on the use of scenario-based assessment, three themes emerged. 1) The literature reveals fundamental components of what scenario-based assessments typically assess. 2) Research studies stress the importance of the situational context which encompasses scenario-based testing as opposed to the decontextualized traditional written exams. 3) Several research studies explain how scenario-based assessment is more effective than traditional non-scenario assessments in measuring the complexity of knowledge and skills in a given domain; and therefore, could be used to predict future performance.

The fundamental components of scenario-based assessment. The literature advocating a scenario-based assessment strategy to measure learner's knowledge and skills indicate that scenario-based assessment incorporates several fundamental components within each assessment. 1) The scenario-based assessment is credible, complex, and easy to evaluate. 2) The assessment motivates the tester. 3) Each question

needs to depend on other questions to reinforce learning. 4) The assessment must have learner transferability to solve real world, domain-specific problems, meaning that the individual should be able to apply what they know to a real world scenario.

First, when using a scenario-based assessment to measure a student's knowledge and skills, Kaner (2003) claims that the assessment scenario must contain credibility, complexity, and creativity. For a scenario to be credible, the tester must believe that this scenario would actually occur in a live/operational environment. For example, a scenario measuring driving ability must contain typical driving tasks and behaviors that a driver would experience on a daily basis. The scenario must be complex, that is, the scenario must require necessary knowledge and skills and those knowledge and skills must be easily evaluated and measured. If the scenario is not measuring a comprehensive assessment of one's knowledge and skills, the assessment fails to meet content validity. Finally, the results of the scenario-based assessment must be easily evaluated. There should be distinct measures of whether the learner passed or failed different elements of the complex scenario.

Second, a scenario-based assessment motivates the test taker by influencing them to make high-level decisions (Dochy, Segers, and Buehl, 1999; Kaner, 2003). A learner who is engaged in a highly complex scenario will have more motivation to make critical decisions over a learner who is assessed with a traditional multiple choice test (Kaner, 2003). Dochy, Segers, and Buehl (1999) suggest that the key to the concept of motivation and scenario-based assessment is investment. If a learner is invested in the outcome of their decisions, they will be motivated to answer questions at a higher level of thinking. A scenario-based assessment achieves this level of investment by making the scenario event

familiar to what students typically experience. Students are more influenced on a test when an interaction is personal than when an interaction is impersonal. Garner (2005) found that individuals who were asked to complete a 24-page survey were 67% more likely to complete it after the survey contained a sticky note that had their own name on it than individuals who received a survey without a personalized sticky note. If the scenarios in the assessment are personalized to what the student is learning, the student will be more motivated throughout the assessment. Furthermore, scenarios also provide learners with the motivation to acquire new knowledge with the perspective to incorporate that new knowledge into their existing knowledge bank. Then, the learner has the opportunity to apply that knowledge with different questions within the scenario (Greeno, Collins, and Resnik, 1996).

Third, each question within a scenario-based assessment should not be independent from other questions. That is interrelated scenario-based questions that build upon each other helps to reinforce learning and recall throughout the assessment (Dochy, Segers, and Buehl, 1999; Greeno, Collins, and Resnik, 1996). The Ebbinghaus (1913) series of studies on repetition showed that learners strengthened their knowledge and understanding of concepts when those concepts were repeated during a performance assessment. Furthermore, through repetition, learners decreased the amount of time needed to relearn what had been previously forgotten. When scenario questions build upon each other through dynamic and complex content, students will have an increased chance at recognizing retrieval cues that will foster a deeper understanding of the assessment (Bjork, 1988).

Fourth, the scenario-based assessment contains transfer and generalizability to real-world domain-specific problems. Standardized multiple-choice tests often contain a set of scores that may not have any use except for the scores themselves. Scenario-based assessments transfer topics within a domain by task specification. The range of tasks and problems to be solved are specified in advance. For example, a scenario-based exam assessing culinary skills might receive a scenario at the beginning of the exam directing the student to prepare a five-course meal to a group of 12 individuals. The student knows what is expected of them at the beginning of the exam and each subsequent question applies to the scenario. There needs to be consistency from one part of the test to another or from one scenario to another to increase reliability. How do the knowledge and skills that lead to successful performance on multiple choice tasks transfer to other tasks? In judging results from traditional standardized tests, there should be evidence regarding the degree to which the skills and knowledge that lead to successful performance on multiple-choice test questions transfers to other tasks. Evidence of both near and far transfer such as the ability to use skills demonstrated on multiple-choice tests to solve real-world problems is needed.

Situational context within scenario-based assessment. A crucial aspect of scenario-based assessment is context. Many researchers argue that it is difficult to fully capture the knowledge and skills a learner possesses independent of context but that scenario-based assessment assesses the learner through a complex situation or framework which provides the essential context (Lindquist, 1951; Kindley, 2002; Stewart and Symonds, 2009; Cobb, Yaker and Wood, 1992; Anderson, Redder, and Simon, 1996; Beach, 1995).

This idea of a context specific scenario to assess learning rests on the theories of situated learning and authentic assessment (Anderson, Redder, and Simon, 1996; Linquist, 1951).

Anderson, Redder, and Simon (1996) describe situated learning as the idea that students recall and understand a greater amount of knowledge when the assessment questions are specific to the context in which the student learned the information. Educational research with the theory of situated learning focuses on mathematical reasoning particularly because of its decontextualization within a classroom environment. In research on mathematical reasoning, most students who begin learning mathematical calculations and problem solving learn these concepts in a classroom that is independent of the real world situations where one would typically deploy these calculations (Cobb, Yakel, and Wood, 1992). Beach (1995) examined this idea of situated learning by comparing two groups of students with a mathematical reasoning task. The first group of students was 13 traditional high school students and the second group was 13 adult students who were working as an apprentice for a shopkeeper. Both groups of students were given an arithmetical reasoning task. This task put the student into a scenario that was similar to the real world. Beach found that the group of adult shopkeepers performed better at the applied reasoning than the high school students. The high school students explained that they viewed the reasoning task as a means to an end with the goal of answering each mathematical problem correctly, whereas the adult shopkeepers had the goal of developing their shop keeping skills as well as learning competencies that will profit their business. Beach's study suggests the idea of a higher transfer of understanding through context-specific scenarios because a greater sense of understanding occurs with students who can apply the context of the question to their affiliated domain.

The concept of authentic assessment derives from Lindquist's (1951) theory of assessing students on the knowledge and skills within an environment that closely mirrors the actual environment where the student will later produce those knowledge and skills within a given task. Lindquist stated, "it should always be the fundamental goal of the achievement test constructor to make the element of his test series as nearly equivalent to, or as much like, the elements of the criterion series as consequences of efficiency, comparability, economy, and expediency will permit" (p. 152). Lindquist advises those test constructors who intend to measure higher-order thinking and critical reasoning skills and suggests that these test constructors need to ensure that the test questions will require the tester "to do the same things, however complex, that he is required to do in the criterion situations" (p. 154).

The effectiveness of scenario-based assessment in measuring the complexity of domain-specific knowledge and skills to predict future performance. Problem solving in a live environment requires the user to rely on their knowledge and experience. These problem solving skills include higher-level cognitive thinking such as, decision making, situation awareness, planning, risk assessment, communication, leadership, and teamwork. Many traditional written assessments are not prepared to capture the higher-level cognitive knowledge and skills that are required in some situations where there is uncertainty about a proper course of action. This idea stems from the theory that individuals rely on their experience to attack new challenges (Ericsson and Towne, 2010). Additionally, other studies suggest that there is evidence that if a learner has prior knowledge of the subject at hand, the student will have an easier time comprehending the material (Bransford & Johnson, 1973; Pearson & Sprio, 1980). This concept indicates

that the contextual information provided through a scenario-based assessment captures the students' knowledge and experience more effectively through problem solving measurements over traditional assessments.

Healthcare educators often use simulated environments to assess their students' knowledge and skills and these simulated environments also include scenario-based written exams. The following paragraphs illustrate examples from healthcare educators on the efficacy of these assessments and how they can be used to predict future performance.

Brailovsky , Charlin , and Beausoleil (2001) attempted to predict clinical reasoning performance with 24 medical students using a scenario-based written exam. The study used different assessment strategies to examine whether test results after the students' clerkship predicted performance during the subsequent students' residency program. The researchers tested the 24 students with the scenario-based assessment two years before the end of their clinical residency and then tested them at the end of their residency on clinical reasoning assessments (i.e., Short-Answer Management Problems, Simulated Office Orals, and Objective Structured Clinical Examination). The researchers hypothesized that students' scores on the scenario-based test would correlate with scores on similarly designed tests (i.e., Short-Answer Management Problems and Simulated Office Orals) at the end of their residency and not correlate with a more traditional assessment (i.e., Objective Structured Clinical Examination). The researchers concluded that a scenario-based written assessment better predicted clinical reasoning performance at the end of their residency over a traditional written assessment. Furthermore, the researchers suggest that if a student shows high levels of cognitive understanding of

clinical knowledge early in the training, the student will reflect the same level of cognitive knowledge during subsequent clinical assessments. This illustrates the possible need for informal cognitive benchmark assessments to tailor the student's training needs.

In addition, Meterissian (2006) found that the scenario-based assessment called the Script Concordance Test (developed by Charlin et al., 2000) showed predictive validity over a traditional written exam and differentiated between cognitive and technical skills in relatively experienced anesthesiologists. The theory behind the Script Concordance test is that it assesses differences in clinical reasoning skills between experienced and less experienced clinicians. Meterissian (2006) suggests that experienced clinicians contain elaborate networks of knowledge which coincide with the tasks they perform on a daily basis. These elaborate networks are called scripts and these scripts are organized to fulfill certain goals within their respected tasks. Meterissian explains that this type of clinical knowledge is only revealed in authentic situations where clinicians receive the opportunity to practice reflecting on real, clinical issues. Therefore, unlike traditional written assessments that measure a student's accumulation of knowledge, the Script Concordance Test measures how a student organizes, structures, and connects knowledge.

Sidi, Berkenstadt, Ziv, Euliano, and Lampotang (2014) utilized a scenario-based assessment to evaluate 47 anesthesiology residents' knowledge and experience on cognitive reasoning tasks in the operating room. The researchers postulated that clinical problem solving requires knowledge and experience and that traditional written examinations would not capture the knowledge and skills of those clinicians with more experience. Researchers tested the 47 residents with a scenario-based exam early in their

residency and found that scores on the scenario-based exam better correlated with clinical performance during their last year of residency. The researchers concluded from their results that a scenario-based assessment can differentiate between cognitive skills and technical skills as well as indicate different areas of strengths and weaknesses with anesthesiology residents. As seen from the literature, there is evidence that scenario-based assessment can be used as a predictor of individuals' future performance in domains such as healthcare, business, and academics. The following chapter describes the benefits of using a scenario-based assessment in aviation and how a scenario-based assessment can be used to assess pilot expertise and possibly predict future performance.

Chapter 4

4.1 Assessing Pilot Expertise through Scenario-Based Assessment

Chapter One introduced the high accident rate associated with general aviation and more specifically, the role of degraded weather associated with these accidents. The research on causal factors to these GA weather-related accidents focuses on errors in decision making, poor situation assessment, and lack of experience with weather phenomenology and weather technology. Characterizing pilot expertise typically involves many factors such as counting flight hours, specific rankings, certificates held, instrument experience, as well as time spent in the flight simulator. Traditionally, if a pilot has more than 10,000 hours of experience, they are considered an expert (Ericsson, 1993). But as previously mentioned the broad definition of expertise does not necessarily transfer to more task-specific areas of expertise. This means that a GA pilot with 10,000 hours of flight experience may be an expert at only flying through fair weather conditions, but when faced with deteriorating weather, the pilot lacks the knowledge and skills to make well-informed decisions. Therefore, we could conclude that an expert pilot is not necessarily an expert weather pilot.

Currently, GA student pilots are required to take the Airmen's Knowledge Exam to earn a private pilot certificate, after they have completed the necessary training. As previously mentioned, the Airmen's Knowledge Exam is a written, multiple-choice exam that covers a limited amount of aviation weather information (Wiegmann, Talleur, and Johnson, 2008). As found from previous research, a written, multiple-choice exam does not assess higher-level knowledge and skills such as problem solving, decision making, critical thinking, and complex reasoning (Kaner, 2003). In order to assess this higher-

level thinking, it is necessary to tailor the assessment to elicit expert knowledge and skills through objective measures.

Ericsson and Smith (1991) suggest that when assessing experts, we should focus on individuals who can reproduce superior performance on representative and authentic tasks in their field, and that this superior performance must be reproducible in a complex environment. This suggestion aligns with the concept of utilizing a scenario-based assessment to predict GA pilot performance since scenario-based assessments provide an authentic and complex environment that is representative of the actual live environment that a pilot would encounter (Anderson, Redder, and Simon, 1996). This is preferable over traditional assessments that lack the complexity and contextualization that scenario-based tests offer. Mikenny and Davis (2004) examined expert pilots and their maneuvering abilities during emergency situations. When expert pilots practiced the same emergency event in a complex simulator, they were reliably more successful at reproducing similar performance during the actual event. Since expertise is characterized by actions that are contextually based and intuitive (Fitts and Posner, 1967), it is ideal to capture this expertise through an appropriate measure that places the student in a contextual, authentic environment where they can deploy challenging decision making strategies.

Some level of aviation weather expertise is necessary for GA pilots to successfully maneuver through various weather situations and this requires the need for standardized tests to assess those pilots' aviation weather knowledge and skills. With capturing aviation weather expertise through an effective standardized assessment strategy, instructors can identify those individuals who can problem solve, reason, and think more

critically during complex weather situations than those individuals who lack the knowledge and skills to perform these cognitive tasks. This capability to recognize and capture expertise at a critical point in a GA student pilot's education can possibly predict future GA performance during weather-related events. It is important to assess these pilots with an appropriate measurement that captures high-level cognitive skills that can predict expertise early on in training in order to identify those individuals who may need more training before flying without an instructor.

Recall from Chapter 3 that the literature on expertise suggests that experts can be generalized as holding certain characteristics that distinguish them from non-experts. These generalizations can be narrowed down into two common themes: 1) Experts have the ability to perceive, recognize, and retrieve informational cues faster than non-experts (de Groot, 1978; Ericsson and Smith, 1991; Ericsson and Lehmann, 1996; Wiggins et al., 2002). 2) Experts are capable of linking complex and elaborate information together in order to apply later concepts (Meterissian, 2006; Chi and Glaser, 1988; Ross and Spalding, 1991).

The research on expertise and the capabilities of experts to quickly retrieve information by perceiving and recognizing patterns supports the use of a scenario-based test to assess and predict GA pilot performance over a traditional written exam. Ross and Spalding (1991) claim that routine problems are not solved by choice calculations, but by classifying problems and then drawing from the stored knowledge of those problems to effectively make decisions. Through scenario-based assessment, each event within the

scenario builds upon each other so that the student can make decisions for one question based on the situational information contained in previous questions. Additionally, a scenario-based assessment is likely to capture superior performance of individuals through this scenario question building since experts will have the ability to recognize patterns within each question, hence stimulating better recall (Bjork, 1988; Ericsson and Lehmann, 1996). A traditional exam lacks a systematic storyline, and since each question is independent of each other, the measurement lacks the capability to reveal one's expertise as effectively as a scenario-based assessment.

The second theme that the expertise literature reveals is that experts are capable of linking complex and elaborate information together in order to apply that information to later concepts. Experts are able to organize and conceptualize information into different categories and then form patterns. From an aviation perspective, the preflight decision making phase of flight provides a rich context to examine pilot performance through a scenario-based assessment. According to Kirkbride, Jensen, Chubb, and Hunter (1996), faulty decision making during preflight performance is a significant contribution to aviation accidents in the United States. The preflight phase of flight requires pilots to make decisions in a complex environment and to integrate their knowledge from prior experiences into new situations. Pilots are often asked to assess new situations (e.g., unexpected weather forecasts) quickly so they can make a decision to initiate or cancel their flight. Wiggins et al. (2004) support the report that the preflight phase provides a useful environment to examine human performance through the complexity of the tasks, the requirement to make decisions under time pressure with a high degree of uncertainty, and the associated risk of choosing the wrong option that may lead to an accident.

Wiggins et al. (2004) examined differences between expert and novice pilots during the preflight phase and found that experts use less weather-related resources but more accurate weather resources to make decisions than non-experts. Non-expert pilots used many weather-related resources that were not necessary to the information that they were seeking. Wiggins et al. (2004) is an appropriate illustration of how the information they gained about expert decision making and flight performance could be well-captured through a scenario-based assessment.

Chapter 3 also discussed how a scenario-based assessment tests the learner from a hypothetical story that requires the tester to work through a complex problem or system and allows the tester to be immersed in the mindset of the situation that he/she is working through (Miller, 1990) and the scenario-based assessment provides the test taker with understanding, remembering from experience, and motivation. This applies to aviation in that a scenario-based assessment could assess the student pilot on weather-related tasks from preflight through landing. Using the Cruit and Blickensderfer (2015) aviation weather task analysis, a scenario-based assessment could provide the student pilot with a typical weather scenario that incorporates all of the tasks in a GA flight. The scenario-based assessment would measure the student pilot on the knowledge and skills for each weather-related task. As the complexity of the scenario increases, student pilots can build the knowledge from each question, and apply what they know and remember to other questions. Traditional written tests fail to capture motivation from the learner since the questions do not follow a single scenario and do not require the learner to become immersed in the outcome of the questions. (Wise and DeMars, 2005; Baldwin, Magjuka, Loher, 1991). Therefore, to fully capture the level of GA expertise and then to predict

flight performance, we are advocating a scenario-based assessment strategy to assess GA pilots' weather knowledge and skills.

4.2 Purpose of the Study

Weather-related accidents continue to plague the general aviation community and with the development of advanced weather technology, GA pilots need additional education and training on how to effectively use these weather products to ensure flight safety. Currently, the literature on aviation weather suggests that there is a gap in both training and assessment strategy for GA pilots. Furthermore, several studies suggest that there needs to be more assessment of weather-related scenario/application questions for the private pilot's written knowledge exam in order to assess a deeper level of knowledge for weather-related material. Therefore, the purpose of this study is to design a scenario-based exam that assesses GA pilots' weather knowledge and then to determine whether the scenario-based exam better predicts GA pilot performance in a simulated weather scenario than a traditional weather-related exam.

4.3 Theoretical Model

The literature on the lack of weather-related training and poor assessment strategies for GA pilots suggests that there is variability in weather knowledge and skills among GA pilots. Since the majority of pilots taking the Airmen's Knowledge written exam pass the exam without being required to understand weather-related concepts (Wiegmann, Talleur, and Johnson, 2008), the current assessment strategy for measuring GA pilots' knowledge and skills on the written exam might not capture knowledge as effectively as a weather-related scenario-based exam. After examining the literature on

scenario-based assessment and describing the study's variables, a theoretical model (See Figure 5) was built to hypothesize the relationships between and among variables. As seen from the model in Figure 5, there are eight study hypotheses. First, it is hypothesized that there is a non-significant, positive relationship between the *traditional weather assessment* and *weather salience*. The *traditional weather assessment* consists of multiple-choice questions that only assess a students' knowledge at the rote level of learning. This means that students can memorize the factual based questions and do not have to understand the concepts or even apply those concepts to real world scenarios. Since one's score on the traditional weather assessment should not represent how much they actually know about aviation weather, we expect that there should be a non-significant relationship between one's scores on the traditional weather assessment and how much the extent to which they value weather, which is measured by the *Weather Salience Questionnaire*.

The second hypothesis is that there is a non-significant, positive relationship between scores on the *traditional aviation weather assessment* and *aviation experience scores*. When assessing experts on applied, practical exams, Ericsson and Lehmann (1996) and de Groot (1978) found that those participants with more experience performed better than those with less experience. The *traditional weather assessment* consists of multiple-choice questions that only assess a students' knowledge at the rote level of learning. This means that students can memorize the factual based questions and do not have to understand the concepts or even apply those concepts to real world scenarios. Regardless of how much aviation weather experience a pilot has, all students are expected to score high on the traditional weather assessment. If students have varying

levels of weather expertise, it should not be reflected in their scores on the traditional weather assessment.

The third hypothesis is that there is a positive relationship between aviation weather experience and scores on the *Weather Salience Questionnaire*. The *Weather Salience Questionnaire* assesses the extent to which weather and climate are important in different aspects of people's lives (Stewart, 2005). Stewart (2005) suggests that individuals differ in how they perceive various weather and climate situations and that the degree of weather salience one holds could affect emotional responses and decision-making around weather-related events. The *Weather Salience Questionnaire* addresses one's past experience with weather-related events and explains how those with more weather experience also have a higher degree of weather salience (Grothmann and Reussweig 2006; Stewart, 2005). Additionally, one's degree of weather salience can also affect the way people use and seek out weather information (Stewart, 2005). Therefore, if GA pilots have more weather-related experience, their level of weather salience should also increase.

The fourth study hypothesis is that there is a significant, positive relationship between *aviation weather experience* and *aviation weather performance*. As one's level of aviation experience increases, so should their performance on an *aviation weather performance* measure in a simulator.

The fifth study hypothesis is that there is a significant, positive relationship between one's score on the *scenario-based weather assessment* and one's score on the *Weather Salience Questionnaire*. Since there is evidence that a scenario-based test captures a better representation of one's actual knowledge, scores on the

scenario-based weather assessment positively relate to scores on the *Weather Saliency Questionnaire*. This means that pilots who value weather to a higher degree and are highly motivated by weather should score higher on the *scenario-based weather assessment*. As GA pilots place more value on weather and weather-related events (weather saliency), they are motivated to think through complex weather scenarios. One characteristic of scenario-based assessment is that the scenario event motivates the test-taker through the complexity of the scenario (Kaner, 2003). The test-taker is motivated throughout the scenario from prior experience with weather-related events. If the GA pilot has a high degree of weather saliency, they could be more motivated to think through the scenarios and the scores on the scenario-based assessment should reflect one's score on the *Weather Saliency Questionnaire*.

The sixth study hypothesis is that there is a positive relationship between the amount of *aviation weather experience* and scores on the *scenario-based assessment*. Both the *scenario-based assessment* and the *aviation weather performance* measure are designed to capture variability in GA pilots' weather knowledge and skills. Therefore, those GA pilots who have low weather knowledge should score low on the *scenario-based assessment* and the *aviation weather performance* measure. In return, those GA pilots who have high aviation weather knowledge should first score high on the *scenario-based assessment* and also score high on the *aviation weather performance* measure.

The seventh study hypothesis is that the relationship between the traditional weather assessment and aviation weather performance is fully mediated by both *weather saliency* and *aviation weather experience*. The *traditional weather assessment* is not scenario-based and consists of items devoid of context and it is written largely at the rote

level. Further, the *traditional weather assessment* does not produce much variability in GA pilots' scores (Wiegmann, Talleur, and Johnson; NTSB, 2005; Lanicci, 2011). A GA pilot who scores high on the traditional weather assessment does not necessarily contain a high level of aviation weather-related expertise to perform well on the aviation weather performance measure. Therefore, any relationship between the *traditional weather assessment* and the *aviation weather performance measure* is fully mediated by scores on the *weather salience* measure and one's level of *aviation weather experience*. This is saying that *weather salience* and *aviation weather experience* are stronger predictors of *aviation weather performance* when they are added to the model with the *traditional weather assessment*.

Finally, the eighth study hypothesis is that the relationship between the *scenario-based assessment* and the *aviation weather performance measure* is partially mediated by one's level of *aviation weather experience* and scores on the *weather salience assessment*. Since there is evidence that a scenario-based assessment can predict future performance (Sidi, Berkenstadt, Ziv, Euliano, and Lampotang, 2014; Meterissian, 2006), scores on the *scenario-based assessment* should positively correlate with a weather performance measure (*aviation weather performance measure*). Furthermore, it is predicted that part of the variance in *aviation weather performance* is not only explained by the *scenario-based weather assessment*, but *aviation weather experience* and *weather salience* partially mediate this relationship. This means that when *weather salience* and *aviation weather experience* are added to the model, those measures partially explain the variance in *aviation weather performance*.

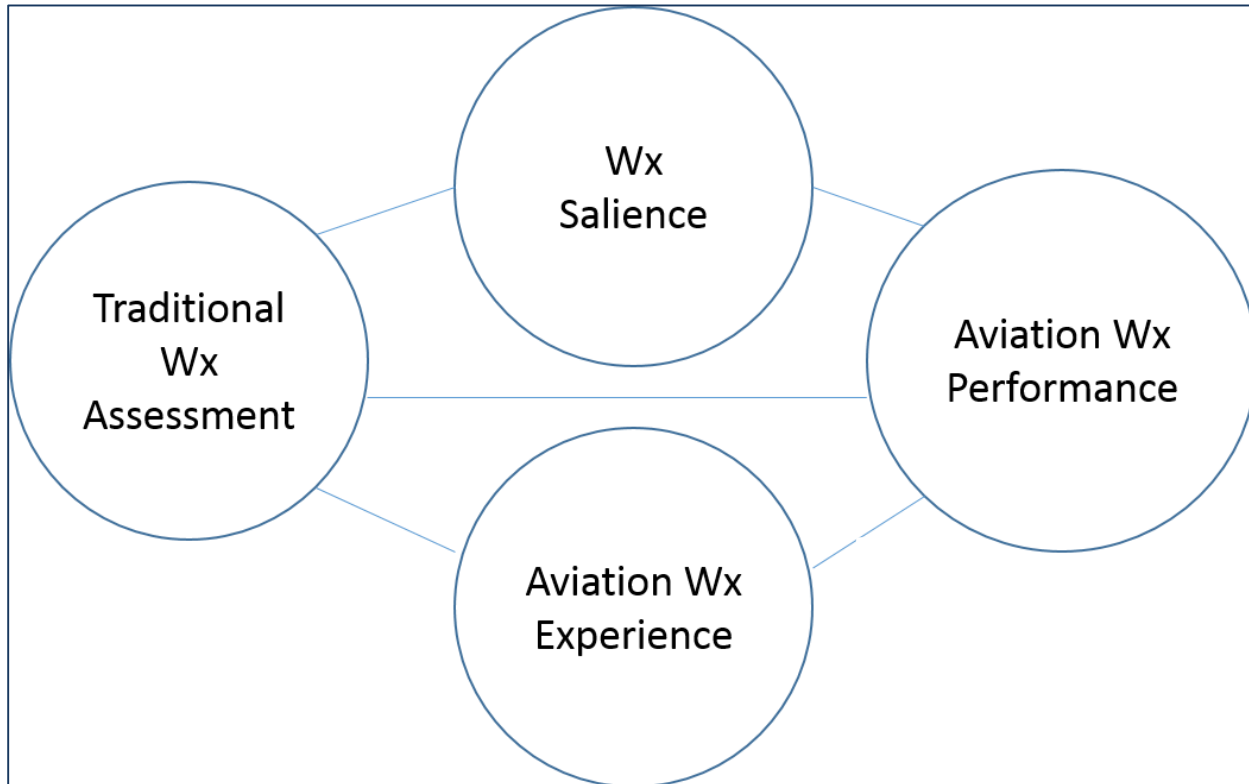


Figure 5. Theoretical model hypothesizing relationships of the variables

4.4 Statement of Hypotheses

Table 4

Statement of Hypotheses

Hypothesis	Statement
1	There is a non-significant, positive relationship between Traditional Wx Assessment and Wx Salience.
2	There is a non-significant, positive relationship between Traditional Wx Assessment and Aviation Wx Experience.

-
- 3 There is a significant, positive relationship between Aviation Wx Experience and Wx Salience.
 - 4 There is a significant, positive relationship between Aviation Wx Experience and Aviation Wx Performance.
 - 5 There is a significant, positive relationship between Scenario-Based Assessment and Wx Salience.
 - 6 There is a significant, positive relationship between Scenario-Based Assessment and Aviation Wx Experience
 - 7 The relationship between the Traditional Wx Assessment and Aviation Wx Performance is fully mediated by both Wx Salience and Aviation Wx Experience.
 - 8 The relationship between the Scenario-Based Assessment is partially mediated by both Wx Salience and Aviation Wx Experience.
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Chapter 5: Method



5.1 Design

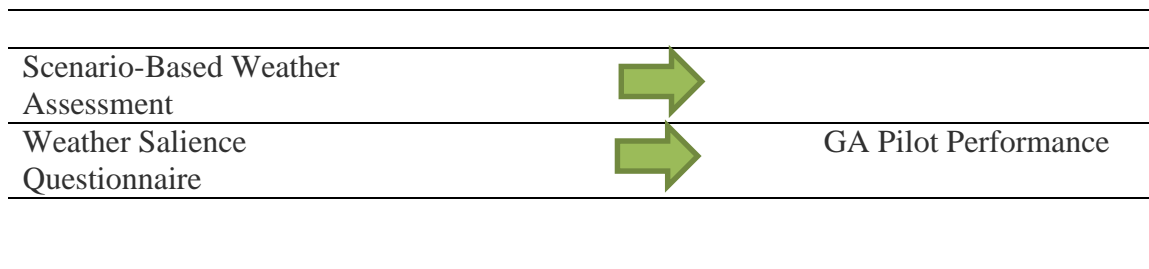
The current study used a predictive correlational, quasi-experimental design with four independent variables (i.e., *aviation weather experience*, *weather saliency*, *traditional weather-related assessment scores*, and *scenario-based weather assessment scores*) and one dependent variable (i.e., *aviation weather performance*). The purpose of this type of design is to establish what types of relationships exist among the variables;

however, there is no manipulation of the independent variables. A multiple regression analysis will be used to predict scores on the dependent variable, *aviation weather-related performance*, based on the values of *weather salience*, *aviation weather experience*, the *scenario-based weather assessment* and the *traditional weather assessment* (See Table 4 for independent and dependent variables). Furthermore, all participants in this study will complete all measures, and therefore, there is no random assignment to different groups. A deeper description of the experimental protocol is explained in the section, *Procedure*.

Table 4:

Table of Independent and Dependent Variables

Independent Variables	Predict	Dependent Variable
Aviation Weather Experience		GA Pilot Performance
Traditional Aviation Weather Assessment		GA Pilot Performance



5.2 Setting and Apparatus

The current study took place in the Simulation Center at Embry-Riddle Aeronautical University. The experimentation room held a desktop table along with a PC-based flight simulator station. Participants completed all independent measures using a PC through SurveyMonkey.com and completed the aviation weather-related performance measure in the flight simulator station.

Flight Simulator Station. The flight simulator station was equipped with a PC-based desktop along with a computer monitor. The flight simulation also included a yoke, throttle, and rudder pedals.

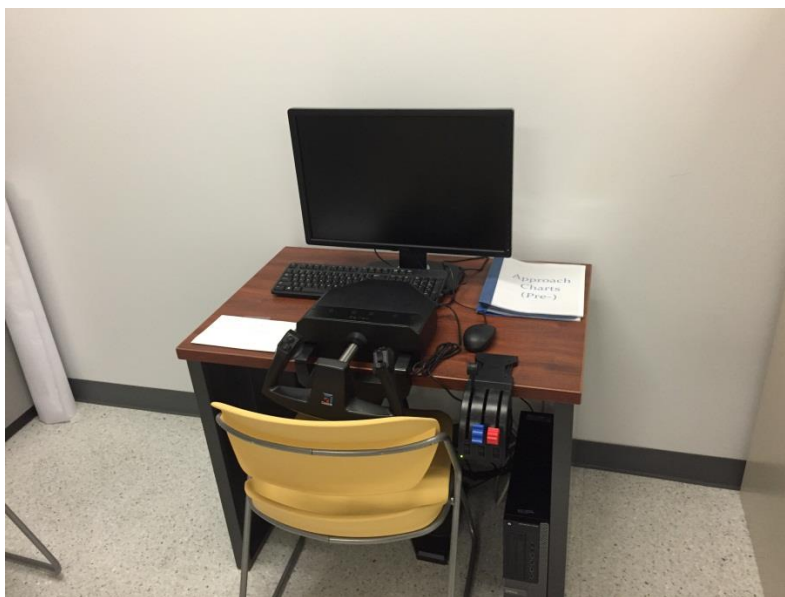


Figure 6. Lab desktop flight simulator

Simulation Software. For the *aviation weather-related performance measure*, we used Lockheed Martin's Prepar3D simulation software (www.Prepa3D.com).

Prepar3D is training-based flight simulator that allows the user to create a variety of aviation scenarios. For purposes of this study, we used a weather scenario with the Cessna 172 aircraft (this aircraft represents the aircraft that most of our participants will be flying during their flight training).

5.3 Participants

This study included a total of 90 GA pilots from a local flight school. Since the current study used a multiple regression analysis to predict GA pilot weather performance from *aviation weather experience*, scores on a *scenario-based assessment*, scores on a *traditional assessment*, and scores on the *Weather Salience Questionnaire*, we determined the number of participants through 50 participants + 8 participants for every independent variable (Tabachnick & Fidell, 2001). To be eligible to participate in this study, pilots had completed the necessary ground school education enabling them to take the written exam to obtain a private pilot's certificate. This is consistent with the FAA requirements for private pilots-in-training to be eligible to take the Airmen's Knowledge exam (FAA, 2015).

5.4 Measures

This section explains the measures of each independent variable and dependent variable as well as the human raters used to score the aviation weather performance

measure. Each variable is described and operationalized and there is a detailed summary of each questionnaire that was used in the study.

Measures of Independent Variables

5.4.1 Aviation Weather Expertise. To capture variance in GA pilots' weather expertise, we define aviation weather expertise by how many hours participants have taken from a meteorology course taken as well as how many flight hours flown. Although this method does not necessarily categorize different levels of expertise, it does help differentiate among GA pilots with various levels of weather training experience. Furthermore, although the amount of flight hours does not guarantee aviation weather expertise, it is assumed that there is a positive relationship between overall aviation experience and flight hours. That is, as flight hours increase, one's overall flying experience increases. Pilots who have only taken ground school training from a non-Embry-Riddle Aeronautical University or AS 121 will be labeled as having three hours of weather course training. The course, AS 121—Private Pilot Operations, is a course that prepares pilots-in-training to take the exam that certifies them to become a private pilot. Topics include, cross country training, pre-solo operations, chart use, communications, weight and balance, aerodynamics, regulations, decision-making, and weather. Although some weather topics are included in the course, weather is not the primary focus of the course.

The second meteorology class available for pilots is called, Wx 201—Survey of Meteorology. This is a survey course in atmospheric conditions including topics such as thermal patterns, atmospheric moisture, horizontal and vertical pressure patterns, clouds,

atmospheric circulation, local winds, stability, air masses, fronts, fog, icing, thunderstorms, jet streams, and turbulence. In the course, students will use surface weather observations, surface maps, and constant pressure maps. Although the course includes topics in meteorology, the course integrates the weather topics with applications to flight.

The third and highest course available includes those student pilots who have completed Wx 301—Aviation Weather. This course was designed to be an extension of the topics included in Wx 201 and focuses on aviation weather hazards. These hazards include convective weather hazards (e.g., thunderstorms, hail, high winds), non-convective weather hazards (e.g., fog, icing, turbulence, wind shear, winter weather. The other topics this course includes are pressure, atmospheric forces, thickness, thermal winds, fronts, jet streams, cyclone formation, and atmospheric stability. Students are taught how to navigate through different online sources of weather products and how to obtain and analyze real time surface observations, upper air observations, satellite data, and radar data. The course also includes lab exercises that provide practical examples on gaining experience in making informed weather-sensitive decisions. Each of these three courses contains various amounts of meteorological concepts; therefore, it is assumed that the level of student pilots' knowledge will reflect the level of the highest course completed. Participants' flight hours will be added to the hours taken from their meteorology classes to create a combined score of *aviation weather experience*. For example, a pilot who has completed Wx 201 and has accumulated 200 flight hours, will receive a total score of 219 (200 + 16 hours from Wx 201 + 3 hours of ground school).

These scores will be used as the independent variable, *aviation weather experience*, in the regression model.

5.4.2 Weather Salience Questionnaire. The Weather Salience Questionnaire (WxSQ) is a 29-item survey that assesses the extent to which weather and climate are important in different aspects of people's lives (Stewart, 2005). Stewart (2005) suggests that individuals differ in how they perceive various weather and climate situations and that the degree of weather salience one holds could affect emotional responses and decision-making around weather-related events. One's degree of weather salience can also affect the way people use and seek out weather information (2005). Stewart et al. (2012) sampled 1465 individuals from around the United States and looked at the relationship between their scores on the Weather Salience Questionnaire and their climate zone of residence along with their weather-related attitudes and behaviors. Stewart et al. (2012) found that one's level of weather salience was positively related to the frequency these individuals sought out weather information from news reports, or online weather services. Additionally, Stewart et al. (2005) found there to be a positive relationship between one's weather salience and how frequently individuals sought weather information throughout the day, a positive relationship between one's weather salience and the frequency of how individuals used weather forecasts to plan activities, a positive relationship between one's weather salience and how they seek out weather information for geographic locations outside of their own location, a positive relationship between one's weather salience and their use of precipitation and temperature forecasts, and finally, a positive relationship between one's weather salience and one's confidence in

the National Weather Service forecast and how individuals perceived the importance of these forecasts.

The purpose of using the WxSQ for the current study was to examine the relationship between GA pilots' weather salience and their aviation weather expertise and GA pilots' weather salience and their scores on a weather-related *scenario-based assessment*. As previously mentioned, GA pilots have challenges using and interpreting some of the modern aviation weather technology along with seeking out additional weather information throughout their flight. We expected to see a positive relationship between GA pilots' *weather salience* and *aviation weather expertise* as well as a positive relationship between GA pilots' weather salience and their scores on the weather-related scenario-based assessment.

Item Content. The 29-items on the WxSQ are divided into seven content areas including, 1) People's weather/climate seeking behaviors, 2) The extent to which weather and climate affects their mood, 3) Their behaviors of sensing and experiencing the atmosphere directly, 4) Their attachment to particular weather conditions, 5) Their needs to experience changes in a variety of weather conditions, 6) The effects of weather on their activities of daily life, and 7) Interest in weather during the possibility during a weather-related holiday. See Table 6 for Cronbach's Alpha coefficients with each of the seven content areas. Overall, the 29-item questionnaire yielded an alpha coefficient of .83, indicating high internal reliability and that all items functioned together to assess the concept of weather salience. Cronbach's coefficient alpha provides an estimate of the internal reliability of the items and the extent to which they consistently assess the construct of weather salience.

Scoring. Stewart (2005) created a 5-point rating scale to score each of the 29-items. Some of the items indicated a frequency of weather-related behaviors (1 = Never through 5 = Always) and then the other items indicated a degree of agreement (1 = Strongly Disagree through 5 = Strongly Agree). See Appendix B for a list of the actual questions on the Weather Salience Questionnaire.

5.4.3 Traditional Weather-Related Assessment. The *traditional weather-related assessment* is based on the FAA Airmen's Knowledge exam (Recreational Pilot and Private Pilot version). The FAA Airmen's Knowledge exam for private pilots states that all test questions are objective, multiple choice questions that are independent of one another, meaning that no question or response to a question will influence the answers to other questions (FAA, 2015). The traditional weather-related assessment for this study contains 21 multiple-choice questions that were selected from the Gleim® testing software for private pilots. The 21 questions were selected based on the Cruik and Blickensderfer (2015) aviation weather task analysis, which includes weather topics from preflight to landing, including a selection of weather phenomenology, weather products, and weather product sources. The question content in the traditional-based assessment was selected to match the question content in the scenario-based weather assessment. To obtain questions for the traditional-based assessment, the researcher logged into the Gleim® software test bank and selected, "private pilot." Then the researcher chose to only view "aviation weather" questions, producing a total of 167 randomly generated questions. Then, the researcher selected questions that contained an equal amount of weather phenomenology, weather products, and weather product sources. These questions were then approved by subject matter experts.

5.4.4 Scenario-Based Weather Assessment. The scenario-based weather assessment is a 20-question exam that was developed using the Cruik and Blickensderfer (2015) GA weather task analysis. This scenario-based exam assesses the GA pilot's ability to think through a scenario and apply their knowledge of aviation weather to solve for the best answer to the question. The 20-question assessment is designed to replicate chronologically, the steps a pilot would take to solve a variety of weather-related tasks during any given flight (preflight-landing phases of flight). The rationale for choosing 21 items to assess pilots' weather knowledge is based on the weather task analysis. It takes approximately 21 questions to provide a thorough assessment of weather-related tasks from preflight through landing. The researchers were also cognizant of the possibility of test-taker fatigue and wanted to avoid overloading the participants with questions that could degrade performance. The goal of the scenario-based test is to draw from a larger pool of pilots' weather-based knowledge, through utilizing scenario-based questions, in order to determine whether a scenario-based exam could better predict GA pilot performance over a traditional, multiple-choice test.

The scenario-based exam is scored using a ranking system for each answer choice. While some questions will only have one correct answer, other questions will ask the pilot to rank the answer choices from best to worst. For example, a question uses a scenario centered on the pilot having to make a decision to either 1) fly through deteriorating weather, 2) turn around and head back to original airport, or 3) land at an alternate airport. Answer choices 2 & 3 are both correct, however, in this particular scenario, it is better to land at an alternate airport rather than going back to the original airport. It is important to note that all questions on the scenario-based exam were

validated with subject matter experts, which included flight instructors and meteorologists.

Measure of Dependent Variable

5.4.5 Weather-Related Aviation Performance. Will scores on a scenario-based written assessment better predict actual aviation weather performance than scores on a traditional multiple-choice assessment? During a typical GA Checkride, student pilots are assessed by a flight instructor on various task requirements. Some of these tasks include the pilots' ability to perform during weather scenarios. However, since weather is variable, student pilots often lack a comprehensive assessment of weather-related tasks from preflight-landing phases of the flight. For this reason, the researchers decided to develop a standard, simulated aviation weather performance measure that could be used to assess how well GA pilots performed weather-related tasks during flight. The weather-related aviation weather simulated performance measure was developed to assess private pilots' aviation weather knowledge on multiple weather-related tasks from preflight through landing. The aviation weather performance simulation is divided into two phases: 1) An oral assessment, which simulates aviation weather tasks of the preflight phase of flight and 2) A flight simulation exercise simulating aviation weather tasks from the taxi phase of flight through the landing phase.

Drawing from the Cruik and Blickensderfer (2015) GA aviation weather tasks analysis, as well as the various literature and documents on rules and regulations for preflight and inflight phases, researchers designed the GA weather simulated

- Icing and Freezing Level Information
 FA
 Surface Analysis Chart
 Radar Summary Chart
 Winds and Temperature Aloft Chart
 Significant Weather Prognostic Chart
 Convective Outlook Chart
 SIGMET
 AIRMET

TAF

Total Points (out of 13 points)_____

Taxi Scenario 2

Scenario 2 simulates a taxi phase of flight where participants would normally be able to look out the window to gather weather information. In the following scenarios, participants will be given three pictures of different cloud types. Participants are required to identify the type of cloud, state the cloud height, describe the associated weather pattern with this type of cloud, and the implications of the cloud for flight.

Directions: Researcher: The researcher gives the participant different pictures of cloud types. Does the participant correctly identify the 1) cloud type, 2) cloud height, 3) associated weather pattern with this cloud type, 4) Implication of cloud for flight?

*Trigger Event 1***Picture 1: Altocumulus Cloud**

- 1) Participant correctly identifies cloud____
- 2) Participant states this is a **middle level cloud**____
- 3) Participant states that this cloud usually indicates **thunderstorms in the afternoon**____
- 4) Participant states that this cloud may impact their return flight if they are planning on returning in the afternoon____ **Turbulence**____ **Icing**____ **Other**____

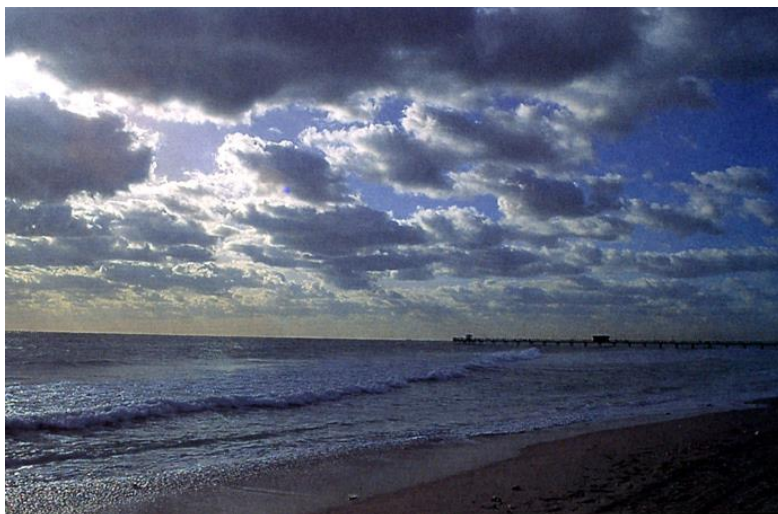
Total Points (out of 6)_____

*Trigger Event 2***Picture 2: Cirrocumulus**



- 1) Participant correctly identifies cloud____
 - 2) Participant states that this is a **high level cloud**____
 - 3) Participant states that this cloud usually indicates **Fair weather**____ **Cold weather**____
 - 4) Participant states that these clouds imply **Icing**____ **Turbulence**____ **Other**____
- Total Points** (out of 6)_____

Picture 3: Stratocumulus



- 1) Participant correctly identifies cloud___
- 2) Participant states that this is a low cloud___
- 3) Participant states that this cloud usually indicates light precipitation___
- 4) Participant states that these clouds imply **low ceiling**___ **low visibility**___ **icing**___
turbulence___

Other___

Total Points (out of 7)_____

Grand Total (out of 19)_____

Scenario 3: Evaluate Weather Information to Make a Weather Plan

Researcher says to participant: I would like for you to imagine that you are following regular preflight procedures to plan a cross country flight from Cross City, Florida to Palatka, Florida. Based on the information provided to you during preflight what decision would you make about going on your flight?

- 1) Participant decides to go (1pt)___
- 2) Participant decides not to go (1pt)___

- 3) Participant decides to go but plans alternate airports to land at if weather deteriorates (3pts)_____
- 4) How many alternate airports does the participant choose (4 pts max)_____
- 5) The participant establishes weather checkpoints along the flight to reevaluate deteriorating weather (yes or no)_____
- 6) The participant plans for how low they can go in altitude to avoid terrain along their flight if they are flying below ceiling (yes or no)_____

Scenario 4: Enroute Phase

Trigger Event 1:

1) Researcher says to participant: If you have the appropriate technology, what inflight weather services are available to you? Check all that participant says.

____HIWAS

____En Route Flight Advisory Service

____ADS-B

____EWINS

____ATC

_____Points (Total of 5 Points)

Enroute: Trigger Event 2

During the flight simulation, the weather will start to deteriorate 8 minutes into the flight. The researcher has explained that they can only communicate with someone from a 2-way radio service like ATC or En Route Flight Advisory Service.

- 1) The participant communicates with a 2-way radio service to check the weather _____; then lands at an alternate airport_____
- 2) The participant flies through bad weather (0points)_____

_____Points (2pts total)

_____Grand Total (7pts)

Scenario 5: Descent/Landing Phase

- 1) What is the best source to obtain information about winds? Participant says ASOS/AWOS (1pt)_____
- 2) The participant contacts ATC (1pt)_____
- 3) If ATC advises vertical low level wind shear, what effect does this have on the aircraft?

_____The change in the velocity alters lift (1pt)

_____alters indicated airspeed (1pt)

_____alters thrust requirements (1pt)

_____altitude can exceed the pilot's capability to recover (1pt)

____Points (6 points total)

Participants can score a total of 76 points for entire assessment: _____ out of 76 = _____%

Human Raters Three human factors professionals were used to rate the items on the *Weather-Related Aviation Performance* measure. Each rater was first trained on the *Weather-Related Aviation Performance* evaluation tool by the primary researcher. Before independently coding GA pilots' performance, the raters jointly analyzed a sample of 5 participants to establish a thorough understanding of the evaluation tool. After the joint rating session, the data from the 5 participants were replaced in the original 90-sample dataset and then each rater watched 30 videotaped performances of the GA pilots in the simulator and independently rated the GA pilots' weather-related performance. To determine consistency between the coders, an inter-rater reliability analysis was performed on Rates A and B and Raters A and C.

5.5 Procedure

After participants were sampled, researchers scheduled participants to come to the Simulation Center one at a time to take part in the current study. Once participants arrived, the participant was handed the informed consent, which explained the purpose of the study. Since there is no deception in the current study, participants were told that they were being assessed on their aviation weather knowledge and skills and to perform at their best. The researchers were interested in capturing the participants' true level of

weather knowledge so it was important to inform the participants to do their best on all measures. Participants were informed that they would be completing a demographic questionnaire, followed by the Weather Salience Questionnaire, followed by a 21-item, weather-related, traditional, multiple choice written assessment, followed by a 21-item, weather-related, written scenario-based assessment, followed by a 30 minute aviation weather-related performance measure in a simulator. The researchers explained to the participants that the entire procedure would take approximately 1.5 hours to complete. Additionally, participants were informed that all information collected from the study would be kept confidential and video recordings of the aviation weather-related performance would be deleted after analysis.

Once the participants signed the informed consent, they were given an assessment packet that included the demographic form, the *Weather Salience Questionnaire*, the *traditional weather-related assessment*, and the *scenario-based assessment*. After completing this packet, participants moved into the next phase which consisted of the *aviation weather-related performance* measure. This phase was videotaped so that additional raters could evaluate the participants' performance.

The *aviation weather-related performance* measure consisted of two parts; the oral, and the flight simulation. First, the researcher administered an oral, weather-related exam, which consisted of the participants planning a cross country flight. The participants were given a flight packet which included maps, charts, and weather products. The researcher asked a series of weather-related questions that coincided with the *aviation weather-related performance* evaluation tool. The oral exam lasted approximately 15 minutes. Upon completion of the oral exam, the participants moved to the flight

simulator. The participants were given a brief overview of how to use the flight simulator. Afterward, participants were told that they would need to fly from Cross City, Florida to Palatka, Florida. Participants were given a weather report stating that the weather conditions were fair at the airport of origin and the destination airport. Along the flight, the participants were asked a series of questions that coincided with the aviation weather-performance evaluation tool. The duration of the flight was 20 minutes.

Finally, participants completed a debriefing which consisted of the researchers explaining that this study involved assessing their aviation weather knowledge and skills through both written assessments and a performance task. Researchers reminded participants that all information gathered throughout the study would be kept confidential and also asked the participants if they had any further questions. At the very end, participants were given \$25.00 compensation for their time.

Chapter 6: Results

This section is divided up into several different categories that explain the results of the analyses. First, there is an explanation of the results of each independent variable (i.e., Aviation Weather Experience, Weather Salience, Traditional Weather Assessment, and Scenario-Based Weather Assessment). Second, there is an explanation of the results from the multiple regression analysis testing both hypothesized theoretical models. Third, there is an explanation of the results from counterbalancing the order in which the participants took the scenario-based assessment and the traditional assessment.

6.1 Aviation Weather Experience

From the sample of 90 student pilots, the *aviation weather experience* scores ranged from 6-364. Recall that an aviation weather experience score is equal to one's flight hours plus hours spent in weather courses. The aviation weather experience scores were divided up into quartiles and Table 6 displays the four different groups of aviation weather experience based on percentile along with the means and standard deviations for each percentile. The total mean *aviation weather experience* score yielded, $M = 189.81$, $SD = 105.98$.

Table 6
Percentile, Means, and Standard Deviations for Aviation Weather Experience Scores

	Percentile	N	M	SD
1	0-25	20	39.35	32.85
2	26-50	25	150.84	30.51
3	51-75	23	236.78	30.77
4	76-100	22	321.77	23.27
		Total	Total	Total
		90	189.81	105.98

Group differences in experience. A One-Way Analysis of Variance (ANOVA) was used to determine if differences exist among the different groups of *aviation weather experience*. A One-Way ANOVA was also used to analyze whether there were any group differences in experience on the *traditional aviation weather assessment*, the *scenario-based weather assessment*, the *weather salience questionnaire*, and the *aviation weather performance measure*. Table 7 displays the results of the One-Way ANOVAs for each of those measures. The results show a significant difference among the four groups of experience on the measures of *aviation weather experience*, the *scenario-based weather assessment*, and *aviation weather performance*.

Table 7
Results of the ANOVA on Experience Level Group Differences by Measure

Measure	df	F	p
Aviation Wx Experience *	89	353.09	≤ .01
Wx Salience	89	1.06	.394
Traditional Wx Assessment	89	1.01	.393
Scenario-Based Wx Assessment *	89	5.12	≤ .01
Aviation Wx Performance *	89	4.28	≤ .01

Note: * indicates that there was a significant difference among different groups of experience.

Post-hoc comparisons using Tukey's HSD examined where group differences exist on the measures of *aviation weather experience*, the *scenario-based weather assessment*, and *aviation weather performance*. Tukey HSD revealed significant differences between Group 1 and Group 2 (i.e., Group 2 scores were higher than Group 1), Group 1 and Group 3 (i.e., Group 3 scores were higher than Group 1), Group 1 and Group 4 (i.e., Group 4 scores were higher than Group 1), Group 2 and Group 3 (i.e., Group 3 scores were higher than Group 2), Group 2 and Group 4 (i.e., Group 4 scores were higher than Group 2), and Group 3 and Group 4 (i.e., Group 4 scores were higher than Group 3). Second, the results of the Tukey HSD on the *scenario-based weather assessment* revealed significant differences between Group 1 and Group 2 (i.e., Group 2 scores were higher than Group 1), Group 1 and Group 3 (i.e., Group 3 scores were

higher than Group 1), and Group 1 and Group 4 (i.e., Group 4 scores were higher than Group 1). Third, the Tukey post-hoc comparison revealed that there were significant differences between Group 1 and Group 3 (i.e., Group 3 scores were higher than Group 1) as well as Group 1 and Group 4 (i.e., Group 4 scores were higher than Group 1) on *aviation weather performance*. In summary, these results indicate that the higher experienced groups performed significantly better than the lower experienced groups on the *scenario-based assessment* and the *aviation weather performance measure*.

The relationship between experience and other measures. The relationship between *aviation weather experience* and scores on the *weather salience questionnaire*, *traditional weather assessment*, *scenario-based weather assessment*, and *aviation weather performance* measure were analyzed using Pearson's Correlation. First, it was hypothesized that there was a positive, significant relationship between *aviation weather experience* scores and scores on the *weather salience questionnaire*. However, there was a non-significant, positive relationship between *aviation weather experience* scores and scores on the *weather salience questionnaire*, $r(89) = .09, p > .05$. Second, it was hypothesized that there was a positive, non-significant relationship between *aviation weather experience* scores and scores on the *traditional weather assessment*. However, there was a significant, negative relationship between *aviation weather experience scores* and scores on the *traditional weather assessment*, $r(89) = -.22, p \leq .05$. Third, it was hypothesized that there was a significant, positive relationship between *aviation weather experience* scores and scores on the *scenario-based weather assessment* and this hypothesis was validated by the results of the Pearson's Correlation, $r(89) = .39, p \leq .01$. Fourth, it was hypothesized that there was a significant, positive relationship between

scores on aviation *weather experience* and scores on the *aviation weather performance* measure. The results of Pearson's Correlation validated this hypothesis, $r(89) = .36, p \leq .01$. Table 8 shows a summary correlation matrix with all variables.

Table 8

Correlation Matrix of Variables

Variable	Traditional	Scenario-Based	Experience	Weather Saliency	Performance
Traditional Wx Assessment	1	-.13	-.22*	.03	.05
Scenario-Based Wx Assessment	-.13	1	.39**	.26*	.74**
Aviation Wx Experience	-.22*	.39**	1	.17	.36**
Weather Saliency	.03	.26*	.17	1	.18
Aviation Wx Performance	.05	.74**	.36**	.18	1

**Correlation significant at the .01 level

*Correlation significant at the .05 level

6.2 Weather Saliency

The Weather Saliency scores from the sample of 90 ERAU student pilots yielded below average results ($M = 97.07, SD = 16.25$). Average scores for the general population ($N = 1465$) taking the Weather Saliency Questionnaire (Stewart, 2005) were higher ($M = 114.38$) than ERAU students. Thropp, Lanicci, Cruitt, Guinn & Blickensderfer (2015) sampled 80 ERAU pilots and found similar results ($M = 72.77$).

Cronbach's Alpha for the sample of 90 student pilots was low ($\alpha = .63$). Table 9 displays the results of the Weather Salience Questionnaire subscales compared to the results from previous studies using the Weather Salience Questionnaire (Stewart, 2005; Thropp et al., 2015). As shown from the table, the current sample ($N = 90$) scored below average on each of the subscales.

Table 9

Results of the Weather Salience Questionnaire Subscales

	Attention to Wx	Observe wx Directly	Effects on Daily Mood	Effects on Daily Activities	Attachment to Wx	Need for wx Variability	Attention to wx for a Holiday
	M	M	M	M	M	M	M
Current Study ($N = 90$)	22.03	8.81	15.12	6.97	7.07	7.28	6.21
Student Pilots ($N = 80$) (Thropp et al., 2015).	24.99	8.53	17.91	8.04	8.03	9.61	5.76
General Population ($N =$ 1465)	30.93	17.99	22.64	7.82	10.18	15.97	8.86

The relationship between weather salience and other measures. Pearson's Correlation analysis examined the relationship between *weather salience* and scores on the *traditional assessment*, scores on the *scenario-based assessment*, and scores on the *aviation weather performance* measure. The results of the analysis revealed a non-significant, positive relationship between *weather salience* and scores on the *traditional weather assessment*, $r(89) = .02, p > .05$; a significant, positive relationship between

scores on the *weather salience questionnaire* and scores on the *scenario-based assessment*, $r(89) = .26, p \leq .01$; a non-significant, positive relationship between *weather salience* and scores on the *aviation performance measure*, $r(89) = .18, p > .05$.

6.3 Traditional Weather Assessment

Table 10 displays descriptive statistics of the 90 participants who completed the *traditional weather assessment*. As shown in the table, the average score on this assessment was high ($M = 82.86$). Scores on the Traditional Weather Assessment ranged from 57%-100%.

Table 10

Mean, Mode, and Standard Deviation for the Traditional Weather Assessment

<i>N</i>	<i>M</i>	<i>MO</i>	<i>SD</i>
90	82.86	100	12.23

The relationship between the traditional weather assessment and other measures. The relationships between the *traditional weather assessment*, the *weather salience questionnaire*, and the *aviation weather performance* measure were analyzed using Pearson's Correlation. First, it was hypothesized that there would be a non-significant, positive relationship between scores on the *traditional weather assessment* and scores on the *weather salience questionnaire*. The results of Pearson's Correlation

supported this hypothesis, $r(89) = .025, p > .05$. Second, it was hypothesized that there was a non-significant, positive relationship between scores on the *traditional assessment* and scores on the *aviation weather performance measure*. The results of Pearson's Correlation support this hypothesis, $r(89) = .048, p > .05$.

6.4 Scenario-Based Weather Assessment

Table 11 shows the results of descriptive statistics for the 90 participants taking the scenario-based weather assessment. As shown from the table, the average score on the *scenario-based assessment* ($M = 66.77$) was lower than scores on the *traditional weather assessment* ($M = 82.86$). Scores on the scenario-based assessment ranged from 26%-100%. These results and their implications are discussed in the following chapter.

Table 11

Mean, Mode, and Standard Deviation for the Scenario-Based Weather Assessment

<i>N</i>	<i>M</i>	<i>MO</i>	<i>SD</i>
90	66.77	64.00	16.48

Additionally, Cronbach's alpha was calculated to determine the reliability of the scenario-based weather assessment. The analysis revealed that the measure has high internal consistency, $\alpha = .91$.

The relationship between the scenario-based weather assessment and other measures. The relationship between the *scenario-based weather assessment* and the

aviation weather performance measure was analyzed using Pearson's Correlation. It was hypothesized that there is a positive relationship between scores on the *scenario-based weather assessment* and the *aviation weather performance* measure. The results of Pearson's Correlation support this hypothesis, $r(89) = .744, p \leq .01$.

6.5 Aviation Weather Performance

Table 12 displays descriptive statistics for the 90 participants who completed the *aviation weather performance* measure. As shown from the table, the average score for this measure is low ($M = 59.44$). Scores on the aviation weather performance measure ranged from 13%-96%.

Table 12

Mean, Mode, and Standard Deviation for the Aviation Weather performance Measure

<i>N</i>	<i>M</i>	<i>MO</i>	<i>SD</i>
90	59.44	62.00	19.80

Scenarios. There were five scenarios within the aviation weather performance assessment. Below are the results of the different scenarios (Preflight-Landing). Tables 12-17 display the results of the different scenarios.

Table 13

Scenario 1—Preflight. Weather Products and Weather Product Sources

Question	N	FAA Approved Product/Source	Percent Correct
Recall Weather Products	90	METARS	88%
		TAF	82%
		Tornado Warnings	0%

Recall Weather Sources	90	AFSS (1800-wx-brief)	94%
		ADDS	85%
		DUAT/DUATS	23%

Note: Percentages do not sum to 100% because multiple responses could be accounted for in one question.

Table 14

Scenario 2—Preflight. Look at the Sky for Guidance

Question	N	Percent Correct
	90	
Identifies Cloud		Cirrus 19%
		Cumulus 12%
		Stratus 45%
States Level of Cloud		Low 52%
		Medium 38%
		High 67%
Weather Pattern Associated with Cloud		Cirrus 32%
		Cumulus 26%
		Stratus 64%

Table 15

Scenario 3—Preflight. Evaluate Weather Information to Make a Weather Plan

Question	N	Percent
	90	
Evaluated weather information correctly.		79%
Participant decided not to take the flight.		21%
Participant plans alternate airports in bad weather.		24%

Table 16

Scenario 4-Enroute Phase.

Question	N	Percent
	77	
Participant turns around or lands at an alternate.		21%
Participant maintains attitude during thunderstorm (VA 90-110 knots).		100%
Participant crashed during the flight.		9%
Time in seconds it takes to notice cloud formation.		Avg Time
		120 Seconds

Note: The sample size dropped to 77 because 23 participants decided not to take the flight.

Table 17

Scenario 5-Landing.

Question	N	Percent
	90	
Participant said ATIS/ASOS/AWOS was best source to obtain information about the winds		87%
Participant said ATC was the best source to obtain information about the winds.		62%
If ATC advises vertical low level wind shear, what effect does this have on the aircraft?	Alters lift	56%
	Alters indicated airspeed	49%
	Alters thrust requirements	2%
	Altitude can exceed the pilots' capability to recover	44%

Note: Sample size is 90 because these questions were still asked to participants who decided not to fly the simulator.

Human Raters. For reliability measures, three trained human raters individually coded 30 participants on the aviation weather performance measure. One of the three

raters coded all 90 participants on the performance measure. Using Cohen's Kappa, inter-rater reliability was tested on scores from Rater A and Rater B and scores from Rater A and rater C. The results from Raters A and C revealed a high level of consistency, $k = .83, p \leq .05$ and the results from Raters A and B also revealed a high level of consistency, $k = .78, p \leq .05$.

6.6. Theoretical Models

In Figure 8, it was hypothesized that any relationship between the *traditional weather assessment* and the *aviation weather performance* measure would be fully mediated by *weather salience* and *aviation weather experience*. Using Baron and Kenny's (1986) test for mediation, step one examined whether scores on the *traditional weather assessment* predicted scores on the *aviation weather performance* measure. The results of the regression equation were non-significant, $b = .08, t(89) = .45, p > .05$. Because the results of step one are non-significant, the remaining steps of Baron and Kenny's (1986) test for medication were not tested. Table 18 shows the regression analysis results for Model 1.

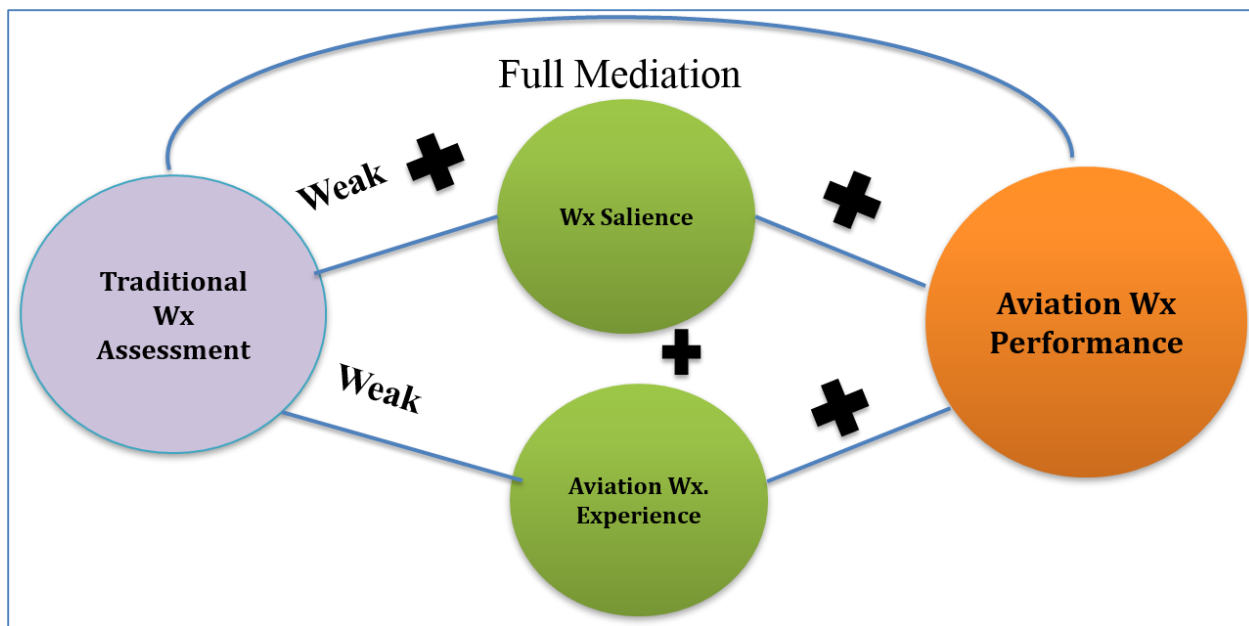


Figure 8. Theoretical model one.

Table 18

Regression Analysis Model 1 for Variables Predicting Aviation Weather Performance

Model 1				
Variable	<i>B</i>	<i>SE B</i>	β	R^2
Traditional Wx Assessment	.08	.17	.05	.002
Weather Saliency	.21	.13	.18	.03
Aviation Weather Experience**	.07	.02	.36	.13

Note: **Indicates significance at the .001 level.

Figure 9 displays Theoretical Model Two, which hypothesized that there would be a significant relationship between the *scenario-based weather assessment* and the *aviation weather performance* measure. Further, it was hypothesized that the relationship between the *scenario-based assessment* and the *aviation weather performance* measure is partially mediated by both *weather salience* and *aviation weather experience*. Using Baron and Kenny's (1986) test for mediation, step one examined whether scores on the *scenario-based assessment* predicted scores on the *aviation weather performance* measure. The results of the regression equation were significant, $b = .89$, $t(89) = 10.50$, $p \leq .001$. The *scenario-based weather assessment* predicted a significant portion (54%) of the variance in *aviation weather performance* scores, $R^2 = .54$, $F(1, 88) = 109.18$, $p \leq .001$.

Step two of the Baron and Kenny (1986) Test for Mediation tests whether scores on the *weather salience* questionnaire predicted scores on the *aviation weather performance* test. The results of the regression were not significant, $b = .21$, $t(89) = 1.71$, $p > .05$. Because the results of step two of the test for medication were not significant, the remaining steps were not completed. However, since this model predicts two mediating variables, *aviation weather experience* was tested to determine whether it predicted scores on the *aviation weather performance* measure. The results of the regression analysis were significant, $b = .067$, $t(89) = .36$, $p \leq .001$. Additionally, the test revealed that *aviation weather experience* contributed to a significant portion of the variance in

aviation weather performance scores, $R^2 = .13$, $F(1, 88) = 13.44$, $p \leq .001$. The remaining steps focus only on the *aviation weather experience*, mediating variable.

Step three of the Baron and Kenny (1986) Test for Mediation determines whether scores on the *scenario-based assessment* predict scores on *aviation weather experience*. The results of the regression analysis were significant, $b = 2.57$, $t(89) = 4.04$, $p \leq .001$. Additionally, scores on the *scenario-based assessment* contributed to a significant portion of the variance in *aviation weather experience*, $R^2 = .15$, $F(1, 88) = 16.33$, $p \leq .001$.

Step four of the Baron and Kenny (1986) Test for Mediation examines whether the significant relationship between the *scenario-based weather assessment* and the *aviation weather performance* measure is mediated by *aviation weather experience*. We hypothesized that *aviation weather experience* partially mediates the relationship between the *scenario-based weather assessment* and the *aviation weather performance* measure. The results of the regression analysis do not support this hypothesis. *Aviation weather experience* does not have a mediating relationship between the *scenario-based weather assessment* and scores on *aviation weather performance*, $b = .082$, $t(89) = 1.06$, $p > .05$. Additionally, when both predictors (*scenario-based weather assessment* and *aviation weather experience*) are added to the regression model, the *scenario-based assessment* contributes to 56% of the variance in scores on the *aviation weather performance* measure, $R^2 = .56$, $F(1, 88) = 55.23$, $p \leq .001$. Table 19 shows the results of the regression analysis for Model 2.

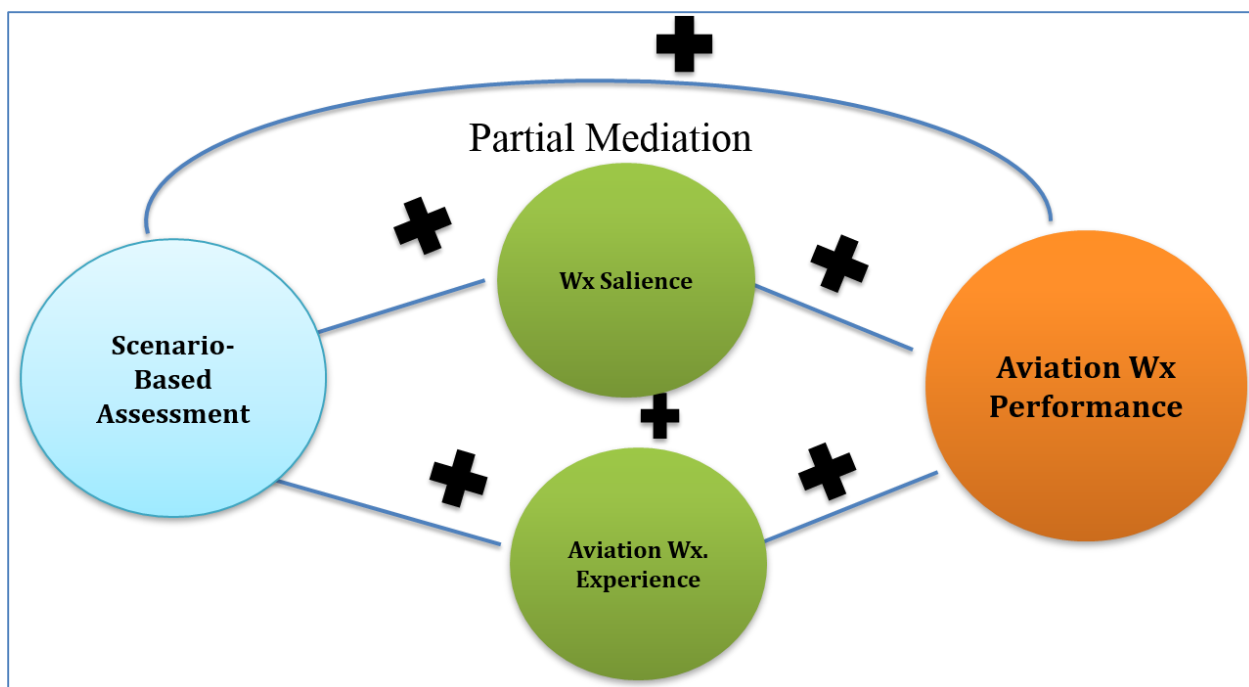


Figure 9. Theoretical model two.

Table 19

Regression Analysis Model 2 for Variables Predicting Aviation Weather Performance

Variable	Model 2			
	<i>B</i>	<i>SE B</i>	β	<i>R</i> ²
Scenario-Based Wx Assessment**	.89	.09	.74	.55
Weather Salience	.21	.13	.18	.03
Aviation Weather Experience**	.07	.02	.36	.13

Note: **Indicates significance at the .001 level.

6.7. Counterbalancing the Scenario-Based Weather Assessment and the Traditional Weather Assessment

All 90 participants completed all measures; however, half of the participants (Group A) completed the scenario-based weather assessment followed by the traditional weather assessment before the aviation weather performance exam and the other half of the participants (Group B) completed the traditional weather assessment followed by the scenario-based weather assessment before completing the aviation weather performance exam. To determine whether differences existed between the two groups of participants, a 2 x 2 ANOVA was performed. The results of the 2 x 2 ANOVA concluded that there was no significant difference between Group A and Group B; $F(1, 88) = 1.98, p > .05$.

6.8. Summary of Hypotheses

Table 20

Summary of Hypotheses

Hypothesis	Summary	Finding
1	Non-significant, positive relationship between Traditional Wx Assessment and Wx Salience	Supported
2	Non-significant, positive relationship between Traditional Wx Assessment and Aviation Wx Experience	Non-significant, negative relationship
3	Significant, positive relationship between Aviation Wx Experience and Wx Salience	Non-significant , positive relationship
4	Significant, positive relationship between Aviation Wx Experience and Aviation Wx Performance	Supported
5	Significant, positive relationship between Scenario-Based Assessment and Wx Salience	Supported
6	Significant, positive relationship between Scenario-Based Assessment and Aviation Wx Experience	Supported
7	The relationship between the Traditional Wx Assessment and Aviation Wx Performance is fully mediated by both Wx Salience and Aviation Wx Experience	Non-significant relationship between Traditional Wx Assessment and Aviation Wx Performance
8	The relationship between the Scenario-Based Assessment is partially mediated by both Wx Salience and Aviation Wx Experience	No mediated relationship exists with either variable

Chapter 7: Discussion

The purpose of this study was to design a scenario-based weather assessment to test GA pilots' weather knowledge and then determine whether that scenario-based assessment better predicts GA pilot performance over the currently used traditional weather assessment that only captures a rote level of learning. The aviation weather literature supports the need for a GA pilot weather assessment that captures a deeper level of expertise through scenario or application type questions. Furthermore, the literature on expertise suggests that a scenario-based exam draws a larger variety of experience through the design of their scenario-based questions. Recall from Chapter 3 that as opposed to a traditional, multiple-choice assessment, a scenario-based assessment measures higher-level thinking and complex problem solving skills. The scenario-based assessment provides the test taker with understanding, remembering from experience, and motivation (Kang, McDermott, Roediger, 2007; Meterissian, 2006). A test-taker who does not have a higher level of expertise in an area such as aviation weather should not be able to perform as well on the scenario-based assessment as those test-takers with more experience. For example, a pilot with more experience could possibly recall more weather products for their flight and then look for weather trends within these different weather products. Consequently, the pilot has more knowledge to make more informed decisions during weather situations and because a scenario-based test could ask the pilot to make inferences about weather trends, the scenario-based test could capture the extent of knowledge the pilot has about aviation weather. The results of this study suggested

that a scenario-based exam was in fact a better predictor of GA pilot performance compared to a traditional weather-related assessment. The following sections highlight the results of the study and how each measure played a role in the outcome of the study. This chapter ends with recommendations for future research in aviation weather.

7.1. Traditional Weather Assessment

Not surprisingly did participants' scores on the *traditional weather assessment* not predict their *aviation weather performance* scores. This finding supports the literature (Wiegmann et al., 2008) suggesting private pilots can score high on the FAA Written Exam while not fully understanding weather phenomena and the implications of weather for their flight. What was surprising was the significant, negative relationship between *aviation weather experience* and their scores on the *traditional weather assessment*. This finding implies that as pilots become more experienced in aviation weather, they perform worse on the traditional weather assessment. If the traditional weather assessment is only measuring a rote level of learning and if student pilots can memorize all of the questions and answers to the private pilot exam's study guide, there is most likely some type of memory decay occurring as evident by these results. That is, lower experience level pilots may perform better on the *traditional weather assessment* if they have recently studied for or taken the FAA Written Exam, which the traditional weather assessment is based off of. To determine if memory decay is a factor, future studies could compare the gap of time between when student pilots take the FAA Written Exam and their performance on the *traditional weather exam*.

7.2. Scenario-Based Weather Assessment

The results of the *scenario-based weather assessment* indicate that the assessment is a highly reliable measure and might be used to predict aviation weather performance. Scores on the *scenario-based assessment* positively correlated with *aviation weather experience* which suggests that as one becomes more knowledgeable in aviation weather, the better they will perform on the *scenario-based weather assessment*. Furthermore, the *scenario-based assessment* was the single best predictor of aviation weather performance scores over all other predictors. What this indicates is that the *scenario-based weather assessment* is capturing a larger variety of aviation weather knowledge from pilots at varying levels of aviation weather experience. Compared to the *traditional weather assessment*, the *scenario-based weather assessment* can be used to determine in what areas pilots may need more training. And because the *scenario-based weather assessment* divides the exam into different sections (i.e., preflight through landing), it can make it easier for instructors to give specific feedback to their students in the areas in which they may need more training or education. For example, during the *enroute* portion of the *scenario-based assessment*, there is a question that tests the student pilot on their knowledge of how to read both satellite imagery and weather radar for a specific location along the pilot's flight path. If the student pilot is only able to read the satellite imagery but not the radar, it suggests that the pilot needs more training on how to read one product over the other. And because the scenario-based exam is designed to capture the specificity of the pilots' knowledge, this type of assessment can point instructors in the right direction for a well-tailored training program for their student pilots.

Ultimately, the results from the scenario-based assessment suggest that it is a stronger measure than the current method used for assessing aviation weather knowledge

on the FAA Written Exam that grants private pilots their certificate. If a scenario-based assessment was implemented as the type of test used in the FAA Written Exam for private pilots, it could prevent students from passing the exam who lack the weather knowledge needed to safely maneuver a flight through weather events. Consequently, those students who do not pass the exam could receive much needed training so that they can gain the knowledge needed to make safer decisions during weather events inflight. It is important that more research is conducted with a larger and more representative sample of GA pilots using this new measure to confirm its validity and reliability.

7.3. Weather Salience Questionnaire

One of the most surprising results of the study were those from the *weather salience measure*. The sample of 90 student pilots' scored below average (compared to the general population) on all 29 questions of this measure as well as the seven subscales for the measure. These results were similar to the Thropp et al. (2015) study that used a similar sample of student pilots. Additionally, the *weather salience measure* did not have a significant relationship with any of the measures except the *scenario-based weather assessment*. However, the low reliability of this measure calculated with our sample suggests that any of the results from this study, with respect to *weather salience*, should be considered lightly. One key difference between the current study's sample and the general population's sample was our sample of young, student pilots ($M = 19.2$ years-old). Two conclusions can be drawn about these results. First, the questions on the *weather salience measure* are outdated with respect to technology. Some of the questions refer to using the radio or television to check weather information when it is most likely

that our sample of young pilots uses their smartphones or tablets to gather weather information. Second, anecdotal evidence suggests that this sample of student pilots as well as other student pilots do not particularly appreciate weather or weather phenomena. To this sample of student pilots, weather is associated with a canceled flight, a difficult concept to grasp, or a dangerous situation that could lead to fatalities. All of these reasons could be possibilities for the low *weather salience* score. Future studies could develop a stronger and more updated weather salience measure specifically for pilots.

7.4. Aviation Weather Performance

The main focus of the *aviation weather performance measure* for this paper is with respect to how well each of our predictors accounted for the variance in *aviation weather performance*. As previously mentioned, the *scenario-based weather assessment* and *aviation weather experience* did contribute to a significant portion of the variance in *aviation weather performance*. However, an interesting finding was that when both the *scenario-based weather assessment* and *aviation weather experience* were added to the regression model, only the *scenario-based weather assessment* contributed to the variance in *aviation weather performance*. This indicates that the scenario-based assessment is a stronger predictor of GA pilot weather performance than the traditional exam that is currently used. This model can predict that with every unit increase in one's score on the scenario-based assessment, there will be a .89 increase of one's aviation weather performance score. The impact of these results lends guidance for both the aviation industry and aviation educators with respect to assessment design and aviation weather training. These results indicate that when an assessment is designed to include scenario-based or application type questions that require the student pilot to remember

from experience and use their knowledge of aviation weather to problem solve, the student's score on the scenario-based assessment is more representative of their actual aviation weather knowledge and thus aviation weather performance.

Another finding worth discussing are the results from the scores from the different scenarios on the *aviation weather performance measure*. The entire measure was intended to simulate an aviation weather checkride from preflight through landing. Regardless of experience level, the majority of the pilots scored low on this exam; however, more experienced pilots did score significantly higher than less experienced pilots. The measure was designed to capture a wide range of aviation weather expertise. During the *preflight* phase of flight, the results indicate that the majority of pilots only gather weather information from a couple of FAA approved sources (i.e., Flight Service Station, AviationWeather.gov) and a few weather products (i.e., METARS, TAFS, Area Forecast). Even when asked to recall as many weather products and sources as possible, pilots were only able to recall a few. This finding is consistent with other studies that suggest that pilots might not be looking at all available weather products and sources to make weather trends for their flight (Lanicci et al., 2011; Shappell et al., 2012). If pilots are not gathering and interpreting a variety of weather products and sources, they narrow their scope of how weather situations could impact the safety of their flight. For example, a pilot may gather weather information from a product such as, "METARS" that indicates a thunderstorm is moving in a direction that is opposite of their flight path. However, while in flight, the pilot's radar display is showing that the storm is now shifting in the direction of their flight plan. If the pilot lacks the knowledge necessary to understand

how to interpret radar technology or they neglected to gather radar information before their flight, the pilot could potentially fly through a thunderstorm and crash. This is why it is important for pilots to gather and understand a large variety of weather products before and during their flight so they can make well-informed decisions.

The scores of the *taxi* phase of flight were the lowest out of all the other scenarios. The majority of participants had difficulty identifying cloud types and then the associated weather patterns with these clouds and then the implications of these clouds for their flight. If pilots are only learning material to pass a weather exam or a weather course, they are not retaining the weather knowledge needed to navigate a safe flight. If a pilot cannot identify the type of cloud that is associated with weather such as icing conditions or afternoon thunderstorms, the pilot could fly through weather that they are not trained to fly through. This finding is supporting the implementation of a scenario-based assessment (to better capture weather knowledge) that can replace the current exam, which only assesses rote knowledge. Once instructors identify pilots' areas of weak weather knowledge, training strategies can be implemented to mitigate these weaknesses.

During the *enroute* portion of the flight, the majority of the participants interpreted the weather products correctly and decided to take the flight. However, a large percentage of participants did not plan for deteriorating weather throughout the flight. This result could be due to the fact that it was a simulation and they might not have felt pressured to plan alternate routes in the case of bad weather or it could be due to pilots' lack of knowledge for planning for weather situations. During this phase of the simulation, several of the participants mentioned that they would rely on their flight

instructor to tell them what decision to make in terms of what to do during a particular weather situation. Additionally, during the *enroute* portion the weather started to deteriorate several minutes into the flight. Only 21% of participants turned around or landed at an alternate airport to avoid the storm. Many participants talked through their decision-making throughout the flight and several participants stated reasons for flying through the bad weather such as, “the weather products you gave me stated that the weather would be clear enough to fly” or “I already traveled this far so I should continue.” These statements are consistent with theories of sunk cost and cognitive anchoring which have been explored in previous studies (Saxton, 2008; Wiegmann, 2001). These statements could also indicate that the student pilots are weighing their decisions based on their reliance of weather technology. In fact one participant in the study stated, “I do not need to know how to interpret weather products because I am going to work for the airlines. They have technology that will do that for me.” However, as several studies show, GA pilots may be relying on weather technology that they do not understand or do not know how to interpret (Cobbett et al., 2014; Lanicci et al., 2011; Shappell et al., 2012). The following paragraph explains the theories of sunk cost and cognitive anchoring and their consequences on GA flight.

If the theory of sunk cost is a factor with GA pilots’ decision making, GA pilots are risking their safety by flying through dangerous weather conditions because they have invested a large amount of time into the flight. In this situation, the pilot is choosing to save time over safety and the reason this occurs is likely because the pilot lacks the experience to know the consequences of their decisions of flying through deteriorating weather. The second factor could be a decision-making bias known as cognitive

anchoring. Cognitive anchoring occurs when individuals make their decisions based on the first piece of information received in a given scenario (Tversky & Kahneman, 1975). In the current study, the participants received a weather packet during the preflight phase with weather products that indicated a fair-weather flight. The participant should have made the decision to take the flight based on the weather information given. However, the actual weather in the flight simulation scenario did not match the weather given during preflight (i.e., the weather included low ceilings, low visibility, and thunderstorms). However, only 21% of the participants chose to land at an alternate airport. If participants in this study were demonstrating cognitive anchoring, they would have made the decision to keep flying through degraded weather based off of the fair-weather report they received during preflight. Research targeted at designing training programs around remedying decision-making biases such as cognitive anchoring are marginally successful (George, Duffy and Ahuja, 2000). Block and Harper (1991) found that warning individuals of anchoring through training programs helped to reduce this anchoring bias, but individuals failed to fully eliminate anchoring. More research is needed in the area of mitigating aviation weather decision-making biases.

The results from the *landing* phase of flight were relatively high compared to the other scenarios in the simulation. The majority of the participants understand whom to contact to gather information about the winds upon landing and understand the devastating effects of wind shear. Future studies could look at refining this checklist and creating a standardized checklist for flight instructors to use when assessing their students on weather during their checkride.

7.5. Recommendations

Several revelations were drawn from the current study and some of the methods and measures could be improved upon for future research in the area of aviation weather. First, the desktop simulator used for the *enroute* portion of the *aviation weather performance* measure was low fidelity and some of the participants complained that it was not what they were accustomed to. Although several simulation experts calibrated the simulator repeatedly and two flight instructors validated the simulator, participants still noted the high sensitivity of the controls. If the participant was concentrating on the mechanics of flying the simulator, they may have not been paying attention to their surroundings, including the deteriorating weather. Although the researcher gave participants time to become used to the simulator, there was not a separate scenario designed for only practice. Future studies could design a scenario without deteriorating weather conditions as a form of practice for the participant prior to letting them fly in the weather scenario. Also, future studies could use a simulator with higher fidelity than the one used for this study.

Another measure that could be improved upon is the *weather salience questionnaire*. This questionnaire was used to determine if pilots who appreciate the weather and who are motivated by weather phenomena, score higher on an assessment of aviation weather performance. Since the weather salience questionnaire used for this study showed both low reliability and did not predict their aviation weather performance, a stronger measure of weather salience is recommended for studying pilots. Recall that the *Weather Salience Questionnaire* (Stewart, 2005) was designed to measure beliefs and

attitudes about weather phenomena from the general population. The general population might experience and value weather differently than the aviation population. Because pilots are often faced with making decisions about their flight's safety with respect to weather and weather events, pilots may not have the same values toward weather that were measured in the *Weather Salience Questionnaire*. Pilots may respect and use weather completely different from the general population and a separate weather salience questionnaire designed for pilots could measure those values.

The current study sampled a specific type of young aviators from a small, private university in one geographic region of the United States. Since most of the pilots from the sample learned to fly in only one region, and most of the pilots were under the age of twenty-five, it is recommended that future studies sample a diverse group of GA pilots from different regions who fly a variety of both weather patterns and terrain. With the inclusion of a more diverse group of GA pilots, researchers can study how those pilots differ in terms of their knowledge and training of weather technology.

7.6. Conclusion

While the GA accident rate continues to rise, weather-related GA accidents continue to contribute to the greatest number of fatalities associated with all GA accidents. Remember that although weather-related accidents account for a smaller portion of the total number of GA related accidents, they account for roughly 83% of the fatality rate (AOPA, 2010; Li and Baker, 2007). Prior research in aviation weather examined GA pilots' lack of knowledge and training with weather and weather technology. One particular area of concern was the high pass rate of the FAA Written

Exam for private pilots and the lack of scenario-based/application weather questions on the exam. The literature on assessing expertise suggests using a scenario-based assessment to fully capture a person's knowledge and skills as opposed to a traditional assessment that only tests rote knowledge.

The purpose of this study was two-fold. First, a scenario-based weather assessment was created based on the specific weather tasks, knowledge, and skills GA pilots are required to perform and know for all phases of GA flight. Second, the researchers attempted to determine whether that scenario-based weather assessment was a better predictor of GA pilot performance over the current, traditional exam.

The results of the study suggest that the scenario-based exam was a better predictor of aviation weather performance over the traditional exam. Furthermore, one's level of aviation weather experience is associated with both pilots' scores on the scenario-based assessment and their aviation weather performance scores. These findings suggest that the more training and education a GA pilot has with both aviation and weather, the better their decisions may be during an actual weather event. Additionally, if a scenario-based weather assessment is used to certify private pilots, it can help identify those pilots who are having trouble understanding weather and weather technology and aid in developing better weather training programs targeted at increasing GA pilots' weather knowledge and skills. Hopefully, the results of this study can spark awareness with industry officials on the importance of capturing a more realistic level of GA pilots' weather knowledge through a scenario-based assessment in order to develop a richer level of training so that all GA pilots have the education and the tools to make well-informed decisions during weather-related situations.

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Appendix

A. Demographic Questionnaire

Demographic Information

1. What is your current age? _____

2. Country of residence _____ If you reside in the U.S., what city/state? _____

3. Indicate where you received training for each of your Certificates:

Certificate	Part-61 (FBO, etc)	Part-141 Flight School	Part-142 Flight Training Center
Student			
Sport			
Recreational			
Private			
Commercial			
Airline Transport			
Student			
Rotorcraft			
Glider			

4. Do you have an instrument rating? _____

5. Are you a CFI? _____

6. Are you a CFII? _____

7. Total number of flight hours (approximate) _____

8. Total number of hours under instrument flight rules (actual) _____

9. Total number of hours under instrument flight rules (simulated) _____

10. Number of years flying _____

11. Which state did you complete the majority of your total flight hours (e.g., Nevada, Montana, and Florida)?

12. Please rate how familiar you think you are with United States geography (i.e., state borders, mountains, rivers, and climate of different regions)?

1 2 3 4 5 6 7

Not Familiar

Very Familiar

13. What was the name of the institution where you received your flight training? _____

14. List the residential meteorology courses you have taken:

- _____
- _____
- _____

15. List any seminar or workshop meteorology courses you have taken:

- _____
- _____
- _____

16. List any online meteorology courses that you have taken (i.e., FAA safety.gov courses)

- _____
- _____
- _____

17. How many times have you taken the FAA Airmen's Written Exam? Circle one

0**1-2****3 or more****B. Weather Salience Questionnaire (Stewart, 2005)**

Directions: Please rate the degree of which you agree or disagree with the following statements.

1. I use the Internet to obtain weather forecasts or weather information (temperatures, radar images).

Strongly Disagree**Agree****Neither****Disagree****Strongly Disagree**

2. I look at the weather radar on television or on the Internet to see where precipitation (i.e., rain, thunderstorms, snow, etc.) may be occurring.

Strongly Disagree**Agree****Neither****Disagree****Strongly Disagree**

3. I seek out more up-to-date weather information than what is provided on the television or radio.

Strongly Disagree**Agree****Neither****Disagree****Strongly Disagree**

4. I watch television or listen to the radio to get a weather forecast so that I can know what to expect.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

5. I plan my daily routine around what the weather may bring.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

6. If a friend or family member asked me what the weather forecast was for today I could not tell him or her what to expect.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

7. The weather or changes in the weather really do not matter to me.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

8. I only pay attention to what the weather is doing when the conditions become severe (e.g., flooding, heat wave, hurricane, thunderstorm, tornado, winter storm, etc.).

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

9. I take notice of changes that occur in the weather.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

10. How the weather makes the outside environment appear tends to affect my mood during that weather.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

11. The changes in the weather cause my mood to change.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

12. There is a particular kind of weather that makes me feel good emotionally.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

13. The weather affects my mood from day to day.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

14. Certain types of weather make me feel better emotionally than other types of weather.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

15. I am attached to the weather and climate of my hometown (or the place of where my family of origin lives or lived).

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

16. I am attached to the climate of the place where I live or used to live.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

17. I am attached to the climate that exists in the location where I lived as a child or adolescent.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

18. I can tell when there seems to be a lot of moisture in the air.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

19. I take notice of how the air outside sometimes smells differently after it rains.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

20. I notice how the clouds look during various kinds of weather.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

21. I look forward to what changes the weather may bring.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

22. There are some geographical locations where the weather changes so little that it would be boring to live there.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

23. It is important to me to live in a place that offers a variety of different weather conditions throughout the year.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

24. I like to experience variety in the weather from day to day.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

25. I become interested in the weather when there is a possibility that I may have a weather-related holiday (e.g., snow day from school or work).

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

26. I enjoy having a weather-related holiday (e.g., a holiday stemming from snow or ice).

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

27. In the past I have wished for weather that would result in a weather-related holiday.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

28. During certain seasons of the year, the weather conditions routinely (i.e., at least once per week) affect my ability to perform tasks at school or work.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

29. The work that I do (or did previously) is affected by the daily weather conditions.

Strongly Disagree **Agree** **Neither** **Disagree** **Strongly Disagree**

To score the WxSQ, add each response number together for a total score. Items 6, 8, 12, 13, 15, 16, 22, 23, 24, 26, and 28 are reversed scored. All other items are scored normally. The total scores on the WxSQ can range from a minimum of 29 to a maximum of 145. The mean total weather salience score for women was 116.36 and the mean total score for men was 112.29. Table 7 displays the mean and standard deviation for males and females for all seven content areas of the WxSQ.

C. Means and Standard Deviation for Males and Females on the WxSQ

Content Area	Men		Women	
	Mean	Std dev	Mean	Std dev
Seeking Weather Information	30.95	5.54	30.91	5.66
Effects of Weather on Mood	21.62	5.23	23.60	5.11
Sensing and Observing Weather	17.66	3.77	18.30	3.73
Attachment to Kinds of Weather	10.14	2.35	10.22	2.62
Need for Variety in Weather	15.72	3.58	16.21	3.91
Holiday-Related Weather Interest	8.15	2.91	9.53	3.20
Effects of Weather on Daily Life	8.05	2.74	7.59	2.52

All Items (Total Saliency)	112.29	18.02	116.36	18.07
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D. Traditional Weather Assessment

1. For aviation purposes, ceiling is defined as the height above the Earth's surface of the:

- A. Lowest reported obscuration and the highest layer of clouds reported as overcast
 - B. Lowest broken or overcast layer or vertical visibility in an obscuration
 - C. Lowest layer of clouds reported as scattered, broken, or thin
-

2. What are the current conditions depicted for Chicago Midway Airport (KMDW)? Please use the information below to answer this question.

- A. Sky 700 feet overcast, visibility 1-1/2 SM, rain.
- B. Sky 7000 feet overcast, visibility 1-1/2 SM, heavy rain.
- C. Sky 700 feet overcast, visibility 11, occasionally 2 SM, with rain.

METAR KINK 121845Z 11012G18KT 15SM SKC 25/17 A3000
 METAR KBOI 121854Z 13004KT 30SM SCT150 17/6 A3015
 METAR KLAX 121852Z 25004KT 6SM BR SCT007SCT250 16/15 A2991
 SPECI KMDW 121856Z 32005KT 1 1/2SM RA OVC007 17/16 A2980 RMK
 RAB35
 SPECI KJFK 121853Z 18004KT 1/2SM FG R04/2200 OVC005 20/18 A3006

3. Which of the reporting stations have VFR weather? Use the information below to answer this question.

- A. All
- B. KINK, KBOI, and KJFK
- C. KINK, KBOI, and KLAX

METAR KINK 121845Z 11012G18KT 15SM SKC 25/17 A3000
 METAR KBOI 121854Z 13004KT 30SM SCT150 17/6 A3015
 METAR KLAX 121852Z 25004KT 6SM BR SCT007SCT250 16/15 A2991
 SPECI KMDW 121856Z 32005KT 1 1/2SM RA OVC007 17/16 A2980 RMK
 RAB35
 SPECI KJFK 121853Z 18004KT 1/2SM FG R04/2200 OVC005 20/18 A3006

4. The section of the Area Forecast titled, "VFR CLDS/WX" contains a general description of

A. Cloudiness and weather significant to flight operations broken down by states or other geographical areas

B. Forecast sky cover, cloud tops, visibility, and obstructions to vision along specific routes

C. Clouds and weather which cover an area greater than 3,000 square miles and is significant to VFR flight operations

5. What is indicated when a current CONVECTIVE SIGMET forecasts thunderstorms?

A. Moderate thunderstorms covering 30 percent of the area

B. Moderate or severe turbulence

C. Thunderstorms obscured by massive cloud layers

6. What information is contained in a CONVECTIVE SIGMET?

A. Tornadoes, embedded thunderstorms, and hail $\frac{3}{4}$ inch or greater in diameter

B. Severe icing, severe turbulence, or widespread dust storms lowering visibility to less than three miles

C. Surface winds greater than 40 knots or thunderstorms equal to or greater than video integrator processor (VIP) level 4

7. Which in-flight advisory would contain information on severe icing not associated with thunderstorms?

A. Convective SIGMET

B. SIGMET

C. AIRMET

8. What would decrease the stability of an air mass?

A. Warming from below

B. Cooling from below

C. Decrease in water vapor

9. An almond or lens shaped cloud which appears stationary, but which may contain winds of 50 knots or more is referred to as

A. an interactive frontal cloud

B. a funnel

C. a lenticular cloud

10. Crests of standing mountain waves may be marked by stationary, lens-shaped clouds known as

A. Mammatocumulus clouds

B. Standing lenticular clouds

C. Roll Clouds

11. Clouds are divided into four families according to their

A. Outward shape

B. Height range

C. Composition

12. Moist stable air flowing upslope can be expected to

- A. Produce stratus type clouds
 - B. Cause showers and thunderstorms
 - C. Develop convective turbulence
-

13. Low-level turbulence can occur and icing can become hazardous in which type of fog?

- A. Rain-induced fog
- B. Upslope fog

C. Steam fog

14. Possible mountain wave turbulence could be anticipated when winds of 40 knots or greater blow

- A. across a mountain ridge, and the air is stable
- B. down a mountain valley, and the air is unstable
- C. parallel to a mountain peak, and the air is stable

15. The destination airport has one runway, 08-26, and the wind is calm. The normal approach in calm wind is a left hand pattern to runway 08. There is no other traffic at the airport. A thunderstorm about 6 miles west is beginning its mature stage, and rain is starting to reach the ground. The pilot decides to

- A. Fly the pattern to runway 08 since the storm is too far away to affect the wind at the airport

B. Fly the normal pattern to runway 08 since the storm is west and moving north and any unexpected wind will be from the east or southeast toward the storm

C. Fly an approach to runway 26 since any unexpected wind due to the storm will be westerly

16. One in-flight condition necessary for structural icing to form is

A. Small temperature/dewpoint spread

B. Stratiform clouds

C. Visible moisture

17. In which environment is aircraft structural ice most likely to have the highest accumulation rate?

A. Cumulus clouds with below freezing temperatures

B. Freezing drizzle

C. Freezing rain

18. To determine the freezing level and areas of probable icing aloft, the pilot should refer to the

A. Inflight Aviation Weather Advisories

B. Weather Depiction Chart

C. Area Forecast

19. What conditions are necessary for formation of thunderstorms?

A. High humidity

B. Lifting force, moist air, and extensive cloud cover

C. High humidity, lifting force, and unstable conditions

20. If there is thunderstorm activity in the vicinity of an airport at which you plan to land, which hazardous atmospheric phenomenon might be expected on the landing approach?
- A. Precipitation static
 - B. Wind-shear turbulence**
 - C. Steady rain
-
21. The most frequent type of ground or surface-based temperature inversion is that which is produced by:
- A. Terrestrial radiations**
 - B. Warm air being lifted rapidly aloft in the vicinity of mountainous terrain
 - C. The movement of colder air under warm air, or the movement of warm air over cold air

E. Aviation Weather Performance

Preflight Scenario 1:

Weather Products and Weather Product Sources. Researcher says to participant: I would like for you to imagine that you are following regular preflight procedures to plan a cross country flight from Cross City, Florida to Palatka, Florida. If this was a typical preflight procedure, you would be gathering weather information for your flight.

Trigger Event 1 What types of weather sources would you use to gather weather information about your flight?

___DUAT/DUATS

___Flight Service Station

___ADDS

TIBS AFSS AWOS ASOS ATIS**Total Points** (out of 8
points)_____

Trigger Event 2 What types of weather products would you look at from these weather sources?

sources?

<input type="checkbox"/> PIREP	<input type="checkbox"/> METAR
<input type="checkbox"/> Wind Shear Reports	<input type="checkbox"/> TAF
<input type="checkbox"/> Icing and Freezing	
<input type="checkbox"/> Level Information	<input type="checkbox"/> FA

 Surface Analysis Chart Radar Summary Chart Winds and Temperature Aloft Chart Significant Weather Prognostic Chart Convective Outlook Chart SIGMET AIRMET**Total Points** (out of 13
points)_____

Taxi Scenario 2

Scenario 2 simulates a taxi phase of flight where participants would normally be able to look out the window to gather weather information. In the following scenarios,

participants will be given three pictures of different cloud types. Participants are required to identify the type of cloud, state the cloud height, describe the associated weather pattern with this type of cloud, and the implications of the cloud for flight.

Directions: Researcher: The researcher gives the participant different pictures of cloud types. Does the participant correctly identify the 1) cloud type, 2) cloud height, 3) associated weather pattern with this cloud type, 4) Implication of cloud for flight?

Trigger Event 1

Picture 1: Altocumulus Cloud



- 1) Participant correctly identifies cloud____
- 2) Participant states this is a **middle level cloud**____
- 3) Participant states that this cloud usually indicates **thunderstorms in the afternoon**____

4) Participant states that this cloud may impact their return flight if they are planning on returning in the afternoon___ **Turbulence**___ **Icing**___ **Other**___

Total Points (out of 6)_____

Trigger Event 2

Picture 2: Cirrocumulus



1) Participant correctly identifies cloud___

2) Participant states that this is a **high level cloud**___

3) Participant states that this cloud usually indicates **Fair weather**___ **Cold weather**___

4) Participant states that these clouds imply **Icing**___ **Turbulence**___ **Other**___

Total Points (out of 6)_____

Picture 3: Stratocumulus



- 1) Participant correctly identifies cloud____
- 2) Participant states that this is a low cloud____
- 3) Participant states that this cloud usually indicates light precipitation____
- 4) Participant states that these clouds imply **low ceiling**____ **low visibility**____ **icing**____
turbulence____

Other____

Total Points (out of 7)_____

Grand Total (out of 19)_____

Scenario 3: Evaluate Weather Information to Make a Weather Plan

Researcher says to participant: I would like for you to imagine that you are following regular preflight procedures to plan a cross country flight from Cross City, Florida to Palatka, Florida. Based on the information provided to you during preflight what decision would you make about going on your flight?

- 1) Participant decides to go (1pt)____

- 2) Participant decides not to go (1pt)____
- 3) Participant decides to go but plans alternate airports to land at if weather deteriorates (3pts)_____
- 4) How many alternate airports does the participant choose (4 pts max)_____
- 5) The participant establishes weather checkpoints along the flight to reevaluate deteriorating weather (yes or no)_____
- 6) The participant plans for how low they can go in altitude to avoid terrain along their flight if they are flying below ceiling (yes or no)_____

Scenario 4: Enroute Phase

Trigger Event 1:

1) Researcher says to participant: If you have the appropriate technology, what inflight weather services are available to you? Check all that participant says.

____HIWAS

____En Route Flight Advisory Service

____ADS-B

____EWINS

____ATC

_____Points (Total of 5 Points)

Enroute: Trigger Event 2

During the flight simulation, the weather will start to deteriorate 8 minutes into the flight. The researcher has explained that they can only communicate with someone from a 2-way radio service like ATC or En Route Flight Advisory Service.

1) The participant communicates with a 2-way radio service to check the weather _____; then lands at an alternate airport_____

2) The participant flies through bad weather (0points)_____

_____Points (2pts total)

_____Grand Total (7pts)

Scenario 5: Descent/Landing Phase

1) What is the best source to obtain information about winds? Participant says

ASOS/AWOS (1pt)_____

2) The participant contacts ATC (1pt)_____

3) If ATC advises vertical low level wind shear, what effect does this have on the aircraft?

_____The change in the velocity alters lift (1pt)

_____alters indicated airspeed (1pt)

_____alters thrust requirements (1pt)

_____altitude can exceed the pilot's capability to recover (1pt)

____Points (6 points total)

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