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Combined Report: Aviation Weather Knowledge Assessment & General Aviation (GA) Pilots' Interpretation of Weather Products

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Executive Summary

Prior research has indicated that general aviation (GA) pilots may lack adequate knowledge of aviation weather concepts and skill at interpreting aviation weather displays. Therefore, the purpose of the current project was to develop and validate a comprehensive set of aviation weather knowledge and interpretation multiple-choice questions, and in turn, to use the questions to assess pilot understanding of aviation weather concepts and displays. An interdisciplinary research team that included two meteorologists, one Gold Seal Certificated Flight Instructor (CFI), a human factors psychologist, and several human factors graduate students performed this research.

Phase 1

The purpose of the first phase of research was to develop and validate appropriate weather-related multiple-choice questions to assess GA pilots' knowledge of aviation weather concepts and principles, where to obtain the aviation weather products and how to interpret the aviation weather products (e.g., forecasts, observations, etc.). The sample (n = 204) was composed of young pilots, whose certificates and/or ratings ranged from student pilot to commercial with instrument pilot. Overall, the results revealed that the pilots performed with low to moderate scores on the exam. Further, the results indicated that GA pilots with a commercial certificate and an instrument rating had a higher level of aviation weather knowledge than did private pilots with an instrument rating as well as private pilots without an instrument rating. Student pilots had the lowest levels of aviation weather knowledge.

Phase 2

As the research sample in Phase 1 was primarily young pilots, the purpose of the Phase 2 study was to use a sample more generalizable to the GA population in terms of pilot age, ratings and flight time. Participants for this study were GA pilots who were current members of the Aircraft Owners & Pilots Association (AOPA). The results of Phase 2 indicated that, overall, these pilots scored at moderate levels on the weather questions. In this sample, Airline Transport Pilot (ATP) certificated pilots scored significantly higher than Private with Instrument-rated pilots and Private pilots, and CFIs scored significantly higher than Private pilots, but no other significant differences between certificate/ratings were found. In terms of the content, pilots scored highest on concepts relating to Sources of weather information (e.g., Aviation Weather Center website, 1800Wxbrief, etc.), Significant Weather, Storm Definition and Flight Planning, and lowest on weather product interpretation questions pertaining to Ceiling and Visibility Analysis (CVA), Radar, Satellite, Station Plots and Surface Prognostic charts.

Conclusion and Recommendations

Overall, the results of this research indicate that GA pilots of all certification levels have difficulty interpreting many aviation weather products. A pilot who does not understand aviation weather products may be at higher risk of encountering hazardous weather. Future research should include emphasizing both increasing the usability of the weather products as well as improving pilots' weather training. Specifically:

- Implement human factors principles and methods to develop and test general aviation pilot-centered weather product display prototypes. Establish collaborative research with Industry partners (e.g., Foreflight; Delta) on weather display technology.
- Develop an Aviation Weather handbook that consolidates weather information and provides instruction to general aviation pilots.

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- Develop and validate training tools that 1) equate what general aviation pilots see in weather self-briefing with inflight images and 2) help general aviation pilots to perform effective self-briefings.
- Investigate weather training tools and strategies for flight instructors.

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Glossary of Abbreviations/Symbols

Acronym	Definition
η^2	Measure of strength of relationship (eta squared)
AIRMET	Airmen's Meteorological Information
ANOVA	Analysis of Variance
AOPA	Aircraft Owners and Pilots Association
ATC	Air Traffic Control
ATP	Airline Transport Pilot
AV	Aviation
AVWX	Aviation Weather
CFI	Certified Flight Instructor
CFII	Certified Flight Instructor Instrument
CIP	Current Icing Potential
CVA	Ceiling and Visibility Analysis
d	Cohen's measure of sample effect size for comparing two sample means
DV	Dependent Variable
EFAS	En-Route Flight Advisory Service
ERAU	Embry-Riddle Aeronautical University
f	Frequency
FA	Area Forecast
FAA	Federal Aviation Administration
FBO	Fixed-base operator
FOUO	For Official Use Only
GA	General Aviation
GFA	Graphical Forecast for Aviation
GTG	Graphical Turbulence Guidance
HIWAS	Hazardous Inflight Weather Advisory Service
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LIFR	Low Instrument Flight Rules
LOC	Loss of Control
M	Sample Mean
MANOVA	Multivariate Analysis of Variance
Mdn	Median
METAR	Meteorological Aerodrome Report
MVFR	Marginal Visual Flight Rules
n	Total number of cases

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NEXRAD	Next-Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration
NTSB	National Transportation Safety Board
p	Probability
PIREP	Pilot Report
r	Estimate of the Pearson product-moment correlation coefficient
SD	Standard Deviation
SE	Self-efficacy
SIGMET	Significant Meteorology Information
TAF	Terminal Aerodrome Forecast
TFR	Temporary Flight Restrictions
TRX	Training
TSTM	Thunderstorm
UGA	University of Georgia
VFR	Visual Flight Rules
WxSQ	Weather Salience Questionnaire

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Introduction/Background

Hazardous weather has a long history of contributing to General Aviation (GA) accidents (Fultz & Ashley, 2016). GA remains the area of aviation with the highest accident rate, both with and without hazardous weather as a contributing factor, and when hazardous weather is involved, the probability of fatalities increases (FAA, 2010). Weather-related accident and fatality rates are higher in GA because the GA planes are smaller/less equipped, fly at lower altitudes, may not receive as much weather information, and may have less experienced pilots (Lanicci et al., 2012). In response to the accident and fatality rates, in 2014 the National Transportation Safety Board (NTSB) named "Identifying and Communicating Hazardous Weather" for GA as one of the "Most Wanted" areas to improve safety (NTSB, 2014), and noted that pilot misunderstanding of weather information can be just as hazardous as a lack of information. Three years later, the NTSB included Loss of Control (LOC) in GA on the 2017-2018 most wanted list, while recognizing that one contributing factor to LOC is hazardous weather and that better pilot training on "managing weather issues" is needed (NTSB, 2017a).

Efforts to reduce weather-related accidents have spawned considerable research activity. Numerous researchers have examined pilots performing aviation weather simulated scenarios (Ahlstrom, Ohneister, & Caddigan, 2016; Johnson, Wiegmann, & Wickens, 2006; Wiggins et al., 2012; Hunter, 2006). These and other studies provided evidence that expert pilots differ from less experienced pilots and provide general recommendations how to improve the training pilots on the use of aviation weather. With aviation meteorology covering a broad range of topics from understanding fundamental weather phenomena to interpreting complex weather products, a lack of clarity still exists regarding the specific training needs as well as guidance on what technology/performance support tools pilots need.

Interpreting aviation weather information and forecasts and applying the information correctly to flight demands that pilots have a set requires a higher-order cognitive skills. Since knowledge acquisition is a fundamental first step of cognitive skill acquisition (Ackerman, 2003; Anderson, 2000), pilots will not perform well on higher-order tasks without the necessary building block of knowledge. Thus, one essential component to understanding pilots' performance of higher-order aviation weather related tasks is to first assess what pilots do and do not know about aviation weather fundamentals (e.g., the concepts, how to read weather products, sources of weather information) (Lanicci et al., 2017). The purpose of this study was to develop and validate a method to assess pilots' knowledge of aviation weather fundamentals.

A search of the literature on studies that included assessments of pilots' aviation meteorology knowledge produced limited results. Researchers have approached this issue of identifying knowledge gaps from four major perspectives: survey research, analysis based on historical data, simulation studies, and written tests. However, all leave research gaps.

First, multiple researchers have used a survey approach to uncover knowledge gaps (Casner, 2010; Carney et al., 2014). The Casner (2010) study focused on pilot weather reports (PIREPs). Pilots are providing few PIREPs, and when they do submit a PIREP, the reports tend to be inaccurate and incomplete (NTSB, 2017b). As part of research examining why pilots don't submit PIREPs, Casner (2010) examined pilot perceptions of their ability to identify and describe weather phenomena, and the research suggested pilots' lack of knowledge may be related to the lack of PIREPs. However, without data regarding pilots' knowledge of the concepts and procedures involved in PIREPs, the authors could only surmise reasons for the inaccurate and incomplete PIREPs. A more direct assessment of GA pilots' knowledge about weather would provide additional insight as to why PIREP submissions are vague and incomplete as well as how to improve them. In another survey study, Carney et al. (2014) collected pilots' self-perceptions of their weather-related flight training experiences. Based on the responses, the authors provided recommendations for pilot training. Again, asking pilots about what training they received does not necessarily correlate with what knowledge they learned or retained.

In a study combining historical data with pilot interview data, Lanicci et al. (2012) examined GA pilot interview data in conjunction with data mining from historical weather databases and identified pilot knowledge gaps. Lanicci and his colleagues interviewed pilots who had experienced a weather-related deviation, requested flight assistance, made an emergency declaration, or had an incident. Next, the research team compared the interview responses to the results of a meteorological data analysis and the actual weather products available at the time of the encountered event. The results showed that in 80% of the cases, the weather hazards were detected by the observational network, and the associated aviation weather hazard products (Airmen's Meteorological Information (AIRMET), Significant Meteorological Information (SIGMET), Next Generation Weather Radar (NEXRAD) data, Meteorological Aerodrome Reports (METARs), Terminal Aerodrome Forecast (TAFs), Area Forecasts (FAs)) were available for the respective areas and times of the weather encounter. Despite the availability of accurate information, pilots showed a "lack of appreciation" for the weather (Lanicci et al., 2012). Furthermore, the authors noted a few examples of specific errors (e.g., during pre-flight planning pilots checked METARs for the origin and destination airports but did not check METARs for points in-between). The authors concluded that the pilots' lack of understanding was a primary contributing factor to the problems faced during the flights, and recommended future training to include inflight weather hazards (e.g., instrument meteorological conditions (IMC), icing, turbulence, windshear, convective weather), interpretation of all Federal Aviation Administration (FAA) approved weather products (e.g., AIR/SIGMETs, NEXRAD data, METARs, TAFs, FAs), and accessing FAA approved weather sources including en route. While this study's detailed analysis demonstrated the weather was observed and information was accurate, the authors were still left to deduce the pilots' knowledge gaps and, in turn, give somewhat broad weather training recommendations.

Considerable GA aviation weather research has occurred using flight training devices and simulators. Many of these studies also allude to pilots' aviation meteorology knowledge gaps. Johnson and Wiegmann (2016) provided a recent study using indirect measures of knowledge. This study used an advanced weather-simulation system that presented a dynamic weather model representative of an actual visual flight rule (VFR) into IMC weather event derived from historical weather data, and their results revealed that pilots with greater in-flight experience of VFR to IMC were less likely to fly into the IMC. Since this study did not include a direct measure of what these pilots understood about weather concepts, reading weather products, integrating weather information into the context of flight, or knowledge of out-the-window cues, the study did not provide insight into exactly what knowledge or skills or attitudes influenced those pilots to stay away from IMC. Other research on pilots' weather knowledge assessment has focused on the FAA knowledge exams (FAA, 2017). Pilots seeking additional certifications are required to pass a knowledge exam as part of the process to earn the respective certificate. Several authors have criticized the existing FAA knowledge test for Private Pilots in terms of being an inadequate assessment of aviation meteorology (Burian & Jordan, 2002; Dutcher & Doiron, 2008; Kirk et al., 2011; NTSB, 2005; Wiegmann, Talleur, & Johnson, 2008). These authors argued that the FAA knowledge test questions were not up-to-date with current technology and/or current weather products and sources, not content valid (emphasize an unduly degree of weather phenomena rather than product interpretation), and tested at a basic, rote level of knowledge (e.g., verbatim from the manuals). Furthermore, the exam scoring procedure allows a pilot-in-training to fail all the aviation weather section and yet still earn a passing score. Until recent years, the test questions were available to the public, and previously used questions have been published by private organizations as test banks (e.g., Gleim). Based on the critiques of the FAA exam weather questions, these test bank questions are insufficient to assess pilots' aviation weather knowledge.

Some research has included written assessments of pilot's weather knowledge developed for the topic of interest in a particular study. For example, as part of validating a Next Generation Weather Radar (NEXRAD) training module, Blickensderfer et al. (2015) measured GA pilots' knowledge of convective weather concept and principles and convective weather product limitations. The assessment consisted of a multiple-choice test and a paper-based scenario test in which pilots were asked to interpret weather information in the context of a specific scenario. Pre-test scores were a dismal 55% and 65% accuracy on the knowledge and the scenario tests, respectively, although the scores improved dramatically with training. If training researchers and practitioners had access to low-cost knowledge tests of this nature, they could better assess pilot knowledge gaps and fine tune their training to best address the training needs.

An example of an aviation weather knowledge test wider in scope appeared in Burian and Jordan (2002). Using three equivalent 13-item tests, the Burian and Jordan (2002) study directly measured pilots' knowledge relating to six weather categories: Causes of Weather and Weather Patterns, Weather Hazards, Weather Services, Weather Regulations, Weather Interpretation, and

Weather-Related Decision Making. The results showed that, overall, a large sample of certificated U.S. pilots with a wide range of experience and flight hours "lacked operationally relevant weather knowledge and/or have difficulty recalling what was once learned." Burian and Jordan recommended that future research should include more items that cover a broader range of topics. Furthermore, in the 15 years since the Burian and Jordan (2002) study, new weather products and technology have become available to pilots, and pilot knowledge on those products and technology has not been assessed.

After reviewing the literature, it is evident that a research gap exists regarding valid and reliable aviation weather knowledge assessment. A valid and reliable aviation weather knowledge assessment will help aviation weather training researchers to better understand underlying causes of GA pilots' performance decrements in aviation weather tasks. Better understanding of pilots' knowledge will, in turn, aid in assessing the efficacy of training tools and strategies. Additionally, an aviation knowledge assessment will provide the aviation community with a guide for ground school and flight instructors regarding the aviation weather topics to cover with the pilots-in-training, regardless of the rating (e.g., these topics should be covered during CFI initial, recurrent and refresher training). Thus, the purpose of this research was to develop and validate an assessment of GA pilots' knowledge of aviation weather concepts and principles, sources of aviation weather product and how to interpret aviation weather products.

Phase 1: Aviation Weather Knowledge Assessment

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Phase I – Abstract/Overview

Introduction. The Phase I report describes the development and validation of Aviation Weather Knowledge multiple-choice questions for assessing GA pilot knowledge of weather phenomena, aviation weather products, and aviation weather product sources. Phase I included two studies which are referred to as Study 1 and Study 2.

Method. For Study 1, the total number of questions equaled 113. For Study 2, 95 variant questions were developed. Both sets of questions were reviewed by a separate committee composed of aviation subject matter experts for content validation. After content validation, 79 (Study 1) and 204 (Study 2) GA pilots and student pilots completed the knowledge questions. Study participants also completed demographic questionnaires, aviation weather self-efficacy surveys and a weather salience survey.

Results. Analyses of the responses to the knowledge questions included the following: distractor analysis, difficulty level analysis, item-total correlations, and reliability coefficients. The results of the psychometrics analysis were strong. Additionally, a series of analyses were run to determine differences in pilot rating/experience on aviation weather knowledge, self-efficacy, and weather salience.

Discussion. Overall, the pattern of results showed that GA pilots with commercial and instrument ratings have the highest level of aviation weather knowledge and student pilots have the lowest level of aviation weather knowledge. While the former demonstrated the highest levels of knowledge, their scores were still only moderate – around 65%. Private pilots had scores in the 60% range. Taken together, these scores may indicate that pilots flying in GA operations (including private pilots as well as those with commercial certificates and/or instrument ratings) have a relatively low level of aviation weather knowledge. Weather self-efficacy was correlated positively with aviation weather knowledge, but weather salience was not correlated with either weather self-efficacy or aviation weather knowledge. Participants' perceived similar levels of weather training across certificate and/or ratings and flight school, including Part 61, Part 141 (larger programs that emphasize professional pilot training) and Part 142 (flight training centers with simulators).

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Purpose Statement

The purpose of this research was to develop and validate appropriate weather-related test questions to assess GA pilots' knowledge of aviation weather concepts and principles, sources of aviation weather product and how to interpret aviation weather products.

Method

Participants. The assessment of pilots' knowledge of aviation weather was conducted across two studies (Study 1 and Study 2). For both studies, participants were recruited from a southeastern U.S. university. Study 2 also included participants recruited from a Midwestern Airventure airshow. Tables 1 – 4 contain the flight experience demographics for both Study 1 and 2. Participants in Study 1 (n = 79) included certificate holding pilots and student pilots, aged 17 to 33 (Mage = 20.62, SD = 2.57) who were eligible to take, or who had in the past year completed, the FAA Airman's Knowledge Test for either private pilot or commercial pilot certification. A broader sample was included in Study 2. Participants in Study 2 (n = 204), included pilots, aged 15 to 66 (Mage = 22.50, SD = 7.6), with the same eligibility associated with Study 1, as well as pilots with greater flight experience. All pilots held certificates in or were completing training for the following: Private, Private w/ Instrument, and Commercial w/ Instrument. All commercial pilots/commercial-in-training pilots held instrument ratings. Both studies were approved in advance by the Embry-Riddle Aeronautical University Institutional Review Board for the protection of human participants. For incentive, each participant in Study 1 received a compensation of $50 upon completion of the study, while each participant in Study 2 received $20 for participation plus $0.31 per question answered correctly.

Table 1

Mean and Median Flight Hours and Years Flying

	Study 1 (*n* = 79)			Study 2 (*n* = 204)		
		Flight Hours	Years Flying		Flight Hours	Years Flying
	n	M (SD) Median	M (SD)	*N*	M (SD) Median	M (SD)
Student	16	55.31 (33.68) 52.50	1.16 (.91)	41	38.37 (30.83) 35.00	1.82 (2.94)
Private	30	107.77 (44.53) 99.55	1.83 (1.08)	72	128.77 (118.50) 105.00	3.02 (5.32)
Private w/ Instrument	18	148.83 (66.44) 154.50	2.53 (1.27)	50	211.46 (196.68) 172.00	3.55 (2.90)
Commercial w/ Instrument	15	289.07 (94.05) 250.00	3.73 (1.03)	41	479.87 (1015.22) 260.00	6.20 (7.70)

Table 2 displays the average hours for simulated and actual instrument flight hours of the Study 1 and Study 2 participants. As shown, participants completed more simulated instrument hours than actual instrument hours.

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Table 2

Number of Simulated and Actual Instrument Flight Hours per Pilot Rating

	Study 1 *n = 79*			Study 2 *n = 204*		
		Instrument Hours (Simulated)	Instrument Hours (Actual)		Instrument Hours (Simulated)	Instrument Hours (Actual)
	n	M (SD) Median	M (SD)	*n*	M (SD) Median	M (SD)
Student	16	1.67 (2.91) 0	2.71 (7.66)	41	2.01 (3.80) 0	1.38 (4.10)
Private	30	10.43 (8.76) 10	2.61 (4.13)	72	13.07 (12.57) 10	3.06 (5.10)
Private w/ Instrument	18	35.67 (14.55) 34	6.82 (4.25)	50	42.82 (21.75) 40	11.59 (13.74)
Commercial w/ Instrument	15	55.93 (30.48) 50	5.59 (9.04)	41	53.01 (32.96) 50	28.52 (69.10)

Table 3 reveals the U.S. regions in which the majority of the participants' flight hours were achieved. Regions are based on the FAA Chart Supplements (FAA, 2016). A majority of the flight-hour experience was achieved within the Southeastern region for Study 1 and Study 2, with East Central as the second most achieved region for Study 2.

Table 3

Region in which majority of flight hours were experienced

	Study 1	Study 2
	F	*F*
Northwest	0	2

Southwest	1	10
North Central	1	11
South Central	0	6
East Central	1	36
Northeast	3	20
Southeast	72	115
No Response	1	4
Total	79	204

As shown in Table 4, a majority of the Study 1 participants completed most of their flight hours at a Part 141 Collegiate Flight Training program. Study 2 participants had more variability in training affiliation. Most Study 2 participants completed their flight hours at a Part 141 Collegiate Flight Training program, while the second highest number of participants completed their hours at a Part 61 flight school.

Table 4

Aviation Flight Training Affiliation for Majority Hours

	Study 1	**Study 2**
	f	*F*
Part 61	8	60
Part 141/142	53	143
Other	9	0
No Response	9	1
Total	79	204

Equipment. The majority of participants completed all questionnaires on a Dell-computer desktop in a secure testing center on the university campus. The participants from Air

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Venture completed the demographics and attitudinal surveys online and completed the knowledge questions using a booklet of the questions, filling in a paper answer sheet.

Measures. The questionnaires were implemented using an online survey system. The knowledge test was implemented in the Canvas Learning Management System as well as a hardcopy form.

Demographic Data Form. The demographic questionnaire consisted of 19-items. The items were designed to obtain basic information about the participants such as age, flight experience and training, and meteorology training.

Weather Training Questionnaire. This questionnaire was developed after data collection for Study 1 and was given to Study 2 participants only. This questionnaire included 14-items pertaining to aviation weather knowledge training. The questions asked the participants when and where they received weather knowledge training/courses, and how frequently they reviewed aviation weather products.

Aviation Weather Knowledge Assessment. The purpose of the Aviation Weather Knowledge Assessment was to evaluate GA pilots' and pilots-in-training levels of aviation weather knowledge. All questions were multiple choice, and each had 3-4 answer options (i.e., a, b, c; or a, b, c, d).

The research team – consisting of two meteorologists, one Gold Seal Certificated Flight Instructor Instrument (CFII), and two human factors specialists – developed the questions based on the type of weather-related knowledge needed for all phases of flight in the context of GA operations, and in accordance with the FAA Advisory Circular 00-45G, Change 2 (FAA, 2014a), the Federal Aviation Regulations and the Aeronautical Information Manual (FAA, 2014b). This included, but was not limited to basic meteorological knowledge, knowledge of how meteorological phenomena influence flight performance, knowledge of aviation meteorological hazards, and knowledge of weather hazards.

Initially, the research team developed 113 questions. A separate committee consisting of one FAA Aviation Safety Instructor, one human factors specialist, and two FAA aviation knowledge assessment personnel reviewed each question and confirmed the content validity of the questions.

After the data was collected for Study 1, the research team reviewed the item difficulty, item discrimination, and distractor analysis for each question in the 113-item assessment. Based on the results, the research team developed 95 question variants for research purposes.

The purpose of the 95 variants was to evaluate GA pilots' and pilots-in-training levels of aviation weather knowledge across a larger sample size. These 95-multiple choice questions each had 2-4 answer options (i.e., a, b; or a, b, c, d) and were used for Study 2. Again, content validity was ascertained by a separate committee of aviation specialists.

***Self-Efficacy*.** The self-efficacy assessment was designed to evaluate the participants' confidence in aviation weather knowledge concepts and aviation weather skills. The self-efficacy assessment was composed of two separate questionnaires. The first questionnaire (Self-Efficacy A) contained 14-items that asked participants to rate their confidence (from 0-100; 0 meaning not confident and 100 meaning most confident) on various weather-related events, skills, and knowledge. This questionnaire was developed according to Bandura (2006). Based on a sufficiently high Cronbach's alpha for both Study 1 ($\alpha = .93$) and Study 2 ($\alpha = .95$), the items were averaged together for each study and each participant had one composite score for self-efficacy.

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The second questionnaire (Self-Efficacy B) contained 11-items that asked participants to rate their confidence on several different weather-related tasks using a seven-point Likert-scale (1 = Strongly Disagree to 7 = Strongly Agree). Again, based on a sufficiently high Cronbach's alpha for Study 1 ($\alpha = .87$) and Study 2 ($\alpha = .82$), the items were averaged together for each study and each participant had one composite score for aviation weather self-efficacy.

Weather Salience. Weather salience refers to the degree to which individuals are aware of their atmospheric environments and the importance they place on the weather during daily life (Stewart, 2009). The Weather Salience Questionnaire (WxSQ; Stewart, 2009; Stewart et al., 2012) was used for the weather salience portion of the survey. The objective of this questionnaire was to measure various behaviors, beliefs, and attitudes different individuals have about weather-related events. The pilots' weather salience scores were later compared to those from previously tested general populations to see if their scores differed from non-aviation-specific populations. The survey contained 29 questions, with a Cronbach's alpha of .79 and .83 for Studies 1 and 2, respectively.

Responses to items were Likert-style, ranging from 1 (Strongly disagree/Never) to 5 (Strongly agree/Always). All WxSQ scoring was performed in accordance with the procedure described by Stewart (2009). Mean scores were calculated for each of the seven subscales by summing the mean numerical ratings for all items within each subscale. The total WxSQ score was computed by summing the mean numerical ratings for all items. Higher scores on both the total WxSQ score and subscales indicate higher weather salience. Total WxSQ scores can range from 29 to 145. Questions 6, 7, and 8 were reverse scored and four items loaded onto multiple subscales. Weather salience scores from the pilots sampled in Studies 1 and 2 were compared to previously sampled groups studied by Stewart (2009) and Stewart et al. (2012). These groups were students at the University of Georgia (UGA) and a sample of the U.S. population across geographic regions and different age groups.

Procedure. Participants arrived at the data collection site. Each participant was briefed and given an informed consent form to sign. The participants then completed the computer-based surveys in the following order: the demographic questionnaire, the two-part self-efficacy assessment, the weather salience questionnaire, and the weather knowledge assessment test. No time restriction existed; all participants could to take the tests at their own pace. After completing the tests, Study 1 participants were debriefed and received the $50.00 compensation, while Study 2 participants were debriefed and received $20 for participation plus $0.31 per question answered correctly for incentive.

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Results.

The results are described in four sections: Psychometrics, Aviation Weather Knowledge Taxonomy Categories, New Generation products, and Attitudinal results.

Analysis Set I: Psychometrics. A series of analyses were conducted to evaluate the integrity of each individual item on the Aviation Weather Knowledge Assessment. This was to ensure that the aviation weather knowledge results were not skewed by overly difficult, overly easy, or poorly written questions and/or distractors.

Item Difficulty. Item difficulty was assessed by examining the proportion of participants who answered each item correctly. The possible range of the item difficulty index is 0.0 (no participant answered the item correctly) to 1.0 (all participants answered the item correctly).

Table 5 and Table 6 display the stem and leaf plot of the item difficulty analysis for Studies 1 and 2, respectively. Following FAA (2015), P-values above .90 are very easy items as most of the examinees got those items correct, and it may not be worth testing on that concept. In contrast, P-values below .20 are very difficult items and/or may include confusing language and need revision.

For Study 1 (Table 5), the results showed that of the 113 aviation weather knowledge questions, 20 items had P-values of .90 or higher, while nine items achieved a P-value of .29 or below. The median level of difficulty was .72.

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Table 5

Study 1: Stem and Leaf Plot of Difficulty Level Analysis

Stem	Leaf	Total (*f*)
1		0
0.9	0 1 3 4 4 4 4 4 5 5 5 6 6 6 8 8 9 9 9 9	20
0.8	0 0 0 0 0 1 1 3 4 4 4 4 5 5 5 5 6 6 8 9 9 9	22
0.7	0 0 0 2 2 2 5 5 5 7 7 7 8 8 8 8 8 9 9	19
0.6	0 0 2 2 3 3 3 4 4 5 5 5 7 7 7 8 8 9	18
0.5	1 1 2 3 4 4 6 6 7 7 9 9 9	13
0.4	0 2 3 3 6 7 7 7 8 9	10
0.3	6 7	2
0.2	0 5 5 5 6 7 7	7
0.1	0	1
0	1	1
	Total	**113**

For Study 2 (Table 6), of the 95 aviation weather knowledge questions, two items had a P-value of .90 or higher, while 14 items achieved a P-value of .29 or below. The median level of difficulty was .58.

Table 6

Study 2: Stem and Leaf Plot of Difficulty Level Analysis

Stem	Leaf	Total (*f*)
1		0
0.9	1 2	2
0.8	0 0 1 3 3 4 4 5 5 5 6 9	12
0.7	0 1 2 2 2 3 5 6 6 6 7 7 7 8 9 9 9 9	18
0.6	0 0 2 2 2 4 6 6 6 8 8 8 9	13
0.5	0 0 1 1 1 2 2 2 3 3 4 6 6 6 7 8 8 8 8 8 8 9 9	23
0.4	0 0 1 2 3 3 3 8 9	9
0.3	2 3 7 8	4
0.2	0 0 0 1 3 4 5 6 6 8 8	11
0.1	1 2 4	3

0		0
	Total	**95**

Item Discrimination. Item discrimination refers to the degree to which an individual item/question can differentiate between examinees who score highly on the test overall versus those who score poorly on the test overall (Murphy & Davidshofer, 2005). Item-total correlations were calculated to assess item discrimination. Item-total correlations are simple correlations between the score on an individual item (1 = correct; 0 = incorrect) and the total score on the test (i.e., point-biserial correlation). The possible range is r = -1.0 to r = +1.0. A positive item-total correlation indicates that performing well on the item is related to a high score on the exam. A negative item-total correlation indicates that performing well on the item is related to a low score on the exam. A zero correlation indicates no relationship between performance on a particular item and the overall exam.

Note that item difficulty is related to item discrimination as those items that have high P-values ("easy" questions) or very low P-values ("difficult" questions), will have limited correlation with the test overall score (Murphy & Davidshofer, 2005). That is, limited variability occurred in the sample for those easy questions (90% of participants got them correct) and difficulty questions (70-80% of participants got them incorrect), and limited variability ("restricted range") in one variable will limit its' correlation with another variable.

FAA (2015) offers the following guidance for interpreting the item-total correlations: $r \leq .19$ = poor items; r = .20 to .29 = fairly good items; r = .30 to .39 = good items; r = .40 or higher = very good items.

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Table 7 displays the item-total correlations for Study 1(the 113 knowledge questions). According to FAA (2015), 79 of the items fall in the fairly good to very good range, and 34 items fall in the poor range.

Table 7

Study 1 - Aviation Weather Item discrimination: Item-Total Correlations

Item-Total Correlation	Question Number	Total
< 0	1, 103, 109	3
0 < r < .1	5, 25, 26, 27, 30, 35, 54, 62, 94, 100, 104, 106, 108	13
.1 < r < .2	17, 20, 21, 22, 33, 34, 38, 51, 52, 53, 61, 78, 90, 96, 98, 101, 105, 113	18
.2 < r < .3	2, 3, 6, 7, 11, 12, 13, 28, 32, 46, 49, 50, 57, 63, 65, 75, 83, 88, 93, 97, 102, 107, 111	23
.3 < r < .4	4, 8, 9, 10, 14, 18, 19, 24, 31, 36, 39, 40, 43, 55, 56, 58, 64, 66, 67, 68, 69, 70, 71, 74, 76, 77, 79, 80, 81, 82, 84, 85, 89, 91, 92, 95, 99, 110	38
.4 < r < .5	15, 16, 23, 29, 37, 44, 45, 48, 59, 60, 72, 73, 86, 87, 112	15
.5 <	41, 42, 47	3

Considering item discrimination together with the item difficulty results, it is unsurprising that 34 items fall into in the poor range for item discrimination. Specifically, 31 items fell in “very easy or very difficult” P-values (Table 5). So, the item difficulty results correspond well with the item-total correlation results.

Table 8 displays the item-total correlations for the 95 knowledge questions in Study 2. According to FAA (2015), 79 of the items fall in the fairly good to very good range, and 16 items fall in the poor range.

Table 8

Study 2 - Aviation Weather Item discrimination: Item-Total Correlations

Item-Total Correlation	**Question Number**	**Total**
< 0	90	1
0 < r < .1	10, 42, 60, 69, 83, 93	6
.1 < r < .2	13, 28, 37, 41, 66, 80, 82, 86, 88	9
.2 < r < .3	8, 12, 16, 23, 25, 27, 32, 50, 53, 55, 59, 71, 77	13
.3 < r < .4	6, 9, 15, 20, 21, 29, 30, 31, 40, 43, 45, 48, 52, 54, 56, 61, 70, 76, 79, 84, 89, 94	22
.4 < r < .5	1, 2, 4, 5, 7, 11, 14, 18, 19, 22, 24, 26, 33, 39, 44, 46, 49, 57, 58, 62, 63, 67, 72, 73, 74, 75, 78, 81, 85, 87, 91, 92	32
.5 <	3, 17, 34, 35, 36, 38, 47, 51, 64, 65, 68, 95	12

Distractor Analysis. A distractor analysis was conducted to access the quality and performance of the distractors for items that fell within the difficulty index of 0.70 to 0.79.

For Study 1 (see Table 9), fourteen of the 19 items contained an unbalanced usage of distractors. Eight of those 14 had only one distractor primarily used, while the remaining six used all the distractors, albeit unevenly. The remaining four out of 19 items contained distractors that were all used equally.

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Table 9

Study 1: Distractor Analysis of Weather Questions with 0.70 - 0.79 Difficulty Index

Number of distractors used	Balance of distractor use	Item Number	Total (*f*)
Primarily 1 Distractor	Unbalanced	5, 8, 14, 39, 47, 74, 87, 101	8
All Distractors	Unbalanced	19, 44, 70, 99, 108, 110	6
All Distractors	Balanced	18, 31, 42, 51	4

For Study 2, as shown in Table 10, eighteen of the 20 items contained an unbalanced usage of distractors. The remaining two items contained distractors that were all used about equally.

Table 10

Study 2: Distractor Analysis of Weather Questions with 0.70 - 0.79 Difficulty Index

Number of distractors used	Balance of distractor use	Item Number	Total (*f*)
Primarily 1 Distractor	Unbalanced		0
All Distractors	Unbalanced	1, 2, 9, 22, 23, 24, 30, 38, 47, 52, 56, 58, 64, 68, 72, 81, 84, 91	18
All Distractors	Balanced	17, 35	2

This pattern indicates improvement in the distractors in Study 2 compared with Study 1.

Reliability. Reliability was assessed using Cronbach's Alpha measure of internal consistency (i.e., the KR-20 on dichotomous items). Internal consistency is a method of calculating reliability that involves consistency of performance across items—in other words, inter-item correlations (Murphy & Davidshofer, 2005). As described in Murphy and

Davidshofer (2005), factors affecting reliability include characteristics of people taking the test (e.g., how homogeneous they are) and characteristics of the test itself (e.g., both correlations between items and the number of items—more items are better).

For Study 1, across all 113 knowledge questions, α = .88. In Study 1, the participants had some variability in terms of aviation weather and flight experience, but in general they had a fairly low number of flight hours, years flying, and a limited geographical region of experience. The homogenous nature of the Study 1 participants may have reduced the calculated level of internal consistency. At the same time, the test was 113-items. The length likely increased the reliability/internal consistency, as longer tests are more reliable (Murphy & Davidshofer, 2005).

For Study 2, across all 95 knowledge questions, C = .92. It is unclear why the internal consistency increased from Study 1 to Study 2. The .04 increase may be from the more varied nature of the Study 2 participant

This concludes the psychometric portion of this report. The next sections contain analyses of the aviation knowledge scores.

Analysis Set II. Aviation Weather Knowledge Taxonomy.

Overall aviation weather knowledge results. A series of analyses were conducted on the aviation weather knowledge results. As the Study 1 questions were for official use only (FOUO), the analyses focused primarily on the data collected on the 95-knowledge questions in Study 2. Means and standard deviations, however, are reported for both Study 1 and Study 2 as appropriate.

First, the means for overall score (percent correct) on the aviation weather knowledge questions by pilot rating for Study 1 and Study 2 are shown in Table 11.

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Table 11

Overall Aviation Weather Knowledge Score (Percent Correct) by Pilot Rating

	Study 1 – Question Set 1		**Study 2 – Question Set 2**	
	n	M (SD)	n	M (SD)
Student	16	62.33 (7.35)	41	47.65 (13.61)
Private	30	67.17 (8.61)	72	56.62 (15.67)
Private w/ Instrument	18	73.11 (9.80)	50	61.77 (12.93)
Commercial w/ Instrument	15	77.52 (8.49)	41	65.62 (14.50)
Total	79	69.51 (9.99)	204	57.89 (15.55)

As can be seen in Table 11, the percent correct appear higher in Study 1 than Study 2. This likely corresponds to the increased level question difficulty discussed previously in this paper.

Figure 1 displays Study 2's overall aviation weather knowledge scores by pilot certificate/rating. For study 2, a one-way between group analysis of variance (ANOVA) was conducted to analyze differences between pilot certificate/rating (Student, Private, Private w/ Instrument, and Commercial w/ Instrument) on overall aviation weather knowledge scores. A statistically significant difference between groups did appear F (3, 200) = 12.25, $p < .01$. To test for homogeneity of variance, Levene's Statistic was found to be insignificant ($p > .05$) and therefore our group variances can be treated as equal. A Tukey post hoc test revealed that the overall percent correct of Student pilots (M = 47.65, SD = 13.61) was significantly less than that of Private pilots (M = 56.62, SD = 15.67, $p < .01$), Private pilots with Instrument rating (M = 61.77, SD = 12.93, $p < .01$), and Commercial pilots with Instrument rating (M = 65.62, SD = 14.50, $p < .01$). The post hoc test also revealed that Commercial pilots with Instrument rating had significantly higher composite test scores compared to Private pilots (p = .009). No other between group differences appeared.

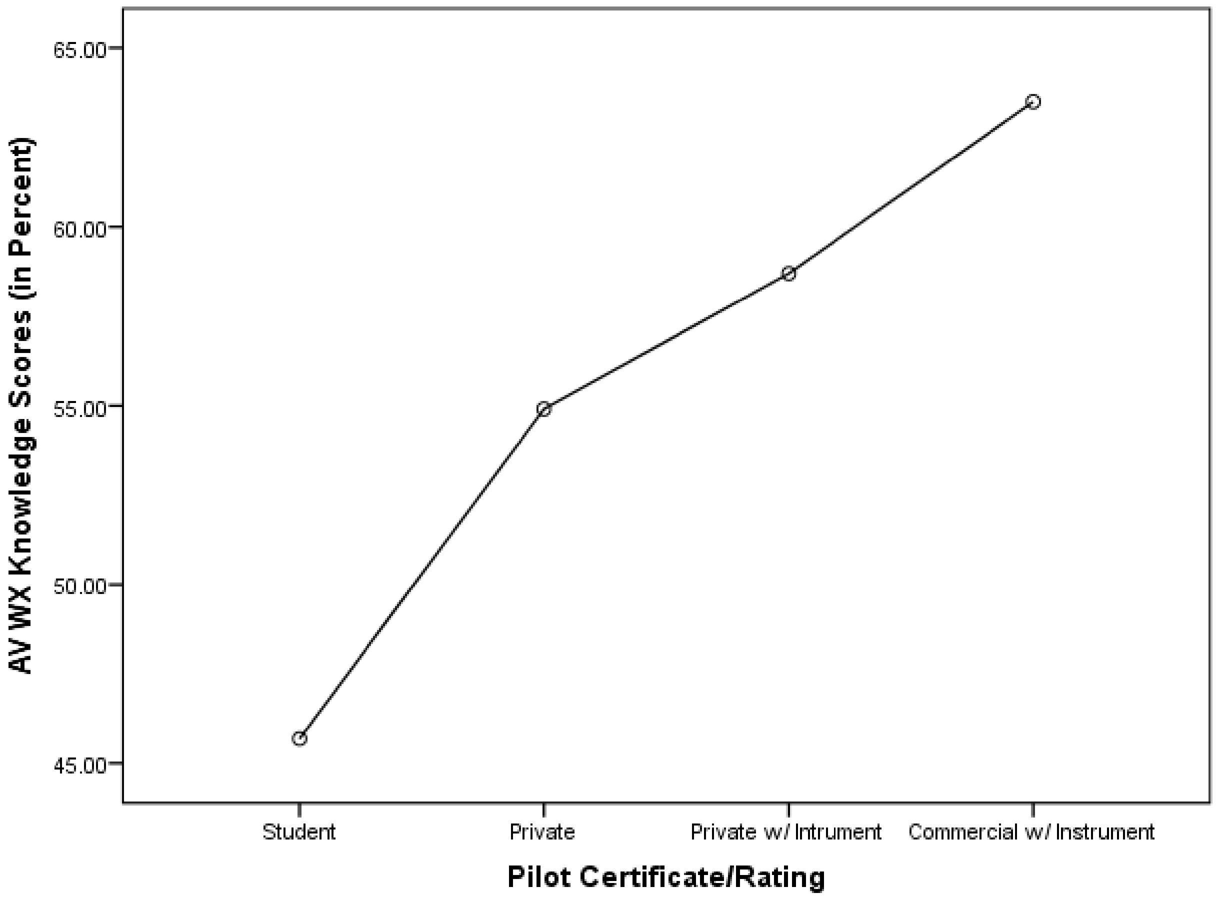

Figure 1. Overall Aviation Weather Knowledge Score by Pilot Certificate/Rating (Study 2)

Summary: Overall knowledge. Student pilots scored the lowest and were significantly lower than all other groups. Commercial pilots scored the highest, but not significantly higher than private w/ instrument pilots. This indicates that while weather knowledge increased across the certificate and/or rating continuum, the biggest differences appeared between student pilots and private pilots and also between private pilots and commercial pilots with instrument ratings.

Overview: Knowledge Taxonomy Categories. Next, the 95 questions for Study 2 were grouped conceptually according to an Aviation Weather Knowledge Taxonomy developed by

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Lanicci et al. (2017) (for the full Taxonomy, see Appendix A). This taxonomy was created to provide a framework for developing appropriate materials for pilot education and training in aviation weather principles and determining the necessary skills for proper interpretation of weather information and integration into aeronautical decision making. The taxonomy was developed by a team of aviation meteorologists, certificated flight instructors, and human factors specialists. The framework categorizes aviation weather knowledge into three major categories: a) weather phenomena and hazards, b) weather hazard products, and c) weather hazard product sources. The goal for the third category is to help pilots make sense of the vast number of available options for including weather information into flight planning and real-time aeronautical decision making.

The weather phenomena and hazards category encompass fundamental meteorological principles that are necessary for pilots to know for ensuring safety of flight. The weather phenomena and hazards category are subdivided into three sub tiers: a) basic knowledge of meteorological phenomena, b) knowledge of how meteorological phenomena affect flight performance, and c) knowledge of aviation weather hazards. Within knowledge of basic meteorological phenomena, there are subcategories containing elementary meteorological principles and processes (e.g., forces that create wind). Knowledge of how meteorological phenomena affect flight performance consists of subcategories organized by principle of flight performance (e.g., drag, thrust, weight). Next, knowledge of aviation weather hazards lists the various hazards such as IMC, turbulence, icing, thunderstorms and lightning, non-convective low-level wind shear, and volcanic ash.

The weather hazard products category includes all standard aviation weather analysis and forecast products (e.g., METARs, PIREPs, TAFs, SIGMETs and AIRMETS), as well as more general weather products that would be used by meteorologists (e.g., satellite, radar). This category also includes knowledge of how to use different hazard products during various flight phases, and includes specifics such as knowledge of product limitations, product availability times, and product providers. An example would be the proper use of real-time, data-linked NEXRAD during flight by being cognizant of the data latency issues.

The weather hazard product sources category provides information regarding how vendor weather products are derived, with the purpose of making reliable and appropriate decisions when integrating weather into aeronautical decision-making, whether in planning or in-flight. This category is divided into three sub tiers: a) understanding how products are created, b) knowledge of differences between various vendor products, and c) knowledge of how and when to use different product during different flight phases. An important part of this category involves basic principles of flight planning and how to integrate various approved products into the decision-making process.

The taxonomy was applied to the 95 aviation weather knowledge questions in order to facilitate assessment on multiple levels of aviation knowledge principles and skills. The differences in student knowledge scores between the three major categories of aviation weather knowledge (weather phenomena and hazards, weather hazard products, and weather hazard product sources) were examined. The mean knowledge scores for the three major categories are shown in Table 12. Note that the overall scores for the different pilots' ratings differ somewhat from the means in Table 11. The difference is due to some questions falling in more than one of the three knowledge categories.

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Table 12

Mean Scores by Knowledge Taxonomy Category and Pilot Rating (Study 2)

		WX Phenomenology	WX Products	WX Product Sources	Overall Knowledge Score
	n	M (SD)	M (SD)	M (SD)	M (SD)
Student	41	48.47 (14.38)	47.71 (14.06)	59.27 (19.92)	51.82 (2.38)
Private	72	57.34 (16.28)	56.72 (15.90)	67.08 (20.52)	60.41 (1.80)
Private w/ Instrument	50	64.13 (14.47)	61.65 (13.71)	71.60 (18.22)	65.79 (2.16)
Commercial w/ Instrument	41	65.93 (14.45)	66.34 (16.05)	77.56 (20.59)	69.95 (2.38)
Total	204	58.98 (16.26)	58.05 (16.05)	68.73 (20.64)	

Taxonomy major categories and pilot certification/rating on scores. A 3 x 4 mixed analysis of variance was conducted to assess the impact of pilot rating (the between factor - Student, Private, Private w/ Instrument, Commercial w/ Instrument) and category of knowledge (the within factor - Weather phenomena, Weather hazard products, and Weather hazard product sources) on knowledge score (see Figure 2).

Figure 2 displays the main effect means for knowledge category on score. A main effect occurred for knowledge categories on scores, Wilks' Lambda = .62, $F(2, 199) = 62.19$, $p < .01$, partial $\eta^2 = .39$; 39% of variance in scores is accounted for by knowledge categories. Post hoc paired-samples t-tests with a Bonferroni correction of the three knowledge categories revealed weather hazard product source scores ($M = 68.73$, $SD = 20.64$) were significantly higher than both weather phenomena ($M = 58.98$, $SD = 16.26$) with $t(203) = 9.74$, $p < .01$, and weather hazard products ($M = 58.05$, $SD = 16.05$) with $t(203) = 11.45$, $p < .01$. No significant difference

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between scores on knowledge of weather phenomena and weather hazard products, $t(203) = 1.82$, $p = .07$.

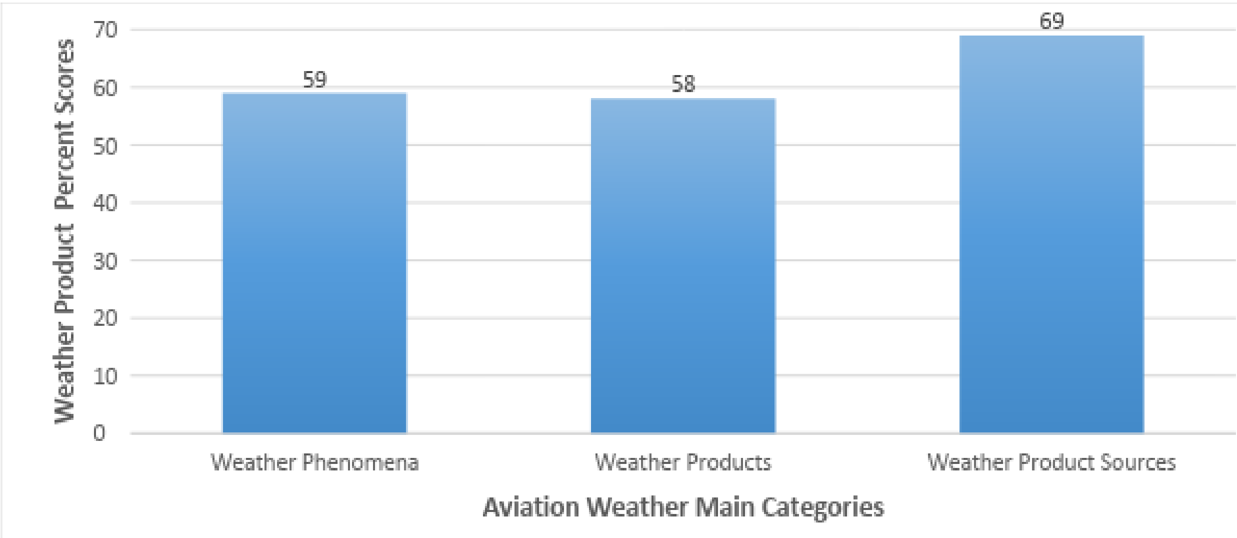

Figure 2. Main Effect of Aviation Weather Main Categories on Aviation Weather Knowledge Scores

Higher scores on weather hazard product sources questions may be indicative of the product source questions being easier than the questions about phenomenology and/or weather products themselves. Alternately, it may be pilots are better trained in weather product sources than the other two categories of knowledge.

Figure 3 displays the main effect means for pilot certificate/rating on score. The main effect comparing the four pilot ratings was also significant, $F(3, 200) = 11.07$, $p < .01$, partial $\eta^2 = .14$, suggesting there was a difference between the ratings on knowledge scores; 14% of the variance in knowledge scores was accounted for by pilots' certificate/rating. Post hoc analysis showed student pilots ($M = 51.82$, $SD = 2.38$) scored significantly lower than private ($M = 60.41$, $SD = 1.80$), private w/ instrument ($M = 65.79$, $SD = 2.16$), and commercial w/ instrument pilots ($M = 69.95$, $SD = 2.38$). However, private pilots did not differ significantly from private pilots with instrument ratings (p = .23), and private pilots with instrument ratings did not differ significantly from commercial pilots with instrument (p = .57).

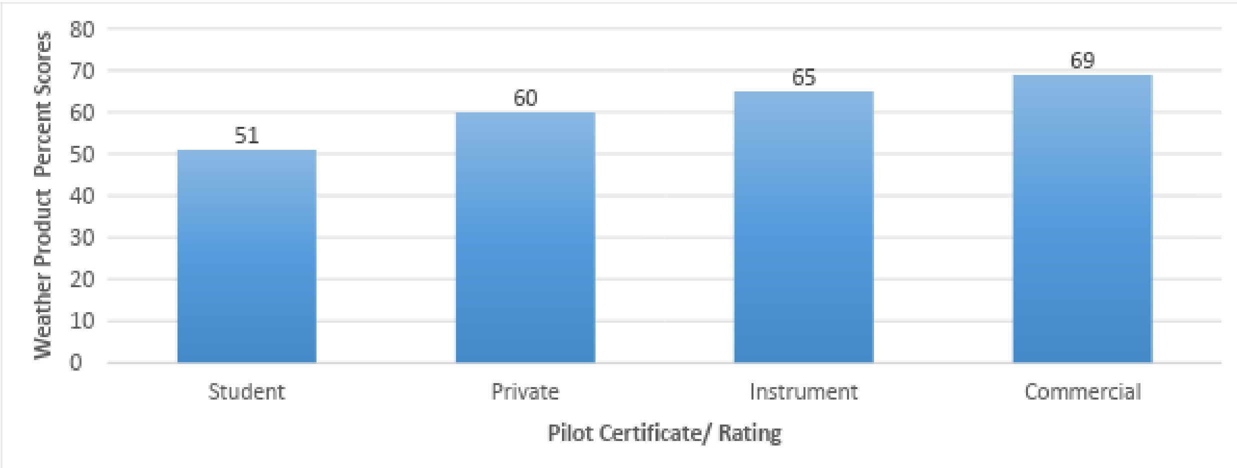

Figure 3. Main Effect of Pilot Certificate/Rating on Aviation Weather Knowledge Scores

Figure 4 shows the means for score in the categories by pilot certificate and/or rating. No significant interaction appeared between pilot rating and the three knowledge categories, Wilks' Lambda = .02, $F(6, 398) = .75$, $p = .61$, partial $\eta^2 = .01$.

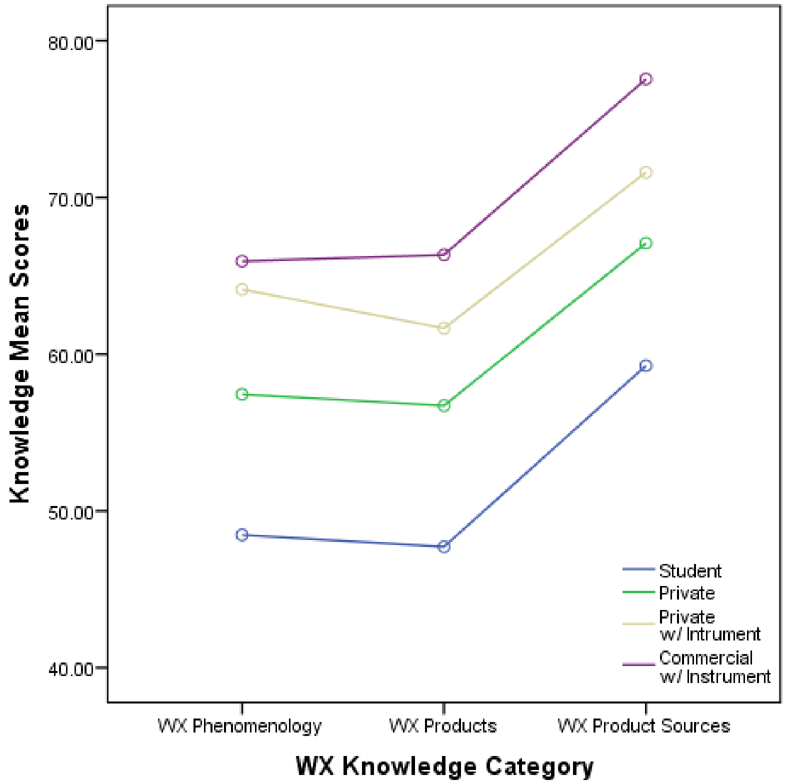

Figure 4. Aviation Weather Knowledge Category by Pilot Certificate/Rating (Study 2)

Summary: Phenomena, Hazard Products, Hazard Product Sources. Regardless of pilot experience or ratings, pilots scored higher on weather product source questions then they did on weather phenomena and weather product questions. These results suggest that pilots may have more difficulty answering questions concerning the basic principles of weather phenomena and weather product interpretation, and in turn, have a better understanding of where to find products and product limitations.

Additionally, the analysis determined that student pilots scored significantly lower on all weather knowledge questions when compared to private, private w/ instrument, and commercial pilots. These results may suggest that as student pilots gain private-pilot certification, they also gain more aviation weather knowledge. However, beyond private-pilot certification, no significant differences in experience occurred.

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Aviation Weather Knowledge Subcategories. Next the questions in the three major categories (weather phenomena, weather hazard products, and weather hazard product sources) were grouped conceptually into the subcategories of the respective taxonomy categories (see Appendix A).

Tables 13a and 13b, 14a and 14b, and 15a and 15b provide the names of the subcategories, Cronbach's alphas, and means. A series of mixed (between and within) ANOVAs examined the effects of rating and knowledge subcategory on knowledge score.

Weather Phenomena Subcategories. The weather phenomena category encompasses all basic fundamental principles about weather conditions and phenomena, definitions, and weather processes. Weather phenomena includes: basic knowledge of aviation weather knowledge, knowledge of how meteorological phenomena affect flight performance, and knowledge of aviation weather hazards. The weather phenomena questions include concepts relating to satellite data, weather radar, lightning and thunderstorms, definitions of Low Instrument Flight Rules (LIFR), Instrument Flight Rules (IFR), Marginal Visual Flight Rules (MVFR), Visual Flight Rules (VFR), turbulence, thunderstorms, and icing (see Table 13a and 13b for definitions and means).

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Table 13a

Aviation Weather Phenomena Questions (based on the Lanicci et al., (2017) taxonomy)

Category	Taxonomy Code	Taxonomy Label	Question #	Frequency	Des
Satellite Data	1003	Satellite Data	4, 19, 32, 33	4	Knowledge of Basi
	1003-d	Relating cloud temperature to height	30, 92	2	Knowledge of Basi relating cloud temp
Weather Radar	1011	Weather Radar	11, 88	8	Knowledge of Basi
	1011b	Composite and Base Reflectivity	21, 25, 55, 78, 80	5	Knowledge of Basi Composite and Bas
	1011c	Decibels, Echo intensity, VIP levels	21, 25, 32, 80	4	Knowledge of Basi Decibels, Echo inte
Lightning and Thunderstorms	1013	Lightning and Thunderstorms	11, 42, 53	3	Knowledge of Basi Thunderstorms Phe
	1013i	Type of thunderstorm complexes (single cell, multi cell, super cell)	10, 20, 41	3	Knowledge of Basi Thunderstorms Phe thunderstorm type.
Knowledge of LIFR, IFR, MVFR, VFR definitions	1201e	Definitions of LIFR,IFR,MVFR and VFR	1, 12, 14, 28, 36, 61, 68, 75, 79	9	Knowledge of IFR a limitation, and effe
Turbulence	1202	Turbulence	1, 14, 37, 68, 75	5	Knowledge of turbu flight performance
Thunderstorm	1204	Thunderstorms	11, 27, 41, 42, 53	5	Knowledge of basic phenomena and effe performance
Icing	1206	Icing	1, 14, 35, 68, 75	6	Knowledge of Icing effects on flight per
	1206c	Impact of supercooled large droplets (SLDs)Impact of supercooled large droplets (SLDs)	51	1	Knowledge of supe and effects on fligh

Note: * denotes the weather subcategories that were not analyzed within the aviation weather knowledge subcategories a question amount.

Table 13b

Weather Phenomena Means

Weather Phenomena Subcategories		Number of Questions		Cronbach's Alpha		Student		Private		Private w Instrumen
		Study 1	Study 2	Study 1	Study 2	Study 1 *n=16*	Study 2 *n=41*	Study 1 *n=30*	Study 2 *n=71*	Study 1 *n=18*
1003	**Satellite Data**	7	6	.74	.53	52(25)	42(28)	52(25)	53(27)	55(30)
1011	**Weather Radar**	9	8	.34	.43	45(14)	52(22)	52(19)	56(23)	56(21)
1013	**Lightning and Thunderstorm Phenomena**	6	6	.30	.24	53(14)	36(17)	50(24)	49(20)	56(23)
1204	**Thunderstorm Flight Application**	8	5	.23	.34	58(18)	41(21)	59(18)	55(24)	68(15)
1201e	**Knowledge of LIFR, IFR, MVFR, VFR definitions**		9		.55		59(21)		67(20)	
1202	**Turbulence**		5		.43		66(27)		71(25)	
1206	**Icing**		6		.66		65(29)		70(26)	
	Total	30	31	.64	.76	56(11)	48(15)	57(14)	57(16)	66(16)

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A 4 x 7 mixed analysis of variance was conducted to evaluate the impact of pilot certificate/rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and Weather Phenomena Subcategory (satellite data (1003), weather data (1011), lightning and thunderstorm phenomena (1013), definitions of LIFR,IFR,MVFR and VFR (1201), turbulence (1202), Thunderstorms (1204), Icing (1206)) on knowledge score. Figure 5 displays the analysis design/matrix and the main effect means.

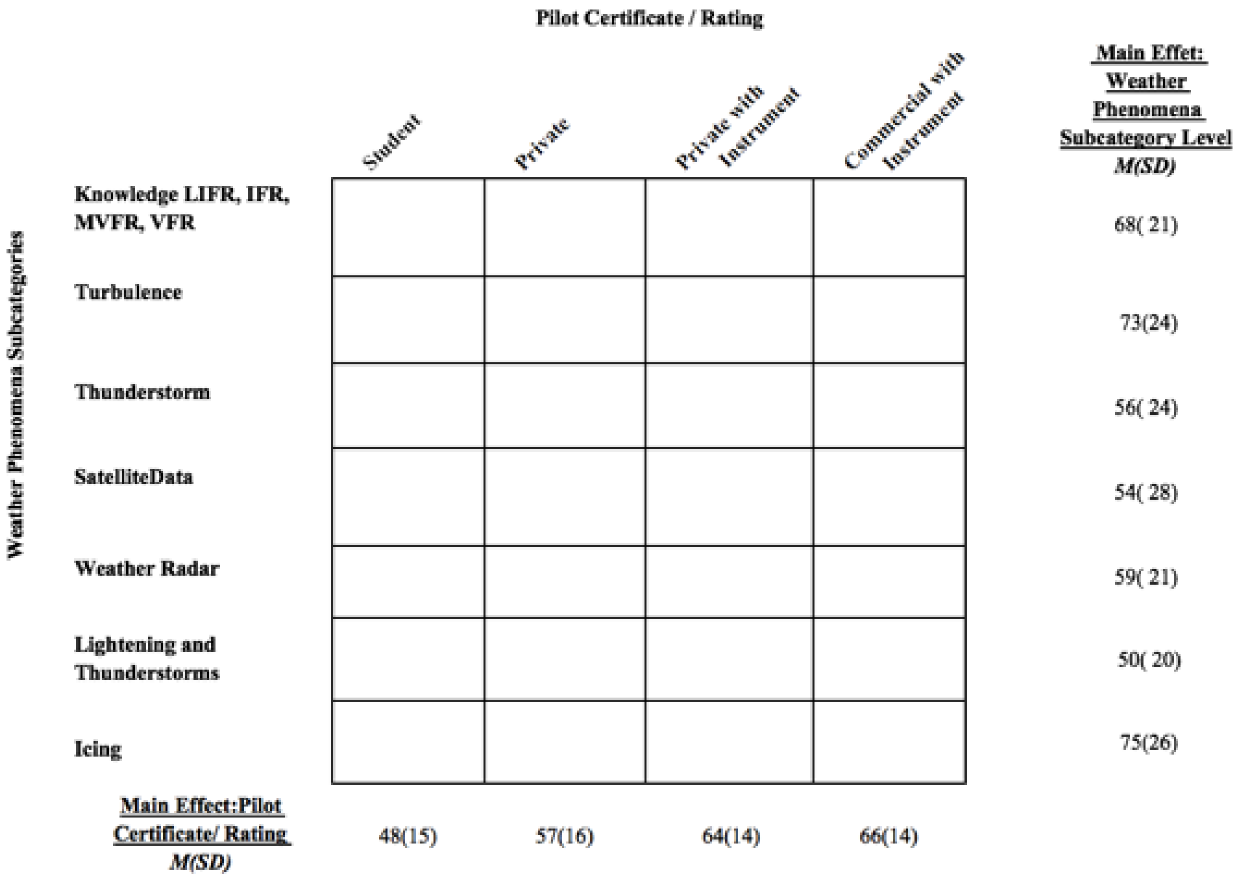

Figure 5. Analysis of Pilot Rating and Weather Phenomena Subcategory on Scores

There was a significant main effect of Weather Phenomena Subcategories on score, Wilks' Lambda = .43, $F(6, 195) = 43.14$, $p < .01$, partial $\eta^2 = .57$. In other words, regardless of participant experiences, differences existed between subcategories of weather phenomena. Partial eta squared indicates that 57% of variances in scores is accounted for by Weather Phenomena Subcategories. Figure 6 displays the means for the weather phenomena subcategories.

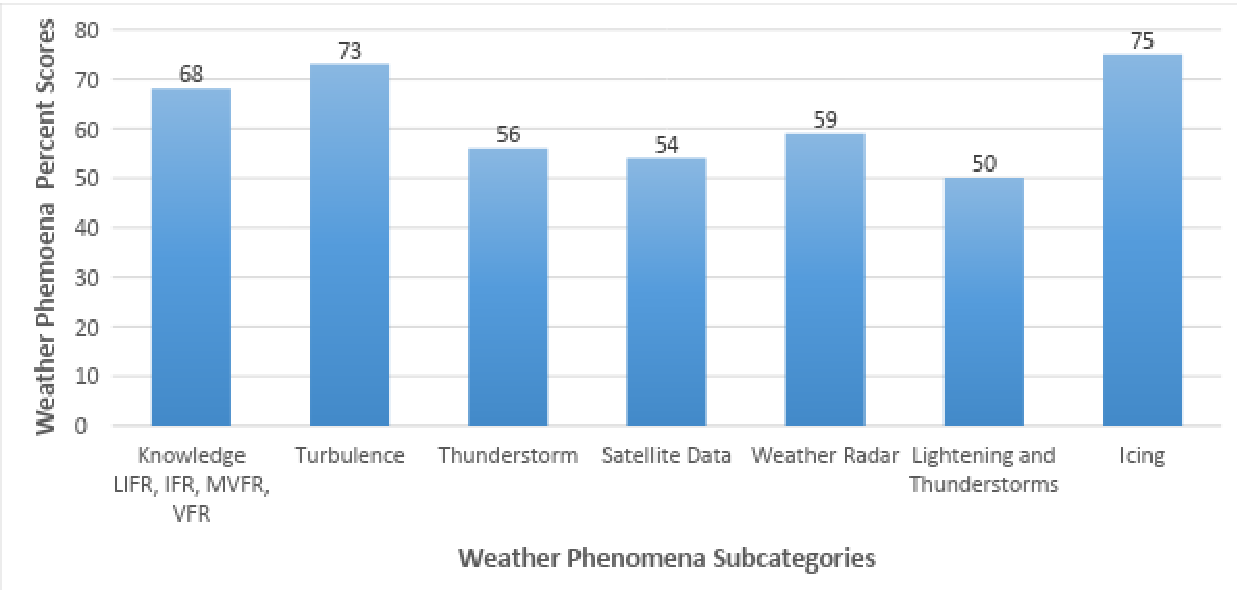

Figure 6. Weather Phenomena Subcategories on Scores

Post hoc pairwise comparisons were performed on Weather Phenomenology Category levels to investigate differences of scores. Regardless of participant experiences, participants' scores on Icing (*M* = 74.84, *SD* = 26) and Turbulence (*M* = 73.04, *SD* = 24) (1206 and 1202) were significantly higher than their scores on definitions of LIFR, IFR, MVFR ($p < .01$) and VFR (1201e) (*M* = 68.52, *SD* = 21; $p < .01$), which, in turn, were significantly higher than their scores on Thunderstorms (*M* = 55.88, *SD* = 24; $p < .01$), Satellite (*M* = 54.08, *SD* = 28; $p < .01$), Radar (*M* = 59.25, *SD* = 21; $p < .01$), and Lightening concepts (*M* = 49.51, *SD* = 20; $p < .01$) (1204, 1003 1011, 1013).

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In addition and regardless of the weather phenomena subcategories, there was a significant main effect of Pilot rating on scores, $F(3, 200) = 12.35$, $p < .01$, partial $\eta^2 = .16$; 16% of variance in scores is accounted for by Pilot rating. Figure 7 displays the means for the main effect of pilot certificate/rating on score. Bonferroni post hoc comparisons were performed to evaluate differences in scores between pilot rating levels. Student pilots performed significantly lower overall on weather phenomena questions than did Private (p =.032), Private w/ Instrument ($p < .01$), and Commercial rated pilots ($p < .01$). Private rated pilots' scores were significantly lower than commercial rated pilot scores ($p = .032$), but not lower than private w/ instrument rated pilot scores, ($p = .068$). There was also not a significant difference between private w/ instrument and Commercial rated pilot scores, p =1.00.

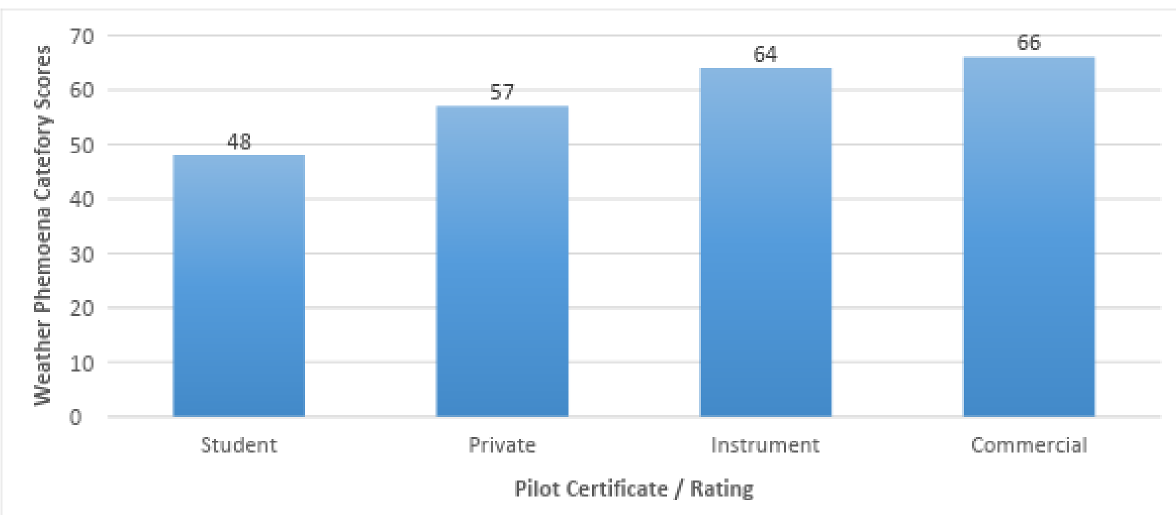

Figure 7. Pilot Certificate and/or rating on Overall Weather Phenomena Score

Next, the interaction effect of pilot certificate and weather phenomena topic was examined. Figure 8 displays the means for the interaction effect of Pilot Certificate/Rating and Weather Phenomena on Score. There was a significant interaction between Pilot Rating and knowledge of Weather Phenomena questions, Wilks' Lambda = .0.856, $F(18, 552) = 1.738$, p = .03, partial $\eta^2 = .05$. This result indicates that there is a combined effect of Pilot rating and Subcategories of Weather Phenomena on scores, and 5% of the variability in score can be explained by a knowing both subcategory and the pilot experience.

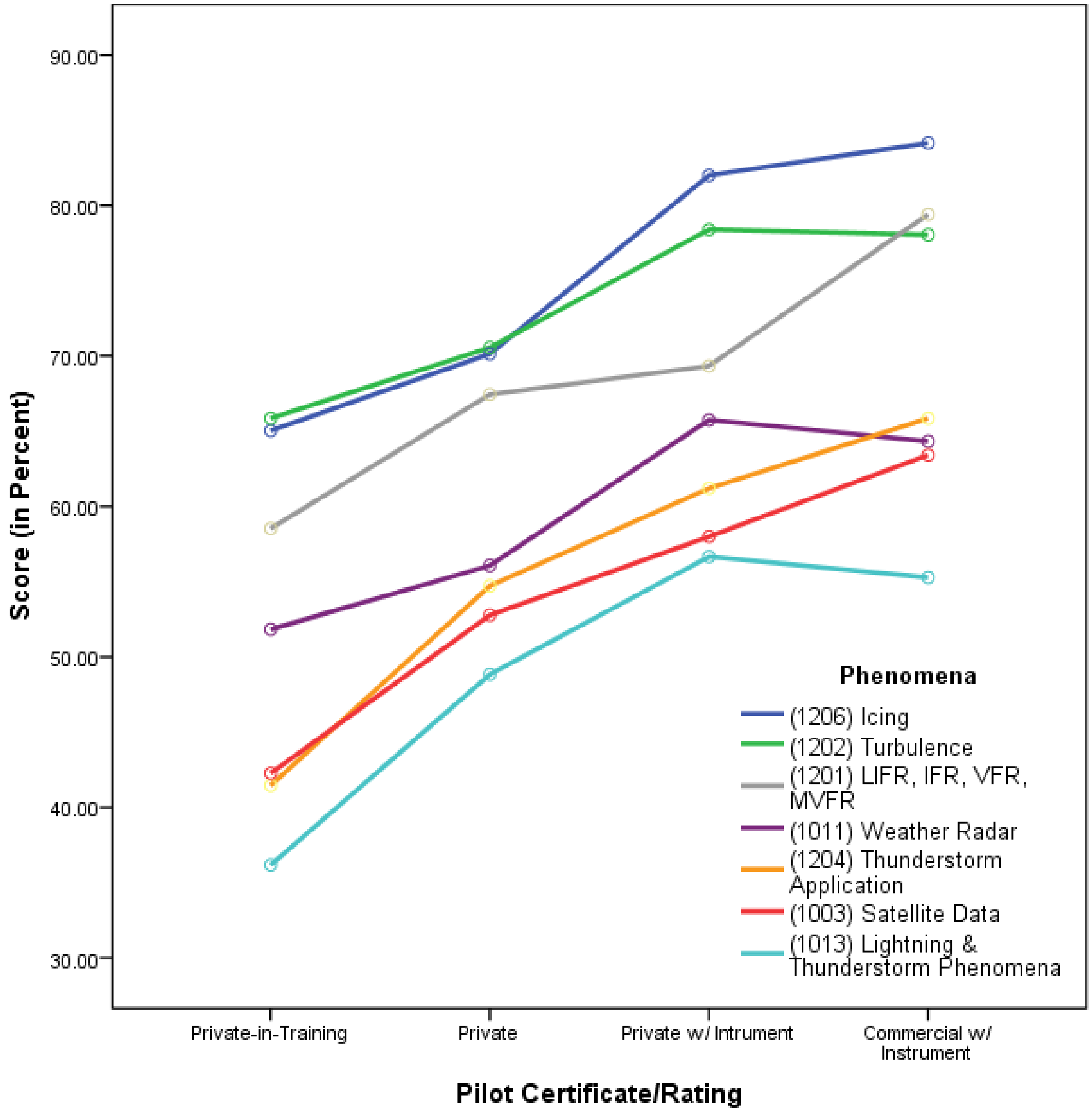

Figure 8. Means for Interaction Effect of Pilot Certificate/Rating and Weather Phenomena on Score

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Simple effect analyses revealed student pilots scored significantly lower on questions relating to satellite data (1003) and lightning and thunderstorm phenomena (1013) than on questions relating to weather radar (1011), LIFR, IFR, MVFR and VFR (1201e), turbulence (1202), and icing (1206), $p < .05$. However, there was no significant difference between satellite data (1003) and lightning and thunderstorm phenomena (1013), $p = .20$, and satellite data and the application of thunderstorms on flight performance (1204), $p = .88$. Student pilots also scored higher on the application of thunderstorm on aircraft performance (1204) than on lightning and thunderstorm phenomena (1013), $p = .01$; however, they scored significantly lower on the application of thunderstorm on aircraft performance (1204) than on weather radar (1011), LIFR, IFR, MVFR and VFR (1201e), turbulence (1202), and icing (1206), $p < .05$. They also scored significantly higher on icing (1206) than on the other subcategories except there was no significant difference between icing and turbulence (1202) ($p = .72$). However, student pilots scored significantly higher on turbulence than on satellite data, weather radar, thunderstorm applications, and LIFR, IFR, MVFR and VFR ($p < .05$).

For private pilots, the simple effect analyses revealed private pilots scored significantly higher on icing (1206) and turbulence (1202) than on the remaining phenomena subcategories ($p < .01$); however, there was no significant difference between icing and turbulence scores ($p = .81$). There was also no significant difference between icing and LIFR, IFR, MVFR and VFR ($p = .19$). Private pilots also scored the lowest on questions relating to satellite data (1003) and lightning and thunderstorm phenomena (1013) than on questions relating to LIFR, IFR, MVFR and VFR (1201e), turbulence (1202), and icing (1206), $p < .01$. However, there was no significant difference between satellite data (1003) and lightning and thunderstorm phenomena (1013), $p = .27$, satellite data and weather radar (1011), $p = .29$, and satellite data and the application of thunderstorms on flight performance (1204), $p = .63$. Private pilots also scored lower on lightning and thunderstorm phenomena than on weather radar ($p = .01$), but weather radar scores were lower than LIFR, IFR, MVFR and VFR and turbulence scores ($p < .01$). Private pilots also scored lower on the application of thunderstorms on flight performance than on turbulence and LIFR, IFR, MVFR and VFR ($p < .01$).

The simple effect analyses also revealed that private w/ instrument pilots scored the highest on questions relating to icing and scored the lowest on questions relating to lightning and thunderstorm phenomena than the other phenomena subcategories ($p < .01$); however, there was no significant difference between icing and turbulence ($p = .08$) or between lightning and thunderstorm phenomena and satellite data ($p = .76$). Satellite data scores were significantly lower than weather radar, turbulence, and LIFR, IFR, MVFR and VFR scores ($p < .05$), but not than thunderstorm applications; there was no significant difference between satellite data and thunderstorm application scores ($p = .51$). Private w/ instrument pilots also scored significantly higher on questions relating to turbulence than on the other phenomena subcategories ($p < .001$), except for on icing (in which there was no significant difference). Lastly, private w/ instrument pilots also scored higher on LIFR, IFR, MVFR and VFR than on the application of thunderstorms on flight performance ($p < .01$).

For commercial w/ instrument pilots, the simple effect analyses revealed commercial pilots scored the highest on questions related to icing and the lowest on questions relating to lightning and thunderstorm phenomena than the other phenomena subcategories ($p < .01$) as well; however, there was no significant difference between icing and LIFR, IFR, MVFR and VFR scores ($p = .08$). Commercial pilots also scored significantly higher on LIFR, IFR, MVFR and VFR than on satellite data, weather radar, and thunderstorm applications ($p < .01$).

Moreover, commercial pilots scored significantly higher on questions relating to turbulence than on questions relating to satellite data, weather data, and thunderstorm applications ($p < .01$).

Weather Phenomena Subcategories. ***Summary: Weather Phenomena Subcategory.*** Disregarding pilot experience, pilots scored higher on icing, turbulence, definitions of LIFR, IFR, MVFR and VFR questions then they did on all other weather phenomena questions. These results suggest that pilots may have more difficulty answering questions concerning other basic principles of weather phenomena (such as Thunderstorms, Satellite, Radar, and Lightning), which may in turn have a negative influence on participants' product interpretation and aviation weather decision making.

Regarding pilot experiences, student pilots scored the lowest on all weather phenomena questions, but only *statistically significantly* lower than commercial pilots on these weather phenomena questions. Additionally, the lack of significant difference between private w/ instrument and private scores results may imply that there is not a significant difference in knowledge of weather phenomena principles between these two populations. This same theory may apply for private w/ instrument and commercial participants.

In terms of the interaction between experience and weather phenomenology topic, simple effect analysis highlighted only very small deviations from the general pattern in weather phenomena question scores.

Weather Hazard Products Subcategories. The weather hazard products category includes subcategories relating to weather products, forecasts, and weather reports. Questions categorized under this section are primarily oriented towards product interpretation (see Tables 14a and 14b for definitions and means).

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Table 14a

Aviation Weather Hazard Product Questions (based on Lanicci et al., (2017) Taxonomy)

Category	Taxonomy Code	Taxonomy Label	Question #	Frequency	Des
Interpreting Surface Weather Information and PIREPs	2001a	Elements of a METAR observation	8, 12, 28, 31, 44, 45, 59, 60, 82, 84, 94, 83	12	Interpretation of ME
	2001e	Elements of a TAF	13, 29, 34, 39, 47, 64, 71	7	Interpretation of TA
	2001g	Change groups (TEMPO, FM, BECMG, PROB)	13, 29, 39, 47, 71	5	Interpretation of var as TEMPO, FM, BE
	2001h	Elements of a PIREP	23, 24, 58, 62	4	Interpretation of PI
	2001i	Elements of a surface station plot	8, 59, 60, 82	4	Interpretation of Su
Interpreting Upper-Level Chart	2002a	Forecast Winds/Temperatures Aloft	7, 22, 48	3	Interpretation of Fo ALOFT
	2002b	Hazards Charts (Low-Level, Upper Level)	1, 14, 37, 68, 75	5	Interpretation of Ha
Interpreting Convective SIGMETs	2003a	SIGMETs	11, 26, 38, 40, 41, 46, 49, 57, 70, 77, 85	12	Interpretation of SI
Interpreting AIRMET	2005a	Turbulence (includes LLWS, sfc winds > 30 kt)	2, 5, 67, 89, 90, 95	6	Interpretation of Tu
	2005b	Icing (includes freezing levels)	5, 15, 35, 43, 50, 65, 66, 67, 89	9	Interpretation of Ici
	2005c	Visibility, Ceiling, & Mountain Obscuration	5, 67, 73, 89	4	Interpretation of Vis AIRMET
Interpreting CIP	2006	CIP	3, 6, 51, 69	4	Interpretation of CI

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Interpreting GTG*	2008*	GTG	9, 74	2	Interpretation of GT
Interpreting CVA*	2014*	CVA	61, 79	2	Interpretation of CV
Interpreting Satellite Data: IR Visible, Water Vapor	2022	Satellite Data	32, 33, 63	3	Interpretation of Sat
	2022a	IR, Visible, Water Vapor strengths and weaknesses	4, 19, 30, 92	4	Interpretation of Sat Water Vapor
Interpreting Weather Radar	2023	Weather Radar	27, 32, 88	3	Interpretation of W
	2023b	Radar Coded Message	56, 87	2	Interpretation of Ra
	2023d	National Convective Weather Forecast	45, 76, 86	3	Interpretation of Ra
Interpreting Surface Chart	2026	Surface Chart	16, 17, 18, 52, 81	5	Interpretation of Su
Knowledge of Product Limitations	2101*	Knowledge of product limitations	11, 79, 88, 91	4	Knowledge of produ
Interpretation of CONVECTIVE Products*	2106*	Interpretation of CONVECTIVE SIGMETS and Outlooks, SPC Convective Outlooks, Severe Weather Watches and Warnings, CCFP, KI/LI Charts, CAPE charts	11	1	Interpretation of CC and Outlooks, SPC Severe Weather Wa CCFP, KI/LI Charts

Note: * denotes the weather subcategories that were not analyzed within the aviation weather knowledge subcategories ar question amount.

Aviation Weather Knowledge Assessment & Interpretation of Products

Table 14b

Weather Hazard Product Means

Weather Hazard Product Subcategories		Number of Questions		Cronbach's Alpha		Student		Private		Private w/ Instrumen	
		Study 1	Study 2	Study 1	Study 2	Study 1 *n=16*	Study 2 *n=41*	Study 1 *n=30*	Study 2 *n=71*	Study 1 *n=18*	Stu *n=*
2001	**Interpreting Surface Weather Information and PIREPs**	30	23	.52	.72	60(9)	44(15)	64(10)	53(17)	68(10)	57(
2005	**AIRMET**	18	13	.60	.67	72(13)	42(18)	76(15)	48(22)	81(12)	56(
2002	**Interpreting Upper Level Charts**	7	8	.63	.61	66(28)	69(25)	81(16)	77(20)	90(13)	81(
2003a	**Interpreting Convective SIGMETs**	9	12	.48	.67	62(20)	50(19)	66(16)	63(21)	78(20)	67(
2022	**Interpreting Satellite Data: IR Visible, Water Vapor**	10	7	.77	.66	53(26)	41(28)	53(26)	52(27)	68(26)	58(
2023	**Weather Radar**	6	8	.51	.41	46(24)	39(18)	58(26)	49(21)	70(27)	56(
2026	**Interpreting Surface Chart**	4	5	.25	.59	56(21)	63(30)	64(26)	68 (27)	64(21)	76 (
2006	**Interpreting CIP**	5		.17		48(24)		47(22)		54 (22)	
	Total	89	80	.85	.91	60(9)	48(14)	65(10)	57(16)	72(10)	62(

Aviation Weather Knowledge Assessment & Interpretation of Products

A 4 x 7 mixed ANOVA was conducted to evaluate the impact of Pilot Certificate/Rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and Weather Hazard Product Subcategory (interpreting surface charts (2001), Interpreting Upper-Level Chart (2002), Interpreting Convective SIGMETs (2003a), Interpreting AIRMET (2005), Interpreting Satellite Data: IR Visible, Water Vapor (2022), Interpreting Weather Radar (2023), Interpreting Surface Chart (2026)) on knowledge scores.

Figure 9 displays the analysis design/matrix (blank to show formatting) and main effect means (shown at the end of each column and row).

Flight Exprierence

Weather Prodcuts Subcategories	Student	Private	Private with Instrument	Commercial with Instrument	Main Effect: Weather Product Level *M(SD)*
Interpreting surface Wx Info & Pireps					54(17)
Upper Level Charts					77(21)
AIRMET					51 (20)
Convective SIGMET					54(28)
Satellite Data					51(21)
Weather Radar					64(21)
Surface Chart					71(27)
Main Effect: Pilot Certificate/ Rating Level *M(SD)*	48(14)	57(16)	62(14)	66 (15)	

Figure 9. Analysis of Pilot Certificate and/or rating on Weather Hazard Product Score

Regardless of Pilot certificate/rating, there was a significant main effect of Weather Hazard Product Subcategories on score, Wilks' Lambda = .27, F (6, 195) = 86.31, $p < .01$, partial $\eta^2 = .73$. Therefore, 73% of variance in scores is accounted for by Weather Hazard Product

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Subcategories. Post hoc pairwise comparisons were performed on the Weather Hazard Products Subcategories to investigate differences in scores (see Figure 10 for a graph of the means). Participants' scores were significantly higher on interpreting upper level charts (2002) (*M* = 77.29, *SD* = 21) than the scores on interpreting convective SIGMETs (*M* = 63.60, *SD* = 21; $p <$ .01) and surface charts (*M* = 70.59, *SD* = 27; $p < .01$) (2003 and 2026), which in turn, were significantly higher than the scores on interpreting surface weather and PIREPs (*M* = 54.06, *SD* = 17; $p < .01$) interpreting AIRMETs (*M* = 51.21, *SD* = 20; $p < .01$) interpreting satellite data (*M* = 53.78, *SD* = 28; $p < .01$), infrared visible, and water vapor, and interpreting weather radar (*M* = 51.04, *SD* = 21; $p < .01$) (2001, 2005, 2022, 2023; $p < .01$).

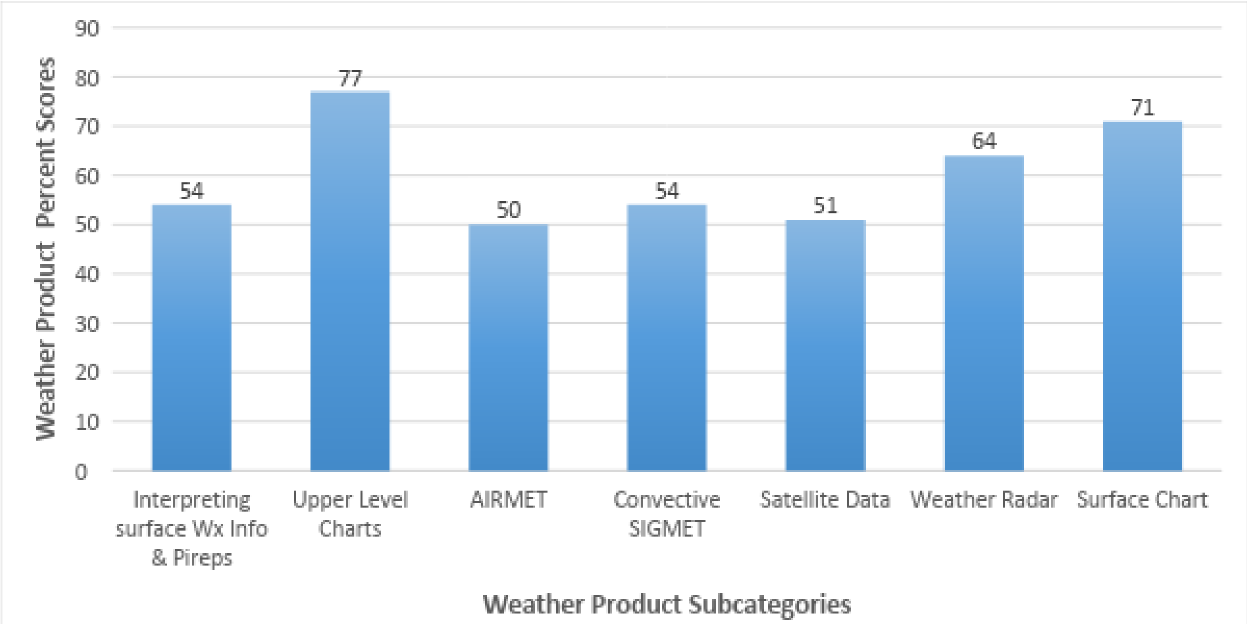

Figure 10. Weather Hazard Product Subcategories on Score

In addition, regardless of Weather Hazard Product Subcategory, there was a significant main effect of Pilot certificate/rating on score, $F(3, 200) = 11.85$, $p < .01$. partial $\eta^2 = .15$; 15% of variance in score is accounted for by pilot certificate/rating (see Figure 11 for a graph of them means). Bonferroni post hoc comparisons were performed to evaluate differences in scores within pilot rating levels. Student pilots performed significantly lower than Private (*p* = .028), Private w/ Instrument (*p* < .01), and Commercial rated pilots (*p* < .01). Private rated pilots' scores were significantly lower than commercial rated pilot scores (*p* =.005), but not significantly lower than private w/ instrument rated pilots' scores (*p* =.229). Scores of private w/ instrument rated pilots did not significantly differ from those of Commercial rated pilots, (*p* = 1.00).

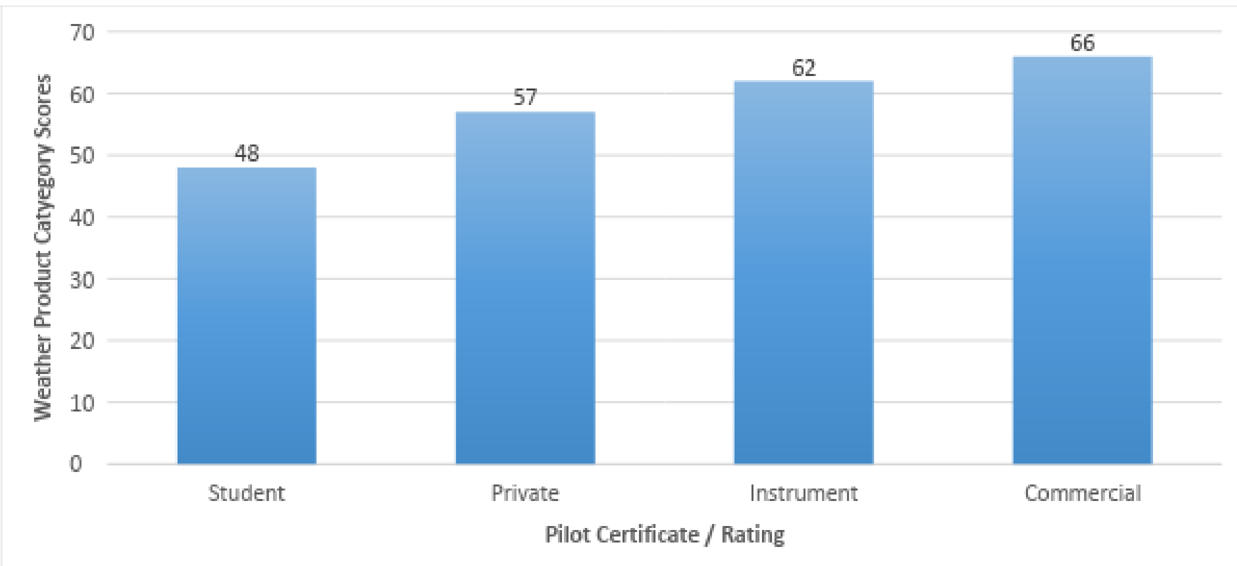

Figure 11. Pilot Certificate and/or rating on Weather Hazard Product Overall Score

No significant interaction occurred between Weather Hazard Product Subcategory and Pilot rating, Wilks' Lambda = .93, $F(18, 552) = .83$, p = .67, partial $\eta^2 = .03$. This result indicates that there is not a combined effect of Pilot rating and Weather Hazard Product Subcategory on score.

Summary: Weather Hazard Products Subcategory. Regardless of pilot experience, pilots scored highest on upper level chart, convective SIGMET, and surface analysis chart questions compared to all other hazard product questions. Conversely, pilots scored the lowest on radar and satellite data questions.

Similar to the prior analysis, the results determined that student pilots scored lower on all weather hazard product questions compared to private, private w/ instrument, and commercial pilots. Moreover, private pilots also scored significantly lower on all weather hazard products than commercial pilots, but private and private w/ instrument pilots scored about the same. These results may suggest that student pilots may lack the knowledge and skills to interpret and apply weather hazard products. The results also seem to indicate that the as training and experience in aviation principles and skills increases, so does aviation weather knowledge.

Weather Hazard Product Sources Subcategories. The weather hazard product sources category focuses on understanding how products are put together, knowledge of differences between various vendor products, and knowledge of how and when to use different products during different phases of flight. The definitions and means are shown in Tables 15a and 15b.

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Table 15a

Aviation Weather Hazard Product Sources Questions (based on Lanicci et al., (2017) Taxonomy)

Category	Taxonomy Code	Taxonomy Label	Question #	Frequency	
Knowledge of approved product sources	3001*	Knowledge of approved product sources	39, 54, 91	3	Knowled
Analysis of primary and supplementary products	3005*	Analysis and interpretation of primary (AIRMETs Tango, SIGMETS) and supplementary turbulence (Ellrod Index, SREF, GTG)	95	1	Knowled Analysis, (AIRME supplem SREF, G
Knowledge when to use Flight Planning Product Sources	3201	Flight Planning	11, 31, 36, 39, 54, 84, 91, 94, 95	9	Knowled product s
Knowledge of how and when to use different product sources during In-flight evaluation*	3205*	In-flight evaluation	88	1	Knowled product s
Interpretation of CONVECTIVE SIGMETS and Outlooks, SPC Convective Outlooks, Severe Weather Watches and Warnings, CCFP, KI/LI Charts, CAPE charts	3006a*	Interpretation of CONVECTIVE SIGMETS and Outlooks, SPC Convective Outlooks, Severe Weather Watches and Warnings, CCFP, KI/LI Charts, CAPE charts	11	1	Knowled Interpreta and Outlo Severe W CCFP, K
Knowledge of product information sources for flight planning basics	3007a	Flight planning basics	11, 31, 36, 54, 84, 91, 94, 95	8	Knowled for flight
Knowledge of product information sources for flight planning	3007	Flight Planning	39	1	Knowled for flight

Note: * denotes the weather subcategories that were not analyzed within the aviation weather knowledge subcategories ar amount.

Table 15b

Weather Hazard Product Sources Means

Weather Hazard Product Source Subcategories		Number of Questions		Cronbach's Alpha		Student		Private		Private Instrun
		Study 1	Study 2	Study 1	Study 2	Study 1 *n=16*	Study 2 *n=41*	Study 1 *n=30*	Study 2 *n=71*	Study 1 *n=18*
3007 a	**Knowledge of how Flight Planning products are constructed**	5	8	.61	.66	66(33)	60(19)	75(27)	67(23)	78(18)
3007	**Flight Planning**		9		.69		62(21)		70(22)	
3201	**Knowledge of when to use Flight Planning Product Sources**		9		.59		62(21)		70(22)	
3001	**Knowledge of approved product sources**	4		.48		89(18)		88(20)		89(21)
3005	**Analysis of primary and supplementary products**	5		.24		64(13)		75(21)		78(20)
	Total	14	10	.60	.66	72(17)	59(20)	76(20)	67(21)	79(23)

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A 4 x 3 mixed ANOVA was conducted to evaluate the impact of Pilot Certificate/Rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and Weather Hazard Product Source Subcategory (Knowledge of product information sources for flight planning (3007), Knowledge of product information sources for flight planning basics (3007a), Knowledge when to use Flight Planning Product Sources (3201)) on knowledge score. Figure 12 displays analysis design/matrix and main effect means

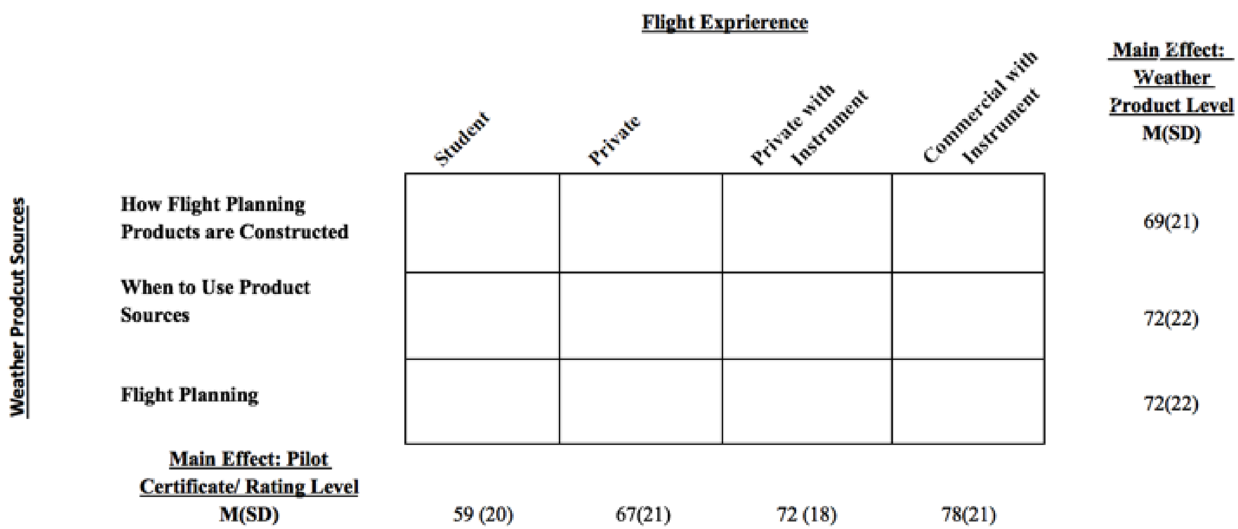

Figure 12. Analysis of Pilot Rating and Weather Hazard Product Source Subcategory on Scores

Regardless of Pilot certificate/rating, there was a significant main effect of Weather Product Source Subcategories on scores, Wilks' Lambda = .732, $F(1, 200) = 73.27$, $p < 0.01$, partial $\eta^2 = .268$ (see Figure 13 for a graph of the means); 27% of variance in scores is accounted for by Weather Product Source Subcategories.

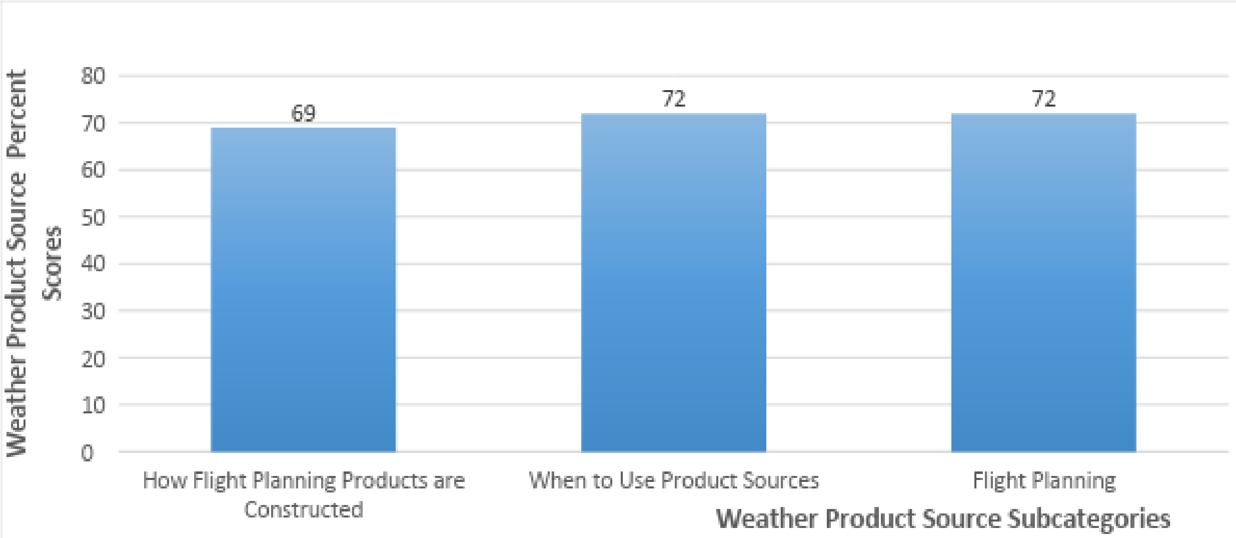

Figure 13. Weather Hazard Product Source Subcategories on Scores

Post hoc pairwise comparisons were performed on the Weather Products Source Subcategories to investigate differences. Participant's scored significantly higher on knowledge of when to use flight planning product sources questions (3201) (*M* = 71.57, *SD* = 22) than they did on knowledge of how flight planning products are constructed (*M* = 69.42, *SD* = 23; p < .01) and flight planning in general (*M* = 71.57, *SD* = 22; p < .01) (3007a and 3007)9. A closer inspection of the means in Table 15, however, indicates pilots with both commercial and private w/ instrument ratings scored highly on subcategory 3201 (although as per below the interaction was not significant).

Figure 14 displays the means for the main effect of pilot certificate/rating on score. Regardless of subcategory of weather hazard product sources, there was a significant main effect on the levels within Pilot rating, $F(3, 200) = 6.428$, $p < .01$, partial $\eta^2 = .09$; 9% of variance in scores is accounted for by Pilot rating. Bonferroni post hoc comparisons were performed to evaluate differences in scores within pilot rating levels. Student pilots performed significantly lower on weather products source questions than Private w/ Instrument (*p*=.047) and

Commercial rated pilots, $p < .01$. However, there was not a significant difference between student pilots' scores and Private pilots' scores, $p = .275$. Private rated pilot scores were significantly lower than commercial rated pilot scores, $p =.031$. However, there was not a significant difference between private w/ instrument and commercial w/ instrument scores, $p = .437$.

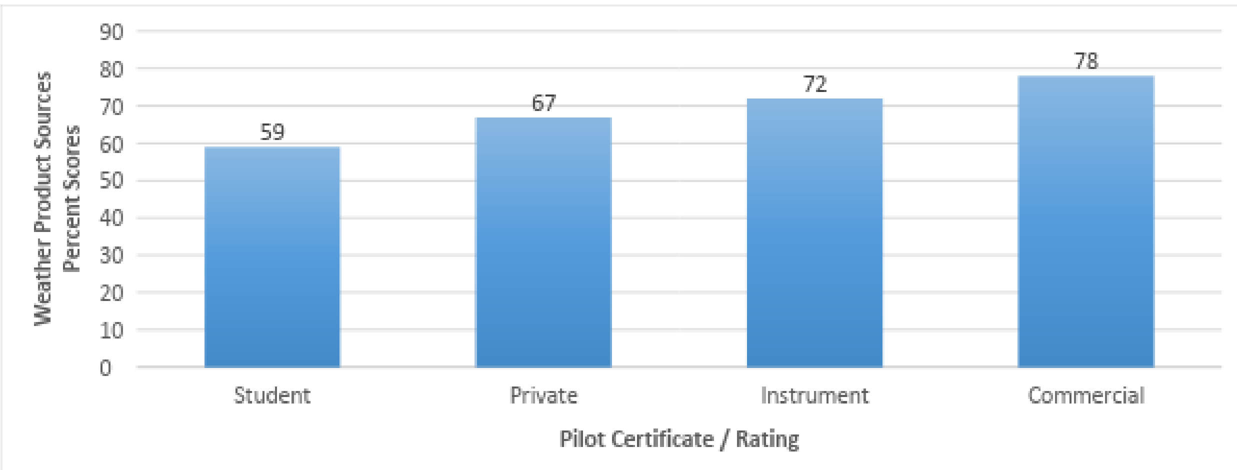

Figure 14. Pilot Rating Effect on Weather Product Source Category Scores

No significant interaction occurred between Pilot Rating and Weather Hazard Products Source subcategories, Wilks' Lambda = .975, F (3, 200) = 1.73, $p = .162$, partial $\eta^2 = .025$. Indicating that there is not a combined effect of Pilot rating and Weather Hazard Products Source subcategories on score.

Summary: Weather Hazard Product Sources Subcategory. Regardless of the effect of pilot rating, pilots scored higher on knowledge of when to use flight planning product source questions then they did on questions pertaining to knowledge of how flight planning products. Furthermore, pilots may have a better understanding of when to use the correct weather product source to access a specific weather product.

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Additionally, the results determined that student pilots scored lower on all weather product source questions compared to private w/ instrument and commercial pilots. Moreover, private pilots also scored significantly lower on all weather hazard products source questions than commercial pilots. These results follow the pattern of previous analyses that knowledge gain occurs as student pilot transition to private-pilots, but then plateaus until pilots have both instrument ratings and commercial certificates.

This concludes the analyses based on the Lanicci et al. (2017) taxonomy.

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Analysis Set III: Old Generation Products vs. New Generation Products. While the Lanicci et al. (2017) taxonomy guided prior analyses in this report, a separate series of analyses were also performed to examine product generation and product topic (icing, turbulence, and visibility).

Specifically, the FAA introduced several new products to augment and/or enhance pilots' situational awareness. The new products are fully automated with little human-in-the-loop interface and include Ceiling and Visibility (CVA), Current Icing Product (CIP), and Graphical Turbulence Guidance (GTG). The related G-AIRMET, while largely automated, still have human oversight. The following analyses investigated whether the product's generation ("new" vs "old") was related to how well pilots' interpreted the weather products.

Tables 16a and 16b provide the names of the subcategories and means.

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Table 16a

Old Generation Products vs. New Generation Products: Aviation Weather Questions

Generation Type	Category	Taxonomy Code	Taxonomy Label	Question #	Frequency	
Old	Interpreting AIRMET	2005a	Turbulence (includes LLWS, sfc winds > 30 kt)	2, 5, 67, 89, 90, 95	6	Interpreta Tango
		2005b	Icing (includes 00s freezing levels)	5, 15, 35, 43, 50, 65, 66, 67, 89	9	Interpreta Zulu
		2005c	Visibility, Ceiling, & Mountain Obscuration	5, 67, 73, 89	4	Interpreta Sierra
New	Interpreting CIP	2006	CIP	3, 6, 51, 69	4	Interpreta
New	Interpreting GTG*	2008*	GTG	9, 74	2	Interpreta
New	Interpreting CVA*	2014*	CVA	61, 79	2	Interpreta

Note: * denotes the weather subcategories that were not analyzed within the aviation weather knowledge subcategories an question amount.

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Table 16b

Old Generation Products vs. New Generation Product Results

Aviation Weather Topic	**Generation Type**	**Number of Questions**	**Cronbach's Alpha**	**Student**	**Private**	**Private w/ Instrument**	**Co In**
				n = 41 M(SD)	***n = 72 M(SD)***	***n = 50 M(SD)***	
Turbulence							
Interpreting G-AIRMET Tango	Old	6		38(24)	43(27)	52(23)	
Interpreting GTG	New	2		78(32)	80(32)	84(31)	
Total		**8**	***0.6***	**48(21)**	**52(25)**	**60(22)**	
Icing							
Interpreting G-AIRMET Zulu	Old	9		40(20)	48(23)	57(15)	
Interpreting CIP	New	4		41(25)	53(28)	58(25)	
Total		**13**	**0.66**	**41(19)**	**50(21)**	**57(14)**	
Visibility							
Interpreting G-AIRMET Sierra	Old	4		39(30)	43(32)	60(26)	
Interpreting CVA	New	2		44(36)	58(38)	52(40)	
Total		**6**	**0.56**	***41(25)***	***48(27)***	***57(25)***	

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A 4 x 2 mixed between-within subjects analysis of variance was conducted to evaluate the impact of pilot certificate or rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and product generation (New vs. Old) on participants' product interpretation scores.

First, the main effect for product generation was examined. There was a significant main effect, Wilks' Lambda = .83, F (1, 200) = 41.95, $p < .01$, partial $\eta^2 = .17$. Thus, 17% of variance in product interpretation can be accounted for by product generation. Regardless of certificate or rating, participants scored significantly higher on questions relating to new weather products (M = 60, SD = 22) than they did on questions relating to old products (M = 51, SD = 20).

There was also a significant main effect of Pilot certificate or rating on product interpretation scores, $F(3, 200) = 6.72$, $p < 0.05$, partial $\eta^2 = .09$. Thus, 9% of variance in product interpretation can be accounted for by pilot certificate or rating. Bonferroni post hoc comparisons revealed that, regardless of the weather product generation, student pilots performed significantly lower (M = 44, SD = 17) than did commercial pilots (M = 62, SD = 21), $p < .01$. However, no other significant differences appeared.

There was not a significant interaction between pilot certificate or rating and product generation, Wilks' Lambda = 2.12, F (3, 200) = .97, $p = .098$, partial $\eta^2 = .03$. Consequently, these results indicate that there is not a combined effect of pilot certificate or rating and weather product generation.

Since pilots score higher overall on new products as compared to old products, we were interested in how the participants performed on the specific products within the generational groups. This led us to the next set of analyses.

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New Generation Product Interpretation Scores. Next, a 4 x 3 mixed between-within subjects analysis of variance was conducted to evaluate the impact of pilot certificate or rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and new generation products type/topic (CIP, CVA, GTG) on product interpretation scores.

There was a significant main effect of new generation product type/topic, Wilks' Lambda = .62, F (2, 199) = 62.19, $p < .01$, partial $\eta^2 = .39$. Thus, 39% of variance in new generation product interpretation scores can be accounted for by the product type/topic. Pairwise comparisons were performed to investigate differences between the product type scores. Participant's scored significantly higher on GTG interpretation questions (M =81, SD = 31), than they did on CIP interpretation questions (M = 53, SD = 28; p < .01) and CVA Interpretation question scores (M = 55, SD = 39; $p < .01$). There was not a significant difference between participants' scores on CIP and CVA interpretation questions, $p = 1.00$.

There was also a significant main effect of pilot certificate or rating, F(3, 200) = 3.06, p = 0.29, partial $\eta^2 = .04$. Thus, 4% of variance in new product interpretation scores can be accounted for by pilot certificate or rating. Bonferroni Post Hoc comparisons were performed to evaluate differences in scores between pilot rating levels. Student pilots performed significantly lower on new products subcategory questions (M = 51, SD = 19) than did commercial pilots (M = 66, SD = 22), p =.025. No other significant differences appeared.

Also, there was not a significant interaction between pilot certificate or rating and new product type/topic, Wilks' Lambda = .97, F (6, 398) = 1.00, p = .425, partial $\eta^2 = .02$. The results indicate that there is not a combined effect of pilot certificate or rating and new product type/topic on scores.

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Old Generation Product Interpretation Scores. Next, a 4 x 3 mixed between-within subjects analysis of variance was conducted to evaluate the impact of pilot certificate or rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and old product type/topic (G-AIRMET Zulu, G-AIRMET Sierra, G-AIRMET Tango) on participants' interpretation scores.

There was a significant main effect of the levels within old products type/topic, Wilks' Lambda = .93, F (2, 199) = 7.92, $p < .01$, partial $\eta^2 = .74$. Therefore, 74% of variance in old product interpretation can be accounted for by old product type. Pairwise comparisons were performed on old products type/topic levels to investigate differences. Participant's scored significantly higher on G-AIRMET Zulu interpretation questions *(M* = 52, *SD* = 22) than they did on G-AIRMET Tango interpretation questions *(M* = 47, *SD* = 26), $p < .01$. However, there were no other significant differences between participant's scores on G-AIRMET Sierra *(M* = 50, *SD* = 31), G-AIRMET Zulu ($p = .498$), or G-AIRMET Tango interpretation questions scores ($p = .072$).

There was also a significant main effect of Pilot certificate or rating, $F(3, 200) = 3.37$, $p < .01$, partial $\eta^2 = .09$. Thus, 9% of variance in old product interpretation scores can be accounted for by pilot certificate or rating. Bonferroni Post Hoc comparisons were performed to evaluate differences in scores within pilot certificate or rating levels. Student pilots performed significantly lower *(M* = 42, *SD* = 18) on old products subcategory questions than did commercial pilots (*M* = 60, *SD* = 21; $p < .01$) and private w/ instrument rated pilots *(M* = 56, *SD* = 16), $p = .04$. Also, commercial pilots scored significantly higher on old products subcategory questions than private pilots did *(M* = 48, *SD* = 22), $p = .02$. No other significant differences appeared.

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Also, there was not a significant interaction between pilot certificate or rating and knowledge of old products subcategory questions, Wilks' Lambda = .96, $F(6, 398) = 1.30$, p = .258, partial η^2= .02.

Finally, we were interested in how scores on the products within overall topic areas compared. This led us to the next set of analyses.

Results by Product Topic: Icing Products, Visibility Products, and Turbulence Products. This set of analyses examined the scores for interpreting particular topics (Icing, Visibility, and Turbulence). Specifically, we examined the relationship between pilot certificate or rating and the product topic on interpretation score.

First, a 4 x 3 mixed between-within subjects analysis of variance was conducted to evaluate the impact of pilot certificate or rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and "Product Topic" questions (Icing Products, Visibility Products, and Turbulence Products) on participants' scores.

There was a significant main effect of product topic, Wilks' Lambda = .93, $F(2, 199)$ = 6.99, $p < .01$, partial η^2 = .07. Thus, 6% of variance in interpretation score can be accounted for by product topic. Pairwise comparisons were performed on product topic levels to investigate differences. Participant's scored significantly higher on turbulence product questions *(M* = 55, *SD* = 23) than they did on icing products *(M* = 52, *SD* = 21; *p* = 013) and visibility product questions (*M* = 51, *SD* = 27), *p* = .006. No other significant difference occurred.

There was also a significant main effect of pilot certificate or rating, $F(3, 200) = 6.61$, $p <$ .01, partial η^2 = .09. Therefore, 9% of variance in interpretation score can be accounted for by pilot certificate or rating. Bonferroni Post Hoc comparisons were performed to evaluate differences between pilot certificate or rating levels. Student pilots performed significantly lower (*M* = 44, *SD* = 17) than did private w/ instrument rated pilots (*M* = 59, *SD* = 16; $p = .004$) and commercial pilots (*M* = 62, *SD* = 21), $p < .01$. No other significant differences appeared.

There was not a significant interaction between pilot certificate or rating and product topic, Wilks' Lambda = .98, F (6, 398) = .72, $p = .637$, partial $\eta^2 = .11$. These results indicate that there is not a combined effect of pilot certificate or rating and products interpretation category.

Icing Product Generation. To examine icing products more closely, a 4 x 2 mixed between-within subjects analysis of variance was conducted to evaluate the impact of pilot certificate or rating (Student, Private, Private w/Instrument, Commercial w/ Instrument) and icing product (old: G-AIRMET Zulu; new: CIP) on participants' scores.

First, there was not a significant main effect of two levels/categories of icing interpretation questions scores, Wilks' Lambda = 1.00, $F(1, 200) = .12$, $p = .726$, partial $\eta^2 < .01$. Overall, pilots interpreted the G-AIRMET Zulu and CIP equally well.

However, there was a significant main effect of the levels within pilot certificate and/or rating, F (3, 200) =7.91, $p < .01$, partial η^2= .11. Therefore, 10% of variance in icing product interpretation scores can be accounted for by pilot rating. Bonferroni Post Hoc comparisons revealed commercial pilots scored significantly higher (*M* = 61, *SD* = 22) on icing interpretation category questions overall than did student pilots (*M* = 41, *SD* = 19; $p < .01$). Also, private w/ instrument rated pilots scored significantly higher (*M* = 57, *SD* = 14) on icing interpretation category questions than student pilots did, $p < .01$. No other significant differences appeared.

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There was not a significant interaction between pilot certificate or rating and knowledge of icing interpretation category questions scores, Wilks' Lambda = .99, $F(3, 200) = .81$, $p = .488$, partial $\eta^2 = .01$. Therefore, there was not a combined effect of pilot certificate or rating and icing category on scores.

Visibility Product Generation. Next, to examine visibility more closely, a mixed 4 x 2 between-within subjects analysis of variance was conducted to evaluate the impact of pilot certificate or rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and visibility product (old: G-AIRMET Sierra; new: CVA) on participants' scores.

There was not a significant main effect of visibility product generation category questions scores, Wilks' Lambda = .99, $F\ (1, 200) = 2.05$, $p = .154$, partial $\eta^2 = .01$. Overall, pilots interpreted G-AIRMET Sierra and CVA equally well.

However, there was a significant main effect of pilot certificate or rating, $F(3, 200) = 3.39$, $p = .019$, partial $\eta^2 = .05$. Therefore, 4% of variance in visibility product interpretation can be accounted for by pilot certificate or rating. Bonferroni Post Hoc comparisons revealed student pilots scored significantly lower ($M = 41$, $SD = 25$) on visibility interpretation category questions than commercial pilots ($M = 59$, $SD = 30$), $p = .019$. No other significant differences appeared.

There was a also significant interaction between pilot certificate or rating and knowledge of visibility interpretation category questions scores, Wilks' Lambda = .96, $F(3, 200) = 2.84$, $p = .39$, partial $\eta^2 = .04$. Therefore, 10% of variance in visibility product interpretation can be accounted for by a combined effect of pilot rating and visibility interpretation category questions scores. Simple effect analyses revealed student rated pilots scored significantly higher on questions relating to CVA (2014) than on questions relating to G-AIRMET Sierra (2005c), $p < .05$. However, there was no other significant differences.

Turbulence Product Generation. To examine turbulence more closely, a 4 x 2 mixed between-within subjects analysis of variance was conducted to evaluate the impact of pilot rating (Student, Private, Private w/ Instrument, Commercial w/ Instrument) and turbulence product (old: G-AIRMET Tango; new: GTG) on participants' scores.

There was a significant main effect of the levels within turbulence products, Wilks' Lambda = .49, F (1, 200) = 205.23, $p < .01$, $\eta^2 = .51$. Therefore, 51% of variance in turbulence product interpretation can be accounted for by the particular turbulence products. Participants' scored significantly higher on the newer GTG *(M* =81, *SD* = 30) than they did on the older G-AIRMET Tango *(M* =47, *SD* = 26), $p < .01$.

Interestingly, there was not a significant main effect of the levels within pilot certificate or rating, F (3, 200) = 2.22, $p = .087$, partial $\eta^2 = .03$. Thus, the pilots performed equally well across these questions regardless of certification/rating.

Also, there was no significant interaction between pilot certificate or rating and knowledge of turbulence interpretation category questions scores, Wilks' Lambda = .98, F (3, 200) =1.40, $p = .243$, partial $\eta^2 = .02$. These results indicate that there is not a combined effect of pilot rating and turbulence interpretation category.

Summary: New Generation vs. Old Generation. Overall, regardless of pilot certificate or rating, participants scored higher on newer generation products than they did on older generation products. That result generated interest in how the participants performed on the specific products within the product generation groups. The analyses that we conducted indicated that:

- New products: regardless of pilot certificate or rating, participants scored higher on GTG (turbulence) product interpretation questions than they did on the rest of the new generation products, CVA (ceiling and visibility) and CIP (icing).
- Old products: regardless of pilot rating, participants scored higher on G-AIRMET Zulu (icing) product interpretation questions compared to the other older product generation questions G-AIRMET Tango (turbulence) and G-AIRMET Sierra (visibility).

Thus, the results support the notion that pilots are better at interpreting the turbulence products compared to the rest of the new generation products. However, when concerning old products, pilots interpret the icing product the best.

For the effect of product topics overall:

- Predominantly, participants scored higher on turbulence product interpretation questions compared to the other topic product interpretation questions (visibility and icing).
- Within icing and visibility, product generation (new, old) did not have a significant effect on participant interpretation scores.
- Within turbulence, product generation had a significant effect on turbulence interpretation scores. Participants scored significantly higher on GTG interpretation questions than they did on G-AIRMET Tango questions.

This concludes the results pertaining to new versus old products.

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Analysis Set IV: Attitudinal Analysis.

Weather Salience. The WxSQ used in this study is the 29-question version with seven subscales outlined in Stewart (2009). The mean responses on the subscales were compared to the mean responses from Stewart's (2009) University of Georgia (UGA) student sample and the mean responses collected from the general population sample (Stewart et al., 2012). Two-tailed one-sample t-tests were used for all analyses.

The mean WxSQ subscale and total scores in both the UGA and general population samples were reported by gender (see Table 2 in Stewart, 2009 and Table 1 in Stewart et al., 2012). Overall means across genders were derived by calculating weighted means.

For Study 1, Table 17 shows the mean scores for total Weather Salience score and subscores for the data in Study 1 compared to that of previously tested populations (UGA students and general population sample). Results of the significance tests and effect sizes are also reported in Table 17. A series of one-sample *t*-tests were performed to compare the means of the pilots to that of the general population. All effect sizes are reported as Cohen's *d*.

For Study 1, participant scores (n = 79) on the WxSQ overall ranged from 62 to 145, with a mean of 107.65 (12.42). Study 1 participant mean scores were significantly higher than the UGA students and significantly lower than the general population samples on the total WxSQ scores (Stewart, 2009; Stewart et al., 2012). They were significantly higher than the UGA students and general population on Subscales 1 through 3. On Subscale 4, Study 1 participants were significantly lower than the general population samples, but UGA and Study 1 participants did not significantly differ. There was also no significant difference between the three groups on Subscale 5. On Subscale 6, Study 1 participants were significantly higher than UGA students and

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significantly lower than the general population. For Subscale 7, Study 1 participants were significantly lower than UGA students and significantly higher than the general population.

Table 17

Study 1 Weather Salience in Comparison with Prior Research (Stewart, 2009; Stewart et al., 2012)

Subscale (possible score range)	**Study 1 Participants** *n = 79* Mean (SD)	**UGA Students** *n = 946* Mean; *t*-statistic; Cohen's d	**Gen. Population** *n = 1465* Mean; *t*-statistic; Cohen's d
1: Attention to weather and weather products (9 to 45) Cronbach's alpha = .50	35.01 (4.54)	29.21 $t(78) = 11.37$, $p < .001^*$ $d = 1.29$	30.93 $t(78) = 8.00$, $p < .001^*$ $d = .91$
2: Sensing and observing weather directly (5 to 25) Cronbach's alpha = .78	21.57 (2.81)	18.30 $t(78) = 10.33$, $p < .001^*$ $d = 1.17$	17.99 $t(78) = 11.31$, $p < .001^*$ $d = 1.28$
3: Effects of weather on daily activities (3 to 15) Cronbach's alpha = .38	9.95 (2.59)	7.61 $t(78) = 8.02$, $p < .001^*$ $d = .91$	7.81 $t(78) = 7.34$, $p < .001^*$ $d = .83$
4: Effects of weather on daily mood (6 to 30) Cronbach's alpha = .82	20.05 (5.09)	21.15 $t(78) = -1.92$, $p = .06$ No Significant Difference	22.64 $t(78) = -4.52$, $p < .001^*$ $d = -.51$
5: Attachment to weather patterns (3 to 15) Cronbach's alpha = .95	10.03 (3.56)	9.98 $t(78) = .11$, $p = .91$ No Significant Difference	10.18 $t(78) = -.386$, $p = .70$ No Significant Difference

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6: Need to experience weather variability (4 to 20) Cronbach's alpha = .77	14.42 (3.38)	13.04 $t(78) = 3.62$, $p < .001^*$ $d = .41$	15.97 $t(78) = -4.08$ $p < .001^*$ $d = -.46$
7: Attention to weather leading to holiday or cancellation (3 to 15) Cronbach's alpha = .85	12.28 (2.89)	13.21 $t(78) = -2.86$, $p < .005^*$ $d = -.32$	8.86 $t(78) = 10.51$, $p < .001^*$ $d = 1.19$
Total WxSQ score (29 to 145) Cronbach's alpha = .79	107.65 (12.42)	98.96 $t(78) = 6.22$, $p < .001^*$ $d = .70$	114.38 $t(203) = -4.82$ $p < .001^*$ $d = -.55$

Note: * denotes a significant difference.

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For Study 2, Table 18 shows the mean scores on each subscale and total score for each sample, along with the results of the significance tests and effect sizes. A series of one-sample *t*-tests were performed to compare the means of the flight students and the general population. All effect sizes are reported as Cohen's *d*.

Study 2's participant scores (*n* = 204) on the WxSQ overall ranged from 62 to 145, with a mean of 104.54 (SD = 13.85). Study 2 participant mean scores were significantly higher than the UGA students and significantly lower than the general population samples on the total WxSQ scores. They were significantly higher than the UGA students and general population samples on Subscales 1 through 3. On Subscales 4 and 5, Study 2 participants were significantly lower than UGA students and the general population samples. On Subscale 6, Study 2 participants were significantly higher than UGA students and significantly lower than the general population samples. For Subscale 7, Study 2 participants were significantly lower than UGA students and significantly higher than the general population samples.

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Table 18

Study 2 Weather Salience in Comparison with Prior Research (Stewart, 2009; Stewart et al., 2012)

Subscale (possible score range)	**Study 2 Participants** *n* = 204 Mean (SD)	**UGA Students** *n* = 946 Mean; *t*-statistic	**Gen. Population** *n* = 1465 Mean; *t*-statistic
1: Attention to weather and weather products (9 to 45) Cronbach's alpha = .58	34.46 (5.02)	29.21 $t(203) = 14.93$, $p < .001^{*}$ $d = 1.05$	30.93 $t(203) = 10.04$, $p < .001^{*}$ $d = .70$
2: Sensing and observing weather directly (5 to 25) Cronbach's alpha = .76	21.25 (2.94)	18.30 $t(203) = 14.30$, $p < .001^{*}$ $d = 1.00$	17.99 $t(203) = 15.81$, $p < .001^{*}$ $d = .68$
3: Effects of weather on daily activities (3 to 15) Cronbach's alpha = .53	9.71 (2.80)	7.61 $t(203) = 10.71$, $p < .001^{*}$ $d = .75$	7.81 $t(203) = 9.69$, $p < .001^{*}$ $d = .68$
4: Effects of weather on daily mood (6 to 30) Cronbach's alpha = .83	19.45 (5.40)	21.15 $t(203) = -4.51$, $p < .001^{*}$ $d = -.32$	22.64 $t(203) = -8.45$, $p < .001^{*}$ $d = -.59$
5: Attachment to weather patterns (3 to 15) Cronbach's alpha = .90	8.90 (3.63)	9.98 $t(203) = -4.24$, $p < .001^{*}$ $d = -.30$	10.18 $t(203) = -5.03$, $p < .001^{*}$ $d = -.35$
6: Need to experience weather variability (4 to 20)	14.10 (3.40)	13.04 $t(203) = 4.47$, $p < .001^{*}$ $d = .31$	15.97 $t(203) = -7.84$ $p < .001^{*}$ $d = -.55$

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Cronbach's alpha = .77			
7: Attention to weather leading to holiday or cancellation (3 to 15) Cronbach's alpha = .82	12.27 (2.73)	13.21 *t*(203) = -4.92, *p* < .001* *d* = -.34	8.86 *t*(203) = 17.82, *p* < .001* *d* = 1.25
Total WxSQ score (29 to 145) Cronbach's alpha = .83	104.54 (13.85)	98.96 *t*(203) = 5.76, *p* < .001* *d* = .40	114.38 *t*(203) = -10.14 *p* < .001* *d* = -.71

Note: * denotes a significant difference.

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Self-Efficacy. As described in the Method section of this paper, data was collected using two separate self-efficacy measures. Table 19 shows the mean Self-Efficacy A (SE A) composite scores for Studies 1 and 2. For both studies, it appears that student pilots had lower self-confidence levels for weather-related skills and knowledge than private, private w/ instrument, and commercial w/ instrument pilots.

Table 19.

Self-Efficacy A: Mean Composite Score

	Study 1 *n = 79*		**Study 2** *n = 204*	
	n	M (SD)	*n*	M (SD)
Student	16	59.78 (17.62)	41	55.85(24.42)
Private	30	71.70 (13.96)	72	67.74 (12.63)
Private w/ Instrument	18	77.83 (9.47)	50	74.34 (11.32)
Commercial w/ Instrument	15	78.23 (10.72)	41	73.07 (12.89)

Table 20 shows the mean Self-Efficacy B (SE B) composite scores for Studies 1 and 2. For both studies, it appears that student pilots had lower self-confidence levels for weather-related tasks than private, private w/ instrument, and commercial w/ instrument participants. Confidence in weather-related tasks also appeared to increase proportionately with participant ratings in Studies 1 and 2.

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Table 20

Self-Efficacy B: Mean Composite Score

	Study 1 *n = 79*		Study 2 *n = 204*	
	n	M (SD)	*n*	M (SD)
Student	16	4.40 (1.05)	41	4.67 (0.96)
Private	30	5.21 (.72)	72	4.95 (0.91)
Private w/ Instrument	18	5.32 (.83)	50	5.00 (0.89)
Commercial w/ Instrument	15	5.73 (.60)	41	5.14 (0.82)

Correlation Analysis. Aviation Weather Knowledge, Self-efficacy, and Salience. The relationships between aviation weather knowledge (AV WX), self-efficacy (SE-A, SE-B), and weather salience were investigated using Pearson product-moment correlation coefficients (see Tables 21 and 22). The Pearson correlation coefficient indicates the strength of the relationship between two variables and can range from r = -1 to 1. A correlation of 0 indicates no relationship, while -1 indicates a perfect negative relationship and +1 indicates a perfect positive correlation. A coefficient of r between .10 and .29 implies a small correlation, an r between .30 and .49 implies a medium correlation, and an r between .50 and 1 implies a strong correlation (Cohen, 1988).

For Study 1, there was a medium, positive correlation between SE A and AV WX knowledge, $r(79) = .42$, $p < .01$, and a high, positive correlation between SE B and AV WX knowledge, $r(79) = .51$, $p < .01$. However, there was no correlation between AV WX knowledge and salience, $r\ (79) = -\ .004$, $p = .97$. Medium correlations occurred between weather self-efficacy and weather salience.

Table 21

Pearson Correlation Matrix: ***Aviation Weather Knowledge, Self-efficacy, and Salience*** *(Study 1)*

	Mean (SD)	1	2	3	4
1. AV WX Knowledge	69.51 (9.99)	1.0			
2. SE A	71.92 (14.78)	.42**	1.0		
3. SE B	5.17 (.90)	.51**	.75**	1.0	
4. Salience Overall	107.65 (12.42)	.00	.35**	.28*	1.0

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

For Study 2, there was a medium, positive correlation between SE A and AV WX knowledge, $r(204) = .31$, $p < .01$, and a medium, positive correlation between SE B and AV WX knowledge, $r(204) = .34$, $p < .01$. However, there was no correlation between AV WX knowledge and salience, $r(204) = .05$, $p = .46$. Also, there were no correlations between self-efficacy and weather salience.

Table 22

Pearson Correlation Matrix: ***Aviation Weather Knowledge, Self-efficacy, and Salience*** *(Study 2)*

	Mean (SD)	1	2	3	4
1. AV WX Knowledge	57.89 (15.55)	1.0			
2. SE A	68.04 (16.79)	.31**	1.0		
3. SE B	4.94 (.90)	.34**	.68**	1.0	
4. Salience Overall	104.54 (13.85)	.05	.05	.11	1.0

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

However, the relation between self-efficacy and aviation weather knowledge accounts for less than 26% of the variance in Study 1 and Study 2 (Study 1: SE A = 18%, SE B = 26%; Study 2: SE A = 10%, SE B = 12%). About 70% to 80% is still unaccounted for which indicates other factors may be influencing the relation between self-efficacy and aviation weather knowledge.

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Impact of Pilot Rating on Self-Efficacy and Salience. For Study 2 data, a one-way between-subject multivariate analysis of variance (MANOVA) was conducted to explore the impact of pilot certification/rating on pilots' perceived confidence on various weather-related skills and knowledge (SE A) and confidence of weather-related tasks (SE B), and on pilots' perceived awareness of atmospheric environments and the importance they place on the weather during daily life (Weather Salience). The three DVs were: SE A, SE B, and Salience. The 4-level independent variable was pilot rating (Student, Private, Private w / instrument, Commercial w/ instrument).

Results of evaluation of assumptions of homogeneity of variance-covariance matrices were non-satisfactory so Pillai's Trace criterion was used instead of Wilks' lambda to evaluate multivariate significance (Olson, 1979; Tabachnick & Fidel, 2013, p. 254). The combined DVs were significantly affected by pilot rating, F (9, 600) = 4.56, $p < .01$; Pillai's Trace = .19; partial $\eta^2 = .06$; 6% of the variance was accounted for by pilot certificate/rating.

Since the results for the assumption of equality of variance for SE A were not satisfactory, a more conservative alpha level for determining significance was used in the univariate F-test. Using a Bonferroni adjusted alpha level of .02, when the results for the DVs were considered separately, the only DV to reach statistical significance was SE A, $F(3, 200) = 12.64$, $p < .01$, partial $\eta^2 = .16$. An inspection of the mean scores indicated that student pilot participants reported lower confidence in weather-related skills and knowledge (M = 55.85, SD = 24.42) than private (M = 67.74, SD = 12.63), private w/ instrument (M = 74.34, SD = 11.32), and commercial w/instrument participants (M = 73.07, SD = 12.89); no other significant differences appeared between the other groups. Figure 15 displays the SE A means by pilot rating.

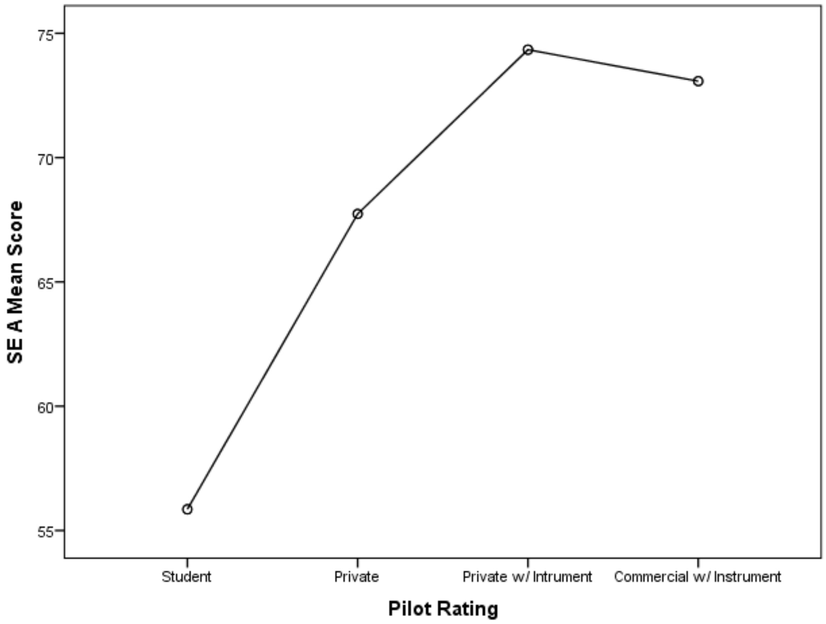

Figure 15. Self-Efficacy A Mean Score by Pilot Certificate/Rating (Study 2)

Weather Training Experience. For Study 2, a series of analyses examined the relationships among pilot certificate/rating, category of flight school (Part 61 vs. Part 141/142), and pilot perceived levels of training.

Study 2 participants received an additional questionnaire related to their perceived weather training experience. Participants were asked to report the elapsed time in months since their last weather training experience, their level of meteorology training, the relative amount of time spent looking at weather information not specific to forecast and flight, and overall experience and time spent using aviation weather products.

As shown in Table 23, Private and Commercial-rated pilots had a longer elapsed time since their most recent weather training experience than did student and private w/ instrument-rated pilots.

Table 23

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Last Weather Training Experience (in Months; Study 2)

	n = 204	M (SD) Median
Student	41	4.65 (7.88) 2.00
Private	72	12.55 (29.46) 5.50
Private w/ Instrument	50	7.69 (8.28) 4.00
Commercial w/ Instrument	41	19.28 (39.71) 7.50

Table 24 shows the perceived amount of meteorology training Study 2 participants received. Each participant rated their training experience along a 7-point Likert-scale, ranging from 1 as being 'Little to No' experience to 7 being 'Extensive' experience. Each ratings overall score fell within a 'moderate' amount of meteorology training.

Table 24

Amount of Training in Weather (Study 2)

	n = 204	M (SD)
Student	41	2.93 (1.49)
Private	72	3.24 (1.75)
Private w/ Instrument	50	3.50 (1.64)
Commercial w/ Instrument	41	3.61 (1.70)

Table 25 shows the composite mean score of four items (Cronbach's alpha, $\alpha = .69$) related to the amount of time spent looking at various weather information not specific to forecast and flight. Study 2 participants rated their experience along a 7-point Likert-scale, ranging from 1 as being 'Not Often' to 7 being 'Very Often'. On average, each rating group spent an 'occasional' amount of time looking at various weather information.

Table 25

Relative Time Spent Looking at WX Materials Not Specific to Forecast and Flight (Study 2)

	n = 204	M (SD)
Student	41	3.40 (1.22)
Private	72	3.42 (1.12)
Private w/ Instrument	50	3.95 (1.03)
Commercial w/ Instrument	41	3.60 (1.27)

Table 26 shows the composite mean score of two items (Cronbach's alpha, $\alpha = .79$) related to overall experience and time spent using aviation weather products. Study 2 participants rated their experience and time along a 7-point Likert-scale, ranging from 1 as being 'Not Often' to 7 being 'Very Often'. On average, each rating group spent a 'regular' amount of experience and time using aviation weather products.

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Table 26

Overall Experience and Time Spent Using Aviation Weather Products (Study 2)

	n	M (SD)
Student	41	4.46 (1.86)
Private	72	5.10 (1.34)
Private w/ Instrument	50	5.66 (1.08)
Commercial w/ Instrument	41	5.61 (1.27)

Correlation Matrix between Aviation Weather Knowledge and Weather Training Experience. The relationship between perceived weather training experience, pilot rating, flight training affiliation, and aviation weather knowledge was investigated using Pearson product-moment correlation coefficient (see Table 27). There was a medium, positive correlation between pilot rating and aviation weather knowledge, $r\ (204) = .38$, $p < .01$, and a small, positive correlation between type of flight school and aviation weather knowledge, $r(204) = .24$, $p < .01$. Pilot certificate/rating accounted for 15% of the variance in aviation weather knowledge, while flight school affiliation accounted for 6% of the variance in aviation weather knowledge. However, there was no correlation between weather training experience and aviation weather knowledge, $p > .05$.

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Table 27

Pearson Correlation Matrix: Aviation Weather Knowledge and Weather Training Experience (Study 2)

	Mean (SD)	1	2	3	4	5	6	7
1. AV WX Knowledge	57.89 (15.55)	1.0						
2. Rating	68.04 (16.79)	.38**	1.0					
3. Flight TRX Affiliation (Part 61 & Part 141/142)	4.94 (.90)	.24**	.19**	1.0				
4. Meteorology TRX Amount	104.54 (13.85)	.104	.16*	.30**	1.0			
5. Last WX TRX Experience	34.46 (5.02)	.01	.10	-.14*	-.04	1.0		
6. Time Spend Reading Alt. Materials	21.25 (2.94)	.01	.15*	.11	.28**	-.24**	1.0	
7. Exp. Using WX Products	9.71 (2.80)	.30	.31**	.21**	.32**	-.23**	.49**	85

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

Impact of Flight Affiliation and Pilot Rating on Weather Training Experience. A 2 x 3 between-subjects multivariate analysis of variance (MANOVA) was performed on four dependent variables related to weather training experience. The two independent variables were flight training affiliation (Part 61 vs. Part 141) and pilot certificate/rating (Student vs. Private vs. Instrument). The four DVs were level of meteorology training, last weather training experience, relative time spent reading weather materials not related to forecast and flight, and relative experience using weather flight products.

Total *n* of 204 was reduced to 203 with the deletion of a case missing an identifier on flight training affiliation. Table 28 displays the cell size for each pilot rating according to affiliation type.

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Table 28

Sample Size of Flight Experience by Flight Training Affiliation (Study 2)

	Student	Private	Private w/ Instrument	Commercial w/ Instrument	Total
Part 61	15	27	12	6	60
Part 141/142	25	45	38	35	143
Total	40	72	50	41	203

However, due to the small *n* in the Part 61 Commercial cell and similar weather training received during Instrument Ground School, the private w/ instrument and commercial w/ instrument cells were collapsed to create a single Instrument cell. Table 29 displays the new *n* for Part 61 and Part 141 that were used for the Weather Training Experience MANOVA analysis.

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Table 29

Collapsed Sample Size of Flight Experience by Flight Training Affiliation (Study 2)

	Student	Private	Instrument*	Total
Part 61	15	27	18	60
Part 141/142	25	45	73	143
Total	40	72	91	203

* Instrument contains private w/ instrument and commercial w/ instrument

Results of evaluation of assumptions of homogeneity of variance-covariance matrices were non-satisfactory so Pillai's Trace criterion was used instead of Wilks' lambda to evaluate multivariate significance (Olson, 1979; Tabachnick & Fidel, 2013, p. 254). The combined DVs were significantly affected by pilot certificate/rating, $F(8, 390) = 2.50$, $p = .01$; Pillai's Trace = .10; partial $\eta^2 = .05$. There was also a significant main effect based of flight training affiliation, $F(4, 194) = 3.83$, $p < .01$; Pillai's Trace = .07; partial $\eta^2 = .07$. However, there was no significant interaction between pilot certificate/rating and flight affiliation on WX training experience, $F(8,390) = .80$, p = .61; Pillai Trace = .03; partial $\eta^2 = .016$.

Since the results for the assumption of equality of variance for last WX training experience and relative experience using WX flight products was not satisfactory, a more conservative alpha level for determining significance was used in the univariate *F*-test. Using a Bonferroni adjusted alpha level of .013, when the results for the DVs were considered separately, the only DV to reach statistical significance was the level of meteorology training between Part 61 and Part 141/142 pilots, $F(1, 197) = 10.60$, $p < .01$, partial $\eta^2 = .05$. An inspection of the mean scores indicated that Part 61 pilots reported lower meteorology training experience (M = 2.62, SD = .22) than Part 141/142 participants (M = 3.47, SD = .15). However, that may be because the overall level of flight experience is higher in pilots from 141/142 schools. Table 30 displays the pilots' perceived meteorology training experience by flight training affiliation.

Table 30

Pilot Certificate/Rating Meteorology Training Experience by Flight Training Affiliation (Study 2)

	Private-in-training	Private	Instrument*	Overall Mean
	M (SD)	M (SD)	M (SD)	M (SD)
Part 61	2.53 (1.55)	2.81 (1.47)	2.50 (1.62)	2.62 (.22)
Part 141/142	3.12 (1.51)	3.49 (1.87)	3.81 (1.58)	3.47 (.15)
Overall Mean	2.90 (1.53)	3.24 (1.75)	3.55 (1.66)	

* Instrument contains private w/ instrument and commercial w/ instrument

Impact of Weather Course Training for Southeastern U.S. University Affiliated Participants. A 2 x 4 two-way between-subjects analysis of variance was conducted to explore the impact of aviation weather college level course training and pilot certificate/rating on the aviation weather knowledge scores of ERAU affiliated pilots. Of the 204 participants, 134 were affiliated with a southeastern U.S. university and had either taken zero to one, or two aviation weather courses. Table 31 displays the participant frequency of weather courses by pilot rating.

Table 31

Aviation Weather College Course Training by Pilot Rating (Study 2)

	Private-in-training *f*	Private *f*	Private w/ Instrument *f*	Commercial w/ Instrument *f*	Total
Two Courses	11	19	22	24	76
Zero to One Courses	16	27	13	2	58
Total	27	46	35	26	134

However, due to the small *n* in the Zero to One Course Commercial cell and similar weather training received during Instrument Ground School, the private w/ instrument and commercial w/ instrument cells were collapsed to create a single Instrument cell. Table 32

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displays the new *n* for WX course experience that were used for the ERAU Affiliated Weather Course Training Experience ANOVA analysis.

Table 32

Collapsed Sample Size of Flight Experience by Flight Training Affiliation (Study 2)

	Private-in-training	Private	Instrument*	Total
Two Courses	11	19	46	76
Zero to One Courses	16	27	15	58
Total	27	46	61	134

* Instrument contains private w/ instrument and commercial w/ instrument

The interaction effect between pilot certificate/rating and amount of AV WX training courses taken was not statistically significant., $F(2,128) = .46$, $p = .64$. There was a statistically significant main effect for pilot rating, $F(2,128) = 12.09$, $p < .01$, partial $\eta^2 = .16$. Post hoc comparisons using the Tukey HSD test indicated the mean knowledge score for instrument rated pilots ($M = 68.52$, $SD = 10.63$) were significantly higher than Private-in-training ($M = 51.89$, $SD = 12.28$) and private certified pilots ($M = 61.08$, $SD = 14.05$), $p < .01$. Private-in-training pilots scored lower than the other two certificate/rating groups ($p < .01$) and private pilots scored lower than instrument rated pilots ($p < .01$). Table 33 displays the means of knowledge scores by pilot certificate/rating and WX course training experience.

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Table 33

Mean Knowledge Scores by Pilot Certificate/Rating and WX Course Training Experience (Study 2)

	Private-in-training	Private	Instrument*	Overall Mean
	M (SD)	M (SD)	M (SD)	M (SD)
Two WX Courses	57.51 (13.34)	68.53 (14.55)	70.55 (9.88)	68.16 (12.38)
Zero to One WX Course	48.03 (10.17)	55.83 (11.23)	62.32 (10.76)	55.35 (11.88)
Overall Mean	51.89 (12.28)	61.08 (14.05)	68.52 (10.63)	

* Instrument contains private w/ instrument and commercial w/ instrument

There was also a significant main effect for the amount of WX courses taken on knowledge scores, F (1, 128) = 21.76, $p < .01$, partial $\eta^2 = .15$). The mean knowledge score for participants who have taken two weather courses (M = 68.16, SD = 12.38) was significantly higher than participants who have taken zero to one weather courses (M = 55.35, SD = 11.88).

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Figure 16 displays the AV WX knowledge mean score by number of WX course training.

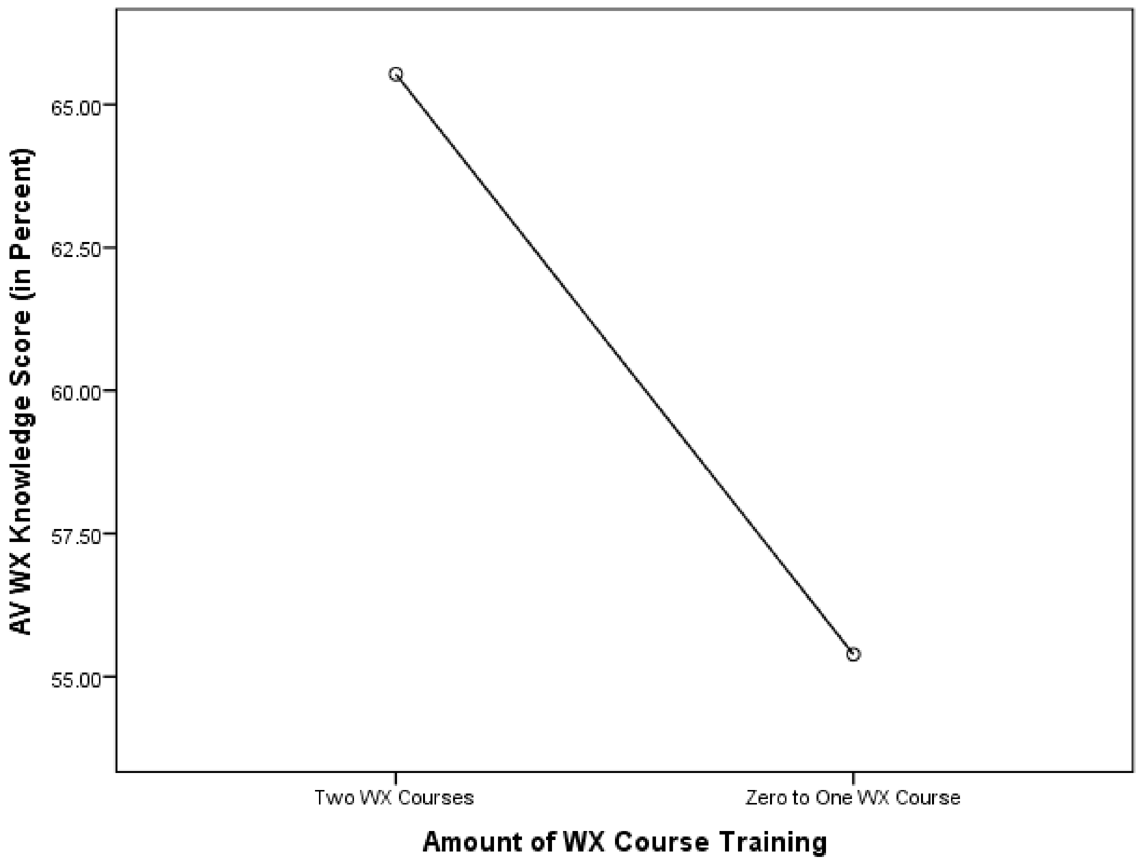

Figure 16. Aviation Knowledge Score by Weather Course Experience (Study 2)

This concludes the attitudinal data results.

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Discussion

Growing research has demonstrated an apparent lack of GA pilot knowledge and skill regarding weather (Ahlstrom, Ohneister, & Caddigan, 2016; Blickensderfer et al., 2015; Johnson & Wiegmann, 2016; Lanicci et al., 2012). Other research has identified serious gaps in existing aviation weather knowledge assessment for GA pilots (Wiegmann et al., 2008). With a growing body of research examining aviation weather technology to assist pilots in the cockpit (e.g., Ahlstrom et al., 2016) as well as efforts underway for training technologies, a key research need is valid and reliable aviation weather knowledge assessment strategies. Thus, the purpose of this research was to develop and validate appropriate weather-related test questions to assess GA pilots' knowledge of aviation weather concepts and principles, sources of aviation weather product and how to interpret aviation weather products.

Psychometrics. Results of the current research indicate that the aviation weather knowledge questions developed and tested have promise as a reliable and valid method to assess aviation weather knowledge in GA pilots. This study used a systematic approach that followed FAA (2015) guidelines in the assessment instrument development. The measure has content validity and initial evidence that test scores discriminate between pilots of differing levels of training as well as between different types of aviation weather information. The test also generated a spread of scores that reflect both high and low aviation weather knowledge.

The sample size for Study 2 was acceptable for a preliminary study. The sample included a cross-section of the target population of low-hour, GA pilots in terms of pilot certificate/rating. Examination of the discriminant validity of the test identified significant group differences between groups that were as expected: pilots-in-training had the lowest knowledge scores and scores increased significantly as level of certificate and/or rating increased. This pattern appeared for both the overall aviation weather knowledge scores as well as for most of the subcategories of aviation weather knowledge.

The internal consistency for the 95 questions together was high (.92). However, when the questions were grouped conceptually according to the Lanicci et al. (2017) aviation weather knowledge taxonomy, the subcategories did not yield high levels of reliability. Inspection of the Cronbach's alpha levels for the subcategories of aviation weather knowledge revealed a range of values (.24 to .77). These values are of concern, as desired levels of internal consistency for a test are over .80. The low levels of internal consistency for the subcategories indicates that the question groupings may not be accurate. A factor analysis would shed additional insight as to which questions are interrelated and provide statistical evidence of more reliable subcategories.

Level of Pilots' Knowledge. The pattern of results also provides evidence of the research and practical value of the instrument. It appears, however, that our young pilots have low levels of aviation weather knowledge. For the 95 questions, the mean scores overall for student pil and private pilots were less than 60% and for private pilots with instrument and commercial pilots with instrument, just over 60%. The results show that proportion of correct responses on individual questions (i.e., the difficulty level) ranged from .11 to .92, with the median being .58. These results indicate either a moderately difficult test or a low level of aviation weather knowledge, or both.

When breaking the questions down into subcategories, pilots scored higher on weather product source questions then they did on weather phenomena and weather product questions. These results suggest that pilots may have more difficulty answering questions concerning the basic principles of weather phenomena and weather product interpretation, and in turn, have a better understanding of where to find products and product limitations. A limitation for the comparisons regarding type of knowledge, however, is a possible confound of question difficulty. Specifically, a distinction may be made between difficult *content* versus difficult *questions* on particular content. For example, it may be that the questions on weather products were inherently more difficult than the product source questions, as they were interpretation questions. Thus, while it appears that pilots know more about product sources than weather products, it may be that they actually know an equivalent level and the lower scores were due to an artifact of the more difficult interpretation style of questions.

Attitudes. Correlation analyses between aviation weather knowledge and attitudinal measures (self-efficacy and salience), revealed self-efficacy could potentially act as a predictor to aviation weather knowledge. The positive correlation between the two indicates that as one variable increases/decreases, a proportional increase/decrease occurs in the other variable. However, the relation accounts for less than 26% of the variance in Study 1 and Study 2 About 70% to 80% is still unaccounted for which indicates other factors may be influencing the relation between self-efficacy and aviation weather knowledge. Instead, further analyses with a larger, more generalizable sample size would be needed to determine if confidence can be used as a predictor of aviation weather knowledge scores.

In terms of weather salience, while no correlation existed between weather salience and weather knowledge, pilots scored significantly higher on weather salience than the UGA sample of the same age group but lower than the general population. Due to the little to no correlation between weather salience and aviation weather knowledge, the WxSQ raises the question of whether this particular instrument is appropriate for assessing weather awareness and use of weather products in specific user groups, notably in the GA community.

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Finally, regarding weather training experience, pilots who had taken meteorological weather courses (geared towards aviation weather phenomena and application) scored higher on the aviation weather knowledge assessment than pilots who had not. This may suggest that introducing additional aviation weather training into flight training may help improve pilot performance in adverse weather situations.

Future Research. A number of avenues of future research exist. First, the test has 95 questions and can take pilots up to 45 minutes to complete. Future work should focus on splitting the questions up into two or more equivalent, reliable forms of the test with 30 – 45 questions on each. A shorter test will be simpler for future researchers to administer in their future studies, and/or flight instructors to use as an instructional tool.

Additional analysis of the current questions may shed insight on the difficulty level of the questions on the different subcategories. Application questions tend to have the highest level of difficulty. It may be that certain subcategories in which pilots had lower scores could be composed entirely of application questions. Further, with the average scores on the test around 60% across all participants, it may be that the test has an overall high level of difficulty rather than that the participating pilots having a relatively low level of aviation weather knowledge. To determine this, future research should inspect the scores of pilots with known high levels of aviation weather knowledge.

Another area for future research is to examine the knowledge of GA pilots in a different age bracket. The current study used participants primarily in their 20s, which is considerably younger than other samples of GA pilots (e.g., Blickensderfer et al., 2015). Thus, further research and analysis is needed to the general population of GA pilots. Work is also needed to examine the criterion validity of the knowledge questions in terms of whether scores on the knowledge questions predict pilots' performance in weather related flight scenarios.

In summary, the preliminary findings described in this report indicate that the aviation weather knowledge questions have considerable potential as a measure of pilots' aviation weather knowledge. The questions have promise to be used in a variety of studies aimed at evaluating aviation weather training programs as well as to evaluate the level of aviation weather knowledge in other populations of pilots, flight instructors, flight service station specialists, and perhaps other professions within aviation, such as air traffic controllers and flight dispatchers.

Phase 2: General Aviation Pilots' Knowledge and Interpretation of Weather Products:

The Broader General Aviation Community

Aviation Weather Knowledge Assessment & Interpretation of Products

Phase 2 - Abstract

Introduction. This phase of the research was a follow-on study to Phase I using a more generalizable sample of GA pilots.

Method. Eight hundred and thirty-seven GA pilots completed an online, 118-item aviation weather knowledge assessment with a focus on interpreting weather hazard products. Participants were divided between five categories of certification and/or ratings: Private, Private with Instrument, Commercial with Instrument, Commercial Flight Instructors and Airline Transport Pilots. All 118 questions were divided into five separate tests and randomly distributed to the participants. Test 1 contained Data Source, Significant Weather, Storm Definition and Flight Planning questions. Test 2 contained METAR, PIREP, Winds Aloft and TAF questions. Test 3 contained CIP, G-AIRMET and GTG questions. Test 4 contained Radar, SIGMET and Thunderstorm (TSTM) questions. Lastly, Test 5 contained questions on CVA, Satellite, Station Plots and Surface Prognostic products.

Results. A series of analyses were conducted to assess the impact weather product and pilot certification on interpretation performance. Private pilots scored significantly lower than Commercial, CFI and ATP pilots. Private with instrument rated pilots scored significantly lower than CFI and ATP pilots. No other significant differences between ratings were found. Further analysis revealed that pilots scored significantly higher on Test 1 (Data Source, Significant Weather, Storm Definition and Flight Planning) than all other tests and significantly lower on Test 5 (CVA, Satellite, Station Plots and Surface Prognostic) than all other tests. Further analyses were conducted to investigate the differences between products within tests.

Discussion. The low scores on weather hazard products interpretation are concerning. Potential reasons include: products are not user-intuitive to pilots, a lack of formal training exists

for many pilots on how to use weather hazard products, and pilots may be unaware of the existence of certain weather hazard products. Further research is needed to identify the causes as to why pilots have low aviation weather interpretation scores.

Phase 2 – Study Problem Statement

The purpose of this study was to assess, in a generalizable sample, GA pilots' capability to interpret weather observation reports and weather forecasts and use the information for flight planning.

Method

Participants. Participants (*n* = 837) were certificate holding pilots aged 18 to 86. The mean age was 57. The pilots were recruited through the use of the Aircraft Owners and Pilots Association's (AOPA) member email listserv. Participation was voluntary and, as an incentive, participants were offered to be entered into a drawing for a small prize package. Although 1702 participants began the survey, only those who completed the survey were included in data analysis. All pilots held certificates in or were completing training for the following: Private, Private with Instrument, Commercial with Instrument, Certified Flight Instructor (CFI), or Airline Transport Pilot (ATP). Figure 1 reveals the U.S. geographical regions in the participants' flight hours were achieved. Regions are based on the FAA Chart Supplements (FAA, 2016).

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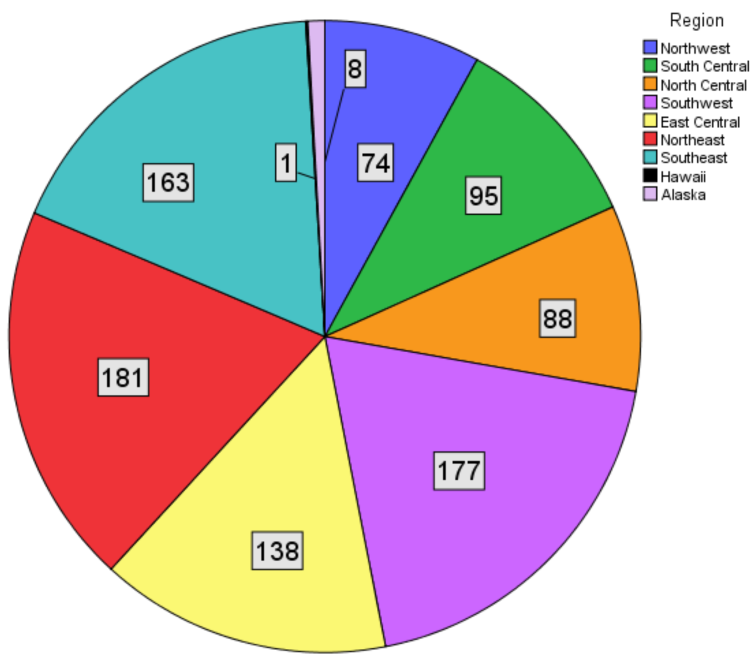

Figure 1: Participant Total by Geographical Regions

This study was approved in advance by Embry-Riddle Aeronautical University Institutional Review Board for the protection of human participants.

Measures. The knowledge and interpretation test, demographics questionnaire and attitudinal surveys were implemented via the online survey system Qualtrics (Qualtrics, 2018).

Demographic Data Form. The demographic questionnaire consisted of 15-items. The items were designed to obtain basic information about the participants such as age, flight experience and weather training.

Aviation Weather Assessment. The purpose of the 118 question Aviation Weather Knowledge and Interpretation Assessment was to evaluate GA pilots' capability to interpret weather products. All questions were multiple-choice, and each had 3-4 answer options (i.e, a, b, c; or a, b, c, d). This included 95 questions from the Blickensderfer et al. (2018) weather interpretation assessment as well as 23 additional questions. The 23 new items were developed by the research team which consisted of one meteorologist, one Gold Seal Certificated Flight

Instructor Instrument (CFII), an Industrial-Organizational psychologist, and two human factors specialists. Reference documents for the 23 new items were the FAA Advisory Circular 00-45H Change 1 (FAA, 2018), the Federal Aviation Regulations/Aeronautical Information Manual (FAA, 2015).

In order to randomize the questions among the participants and to reduce the number of questions any one pilot would be asked to answer, the 118 questions were divided into five separate tests with 20-25 questions in each. The tests were organized by topics and/or weather product such that all questions pertaining to a specific weather product were presented together on a test.

Procedure. All participants completed the questionnaires on their personal electronic devices in a location of their choosing. The devices included laptops, desktops, phones and tablets. Upon receiving the email with the survey link, the participant clicked on the link to open the survey. Participants read the consent form, and if in agreement to continue, they clicked "I Agree," which began the survey questions. Demographic questions were first, and the aviation weather questions were second. Participants were not restricted on time, and they could exit/pause the survey and continue later, as long as they used the same device. At the end of the survey, participants were invited to provide their email address to be entered into a drawing to win the prize package. There was one prize package drawing for each of the 5 tests.

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Table 1. Summary of Forecast Product Questions

	N	*n of Questions*	Cronbach's Alpha	Test Number
LL Hazard	217	5	0.364	1
G-Airmet	147	13	0.629	3
GTG	155	5	0.294	3
TAF	157	6	0.490	2
Surface Prog	182	5	0.344	5
Convective Sigmets	211	7	0.278	5
Winds Aloft	156	5	0.442	2

Table 2. Summary of Observation Product Questions

	n	*n of Questions*	Cronbach's Alpha	Test Number
METAR	160	8	0.551	2
Station Plot	173	6	0.380	5
PIREP	155	6	0.316	2
Satellite	180	7	0.719	5
CVA	181	5	0.366	5
Radar	195	12	0.510	4
CIP	149	5	0.391	3

Table 3. Summary of Flight Planning Questions

	n	*n of Questions*	Cronbach's Alpha	Test Number
Flight Planning	218	5	0.250	1
Storm Definitions	214	5	0.185	1
TSTM	209	5	-0.006	4
Data Sources	209	5	0.359	1

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Results

The researchers downloaded the data from Qualtrics into MS Excel for data clean-up. The data were then exported into the Statistical Package for the Social Sciences (SPSS) for analysis. The analyses are divided into three major sections: equivalency of test groups, comparisons of tests, and topic analysis.

Equivalency of Test Groups Analyses. As not all participants responded to all questions, the purpose of the first set of analyses was to determine equivalency of the groups (e.g., participants who took Test 1 versus Test 2, Test 3, Test 4, and Test 5). Table 4 displays the descriptive statistics for flight hours for each test.

A 5 x 5 two-way, between-groups analysis of variance was conducted to explore the impact of test number (Test 1, Test 2, Test 3, Test 4, Test 5) and pilot rating (Private, Private with instrument rating, Commercial with instrument rating, CFI, and ATP) on flight hours. There was not a significant main effect of test number on flight hours, F (4,850) = 0.51, $p = 0.73$, partial $\eta^2 = 0.002$. There was a significant main effect for rating on flight hours, F (4,850) = 196.99, $p < 0.01$. Partial $\eta^2 = 0.48$ which indicates about 48% of the variability in hours is related to certificate/rating.

A Bonferroni post-hoc comparison indicated that, regardless of the test taken, Private pilots (*M* = 505.56, *SD* = 646.4) had significantly fewer flight hours than all other ratings. Private with Instrument-rated pilots (*M* = 1389.1, *SD* = 1147.4) had significantly fewer flight hours than Commercial with Instrument, ATP, and CFIs. Commercial with Instrument-rated pilots (*M* = 2367.9, *SD* = 2345.2) had significantly fewer than CFI (*M* = 3568.2, *SD* = 2943.2) and ATP-rated pilots (*M* = 8769.5, *SD* = 6067.6).

Table 4. Participant Flight hours by Test and Pilot Rating

	Test 1 ***n*** ***M*** ***(SD)*** ***Mdn***	**Test 2** ***n*** ***M*** ***(SD)*** ***Mdn***	**Test 3** ***n*** ***M*** ***(SD)*** ***Mdn***	**Test 4** ***n*** ***M*** ***(SD)*** ***Mdn***	**Test 5** ***n*** ***M*** ***(SD)*** ***Mdn***	**Totals** ***N*** ***M*** ***(SD)*** ***Mdn***
Private	69 517.6 (550.88) 300	35 508 (731.07) 320	40 465.71 (539.33) 275	55 607.98 (875.05) 325	49 420.2 (517.94) 420	248.00 505.56 (646.4) 290.00
Private w/ Instrument	41 1428.44 (1253.96) 1045	47 1146.94 (1031.03) 780	55 1681.16 (1292.78) 1400	46 1131.46 (983.69) 785.5	51 1550.04 (1099.37) 1333	240.00 1389.08 (1147.4) 1000.00
Commercial w/ Instrument	39 2431.87 (2614.97) 1100	22 1898.68 (1371.51) 1450	11 2052.45 (1609.85) 1175	29 2233.03 (1885.17) 1500	33 2873.42 (3089.18) 1950	134.00 2367.88 (2345.2) 1500.00
ATP	22 8931.59 (6174.36) 7000	24 8501.46 (6735.00) 6062.5	24 8598.04 (6733.78) 6500	7 10971.43 (7281.65) 9000	23 7356.09 (3908.57) 7100	100.00 8769.50 (6067.6) 7000.00
CFI	35 3417.36 (6174.36) 3000	21 3662.76 (3223.94) 2500	19 3092.11 (2899.06) 1650	22 3602.27 (3228.17) 2525	18 4042.78 (3131.46) 4150	115.00 3568.18 (2943.2) 2550.00
Total	206 2452.62 (3584.75) 1048	149 2647.05 (4093.67) 1000	149 2676.32 (4044.36) 1350	159 2791.70 (4321.20) 1000	174 2508.19 (3161.61) 1277	837.00 2611.21 (3847.60) 1100

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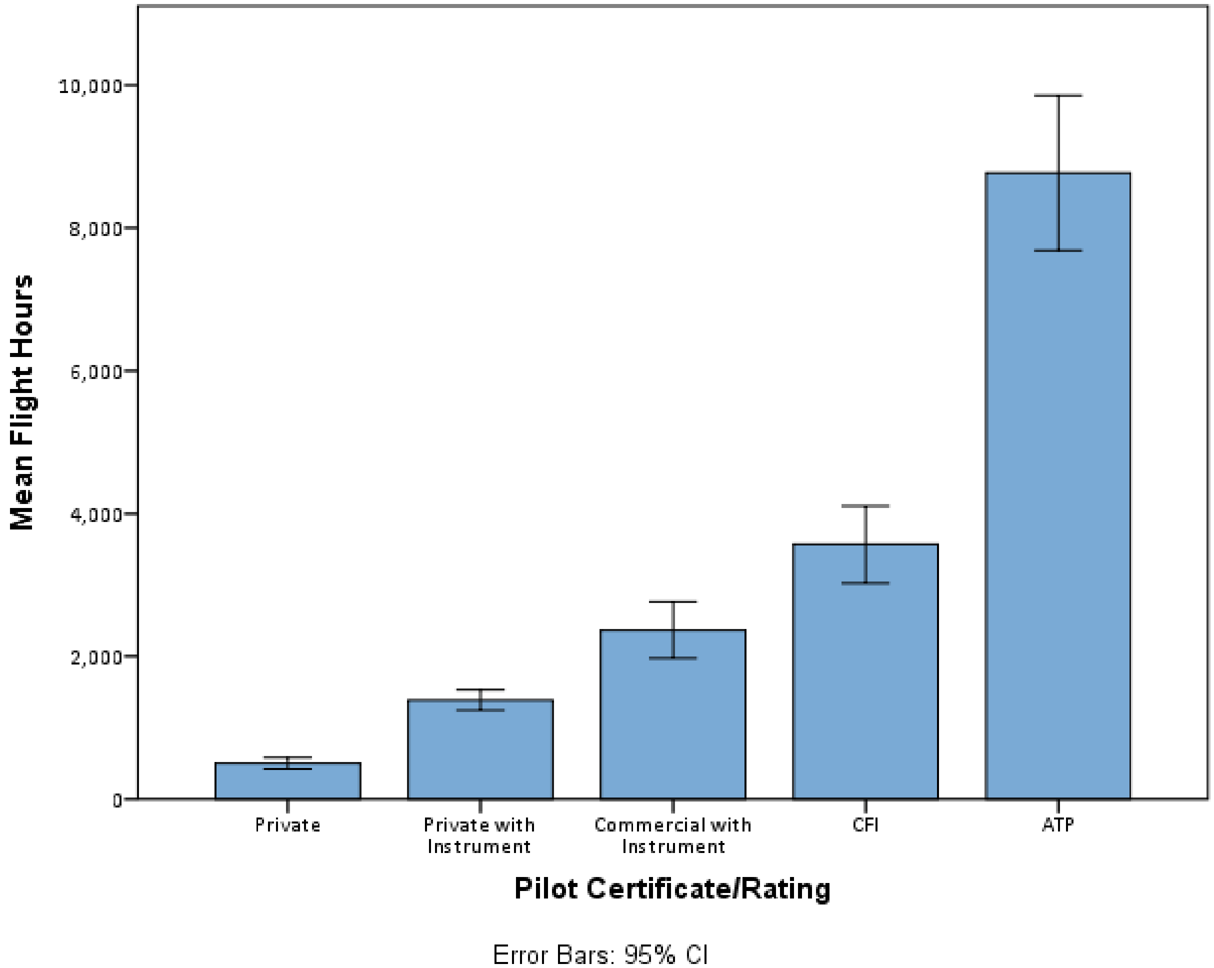

Figure 2 Main Effect of Pilot Rating on flight hours.

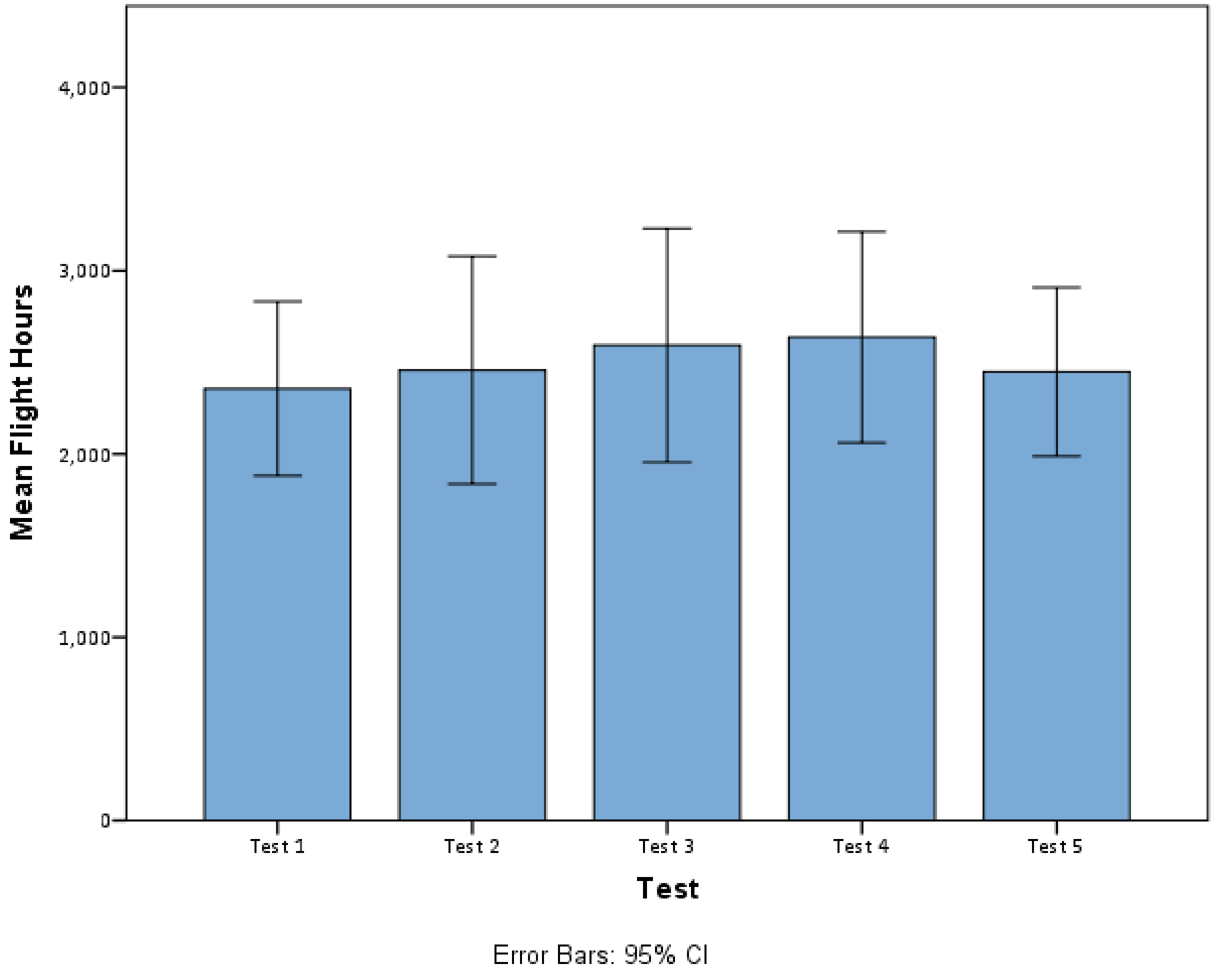

Figure 3 Main Effect of Pilot Rating on flight hours.

The interaction between test number and pilot rating on flight hours was found to be nonsignificant, F (16, 850) = 1.07, $p = 0.38$, partial $\eta^2 = 0.02$ (see Figure 3).

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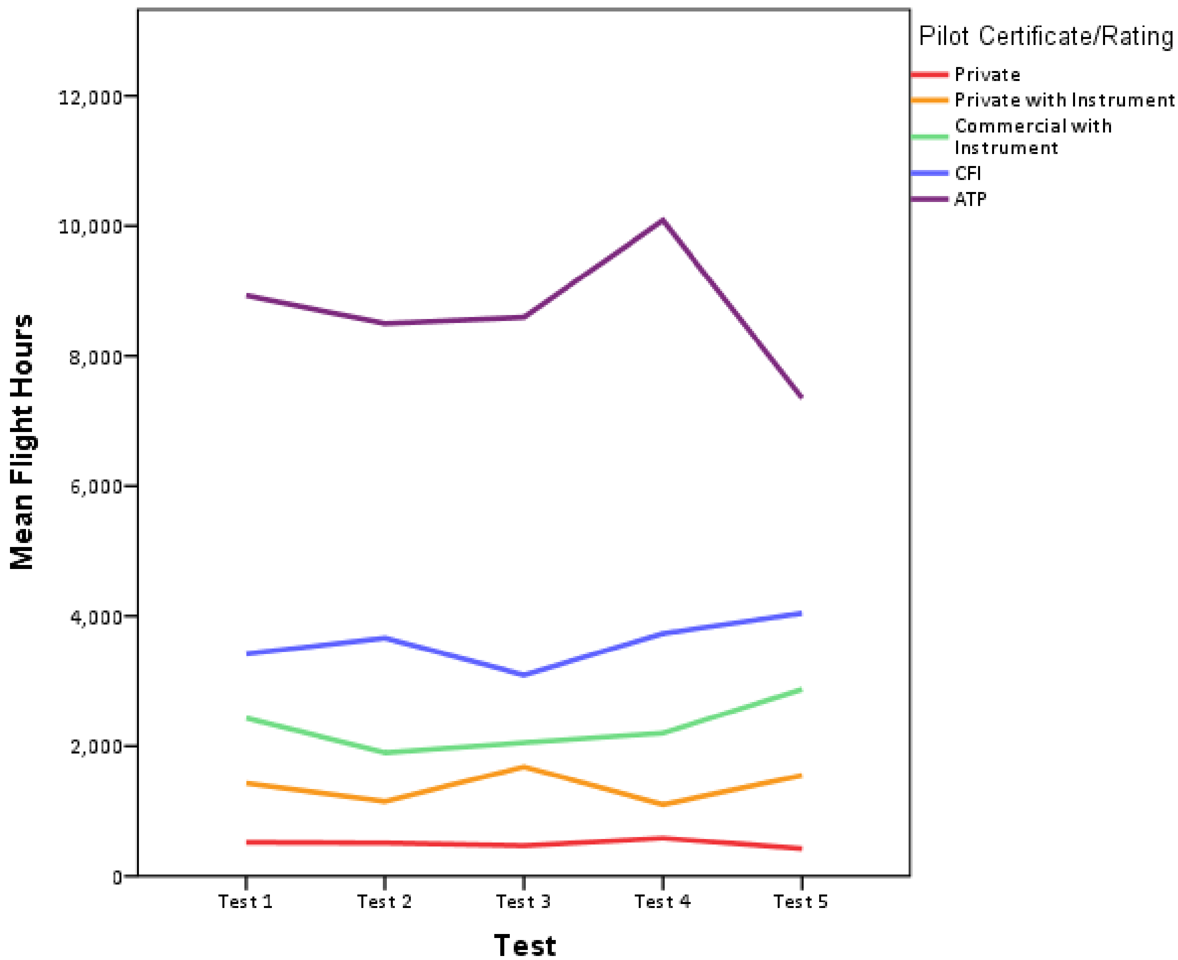

Figure 4. Test number and pilot rating on flight hours.

Taken together, the results indicate that the samples for the respective tests had similar flight hours. This concludes the analyses to determine equivalency of groups.

Overall Test Score Analysis. The next analyses examined the test results. Specifically, a two-way between-groups analysis of variance was conducted to explore the impact of pilot rating (Private, Private with instrument rating, Commercial with instrument rating, CFI, and ATP) and test number (Test 1, Test 2, Test 3, Test 4 and Test 5) on performance/score.

The main effect for pilot certificate/rating on performance was found to be significant, F (4, 857) = 12.48, $p < 0.01$. Partial η^2 equaled 0.55, which indicates that 55% of the variability in

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performance is related to pilot rating.

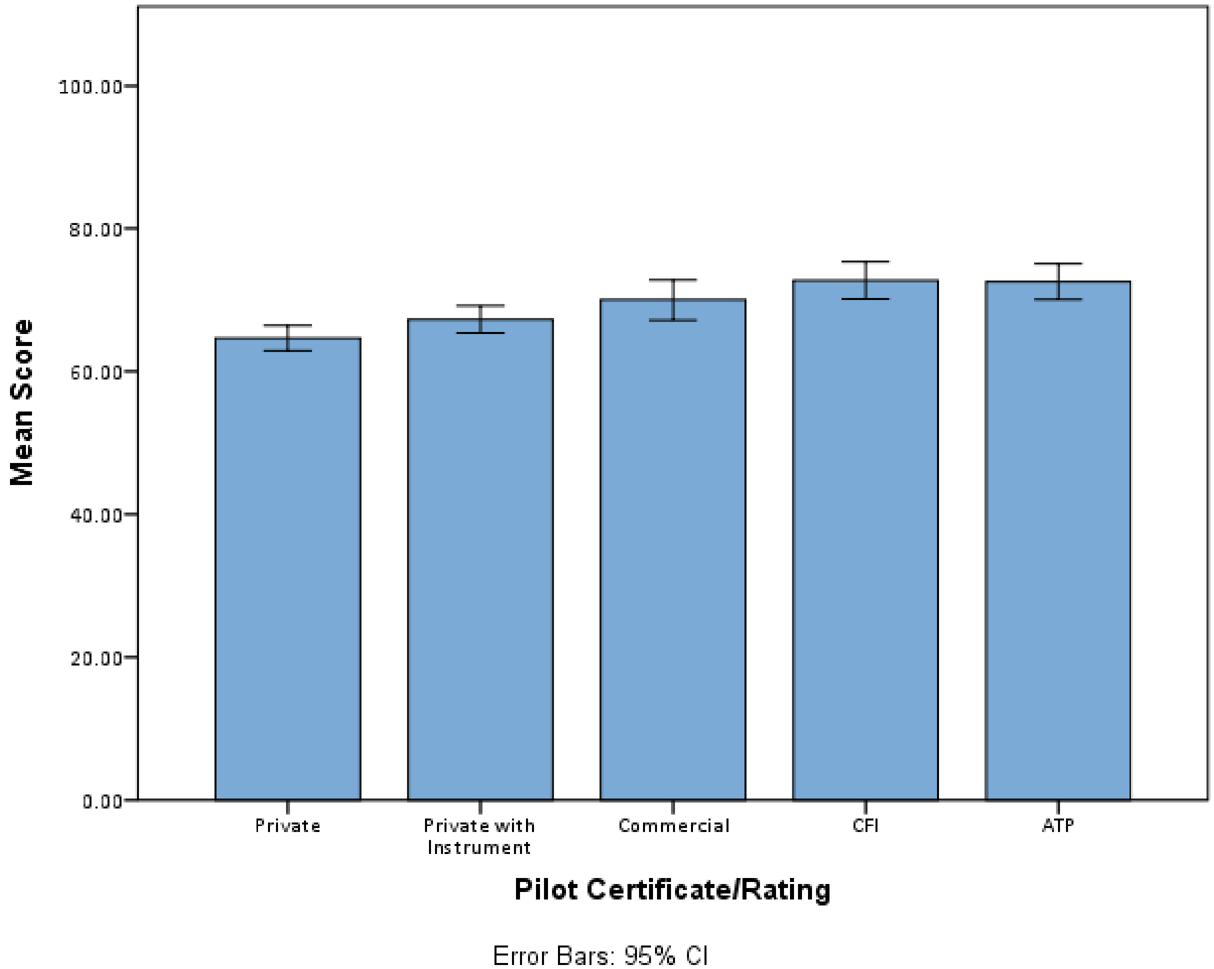

Figure 5. Main effect of pilot rating on score.

Post-hoc comparisons indicated that regardless of test taken, Private pilots (*M* = 64.7, *SD* =14.3) scored significantly lower than Commercial, ATP, and CFI pilots. Private with Instrument-rated pilots (M=67.3, SD=15.1) scored significantly lower than CFI and ATP pilots. Commercial pilots (M=70.0, SD=16.9) did not score significantly lower than ATP or CFI. ATP (*M* = 72.6, *SD* = 14.1) and CFI-rated pilots (*M* = 72.7, *SD* = 14.4) did not score significantly different.

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The main effect of test on performance was also found to be significant, F (4, 857) = 53.39, $p < 0.01$ partial $\eta^2 = 0.20$.

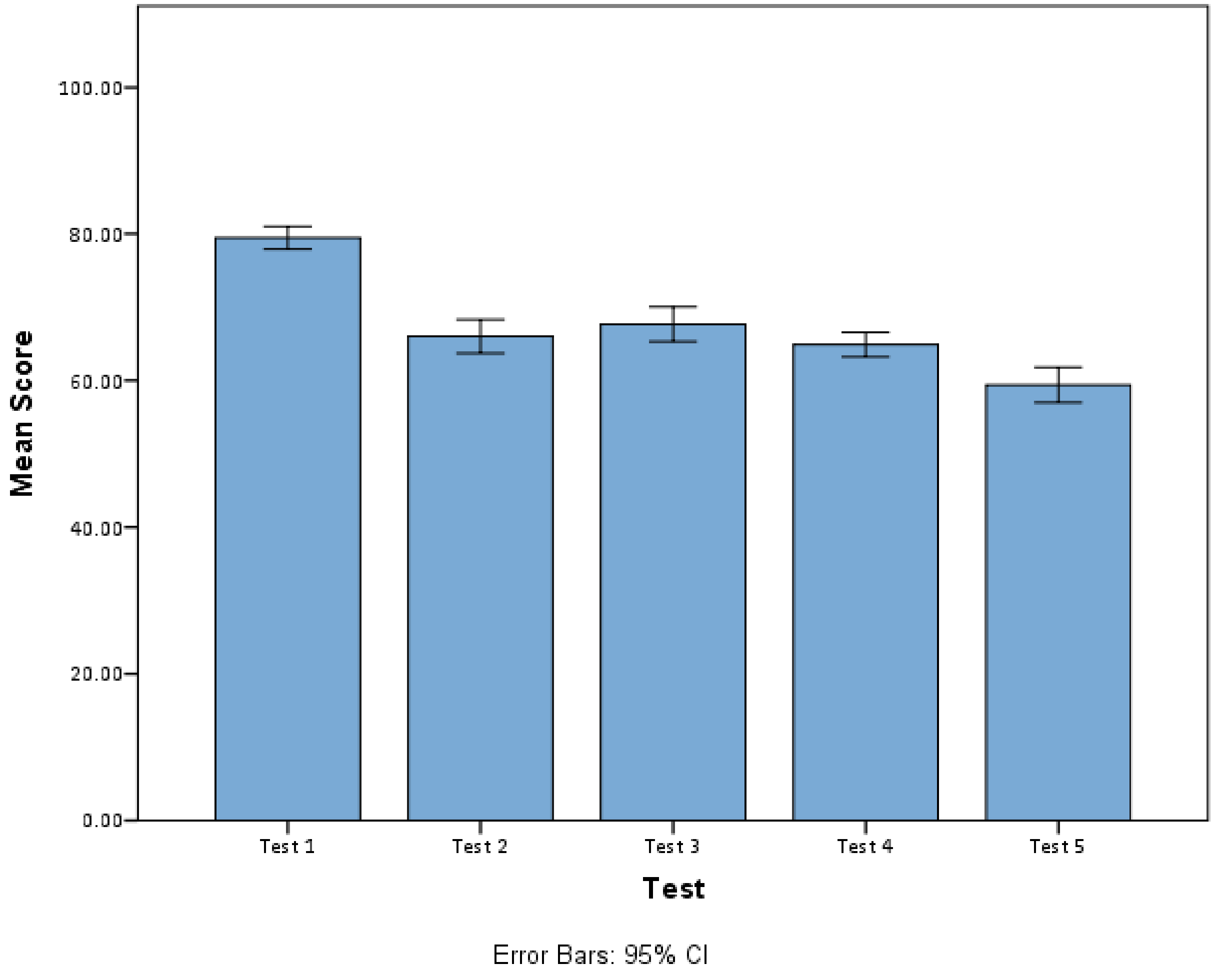

Figure 6. Main effect of Test Number on score.

Post-hoc comparisons indicated that regardless of rating, pilots scored significantly higher on Test 1 (M = 79.4 SD = 11.6) than all other tests. On Test 5 (M = 60.8, SD = 15.7), pilots scored significantly lower than all other tests. No other significant differences were found between the tests. These results indicate that pilots are more proficient on the topics contained in Test 1 than topics in the other tests. Likewise, pilots are least proficient on topics in Test 5. This also indicates that Test 2, 3, and 4 were of equal difficulty.

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Next the interaction between pilot certificate/rating and test on score was examined (see Figure 6). The interaction was not significant, F (16, 774) = 1.35, p = 0.157, partial η^2 = 0.027. This indicates that the performance trend across the different tests is approximately the same for each pilot rating group. Highest scores appear on Test 1, while scores on Test 2 through 4 were somewhat lower, and the lowest scores appeared on Test 5.

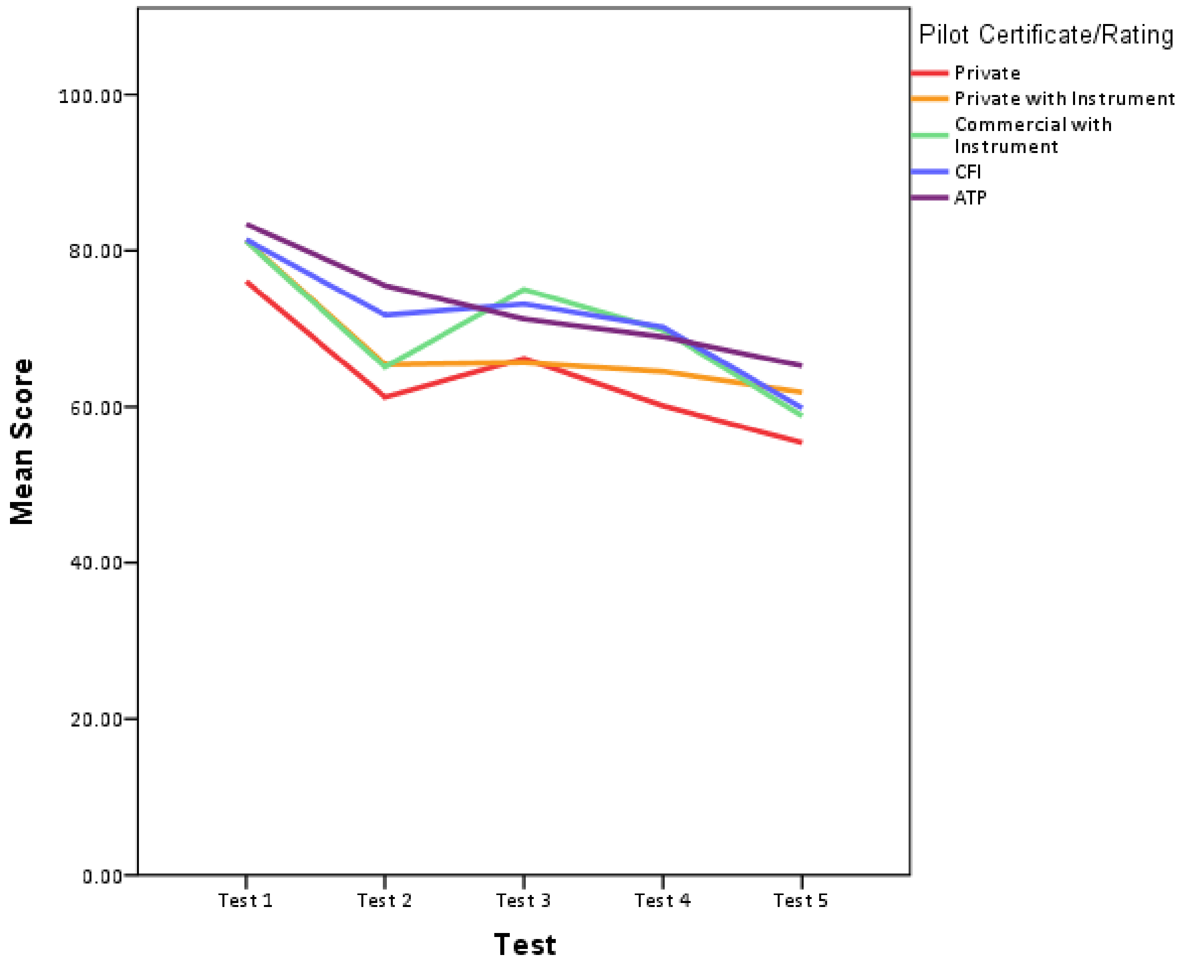

Figure 7. Effect of pilot rating and test on score.

This concludes the analyses comparing the scores on the tests overall.

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Topic Analysis. Test 1. Test 1 consisted of four topics with five questions each for a total of 20 questions. The topics were Data Sources, Significant Weather, Storm Definitions, and Flight Planning. The descriptive statistics are shown in Table 5.

Table 5. Test 1: Descriptive statistics for score by topic and pilot rating

	Private *M(SD)* *n=70*	Private w/ Instrument *M(SD)* *n=43*	Commercial w/ Instrument *M(SD)* *n=39*	CFI *M(SD)* *n=35*	ATP *M(SD)* *n=22*	Total *M(SD)* *n=209*
Data Sources	88.8 (14.8)	94.9 (11.6)	91.2 (16.4)	93.1 (10.8)	96.4 (7.9)	92.0 (13.5)
Significant Weather	76.6 (22.3)	82.3 (17.6)	85.1 (19.9)	81.7 (21.3)	86.4 (16.8)	81.2 (20.4)
Storm Definition	60.4 (19.1)	71.2 (15.9)	68.5 (21.8)	75.4 (22.3)	78.2 (17.4)	68.9 (20.2)
Flight Planning	77.7 (19.7)	77.2 (19.3)	80.0 (16.5)	75.4 (21.7)	72.7 (25.9)	77.1 (20.1)
Total *M(SD)*	76.1 (12.6)	81.3 (10.1)	81.2 (11.9)	81.4 (13.2)	83.4 (11.6)	79.5 (11.5)

A mixed between and within groups analysis of variance was conducted to assess the impact of Pilot Rating and Product within Test 1 on performance score. There was no significant interaction between Pilot Rating and Product, Wilks' Lambda = 0.90, F (12, 534.7) = 1.76, p = 0.053, partial η^2 = 0.03. This indicates that the performance trend across the topics within Test 1 was roughly the same for each pilot rating group (see Figure 7).

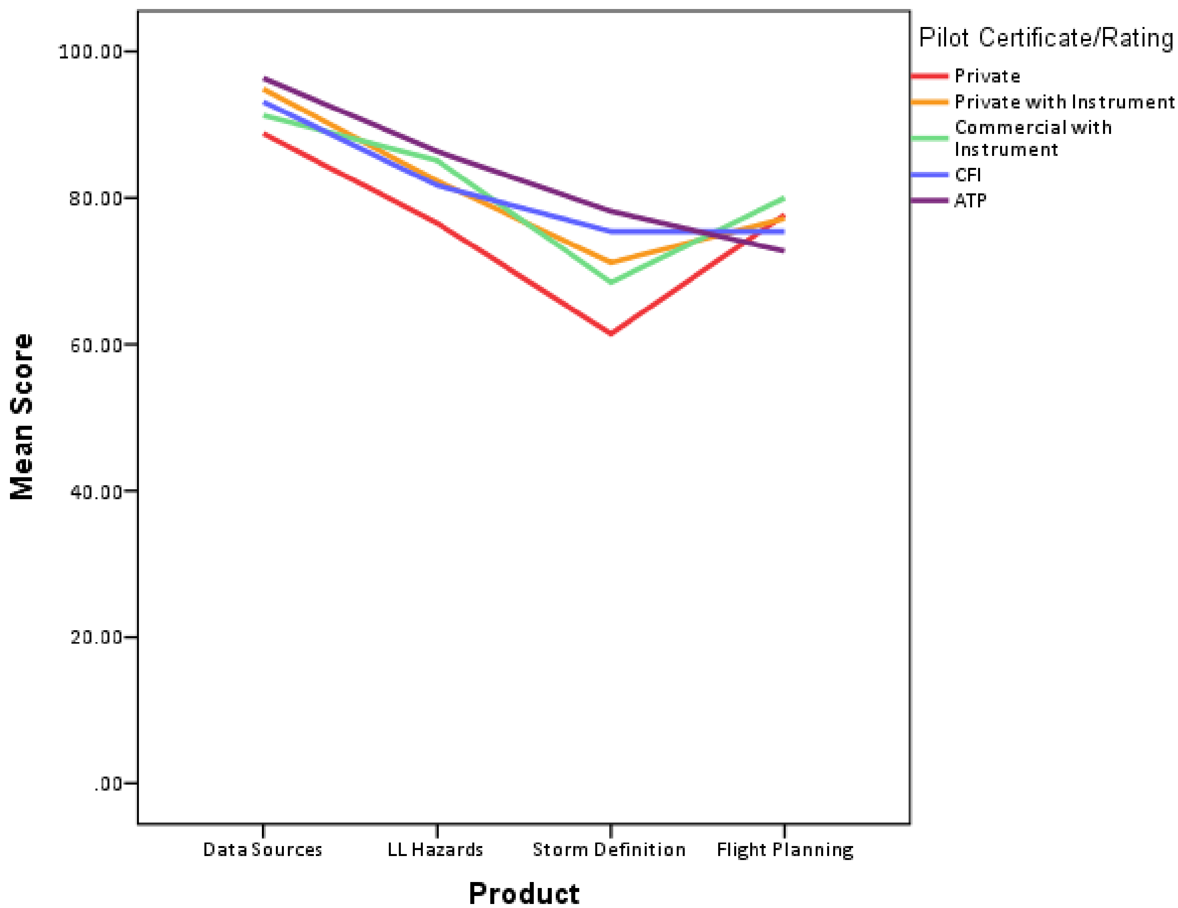

Figure 8. Effect of Pilot Rating and Product within Test 1 on score.

There was a significant main effect for Product type on score, Wilks' Lambda = 0.46, F (3, 202) = 78.29, $p > 0.01$. Partial $\eta^2 = 0.54$ and indicated that over half the variance in score on Test 1 was related to the product/topic of the questions. Using Bonferroni pairwise comparisons, regardless of rating, pilots scored significantly higher on Data Sources than any other product/topic in Test 1, and pilots scored significantly lower on Storm Definition questions than all other products. Additionally, pilots scored significantly higher on Significant Weather questions than Flight Planning (see Figure 8).

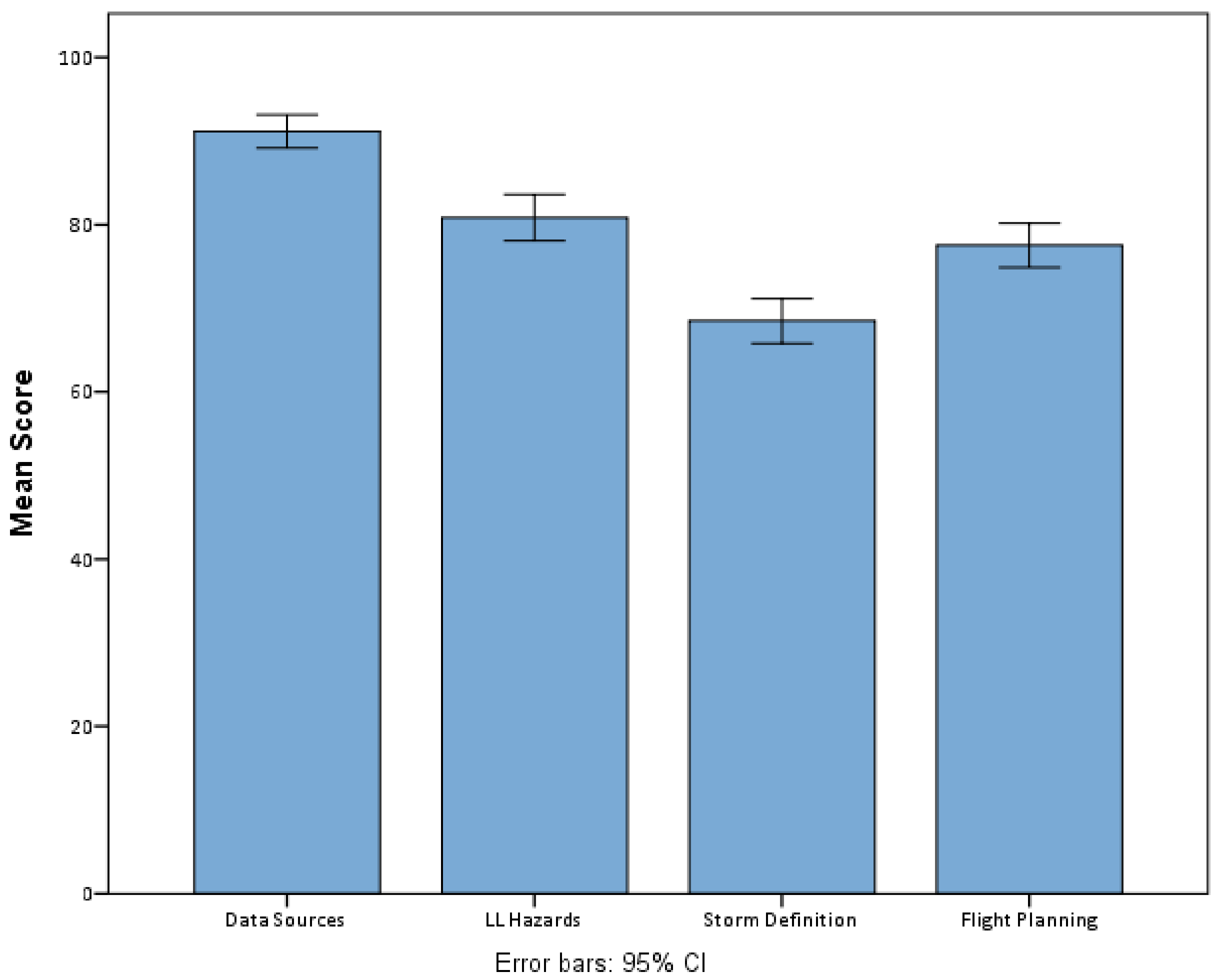

Figure 9: Product Type on Score – Test 1

There was a main effect for Pilot Certificate/Rating on Test 1 score, F (4, 191) = 2.96, p = 0.02. A small partial η^2 (0.06) indicated that only 6% of the variance in score on Test 1 is related to pilot certificate/rating. Using Post-Hoc comparisons, there were no significant differences between Pilot Certificate/Ratings (see Figure 10).

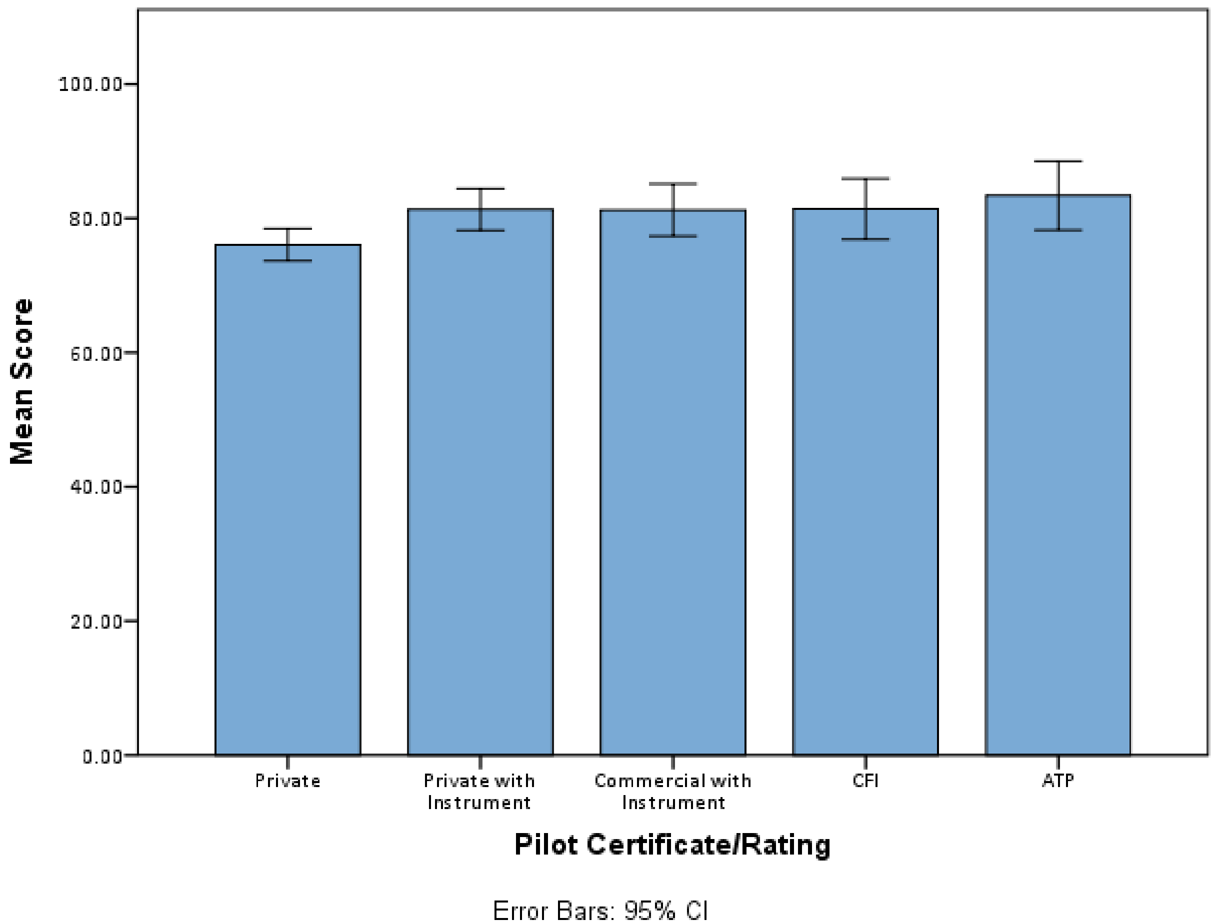

Figure 10: Pilot Certificate/ Rating on Score – Test 1

Aviation Weather Knowledge Assessment & Interpretation of Products

Test 2: Topic Analysis. Test 2 consisted of 25 multiple-choice questions which covered four topics: METARs (8 questions), PIREPs (6 questions), TAFs (6 questions) and Winds Aloft (5 questions). The descriptive statistics for Test 2 are shown in Table 6.

Table 6. Test 2: Descriptive statistics for score by topic and pilot rating.

	Private *M(SD)* *n=35*	Private w/ Instrument *M(SD)* *n=47*	Commercial w/ Instrument *M(SD)* *n=22*	CFI *M(SD)* *n=21*	ATP *M(SD)* *n=24*	Total *M(SD)* *n=149*
METAR	51.1 (19.3)	49.9 (15.5)	49.4 (25.1)	61.3 (12.4)	67.2 (17.2)	54.5 (19.0)
PIREP	72.4 (19.4)	78.9 (15.5)	78.8 (19.4)	80.0 (16.3)	82.6 (18.7)	78.1 (17.8)
TAF	47.1 (20.8)	56.7 (27.7)	56.8 (22.8)	62.4 (21.7)	66.7 (25.1)	56.9 (24.8)
Winds Aloft	81.1 (18.8)	85.1 (16.4)	83.6 (14.7)	89.5 (17.5)	90.8 (13.2)	85.5 (16.6)
Total	61.2 (12.8)	65.4 (12.7)	65.1 (16.2)	71.7 (12.3)	75.5 (14.3)	66.0 (14.6)

A mixed between and within analysis of variance was conducted to assess the impact of Pilot Rating and Product within Test 2 on score. There was no significant interaction found for Product and Pilot Rating/Certificate on score, Wilks' Lambda = .91, F (12, 375.99) = 1.16, p = 0.313, partial η^2 = 0.03. This indicates that the performance trend across the topics within Test 2 was approximately the same for each pilot rating group (see Figure 10).

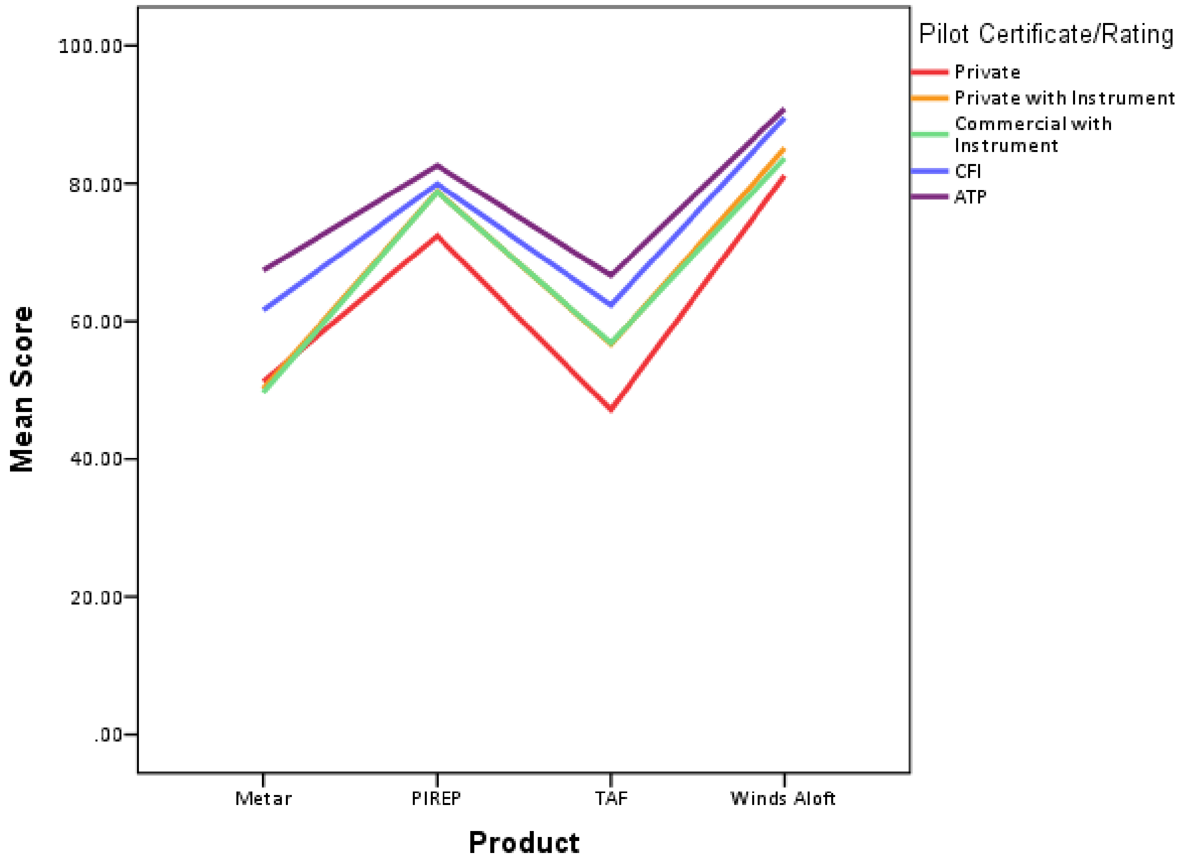

Figure 11. Effect of Pilot Rating and Product within Test 2 on score.

Aviation Weather Knowledge Assessment & Interpretation of Products

There was a significant main effect for product on Test 2 Score, Wilks' Lambda = .30, F (3, 142) = 110.63, $p < 0.01$. The partial η^2 of 0.70, indicated that 70% of the variance in Test 2 score is related to the products. Using Bonferroni post-hoc comparisons, pilots scored significantly lower on METAR questions than PIREP and Winds Aloft questions. Pilots scored significantly higher on PIREP questions than TAF questions. Lastly, pilots scored significantly higher on Winds Aloft than all other products (see Figure 12).

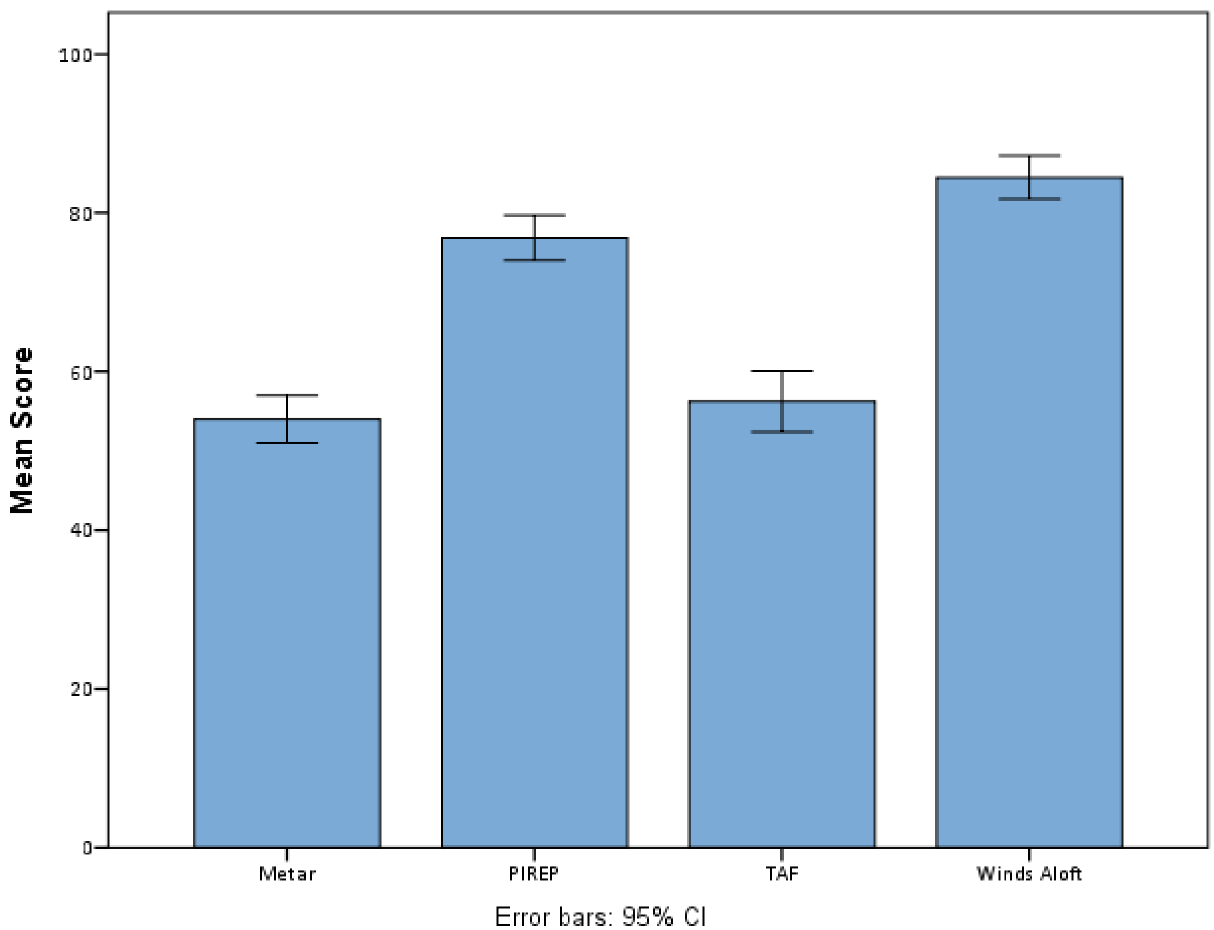

Figure 12: Product Type on Score – Test 2

A significant main effect also occurred for Pilot Rating on Test 2 score, F (4, 144) = 4.67, $p = 0.01$ (see Figure 12 for a graph of the means). The partial η^2 of 0.12 indicates that 12% of the variance in Test 2 score was related to pilot rating. Regardless of specific topic in Test 2, Bonferroni post hoc comparisons revealed that Private pilots scored significantly lower than ATP and CFI. It was also found that ATP-rated pilots scored significantly higher than Private with Instrument and Commercial with Instrument pilots on Test 2. No other significant differences were found.

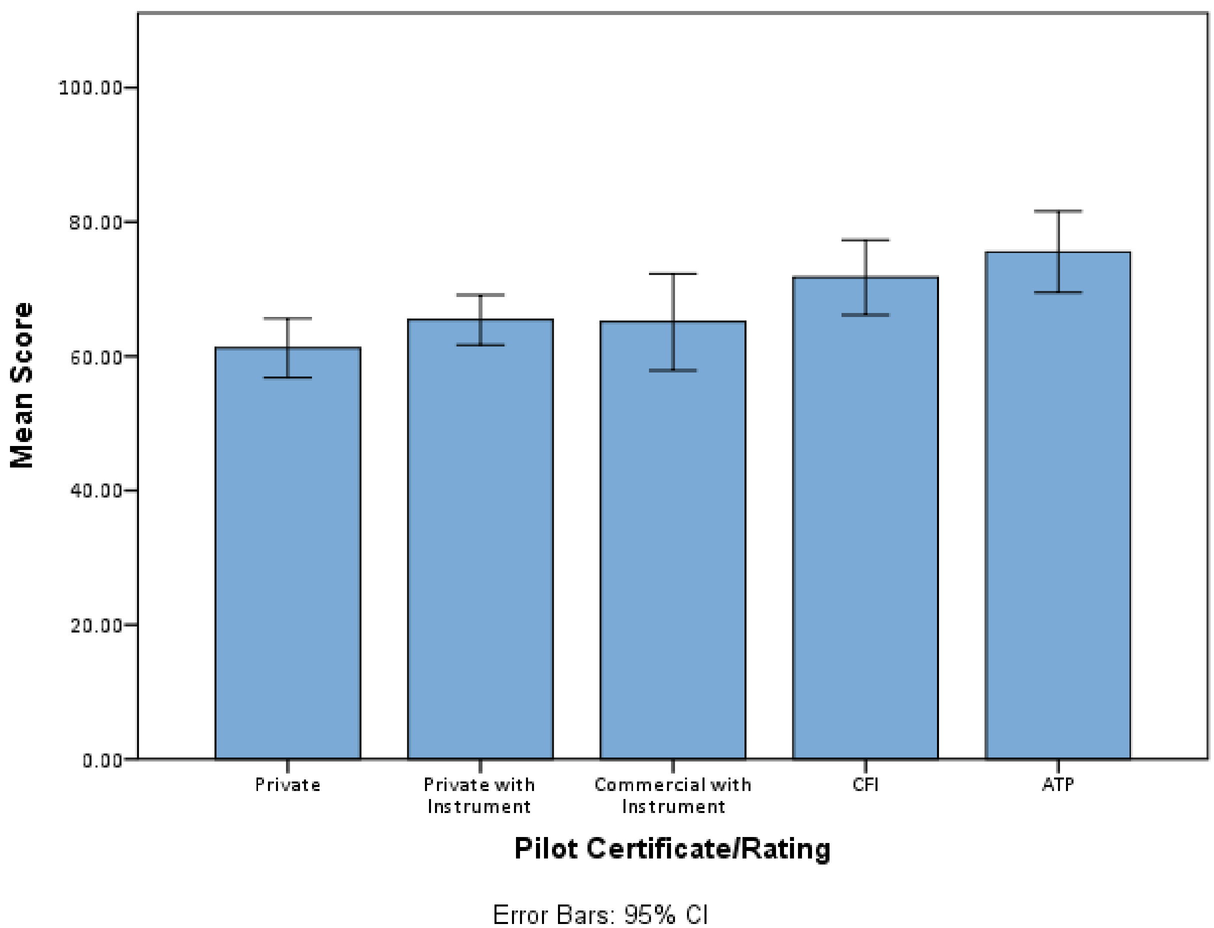

Figure 13: Pilot Certificate/ Rating on Score – Test 2

Test 3: Topic Analysis. Test 3 consisted of 23 multiple-choice questions which covered the topics of CIP (5 questions), G-Airmet (13 questions) and GTG (5 questions). The descriptive statistics for Test 3 are shown in Table 7.

Table 7. Test 3: Descriptive statistics for score by topic and pilot rating.

	Private *M(SD)* *n=40*	Private w/ Instrument *M(SD)* *n=51*	Commercial w/ Instrument *M(SD)* *n=11*	CFI *M(SD)* *n=19*	ATP *M(SD)* *n=24*	Total *M(SD)* *n=145*
CIP	63.0 (25.8)	57.1 (23.4)	72.7 (18.5)	67.1 (19.0)	70.6 (24.2)	63.4 (23.8)
G-Airmet	59.2 (17.4)	59.4 (19.4)	69.7 (18.9)	68.4 (16.6)	63.0 (15.3)	61.8 (18.1)
GTG	87.5 (15.5)	90.4 (14.8)	90.9 (13.8)	91.6 (13.9)	93.3 (11.3)	90.3 (14.2)
Total	66.2 (14.4)	65.7 (14.7)	75.0 (15.4)	73.2 (12.3)	71.2 (11.7)	67.7 (14.8)

A mixed between-within analysis of variance was conducted to assess the impact of Pilot Certificate/Rating and Product within Test 3 on score. There was no interaction found between Product and Pilot Certificate/ Rating on Test 3 score, Wilks' Lambda = 0.94, F (8, 288) = 1.09, p = .37, partial η^2 = 0.03 (see Figure 13).

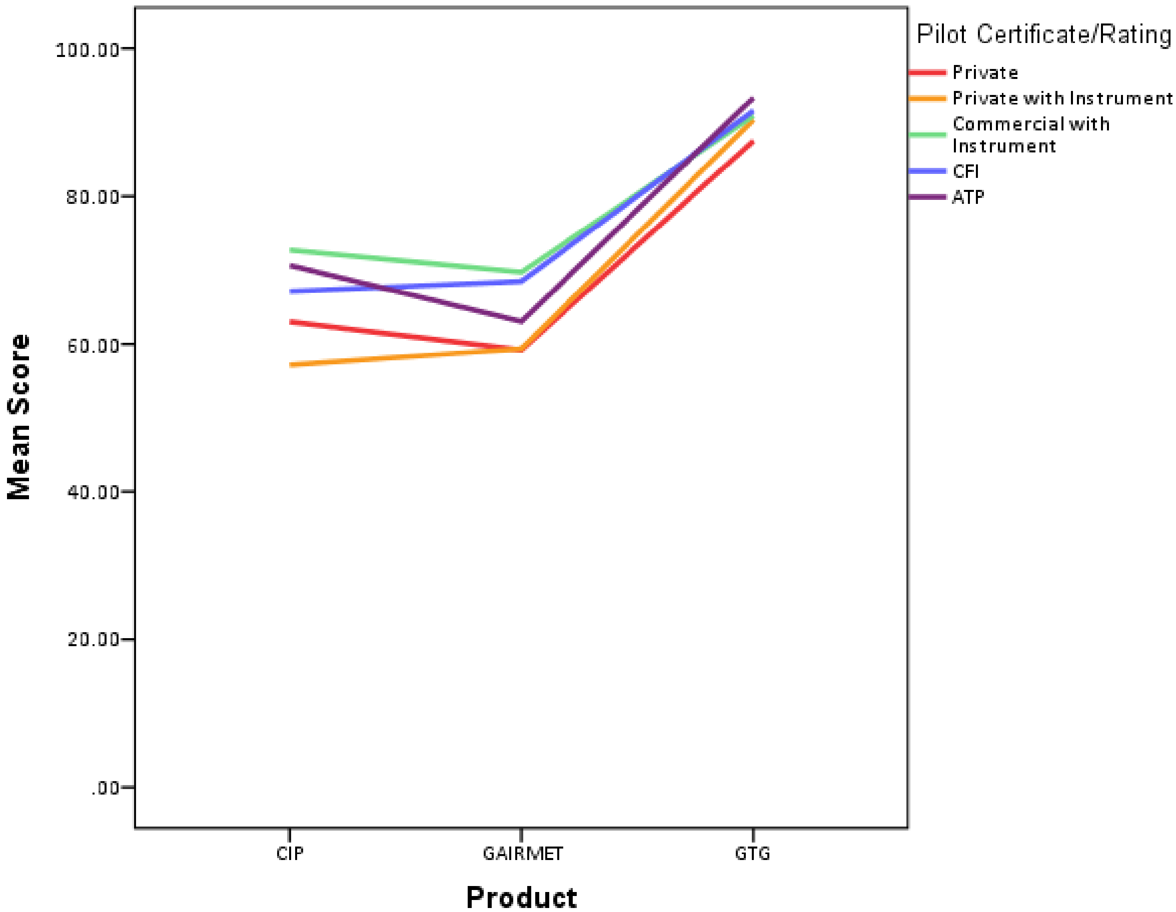

Figure 14. Effect of pilot rating and product on Test 3 score.

There was a significant main effect found for Product on score for Test 3, Wilks' Lambda = 0.44, F (2, 144) = 90.8, $p < 0.01$, partial η^2 .56. This indicates that 56% of the variance in Test 3 score is related to the product. The means are shown in Figure 14. Using Pairwise comparisons, it was found that Pilots scored significantly higher on GTG interpretation questions than all other products. No other significant differences for Products occurred.

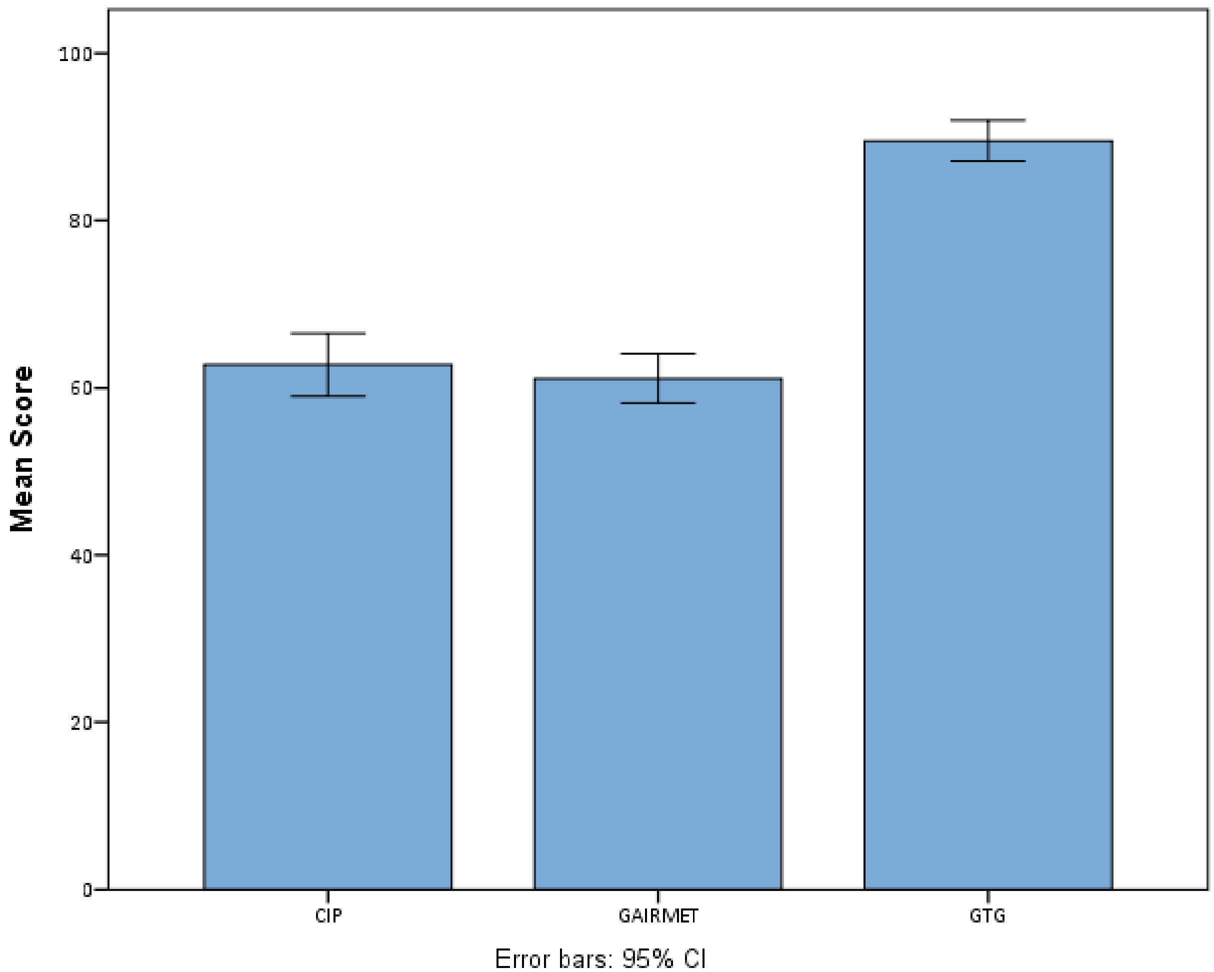

Figure 15: Product Type on Score – Test 3

In contrast to the prior analyses, no main effect was found for Pilot Certificate/Rating on Test 3 score, F (4, 145) = 2.25, p = 0.59, partial η^2 = 0.06. This indicates that despite differences in rating, pilots scored about the same on the topics on Test 3 (see figure 15).

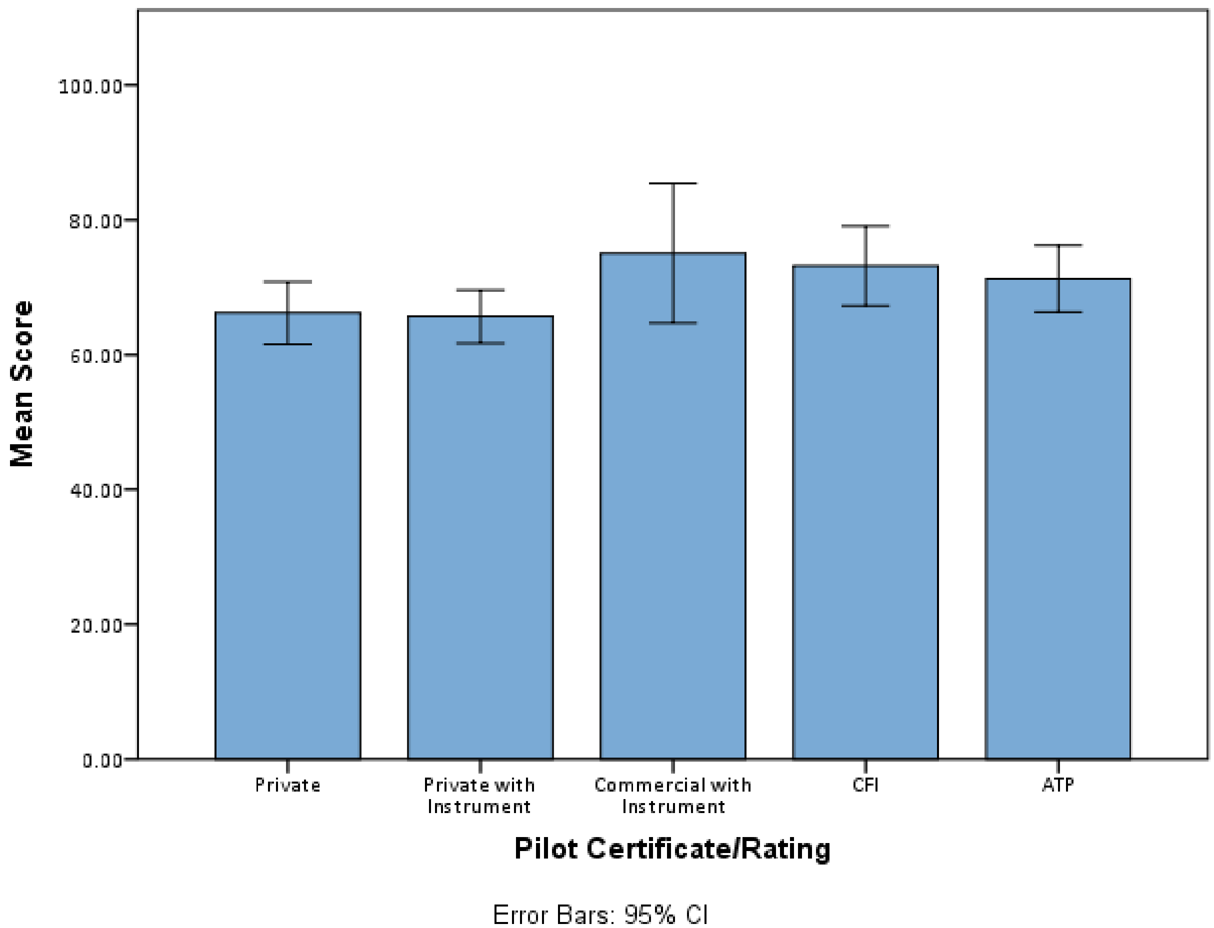

Figure 16: Pilot Certificate/ Rating on Score – Test 3

Test 4: Topic Analysis. Test 4 consisted of 24 multiple-choice product interpretation questions which included Radar (12 questions), SIGMET (7 questions) and TSTM (5 questions). The descriptive statistics for Test 4 are shown in Table 8.

Table 8. Test 4: Descriptive statistics for score by topic and pilot rating.

	Private *M(SD)* *n=62*	Private w/ Instrument *M(SD)* *n=51*	Commercial w/ Instrument *M(SD)* *n=32*	CFI *M(SD)* *n=23*	ATP *M(SD)* *n=30*	Total *M(SD)* *n=198*
Radar	54.0 (16.4)	60.5 (18.3)	66.7 (15.2)	66.5 (19.0)	64.2 (16.8)	60.7 (17.7)
SIGMET	73.5 (14.8)	74.5 (18.8)	83.5 (15.4)	83.9 (18.9)	79.5 (17.5)	77.5 (17.3)
TSTM	56.0 (14.9)	60.0 (15.5)	58.1 (14.7)	60.0 (17.1)	65.3 (16.6)	59.2 (15.7)
Total	60.1 (9.9)	64.5 (12.9)	69.8 (11.3)	70.2 (12.1)	69.0 (12.1)	64.9 (12.3)

A mixed between-within subjects analysis of variance was conducted to assess the impact of Pilot Certificate/Rating and Product within Test 4 on score. There was no significant interaction found between Product and Pilot Certificate/Rating, Wilks' Lambda = 0.95, F (8, 384) = 1.17, p = 0.32, partial η^2 = 0.02 (see Figure 16).

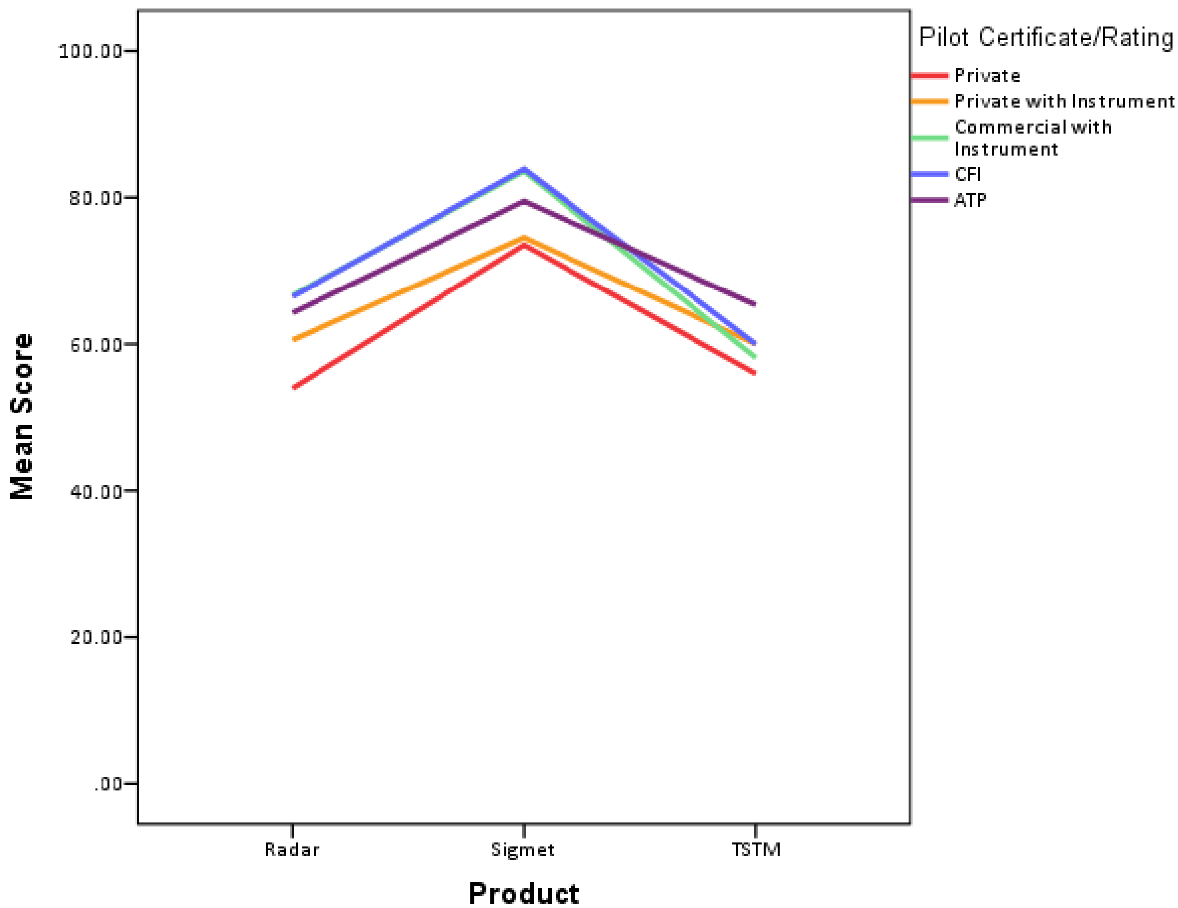

Figure 17. Effect of Pilot Rating and Product within Test 4 on Score

There was a significant effect for product on score, Wilks' Lambda = 0.54, F (2, 192) = 67.69, $p < 0.01$, partial $\eta^2 = 0.46$. Using Bonferroni Pairwise comparisons, Pilots were found to have scored significantly higher on SIGMET questions than all other products. The means are graphed in Figure 18.

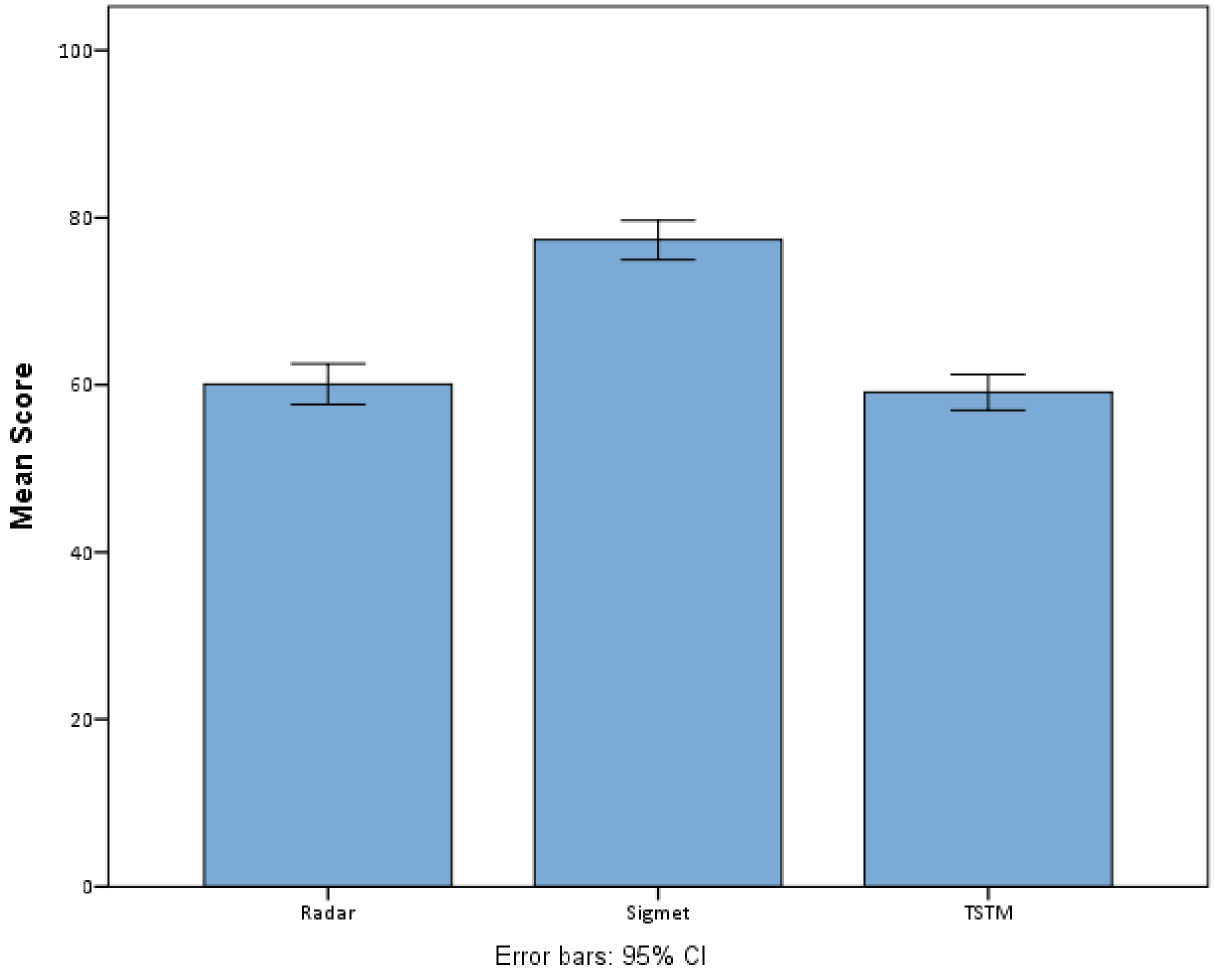

Figure 18: Product Type on Score – Test 4

A significant main effect also occurred for Pilot Certificate/Rating on score, F (4, 193) = 6.16, $p < 0.01$. The partial η^2 of 0.11 indicates that 11% of the variance in score was related to pilot rating. Bonferroni Post Hoc tests revealed that private pilots scored significantly lower than commercial with instrument, ATP and CFI Pilots. No other significant differences in Pilot Certificate/Rating were found (see Figure 18).

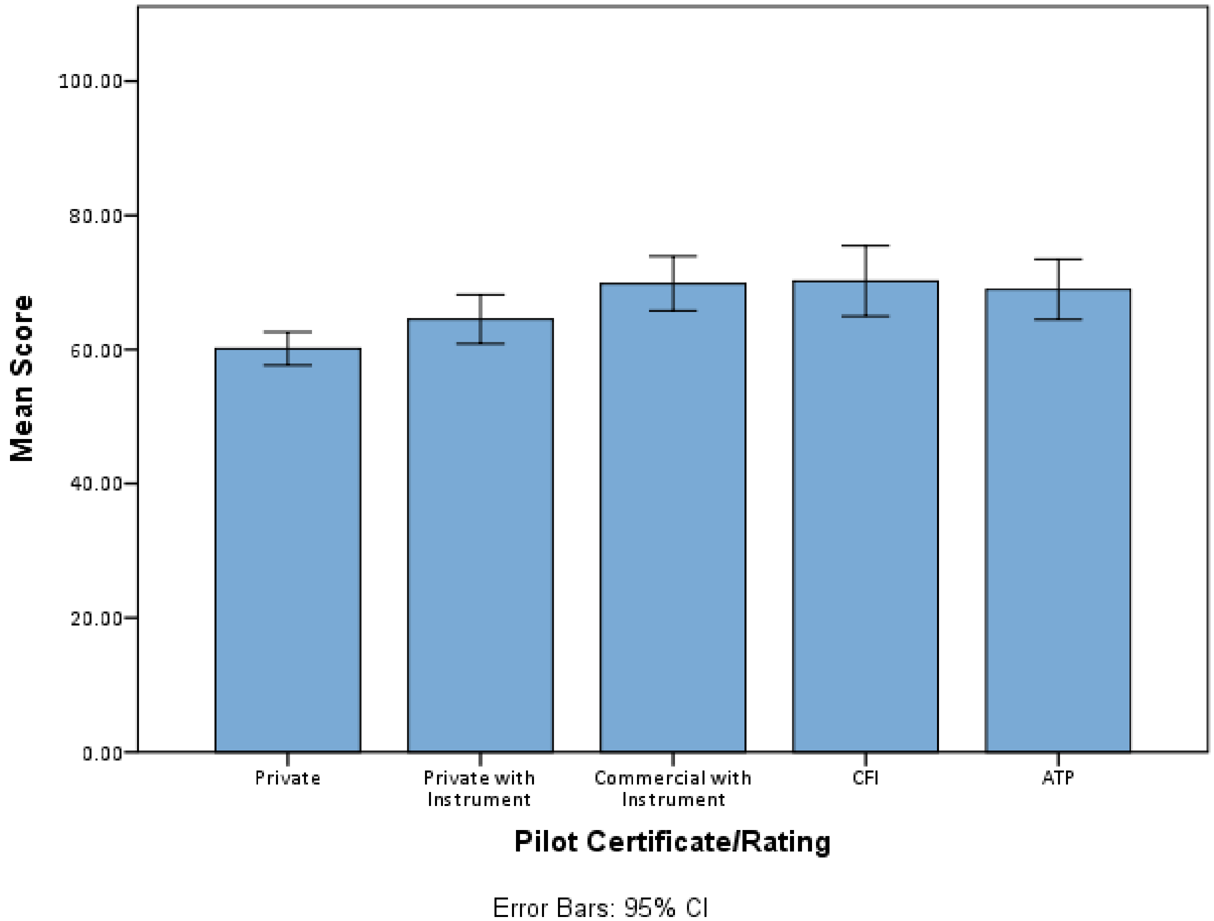

Figure 19: Pilot Certificate/ Rating on Score – Test 4

Test 5: Topic Analysis. Test 5 consisted of 23 multiple-choice product interpretation questions which included CVA (5 questions), Satellite (7 questions) Station Plots (6 questions) and Surface Prognostic Charts (5 questions). The descriptive statistics for Test 5 are shown in Table 9.

Table 9. Test 5: Descriptive statistics for score by topic and pilot rating.

	Private *M(SD)* *n=49*	Private w/ Instrument *M(SD)* *n=52*	Commercial w/ Instrument *M(SD)* *n=34*	CFI *M(SD)* *n=18*	ATP *M(SD)* *n=23*	Total *M(SD)* *n=176*
CVA	69.8 (21.7)	77.3 (19.8)	72.9 (23.0)	77.8 (15.2)	80.9 (25.2)	74.9 (21.5)
Satellite	49.6 (29.8)	61.3 (28.9)	59.2 (32.8)	57.1 (31.0)	68.3 (18.8)	58.1 (29.4)
Station Plots	37.0 (21.6)	38.9 (21.1)	36.5 (22.1)	38.9 (21.4)	47.1 (20.1)	39.0 (21.4)
Surface Prognostic	71.0 (22.4)	74.6 (19.8)	70.6 (21.6)	71.1 (24.9)	67.0 (26.0)	71.5 (22.2)
Total	55.4 (14.8)	61.9 (16.5)	58.8 (19.0)	59.8 (13.3)	65.2 (14.8)	59.4 (16.4)

A mixed between-within subject analysis of variance was conducted to assess the impact of pilot certificate/rating and product within Test 5 on score. There was no significant interaction between Pilot Certificate/ Rating and Product on Score, Wilks' Lambda= 0.93, F (12, 447.4) = .996, p = 0.45, partial η^2 = 0.02. This means that the scoring trends on the topics within Test 5 were about the same despite the different pilot ratings (see Figure 19).

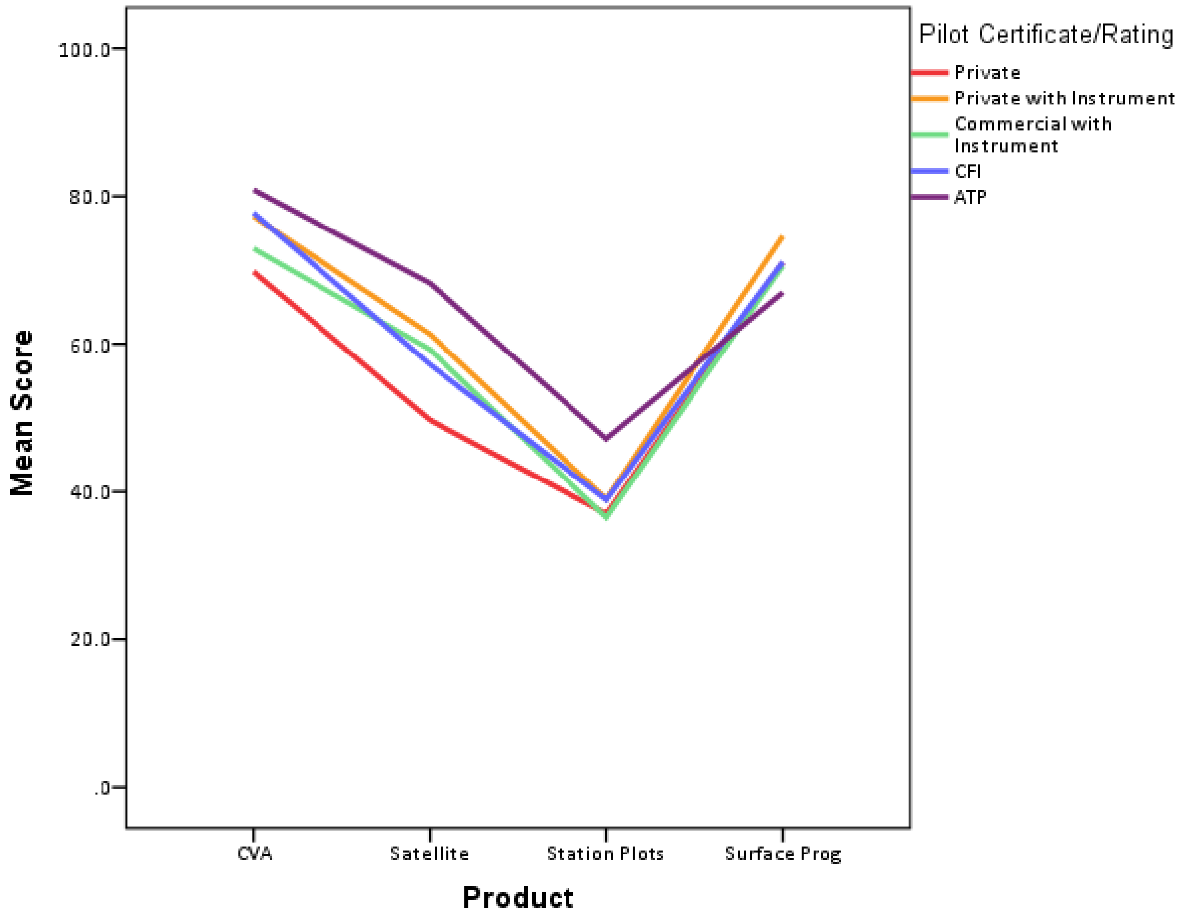

Figure 20. Effect of Pilot Rating and Product within Test 5 on score.

There was a significant main effect for product on score, Wilks' Lambda = 0.37, F (3, 169) = 96.74, $p < 0.01$. The partial η^2 of 0.63 indicated that 63% of the variance in Test 5 scores was related to the particular product. The means are shown in Figure 20. Bonferroni post hoc comparisons revealed that pilots scored significantly higher on CVA questions than on Satellite and Station Plot. Pilots scored significantly lower on Station Plots than all other products. Pilots also scored significantly higher on Surface Prognostic questions than on Satellite questions.

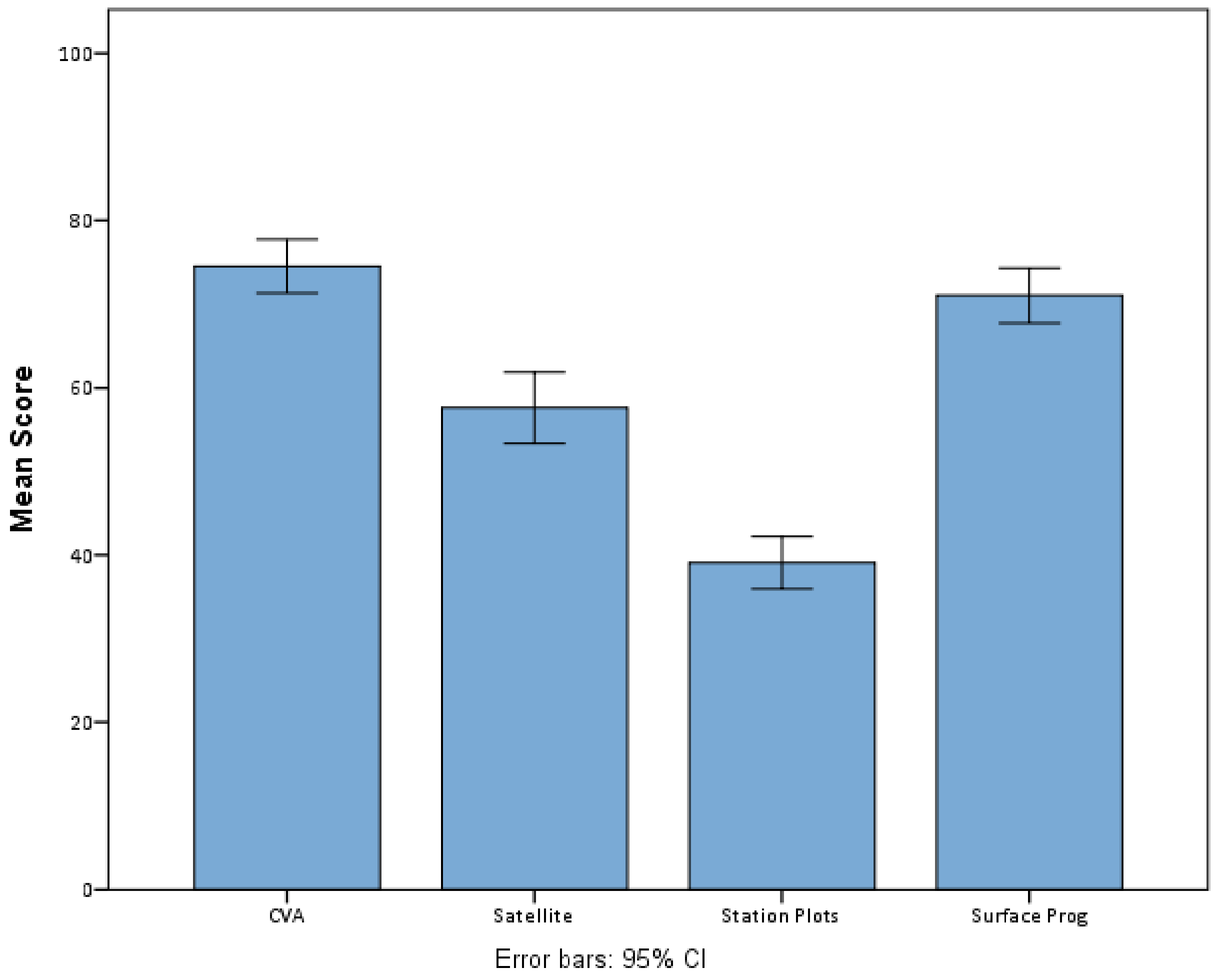

Figure 21: Product Type on Score – Test 5

There was no significant main effect of Pilot Certificate/Rating on score, F (4, 171) = 0.21, p = 0.16, partial η^2 = 0.04. This indicates that pilots with different ratings scored about the same on the topics in Test 5 (see Figure 22).

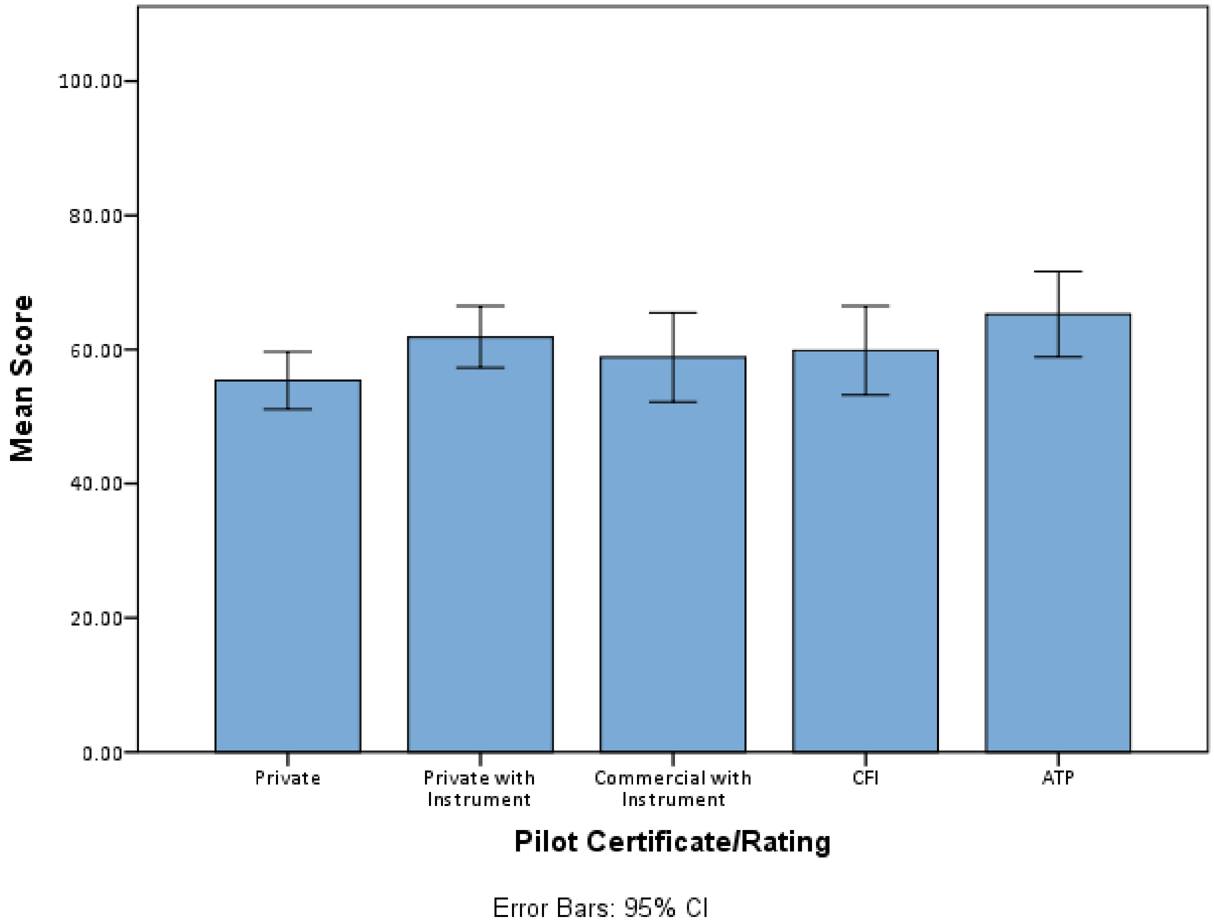

Figure 22: Pilot Certificate/ Rating on Score – Test 5

This concludes the analyses for the separate tests.

Aviation Weather Knowledge Assessment & Interpretation of Products

Forecast Products, Observation Products, and Flight Planning. To aid in interpreting the results by forecast, observation, and flight planning products, Tables 9, 10, and 11 present the descriptive statistics for the results. Due to the manner in which the data was collected, analyzing the differences among the forecast, observation, and planning categories would require an extensive number of tests, and this report does not include those analyses. However, upon inspecting the means, several trends appear.

Among Forecast Product Interpretation scores, pilots scored above 80% on LL Hazards, GTG and Winds aloft. While scores on Convective SIGMETs was slightly lower (77%), and Surface Prognostic interpretations still lower (about 71%). In contrast, the scores on G-Airmet and TAF averaged around 61% and 56%, respectively.

Among Observation Product Interpretation scores, pilots averaged 74% for CVA and 77% for PIREP. In contrast, Pilots scored in the 50-70% range in METAR, RADAR, Satellite and CIP questions. On Station Plot questions, Pilots scored the lowest overall for observation products (39%).

Among Flight Application questions, pilots scored above 90% on Data Source interpretation questions. Pilots scored over 77% on Flight Planning questions. On Storm Definitions and TSTM questions, pilots scored between 50-70%.

Aviation Weather Knowledge Assessment & Interpretation of Products

Table 9. Summary of Forecast Products

	n	*n of Questions*	Cronbach's Alpha	*M (SD)*	Test Number
LL Hazard	217	5	0.364		1
G-Airmet	147	13	0.629		3
GTG	155	5	0.294		3
TAF	157	6	0.490		2
Surface Prog	182	5	0.344		5
Convective Sigmets	211	7	0.278		5
Winds Aloft	156	5	0.442		2

Table 10. Summary of Observation Product Questions

	n	*n of Questions*	Cronbach's Alpha	*M (SD)*	Test Number
METAR	160	8	0.551		2
Station Plot	173	6	0.380		5
PIREP	155	6	0.316		2
Satellite	180	7	0.719		5
CVA	181	5	0.366		5
Radar	195	12	0.510		4
CIP	149	5	0.391		3

Table 11. Summary of Flight Application Questions

	n	*n of Questions*	Cronbach's Alpha	*M (SD)*	Test Number
Flight Planning	218	5	0.250		1
Storm Definitions	214	5	0.185		1
TSTM	209	5	-0.006		4
Data Sources	209	5	0.359		1

Aviation Weather Knowledge Assessment & Interpretation of Products

Comparison of Products Related to the Graphical Forecast for Aviation. Finally, a full set of analyses were run to examine pilot performance on the products that are included in the new Graphical Forecast for Aviation (GFA) product. The GFA is composed of three previously existing weather displays: Radar, Satellite, and Station Plots (AWC, 2019). Between and within groups analyses were run to determine the effect of Certificate and/or Rating on product scores for these three products. Results indicated that pilots are struggling in the interpretation of Radar, Satellite and Station Plot products and, in turn, will likely struggle with the GFA. Training and usability improvements are also discussed. See Appendix B for the full write-up.

This concludes the results section of this report.

Discussion

Overall, General Aviation pilots scored below 70% on Test 2, 3, 4 and 5. However, participants did score somewhat higher on Test 1. Upon further investigation of the topics in Test 1 (Data Sources, Significant Weather, Storm Definitions and Flight Planning), participants scored highest on Data Source-type questions. Based on these results, pilots' knowledge of this topic appears to be strong. In contrast, pilots struggled extensively on all of the other Tests, and the Test 5 scores were the lowest. Upon inspection of the Test 5 subtopics, pilots scored significantly lower on Station Plot questions as compared to CVA, Satellite and Surface Prognostic questions. These low scores on Station Plots indicates a lack of knowledge on a potentially vital product. The results do not explain <u>why</u> pilots performed as they did. One possible reason is a possible gap in GA pilots' aviation weather knowledge. Another reason is that the displays are not user friendly or intuitive.

Aviation Weather Knowledge Assessment & Interpretation of Products

In terms of experience, the research investigated the effect of Pilot Certificate and/or Rating on aviation weather knowledge. Overall, GA Private Pilots scored significantly lower on all tests compared to all other pilot certificate/ rating groups. This finding aligns well with prior research which indicates that low hour Private pilots incur the majority of weather-related incidences. Based on the current results, private pilots' lack of capability to interpret weather products may be a contributing factor to the weather-related accident rate.

While Private with Instrument pilots scored significantly lower than ATP pilots, on most of the products, no other differences appeared between pilot experience levels. This finding also parallels other research findings that indicate performance in weather scenarios is not correlated with flight hours.

Limitations

One major limitation of this study occurred with the inability to directly compare all products against each other because unlike in Phase 1, the participants did not complete the entire test but instead took a portion of the test. This method was enacted in order to achieve as much participation as possible, due to the detracting nature of asking participants to take a 118-question online test without significant contribution.

Another limitation came from the high dropout rate of participates as they proceeded throughout the test. 1702 participants began the demographics section of the online survey. After the demographics section, 1247 participants remained and began the weather product interpretation portion of the survey. 837 participants then finished the entirely of their online survey. This overall retention rate of 49.2% can be concerning due to the possibility of response bias and the results may not be indicative of the true general population. However, the retention rate of 67% from the beginning of the weather product interpretation section to the end of the survey is higher. Retention rates are low due to various factors including a lack of interest by participants, a lack of time by participants or the difficulty of the questions.

Comparisons between Phase 1 & 2

In order to test the generalizability of Study 1, in which the participants were primarily college students ("ERAU"), the Phase 2 study included GA pilots with a higher mean age and higher flight hours ("AOPA pilots"). Overall the pattern of results are very similar between the two studies, however, the AOPA pilots scored higher, on average, then did the younger pilots in Phase 1.

In Table 12 the means of Forecast Product questions are displayed and compared between the two groups studied. For most products in this subgroup, the populations scored within 10% of each other. A notable exception in this category is the product, Convective SIGMETs. This significant difference could be due to more product familiarity or use within the AOPA group than the ERAU group.

Table 12. Summary of Comparisons between Forecast Products

Product	Phase 2: AOPA	Phase 1: ERAU
GTG	89.5	81.13
CIP	62.9	52.82
Significant Weather	80.7	73.04
Convective SIGMETs	77.4	63.6
Surface Prognosis Chart	71.5	70.78

G-Airmet	61.4	50.98
TAF	55.7	50

The trend lines for each population is presented in figure 22. In this figure, it is apparent that both groups are following very similar patterns by product, with the AOPA group scoring slightly higher overall on Forecast products than the college students.

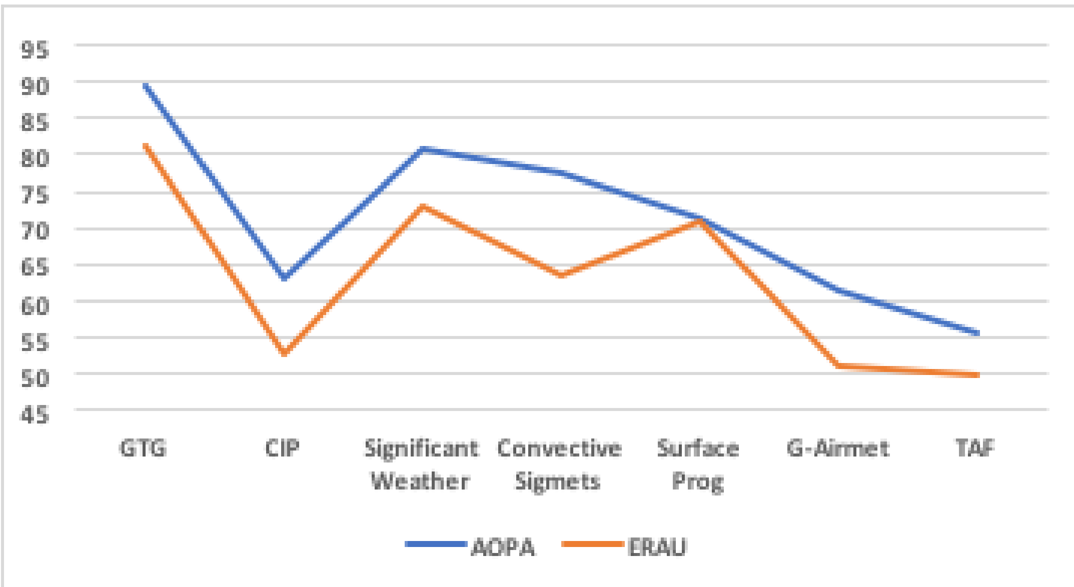

Figure 23: Summary of Comparisons between Forecast Products

In Table 13 the means of Observation Product questions are displayed and compared between the two groups studied. For most products in this subgroup, the populations scored within 5% of each other. A notable exception in this category is the product, CVA. The difference between the AOPA group and the ERAU group for this product is 20% which indicates a large difference in understanding for this product. This could indicate that the initial

Aviation Weather Knowledge Assessment & Interpretation of Products

ERAU group's understanding of CVA differs significantly from the rest of the GA population and more familiarity is needed with that product in ERAU than GA.

Table 13. Summary of Comparisons between Observation Products

Product	Phase 2: AOPA	Phase 1: ERAU
PIREP	77.4	77.66
CVA	74.5	54.66
Radar	60.4	57.27
Satellite	57.4	54.25
METAR	53.5	40.99
Winds Aloft	84.1	84.64

The trend lines for each population is presented in figure 23. In this figure, it is apparent that both groups are following very similar patterns by product, with the AOPA group scoring slightly higher overall on Forecast products than the ERAU group.

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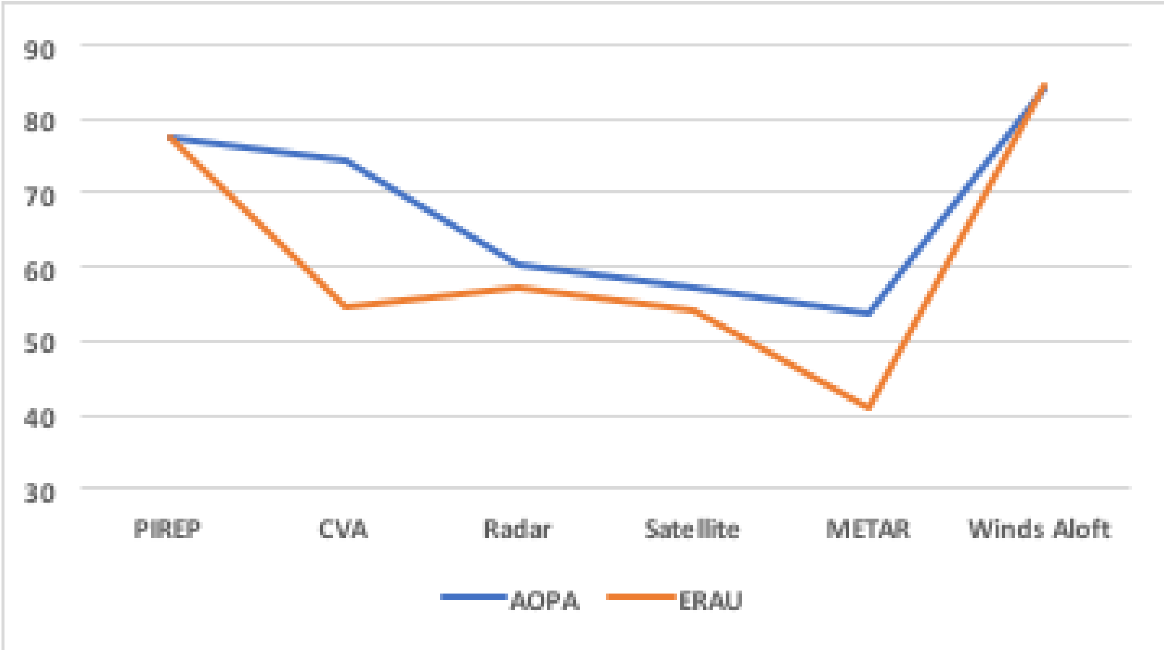

Figure 24: Summary of Comparisons between Observation Products

In Table 14 the means of the common Flight Application questions are displayed and compared between the two groups studied. Due to the addition of questions from after Study 1, there are only two products in this group due to the ERAU group not receiving the new questions. As with the other two subcategories, the AOPA members scored better than the ERAU students. A major difference in score occurred on the Flight Planning questions. The difference between the AOPA group and the ERAU group for this product is about 26% which indicates a large difference in understanding for this product. This difference could be due to the differences in experience between the two groups specifically because the types of questions were Flight Planning and it would be expected that pilots with more experience flying (AOPA) would score better than less-experienced pilots (ERAU). The means are also compared and displayed in figure 24.

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Table 14. Summary of Comparisons between Flight Application Questions

Product	Phase 2: AOPA	Phase 1: ERAU
Data Sources	91	83.82
Flight Planning	77.2	51.53

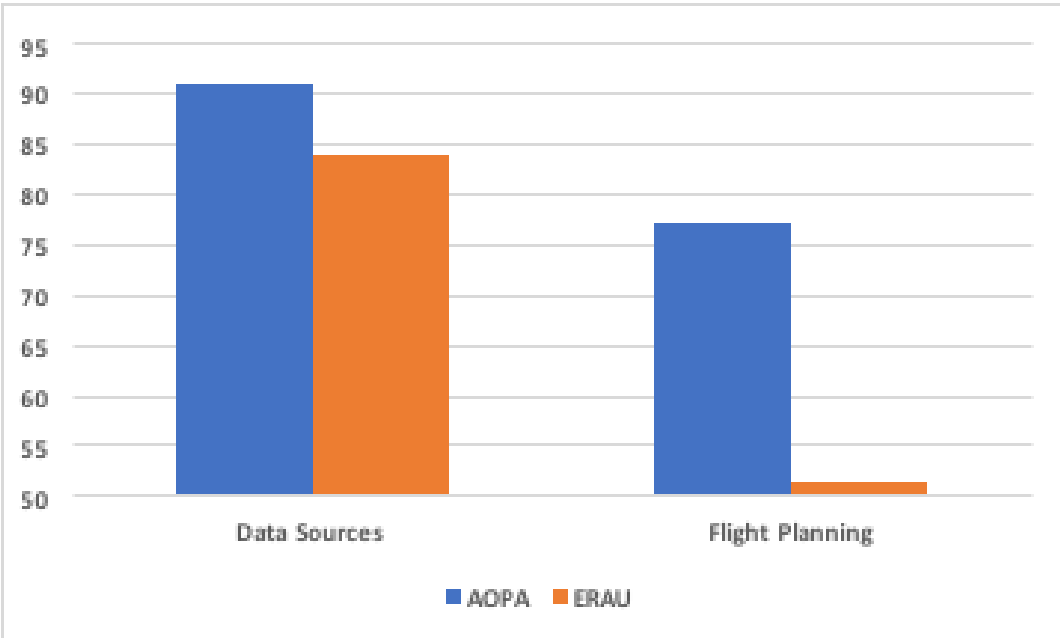

Figure 25: Summary of Comparisons between Flight Application Questions

Acknowledgements

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Disclaimer

The views expressed in this paper are the views of the authors and do not represent the organizations with which they are affiliated.

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Appendices

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Appendix A. Aviation Weather Taxonomy (Lanicci et al., 2017)

The levels of aviation weather knowledge originally proposed by Lanicci et al. (2011) were expanded into an aviation weather taxonomy to include additional granularity. The proposed taxonomy is shown below.

Taxonomy Code	AV-WX Principle Description
WP	**Weather Phenomena**
1000	**Basic Meteorological Knowledge**
1001	Pressure and Altimetry
1001-a	Pressure as a vertical coordinate
1001-b	Common flight levels as pressure levels
1001-c	Sea-level pressure and altimeter setting
1002	Fronts, and Mid latitude cyclones
1002-a	Review the vertical structure of a warm, cold, cold-occluded, and warm-occluded front
1002-b	Geographical regions favorable for cyclogenesis
1002-c	Divergence associated with upper-level troughs
1002-d	Relationship between upper-level divergence and surface low intensification
1003	Satellite Data
1003-a	Radiative transfer basics
1003-b	Polar vs. Geosynchronous orbits
1003-c	Distinguishing low clouds from high clouds
1003-d	Relating cloud-top temperature to height
1004	Space Weather
1004-a	Properties of the Sun
1005	Flight Level and Surface Winds
1005-a	Surface Wind
1005-b	Effect of friction on surface wind speed and direction
1005-c	Basic Atmospheric Forces (Coriolis, PGF, Friction, Centrifugal)
1005-d	Relationship between isobar/height contour gradients to flight-level wind speeds
1005-e	Relationship between isobar/height contour orientation and flight-level wind direction
1005-f	Effect of friction on surface wind speed and direction
1006	Thermal Wind and Jet Streams
1006-a	Thickness and its relationship to average layer temperature
1006-b	Relationship between the horizontal temperature gradient and winds aloft (thermal wind)

1006-c	Primary causes polar and subtropical jets
1006-d	Meridional and zonal jet patterns
1006-e	Winds associated with the polar and subtropical jets (altitude, latitude, direction, speeds)
1006-f	Relationship between the long wave pattern and the surface temperature pattern
1006-g	Divergence patterns associated with jet streaks
1007	Winter Weather
1007-a	Regions of a mid-latitude cyclone favorable frozen or freezing precipitation
1007-b	Critical thickness
1007-c	Using thickness to forecast snow vs. rain
1007-d	Vertical profiles favorable for snow, rain, freezing rain, and sleet
1008	Clouds
1008-a	Knowledge of cloud types: cumulus, stratus, cirrus
1008-b	Knowledge of formation of radiation fog, advection fog, and mixing fog
1009	Icing
1009-a	Fundamental causes of icing
1009-b	Favored icing locations within mid-latitude cyclones
1009-c	Temperature and relative humidity ranges commonly observed with icing
1009-d	Requirements for sustaining icing in a mixed cloud environment
1010	Wind Shear and Turbulence
1010-a	Definitions of Turbulence
1010-b	Definition of wind shear
1010-c	Wind shear vs. turbulence
1010-d	Atmospheric conditions favorable for wind shear
1010-e	Typical onset times for wind shear with frontal passage
1010-f	Two components of low-level turbulence
1010-g	Factors affecting mechanical turbulence intensity
1010-h	Factors affecting thermal turbulence intensity
1010-i	Necessary conditions for Mountain Wave Turbulence (MWT)
1010-j	Commonly observed features associated with MWT (lenticular clouds, roll clouds, hydraulic jump)
1011	Weather Radar
1011-a	Basic radar physics
1011-b	Composite and Base Reflectivity
1011-c	Decibels, echo intensity, VIP levels
1011-d	Z-R relationships
1011-e	Vertically Integrated Liquid Water (VIL)
1011-f	Radial Velocities and Storm Relative Radial Velocities
1012	Stability & Stability Indices

1012-a	Review dry adiabatic lapse rates
1012-b	Review adiabatic warming and cooling
1012-c	Review moist adiabatic lapse rate
1012-d	Effect of latent heat of condensation on the moist adiabatic lapse rate
1012-e	Effect of temperature on the moist adiabatic lapse rate
1012-f	Parcel theory
1012-g	Environmental conditions necessary for unstable, stable and neutral parcels
1012-h	Conditional instability
1012-i	Effect of heating/cooling either aloft or at the surface on environmental stability
1012-j	Thermodynamic diagrams (skew-T, Stüve)
1012-k	Plotting a vertical profile on a skew-T
1013	Lightning and Thunderstorms
1013-a	General and aviation lightning safety
1013-b	Cloud charging and the lightning stroke
1013-c	Lightning climatology
1013-d	Necessary ingredients for thunderstorm formation
1013-e	Trigger mechanisms for thunderstorms
1013-f	Life-cycle of an ordinary thunderstorm
1013-g	Definition of severe thunderstorm
1013-h	Wind shear as related to thunderstorm severity
1013-i	Types of thunderstorms and thunderstorm complexes (single cell, multi-cell, super-cell, squall lines, MCSs)
1014	Volcanic Ash (VA)
1014-a	Volcanic activity climatology
1014-b	Characteristics of VA
1100	**Knowledge of how meteorological phenomena affect flight performance**
1101	Drag
1102	Thrust
1103	Weight
1104	Lift
1105	Gravity
1106	Hold-over times for deicing fluids
1107	Impacts of icing on aircraft performance
1108	Effects of wing size, aircraft speed, attack angle, and exposure time on icing accumulation
1109	General and aviation lightning safety
1110	Wind shear effects on aircraft performance
1111	Downbursts & Microbursts effects on aircraft performance
1112	Space weather hazards to aviation

1113	Volcanic Ash
1113-a	Hazards to aviation
1113-b	Best course of action for exiting VA cloud
1114	Pilot Safety
1114-a	Situation Awareness
1114-b	Navigation
1114-c	Communication
1114-d	Flight Crew Health
1200	**Knowledge of aviation meteorological hazards**
1201	IMC
1201-a	VFR into IMC
1201-b	Flight conditions associated with common cloud types
1201-c	Special clouds that indicate especially hazardous flight conditions (lenticular, billow, mammatus)
1201-d	Flight conditions associated with fog and mist
1201-e	Definitions of LIFR, IFR, MVFR and VFR
1202	Turbulence
1202-a	Locations favorable for Clear Air Turbulence
1202-b	Locations favorable for Low Level Turbulence
1202-c	Locations favorable for Convectively Induced Turbulence
1202-d	Locations favorable for Mountain Wave Turbulence
1203	Volcanic Ash
1203-a	Warning signs of entering VA cloud
1203-b	Best course of action for exiting VA cloud
1204	Thunderstorms
1204-a	Wind shear as related to thunderstorm severity
1205	Lightning
1206	Icing
1206-a	Induction versus structural icing
1206-b	Definition of light, moderate, severe icing
1206-c	Impact of supercooled large droplets (SLDs)
1207	Regions within mid-latitude cyclones most favorable for aviation hazards
1207-a	Potential aviation hazards associated with surface fronts
1208	Non Thunderstorm Wind shear
WH	**Weather Hazard Products**
2000	**Knowledge of official weather hazard products**
Aviation Specific	
2001	Decoding Surface Weather Information and PIREPS
2001-a	Elements of a METAR observation

2001-b	Difference between FG and BR for METARs
2001-c	SPECI
2001-d	Common international code conventions (CAVOK, Q for pressure, meters for visibility)
2001-e	Elements of a TAF
2001-f	Difference between FG and BR for TAFs
2001-g	Change groups (TEMPO, FM, BECMG, PROB)
2001-h	Elements of a PIREP
2001-i	Elements of a surface station plot
2001-j	Prevailing visibility and sector visibility
2001-k	Tower, slant range, and surface visibility
2001-l	Summation rule for determining total sky condition from cloud layers
2002	Upper-Level Chart (Weather map symbols used for turbulence and other hazards)
2002-a	*Forecast Winds/Temperatures Aloft*
2002-b	Hazards Charts (Low-Level, Upper Level)
2003	SIGMETs
2003-a	Convective
2003-b	Turbulence
2003-c	VA SIGMETs
2004	Convection
2004-a	Outlook
2004-b	Watch
2004-c	Warning
2005	AIRMET
2005-a	Turbulence (includes LLWS, sfc winds > 30 kt)
2005-b	Icing (includes freezing levels)
2005-c	Visibility, Ceiling, & Mountain Obscuration
2006	CIP
2007	FIP
2008	GTG
2009	Volcanic Ash Advisory
2010	LLWAS
2011	TDWR
2012	CWA
2013	MIS
2014	CVA
Meteorology Specific	
2020	Sounding
2020-a	Identifying potential icing levels using a skew-T

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2020-b	Skew-T analysis (LI, KI, CT, CCL, LCL, LFC, EL, CAPE)
2020-c	Lifting condensation level, level of free convection, equilibrium level, convective condensation level, convective temperature
2020-d	Stability indices (LI and KI)
2020-e	CAPE
2021	Numerical Weather Prediction (NWP)
2021-a	Four steps of the numerical modeling process
2021-b	Ensemble versus deterministic models
2021-c	Basic model output interpretation (product type, analysis time, valid time, forecast length, and data legends)
2022	Satellite Data
2022-a	IR, Visible, Water Vapor strengths and weaknesses
2022-b	Thunderstorm Detection using Satellite and Radar
2022-c	Using satellite data to identify MWT
2023	Weather Radar
2023-a	Radar Summary Chart
2023-b	Radar Coded Message
2023-c	National Radar Mosaic
2023-d	National Convective Weather Forecast
2024	Space Weather Products
2024-a	Interpreting NOAA Space weather activity scales for Geomagnetic Storms, Solar Radiation Storms, and HF Radio Blackouts
2025	Lightning Observation
2026	Surface Chart
2027	Wind shear & Turbulence
2027-a	Ellrod Index
2027-b	Richardson Number
2027-c	Kelvin-Helmholtz Instability
2027-d	Using satellite data to identify MWT
2100	**Knowledge of how to use different hazard products during different flight phases**
2101	Knowledge of product limitations
2102	Current limitations to prediction
2103	Numerical Models
2103-a	Current limitations to representing the true state of the atmosphere
2103-b	Current limitations to prediction
2103-c	Introduction to SREF Aviation Test Products
2104	Determining flight restrictions given visibility and ceiling
2105	Knowledge of product availability times

2106	Interpretation of CONVECTIVE SIGMETS and Outlooks, SPC Convective Outlooks, Severe Weather Watches and Warnings, CCFP, KI/LI Charts, CAPE charts
2107	Certified product providers
2108	Analysis of AIRMETs SIERRA, Weather Depiction Charts, Graphical METARs , SREF Flight Rules, Areas Forecasts (FAs), and Meteorological Impact Statements (MISs)
3000	**Weather Hazard Product Sources: Understanding how products are put together**
3001	Knowledge of approved product sources
3001-a	ADDS
3001-b	FSS
3001-c	DUAT
3005	Analysis and interpretation of primary (AIRMETs Tango, SIGMETS) and supplementary turbulence products (Ellrod Index, SREF, GTG)
3006	*Sources of thunderstorm and lightning data*
3006-a	Interpretation of CONVECTIVE SIGMETS and Outlooks, SPC Convective Outlooks, Severe Weather Watches and Warnings, CCFP, KI/LI Charts, CAPE charts
3007	Flight Planning
3007-a	Flight planning basics
3008	ADDS Flight Planning Tool Tutorial
3100	**Knowledge of differences between various vendor products , e.g., NEXRAD**
3101	Flight Planning
3200	**Knowledge of how and when to use different product sources during different flight phases**
3201	Flight Planning
3202	Flight planning basics
3203	Weather Overview
3204	Pre-flight evaluation
3205	In-flight evaluation

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Appendix B. Pearson Correlation Matrix: AV WX Knowledge, SE, and Salience Dimensions (Study 1 & Study 2)

Study 1 Pearson Correlation Matrix

	Mean (SD)	1	2	3	4	5	6	7	8	9	10	11
1. AV WX Knowledge	69.51 (9.99)	1.0										
2. SE A	71.92 (14.78)	.42**	1.0									
3. SE B	5.17 (.90)	.51**	.75**	1.0								
4. Salience Overall	107.65 (12.42)	-.01	.35**	.28*	1.0							
5. Attn. to WX & WX Products	35.01 (4.54)	.02	.35**	.33**	.58**	1.0						
6. Sensing & Observing WX	21.57 (2.81)	.04	.36**	.30**	.64**	.26*	1.0					
7. Effects of WX on Activities	9.95 (2.59)	-.07	.18	.11	.41**	.42**	.11	1.0				
8. Effects of WX on Mood	20.05 (5.09)	.01	.07	.06	.65**	.36**	.26*	.22	1.0			
9. Attach. to WX Patterns	10.03 (3.56)	.00	.13	.12	.58**	.06	.30**	.06	.19	1.0		
10. Need to Exp. WX Variability	14.42 (3.38)	-.06	.37**	.30**	.46**	.08	.56**	.00	-.03	.30**	1.0	
11. Attn. to WX Leading to Holiday/Cancellation	12.28 (2.89)	.00	.05	.00	.48**	.09	.36**	-.08	.10	.24*	.27*	1.0

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

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Study 2 Pearson Correlation Matrix

	Mean (SD)	1	2	3	4	5	6	7	8	9	10	11
1. AV WX Knowledge	57.89 (15.55)	1.0										
2. SE A	68.04 (16.79)	.31**	1.0									
3. SE B	4.94 (.90)	.34**	.68**	1.0								
4. Salience Overall	104.54 (13.85)	.05	.05	.11	1.0							
5. Attn. to WX & WX Products	34.46 (5.02)	.09	.14*	.25**	.58**	1.0						
6. Sensing & Observing WX	21.25 (2.94)	.10	.14*	.25**	.54**	.52**	1.0					
7. Effects of WX on Activities	9.71 (2.80)	-.08	.04	-.06	.56**	.27**	.10	1.0				
8. Effects of WX on Mood	19.45 (5.40)	.01	-.07	-.03	.74**	.27**	.22**	.38**	1.0			
9. Attach. to WX Patterns	8.90 (3.63)	.05	-.02	-.05	.57**	.05	.05	.25**	.38**	1.0		
10. Need to Exp. WX Variability	14.10 (3.40)	-.10	.01	.04	.59**	.19**	.42**	.32**	.23**	.24**	1.0	
11. Attn. to WX Leading to Holiday/Cancellation	12.27 (2.73)	.14	.10	.19**	.51**	.18**	.28**	.17*	.20**	.18*	.25**	1.0

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

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Appendix C. Demographic Questionnaire

1. What is your current age? _____________

2. Are you affiliated with ERAU?
    1. Current or previous ERAU student
    2. Current ERAU faculty or staff
    3. ERAU Alumni
    4. Not affiliated with ERAU

3. What is the current pilot certificate you hold?

Student
Private
Private with Instrument
Commercial with Instrument
ATP
Other __________

4. Where did you complete the majority of your flight training?

Part 61 (e.g. Local FBO)
Part 141 Collegiate (ERAU)
Part 141 Non-Collegiate (Phoenix East, Epic)
Other

5. Do you have an instrument rating? Y/N

6. Are you a CFI? Y/N

7. Are you a CFII? Y/N

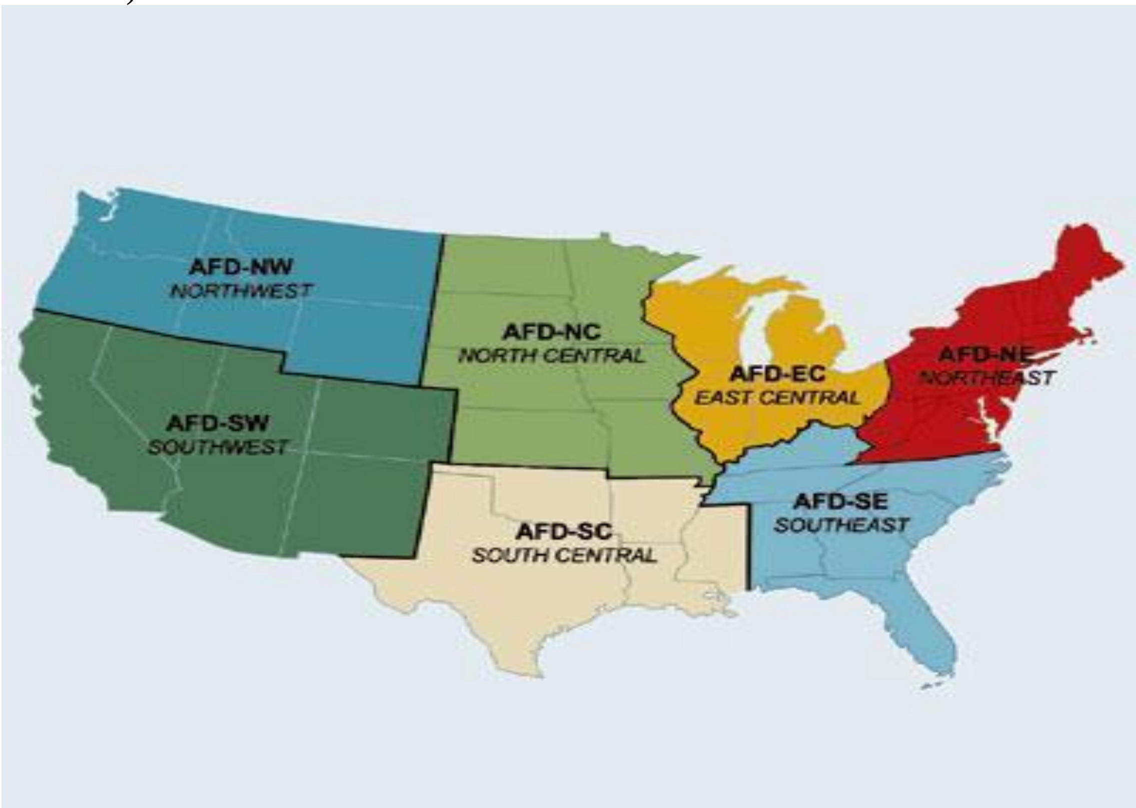
8. Total number of flight hours (approximate) _______

9. Total number of hours under instrument flight rules (actual) _______

10. Total number of hours under instrument flight rules (simulated)______

11. Number of years flying _______
12. Which region did you complete the majority of your total flight hours (e.g., Northwest for Oregon; Southwest for Arizona)?
13. **Northwest** – (Alaska, Idaho, Montana, Oregon, Washington, Wyoming)

14. **Southwest** – (Arizona, California, Colorado, Hawaii, Nevada, New Mexico, Utah)
15. **North Central** – (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota)
16. **South Central** – (Arkansas, Louisiana, Mississippi, Oklahoma, Texas)
17. **East Central** – (Illinois, Indiana, Michigan, Ohio, Wisconsin)
18. **Northeast** – (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia)
19. **Southeast** – (Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee)



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Map of the United States

Note to IRB Reviewers: *In the event that the participants will need to refer to a map of the United States, participants will receive this map as a printed handout.*

Appendix D. Weather Training Questionnaire

20. How much training have you had in meteorology?

1	2	3	4	5	6	7
Little to None						**Extensive**

21. When did you complete and pass the ERAU course **WX 201 Survey of Meteorology**?

Within the last year

One to two years

More than two years

Never Taken or did not complete the course

22. When did you complete and pass the ERAU course **WX 301 Aviation Weather**?

Within the last year

One to two years

More than two years

Never Taken or did not complete the course

23. How often do you read/review FAA publications on weather? (Examples: FAA handbooks, FAA Advisory Circulars)

1	2	3	4	5	6	7
Not Often						**Very Often**

24. How often do you read/review non-FAA publications and information on weather? *(Examples: AOPA study guide, weather materials from class)*

1	2	3	4	5	6	7

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Not Often						**Very Often**

25. How often do you use aviation weather products? *(Examples: METARS, PIREPS, GTG, etc.)*

1	2	3	4	5	6	7
Not Often						**Very Often**

26. How much time have you spent studying/reviewing weather materials on your own? (*Examples: FAA handbooks, FAA publications, online weather courses, AOPA study guide, weather materials from class, etc.)*

1	2	3	4	5	6	7
Not Much						**Very Much**

27. How much overall experience do you have using aviation related weather products? (Examples: Radar Imagery, Surface Chart, METAR)

1	2	3	4	5	6	7
Very Little to None						**Lots of Experience**

28. Please estimate how many **months** have passed since your last weather training. *(Example: 3 months; 18 months; 24 months)*

______ months

29. Please estimate the last time you read or reviewed FAA publications on weather? (Examples: FAA handbooks, FAA Advisory Circulars)

1	2	3	4	5	6	7
At least one year						**Within the last week**

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30. Please estimate the amount of time you spent studying WEATHER in preparation for your most recent FAA Airman's Knowledge Test

1	2	3	4	5	6	7
Little to None						**Extensive Amount of Time**

Appendix E. Self-Efficacy I

This questionnaire is designed to help us get a better understanding of how pilots view different aviation weather concepts/events/skills/knowledge. Please rate how confident you think you are at the following items.
Rate your degree of confidence by recording a number from 0 through 100 using the scale given below that you are able to perform the following tasks.

0	10	20	30	40	50	60	70	80	90	100
Cannot do at all					Moderately certain I can do					Highly certain I can do

	Confidence (0-100)
1. Overall flying ability	____________________
2. Knowledge of weather phenomena (clouds, winds, climate)	____________________
3. Knowledge of aviation weather products (e.g., METARS, TAFS, SIGMETS, AIRMETS, FIP, GTG)	____________________
4. Knowledge of aviation weather product sources (1-800-wx-brief, ADDS, DUAT/S)	____________________
5. Ability to problem solve during unexpected weather events (e.g., facing deteriorating conditions at destination).	____________________
6. Ability to detect different types of weather at night	____________________
7. Knowledge of turbulence	____________________
8. Knowledge of radar products	____________________
9. Knowledge of satellite products	____________________

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10. Knowledge of where to obtain appropriate weather briefings ____________________

11. Knowledge of icing conditions ____________________

12. Knowledge of wind shear ____________________

13. Basic VOR knowledge ____________________

14. Overall meteorological knowledge ____________________

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Appendix F. Self-Efficacy II

This questionnaire is designed to help us get a better understanding of how pilots consider different aviation weather concepts/events/skills/knowledge. Please rate how much you agree with the following statements.

1. I am confident in my ability to apply aviation weather concepts to flight.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

2. There are some tasks using weather information that I cannot do well.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

3. When my flight performance is poor, it is due to my lack of ability to work with weather products (e.g., METARS, TAFS, radar and satellite imagery).

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

4. I doubt my ability to understand various aviation weather concepts.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

5. I doubt my ability to use various aviation weather products (e.g., METARS, TAFS, radar and satellite imagery).

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

6. I have the skills needed to use weather products very effectively.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

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7. Most General Aviation pilots can use weather products very effectively.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

8. I am an expert at weather concepts and the ability to apply my knowledge.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

9. My future as a GA pilot is limited because of my lack of skills with weather concepts.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

10. I am very proud of my skills and abilities using weather products.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

11. I feel nervous when others watch me using weather products.

1	2	3	4	5	6	7
Strongly Disagree						**Strongly Agree**

Appendix G. Weather Salience Questionnaire

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

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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.

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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

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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**

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Appendix H. Forecast Products, Observation Products, and Flight Planning

To aid in interpreting the results by forecast, observation, and flight planning products, Appendix Table 12 presents the flight hour comparisons. Due to the manner in which the data was collected, analyzing the differences among the forecast, observation, and planning categories would require an extensive number of tests, and this report does not include those analyses.

Appendix Table 12. Flight hours of participants for Forecast interpretation topics

	Private	Private w/ Instrument	Commercial w/ Instrument	ATP	CFI	Total
	Private *n* *m (sd)* *Med*	*n* *m (sd)* *Med*	*n* *m (sd)* *Med*	*n* *m (sd)* *Med*	*n* *m (sd)* *Med*	*n* *m (sd)* *Med*
Forecast Interpretations						
LL Hazard	63 477.7 (447.9) 300	38 1357 (1156.1) 1022.5	38 2478.8 (2633. 4) 1225	22 8931.6 (6174.4) 7000	34 3283.0 (2530.4) 2600	196 2469.8 (3633.3) 1075.5
G-Airmet	39 475.5 (543.1) 300	51 1699.3 (1324.0) 1400	11 2085.9 (1577.4) 1175	24 8764.7 (7094.0) 6500	19 3092.1 (2899.1) 1650	144 2758.7 (4235.9) 1375
GTG	42 455.8 (528.3) 275	55 1681.1 (1292.8) 1400	11 2052.5 (1609.8) 1175	24 8598.0 (6733.8) 6500	20 3062.5 (2824.8) 1850	152 2643.3 (4013.6) 1325
TAF	36 512.78 (719.1) 375	46 1112.6 (1003.8) 790	23 1872.7 (1345.8) 1300	23 8427.6 (6876.4) 5925	21 3758 (3232.91) 2500	149 2587 (4054.2) 1000
Surface Prog	52 470.4	52 1742.7 (2057)	32 3526.3 (5464.1)	23 8106.1 (5049.3) 7700	19 4448.4 (3202.2)	178 2802.7 (4088.5)

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	(552.0) 266	1425	2007.5		4600	1316.5
Convective Sigmets	65 595.8 (825.7) 325	51 1095 (942.7) 800	33 2249.6 (1807.7) 1500	32 9908.6 (6210.9) 8950	23 3732.6 (3215.3) 3000	204 2802.6 (4284.8) 1000
CIP	41 458.4 (534.6) 260	50 1762.1 (1323.3) 1475	11 2052.5 (1609.8) 1175	23 8667.5 (6876.3) 6000	18 3025 (2967.9) 1650	143 2680.3 (4101.4) 1350
Observation Interpretations						
Metar	37 504.9 (710.7) 350	47 1110.8 (975.0) 780	23 2053.1 (1355.1) 1600	24 8501.5 (6735) 6062.5	21 3662.8 (3223.9) 2500	152 2625.4 (4057.9) 1025
Station Plot	43 412.8 (561.4) 250	42 1443.1 (991.6) 1366.5	26 3579.4 (5942.7) 1975	21 7430.5 (3976.1) 7700	17 4165.9 (3080.5) 4600	149 2673.1 (3874.9) 1333
PIREP	35 508.0 (731.1) 320	45 1134.6 (1045.3) 750	21 1939.1 (1391.9) 1600	24 8501.5 (6735.0) 6062.5	20 3820.40 (3223.6) 2750	145 2689.7 (4140.9) 1000
Satellite	47 455.4 (565.7) 255	48 1667.5 (1988.3) 1366.5	32 3518.8 (5467.7) 2007.5	20 7349.5 (4061.6) 6950	17 4148.2 (3182.2) 3700	164 2631.5 (3820.7) 1300
CVA	50 462.8 (559.4) 257.5	49 1687.0 (2000.7) 1400	29 3635.9 (5729.2) 2000	22 7410.9 (3881.4) 7350	19 4448.4 (3202.2) 4600	169 2714.8 (3857.3) 4600
Radar	55 608.0 (875.1) 325	46 1131.5 (983.7) 785.5	30 2259.5 (1858.1) 1550	28 10081.3 (6389.2) 8950	22 3602.3 (3228.2) 2525	181 2844.2 (4349.6) 1000
Winds Aloft (Analysis)	34 497.5	44 1116.1 (1026.2)	23 1885.7 (1341.43)	23 7784.1 (5874.6)	21 3662.8 (3223.9)	145 2519.4 (3698.7)

	(738.8) 310	737.5	1600	5925	2500	1050
Flight Sources						
Flight Planning	63 477.7 (447.9) 300	38 1357 (1156.1) 1022.5	36 2535.7 (2693.2) 1225	22 8931.6 (6174.4) 7000	33 3134.0 (2413.4) 2200	192 2462.8 (3641.7) 1075.5
Storm Definitions	63 477.7 (477.9) 300	38 1357 (1156.1) 1022.5	36 2535.7 (2693.2) 1225	22 8931.6 (6174.4) 7000	33 3134.0 (2413.4) 2200	192 2462.8 (3641.7) 1075.5
TSTM	68 582 (797.9) 337.5	55 1119 (935.9) 800	39 2224.6 (1734.7) 1500	32 9908.6 (6210.9) 8950	22 3697.7(3286 .5) 2525	216 2714.4 (4183.6) 1000
Data Sources	65 473.84 (443. 5) 300	38 1357.0 (1156.1) 1022.5	39 2431.9 (2614.97) 1100	22 8931.6 (6174.4) 7000	34 3283.0 (2530.4) 1048	198 2451.1 (3619.5) 1048

Appendix I. ERAU WTIC Papers and Presentations (as of January 2019)

<u>2019</u>

McSorley, J., King, J., Blickensderfer, B. (2019, July). *Aviation weather products in general aviation: interpretability and usability research trends.* Paper presented at 21st International Conference on Human-Computer Interaction, Orlando, FL.

Blickensderfer, B., Lanicci, J., Guinn, T., Thomas, R., Thropp, J., King, J., ... Ortiz, Y. (2019, January). *Combined report: aviation weather knowledge assessment & general aviation pilots' interpretation of weather products.* (FAA Grant #14-G-010). Unpublished project report. Embry-Riddle Aeronautical University, Daytona Beach, FL.

Ortiz, Y., Blickensderfer, B., King, J., Guinn, T., & Thomas, T. (under review). The role of automation in general aviation weather products and tools. Under review in M. Mouloua and P. Hancock (eds.) *Automation & Human Performance Theory & Application.*

Blickensderfer, B., Guinn, T., Lanicci, J., Ortiz, Y., King, J., Thomas, R., & DeFilippis, N. (under review). Assessing the interpretability of weather products. *Under review for publication to Aerospace Medicine & Human Performance*

Blickensderfer, B. (2019, May). Interpretability of aviation weather products by GA pilots. In I. Johnson (Chair), *Weather hazards in general aviation: Human factors research to understand and mitigate the problem*. Symposium conducted at the International Symposium of Aviation Psychology, Dayton, OH.

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McSorley, J., King, J., Blickensderfer, B. (2019, May). *Exploring perceived usability and interpretability of aviation weather products in GA pilots*. Paper presented at the 20th International Symposium on Aviation Psychology, Dayton, OH.

King, J., Ortiz, Y., McSorley, J., Kleber, J., Blickensderfer, B. (2019). Assessing GA Pilots' Ability to Interpret Traditional Weather Symbols and Coding Utilized in New Interactive Weather Product Displays[Abstract xxx]. *Aerospace Medicine and Human Performance, 90*(3). Las Vegas, NV.

Ortiz, Y., Blickensderfer, B., King, J., & Guinn, T. (2019). General Aviation Pilots' Preflight Weather Planning Mental Models[Abstract 424]. *Aerospace Medicine and Human Performance*, *90*(3). Las Vegas, NV.

McSorley, J., Blickensderfer, B. (2019, January). *Usability analysis of convective SIGMETs.* Paper presented at the Human Factors and Applied Psychology Conference, Orlando, FL.

Kleber, J., King, J., Blickensderfer, B. (2019, January). *Utilizing age and experience to predict pilots' ability to interpret coded weather information.* Poster presented at the Human Factors and Applied Psychology Conference, Orlando, FL.

2018

King, J., Ortiz, Y., Guinn, T., Blickensderfer, B., & Thomas, R. (2018, October). *GA pilot preflight weather planning: Weather products usability & limitations.* Presentation given at the Friends and Partners of Aviation Weather (FPAW) Meeting, Orlando, FL.

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Blickensderfer, B. (2018, October). *AOPA Follow-up study: A review of CONUS pilot's capability to interpret weather products.* Presentation given Friends/Partners in Aviation Weather Forum (FPAW), Orlando, FL.

Guinn, T., Blickensderfer, B., Ortiz, Y., & King, J. (2018, October). *Aviation weather education challenges using current FAA guidance, and issues with outdated guidance.* Presentation given at Friends/Partners in Aviation Weather Forum (FPAW), Orlando, FL.

King, J., Ortiz, Y., Guinn, T., Blickensderfer, B., & Thomas, R. (2018, October). *GA pilot preflight weather planning: Weather products usability & limitations.* Presentation given at the Friends and Partners of Aviation Weather (FPAW) Meeting, Orlando, FL.

Thomas, R., & Guinn, T. (2018, October). *Challenges for flight instructors, training trainers.* Presentation given at Friends/Partners in Aviation Weather Forum (FPAW), Orlando, FL.

Ortiz, Y., Blickensderfer, B., & Guinn, T. (2018, October). *New measures for assessing GA pilot's preflight weather planning mental models.* Presentation given at Friends/Partners in Aviation Weather Forum (FPAW), Orlando, FL.

Berendschot, Q., Ortiz, Y., Simonson, R., & Blickensderfer, B. (2018). Simulation development for general aviation weather training. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. Washington, D.C.: HFES.

DeFilippis, N., King, J., Guinn, T., Ortiz, Y., Berendschot, Q., & Blickensderfer, B. (2018). Evaluation of graphical weather product interpretation: Implications for overlaying weather product design. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting.* Washington, D.C.: HFES.

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King, J., Ortiz, Y**.**, Christy, E., & Blickensderfer, B. (2018). Challenges contributing to the general aviation weather problem and decision support systems technology mitigation recommendations. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Washington, D.C.: HFES.

King, J., Ortiz, Y., Blickensderfer, B., Guinn, T., Lanicci, J., Thomas, R., DeFilippis, N. (2018). Assessing the relationship between GA pilots' familiarity and ability to interpret aviation weather products [Abstract 380]. *Aerospace Medicine and Human Performance, 89*(3), 292.

Ortiz, Y., Blickensderfer, B., King, J., Guinn, T., & Thomas, R. (2018). Assessing pilots' knowledge of basic weather planning products [Abstract 400]. *Aerospace Medicine and Human Performance, 89*(3), 298.

Guinn, T., DeFilippis, N., Lanicci, J., Ortiz, Y., King, J., Thomas, R., & Blickensderfer, B. (2018, January). *Using an interdisciplinary approach to assess general aviation pilot weather knowledge.* Paper presented at 6th Aviation, Range, and Aerospace Meteorology (ARAM) Symposium, 98th Annual Meeting of the American Meteorological Society, Austin, TX.

<u>2017</u>

Blickensderfer, B., Lanicci, J., Guinn, T., Thomas, R., King, J., & Ortiz, Y. (2017). Assessing general aviation pilots understanding of aviation weather products. *The International Journal of Aerospace Psychology*, *27*(3-4), 79-91. doi:10.1080/24721840.2018.1431780

King, J., Ortiz, Y., Guinn, T., Lanicci, J., Blickensderfer, B., Thomas, R., & DeFilippis, N.

(2017). Assessing general aviation pilots' interpretation of weather products: traditional and new automated generation products. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. Washington, D.C.: HFES.

Ortiz, Y., Blickensderfer, B., & King, J. (2017). Assessment of general aviation cognitive weather tasks recommendations for autonomous learning and training in aviation weather. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. Washington, D.C.: HFES.

King, J., Ortiz, Y., Guinn, T., Lanicci, J., Blickensderfer, B., Thomas, R., & DeFilippis, N. (2017, August). *Evaluation GA pilots' interpretation of new automated weather products*. Presentation to the 30th National Training Aircraft Symposium, Daytona Beach, FL.

Thomas, R., King, J., Ortiz, Y., Guinn, T., Blickensderfer, B., & DeFilippis, N. (2017, August). *Assessing general aviation pilots' weather knowledge and self-efficacy*. Presentation given at the 30th National Training Aircraft Symposium, Daytona Beach, FL.

King, J., Ortiz, Y., Blickensderfer, B., Guinn, T., Lanicci, J., Thomas, R., & DeFilippis, N. (2017, May). *An assessment of general aviation pilots' IFR knowledge and skills*. Paper presented at the 19th International Symposium on Aviation Psychology, Dayton, OH.

Ortiz, Y., King, J., Blickensderfer, B., Guinn, T., Lanicci, J., Thomas, R., Thropp, J., Cruit, J., & Jennis, A. (2017, May). *The influence of motivational attitudes on general aviation weather knowledge.* Paper presented at the 19th International Symposium on Aviation Psychology, Dayton, OH.

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King, J., Ortiz, Y., Blickensderfer, B., Guinn, T., Lanicci, J., Thomas, R., & DeFilippis, N. (2017*)*. What do general aviation pilots know about thunderstorms? [Abstract 365]. *Aerospace Medicine and Human Performance, 88*(3), 286.

Ortiz, Y., Blickensderfer, B., Lanicci, J., King, J., Guinn, T., Thomas, R., Cruit, J., & Jennis, A. (2017). Assessing general aviation pilots' knowledge of aviation weather [Abstract 259]. *Aerospace Medicine and Human Performance, 88*(3), 246.

Lanicci, J.M., Guinn, T.A., King, J, M., Blickensderfer, E.L., Thomas, R.L., and Ortiz, Y. (2017, January). *A proposed weather taxonomy for general aviation pilot education and training*. Paper presented at the 18th Conference on Aviation, Range, and Aerospace Meteorology, 97th Meeting of the American Meteorological Society, Seattle, WA.

<u>2016</u>

Thropp, J. E., Lanicci, J. M., Blickensderfer, E. L., Cruit, J. A., & Guinn, T. A. (2016, January). *Applying the concept of weather salience to a specific user community: General aviation pilots*. Paper presented at the 11th Symposium on Societal Applications: Policy, Research and Practice (American Meteorological Society), New Orleans, LA. Retrieved from https://ams.confex.com/ams/96Annual/webprogram/Paper290001.html

Blickensderfer, B., Lanicci, J., Guinn, T., Thomas, R., Thropp, J., King, J., & Ortiz, Y. (2016, December). *Aviation weather knowledge questions* (FAA Grant #14-G-010). Unpublished project report. Embry-Riddle Aeronautical University, Daytona Beach, FL.

Blickensderfer, B., Lanicci, J., Guinn, T., Thomas, R., King, J., & Ortiz, Y. (2016, November). *Assessing aviation weather knowledge in general aviation pilots: overview and initial* *results.* Paper presented at the Friends and Partners of Aviation Weather (FPAW) Meeting, Orlando, FL.

Guinn, T., & Thomas, R. (2016, November). *GA pilot weather resources: Challenges and suggestions for improvement.* Paper presented at the Friends and Partners of Aviation Weather (FPAW) Meeting, Orlando, FL.

Lanicci, J. M., King, J., & Ortiz, Y. (2016, November). *A proposed aviation weather knowledge taxonomy for GA pilots.* Paper presented at the Friends and Partners of Aviation Weather (FPAW) Meeting, Orlando, FL.

Thropp, J. E., Lanicci, J. M., Cruit, J. K., Guinn, T. A., & Blickensderfer, E. L. (2016, November). *Applying the concept of weather salience to a specific user community: General aviation pilots*. Paper presented at the Friends and Partners of Aviation Weather (FPAW) Meeting, Orlando, FL.

Ortiz, Y., Blickensderfer, B., Thomas, R., Bois, R., Allen, M., Mikail, S., & Beattie, M. (2016). Flight simulation without an instructor: Teaching missed approaches. *Proceedings of the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC).*

King, J., Ortiz, Y., & Blickensderfer, B. (2016). ATC knowledge and skills: A contributing factor to the General Aviation weather problem? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. Washington, D.C.: HFES.

Cruit, J., K., Blickensderfer, B., Guinn, T., Lanicci, J., & Thomas, B. (2016, July). *How to improve the assessment of general aviation weather-related knowledge and skills.* Paper presented at the 7th International Conference on Applied Human Factors and Ergonomics, Orlando, FL.

<u>2015</u>

Blickensderfer, B., Lanicci, J., Vincent, M., Thomas, R. L., Smith, M. J., & Cruit, J. (2015). Training general aviation pilots for convective weather situations: A replication and extension. *Aerospace Medicine and Human Performance, 86*(10)*, 881-888.*

Blickensderfer, B., Cruit, J., Lanicci, J. M., & Thomas, R. (2015, August). *A framework for assessing weather related knowledge and skills in general aviation.* Paper presented at the Annual Convention of the American Psychological Association, Toronto, CA.

Cruit, J. A. Blickensderfer, B. Lanicci, J., Guinn, T., Thomas, R. (2015, August). *WTIC research at ERAU: An overview.* Paper presented at Friends/Partners in Aviation Weather Forum (FPAW), Washington, D. C.

Thomas, R., Cobbett, E., Lanicci, J., Cruit, J., & Blickensderfer, B. (2015). Using NEXRAD products during convective weather situations. *Embry-Riddle Aeronautical University: online course.* Retrieved from www.FAAsafety.gov

<u>2014</u>

Cobbett, E. A., Blickensderfer, E. L., & Lanicci, J. (2014). Developing general aviation pilots' knowledge and skills to interpret NEXRAD based weather products. *Aviation, Space, and Environmental Medicine, 85,* 1019-1025.

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2013

Vincent, M., Blickensderfer, E., Thomas, R., Smith, M. J., Lanicci, J. (2013). In-cockpit NEXRAD products: Training general aviation pilots. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting, 57*(1), 81-85.

Blickensderfer, B., Lanicci, J., Smith, M.J., Vincent, M., & Thomas, R. L. (2013, August). *Datalink weather in the cockpit training: Final project report.* Embry-Riddle Aeronautical University, Daytona Beach, FL.

Blickensderfer, B., Cruit, J., & Vincent, M. (2013, July). *Aviation weather decision making: A human factors perspective.* Paper presented at the Friends/Partners in Aviation Weather Forum (FPAW), Washington, D. C.

Vincent, M., Blickensderfer, E., Thomas, R., Smith, M.J., & Lanicci, J. (2013, April). *Fostering meteorology knowledge in GA pilots.* Paper presented at the Human Factors and Applied Psychology Student Conference, Daytona Beach, FL.

2011

Roberts, E. A., Lanicci, J. M., & Blickensderfer, E. (2011, August). *Assessing the effectiveness of an education and training module for general aviation pilots on the use of NEXRAD-based products in the cockpit.* Paper presented at the 15th Conference on Aviation, Range, and Aerospace Meteorology, Los Angeles, CA.