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Validated Question Bank for Assessing Pilot Knowledge of Aviation Weather

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The rate of weather-related accidents is decreasing at a rate 2.57 times slower than all general aviation (GA) accidents (Fultz and Ashley, 2006). This illustrates that despite there being projects aimed at addressing this accident rate, these interventions are not occurring fast enough. The Federal Aviation Administration (FAA) found that 88% of all aviation weather-related accidents in the U.S. occurred among GA pilots (Federal Aviation Administration, 2010). From 2008 to 2019, there were 381 non-commercial fixed-wing GA aircraft accidents identified to be weather-related, and that resulted in at least one fatality (Air Safety Institute, 2022). This paper validates a set of weather product interpretation questions that can be used to measure a pilot's understanding of weather. To address the gaps in a GA pilot's understanding of the weather, the first step is assessing their current knowledge. Thus, this scale can be used as a metric for measuring a person's understanding of weather and weather products. The assessment consists of 15 weather product interpretation topics which can be administered as a single 65-question survey or, as in the current study, two assessments of 33 and 32 questions each separated by topic. These questions may be used to identify areas of strength and weaknesses regarding a pilot's understanding of weather. With this knowledge, pilots can better direct their studies to specific weather topics and fortify their understanding of weather and weather products. The long-term goal is for these questions to help address and fortify pilots' weather knowledge and reduce the rate of GA weather-related accidents by promoting safe, informed weather-related decision-making.

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Between 1990 and 2003, 83% of all aviation-related fatalities occurred within general aviation alone (Bazargan & Guzhva, 2011). Among these accidents, a quarter cited weather as the cause or contributing factor (Capobianco & Lee, 2001). From 2010 to 2011, 29% of aviation accidents were attributed to weather (Eick, 2015). In fact, weather-related accidents decreased at a rate 2.57 times slower than the trend of all general aviation (GA) accidents. Fatal weather-related accidents decreased at a rate 1.73 times slower than that of *all* fatal GA accidents (Fultz and Ashley, 2016.). While there is work intending to address these weather-related accidents in GA, these rates suggest it is not occurring fast enough, and more immediate interventions are needed. Our goal is to validate a set of weather product interpretation questions that can be used as a metric for measuring a person's understanding of weather which may be used to identify gaps in knowledge and fortify pilots' weather knowledge with the aim of reducing the rate of GA weather-related accidents.

Weather

Weather-related accidents in GA are most associated with icing conditions and flying into instrument meteorological conditions (IMC), both of which are established problems in the domain (Air Safety Foundation, 2020). IMC was present in only 20% of GA accidents, yet these same conditions were associated with 60% of fatal weather-related accidents (Fultz and Ashley, 2016). IMC, however, is not the only challenge. Icing is listed as a contributing factor to many accidents and presents a more nuanced challenge to pilots as there are many complex factors to consider (e.g., ground icing concerns, varying implications from where icing may occur on the plane, etc.). Between 1982 and 2013, Fultz and Ashley (2016) found there were a total of 3,972 fatal weather-related accidents, causing a total of 8,052 fatalities. Misunderstanding weather can be deadly to GA pilots. Thus this study aims to produce a set of validated questions that can be used as part of targeted weather-related training programs.

Pilot Training

The type of weather-related training a pilot receives impacts both their comprehension of weather and weather products as well as their subsequent ability to make safe flight decisions. For clarification, weather products refer to any weather display or source of information that may be observed (i.e., currently occurring) or forecasted (i.e., predictions of weather development). To accurately utilize weather products, pilots must also understand the limitations of each weather product (e.g., that convective SIGMETS are valid for no more than two hours once issued). Title 14 of the Code of Federal Regulations (CFR) Part 61 defines the requirements of aeronautical knowledge and flight proficiency needed to obtain pilot certificates. For GA pilots, 14 CFR 61.105(b)(13) states that pilots must learn how to conduct preflight action, which includes how to obtain information on runway lengths at airports of intended use, data on takeoff and landing distances, weather reports and forecasts, and fuel requirements. It also states pilots must know how to plan for alternatives if the planned flight cannot be completed or delays are encountered (Federal Aviation Regulation, 1997). This is the foundation of private pilot training.

Regarding flight schools, each will have a defined and FAA-approved training course outline (TCO) that must meet the same aeronautical knowledge requirements stated in Part 141. Students enrolled in accredited professional flight baccalaureate degree programs may be required to take additional meteorology courses. However, the number of required meteorology courses and the number of required meteorology credit hours varies between programs (Guinn & Rader, 2012). This is an example of what can often be a drastic disparity between the type of weather-related training GA pilots receive.

The training provided in Part 61 flight schools is structured solely by the individual certified flight instructor (CFI) and can be tailored to students' timeline. Uniformly, the aeronautical knowledge listed in 14 CFR Part 61 must be taught, but the order and actual lesson content by the hour may vary between each CFI (Federal Aviation Regulation, 1997). The weather product interpretation questions from this study could be used by these flight instructors to identify gaps in weather knowledge and may create a more unified approach to the weather-related education GA pilots receive.

Only 5-10% of questions on the Private Pilot Airplane Knowledge Test are about the weather (Table 1). Furthermore, pilots-in-training can pass this knowledge exam with a minimum score of 70% (FAA, 2019). Taken together, this means that it is possible to miss every weather question presented and still pass the exam. Flight instructors are required by 14 CFR 61.39 to review all areas found deficient on the knowledge test before endorsing the student for the practical test. However, students are not required to retake the knowledge test if they achieve a passing score (Federal Aviation Regulation, 1997).

To obtain a private pilot’s certificate, a person must pass both a knowledge test and a practical test. The knowledge test must be administered at an authorized FAA testing center; students must score passing marks here prior to taking the practical test. When CFIs review the subject areas found deficient on the test, the manner in which the review is conducted is at the discretion of the CFI. During the practical test, the pilot is tested by an examiner on preflight weather and cross-country flight planning which includes the pilot’s ability to gather the proper weather information and determine if the weather allows for a safe and successful flight (FAA, 2019). These are further examples of the wide variability found within weather-related training for GA pilots, which only amplifies the need for intervention.

Table 1
FAA Private Pilot Airplane Knowledge Test Blueprint (FAA, 2019)

PAR Knowledge Areas Required by 14 CFR part 61, section 61.105 to be on the Knowledge Test	Percent of questions per test
Regulations	5-15%
Accident Reporting	5-15%
Performance Charts	5-15%
Radio Communications	5-15%
Weather	5-15%
Safe and Efficient Operations	5-15%
Density Altitude Performance	5-15%
Weight and Balance	5-15%
Aerodynamics, Powerplants, and Aircraft Systems	5-15%
Stalls and Spins	5-15%
Aeronautical Decision-Making (ADM)	5-15%
Preflight Actions	5-15%
Total Number of Questions	60

Weather Test Development

Prior to 2017, a gap in literature existed pertaining to the interpretability of aviation weather products by GA pilots. A team of researchers has focused on this problem for several years (Blickensderfer et al., 2017; King et al., 2021; Blickensderfer et al., 2021). Blickensderfer et al. (2017) previously created and validated an aviation weather product interpretability test to use among GA pilots. The test included 95 weather questions that encompassed a variety of topics: observation product interpretation, forecast product interpretation, and product attributes. Observation products are described as raw weather data collected by sensors that can be either in situ (i.e., surface or airborne) or remote (i.e., weather radar, satellite, and lightning). Observation products include METARs, radar, and satellite displays (Federal Aviation Administration, 2016). Forecasts portray predictions of weather development and/or its movement formed from meteorological observations and mathematical modeling. Forecast products include prognostic charts, wind/temperature, TAFs, etc. (Federal Aviation Administration, 2016). Product attributes will refer to the characteristics of a weather product that influences the interpretation of said product (e.g., how long certain products are valid) (Federal Aviation Administration, 2016). The research team who developed these questions consisted of meteorologists, Gold Seal Certificated Flight Instructors, an Industrial-Organizational psychologist, and human factors specialists. All questions were multiple-choice with only one correct answer per. According to the results of the initial validation (Blickensderfer et al., 2017), student pilots scored significantly lower than all other pilot certificates/rating holders. Commercial pilots with an instrument rating scored higher than all other groups; however, they still only achieved a score of 65% correct on average. Across all certificate/rating groups, scores were highest for upper-level charts, SIGMETs, and surface analysis charts among hazard products. Scores were lowest for textual METARs, Radar, and Satellite imagery (Blickensderfer et al., 2017).

A follow-up study was conducted to assess interpretability among a more generalizable GA pilot sample (Blickensderfer et al., 2021). A revised test bank of 118 questions, developed by the same team as the initial study, was created wherein an overall score was calculated for each participant as well as a category score for each weather topic. In the Blickensderfer et al. (2021) study, private pilots scored significantly lower than all other pilot certificates/ratings. The following categories resulted in the lowest scores overall: Station Plots, CVA, Satellite, and Surface Prognostic charts. The following categories received the highest scores overall: Winds Aloft, PIREPs, and GTG. There was a wide disparity between these category scores, which could be due to the complexity of certain weather concepts or possibly the usability of the weather products themselves. The results indicated to researchers which weather concepts or products GA pilots may be struggling to understand so that further research could be conducted. It also provides important data that can be used to create further weather product interpretation tests. The results from Blickensderfer et al. (2021) provided the foundation for the effort to validate this truncated set of weather interpretation questions that examines GA pilots' ability to understand various weather-related products.

This study aims to validate a truncated set of weather-product interpretation questions that may be used as a metric for judging GA pilots' weather-related knowledge, be used to fortify their weather knowledge, and ultimately reduce the rate of weather-related GA accidents.

Method

Participants

Participants (n=34) were pilots with a current private pilots' certificate aged 18 or older. All participants were members of a GA high-performance aircraft pilot association. Participants voluntarily self-selected into the study, which was advertised to the association members through their email listserv. Only participants who completed the survey in full were included in our analysis. All participants reported being instrument-rated pilots. Mean flight hours are shown in Table 2. Participants were randomly assigned to one of two tests which were similar in length but differed in content (Table 3).

Table 2

Demographics of Participating Pilots

	Sample Size	Mean Flight Hours (SD)	Median Flight Hours	Mean Years Flying (SD)
Test 1 Participants	15	1,848.21 (1061.23)	1,900	22.0 (11.88)
Test 2 Participants	16	2,213.13 (1272.15)	2,000	17.1 (8.07)

Note. T-Test results indicated no significant difference in flight hours between participants randomly assigned to tests 1 and 2. See the results section for analysis.

Measures

Two measures were addressed in this study: the demographics questionnaire and the Weather Product Interpretation Tests, both of which were hosted on the online survey system Qualtrics.

Demographics Questionnaire

The demographic questionnaire consisted of 12 questions about participants, such as their current age, what pilot certificates and ratings they hold, and the type of weather training they have experienced.

Weather Product Interpretation Tests

Overall, the purpose of these weather product interpretation tests is to determine the pilots' ability to understand information obtained from various weather products. Test 1 was a total of 33 questions and tested pilots on their ability to interpret Winds Aloft, radar, PIREPs, Graphical Forecasts for Aviation (GFA), satellite, and METAR products. Test 2 was 32 questions long and addressed station plots, Graphical Turbulence Guidance (GTG), Low-Level Significant Weather (LLSigWx), surface prognostics, SIGMETs, Current Icing Products (CIP), Terminal Aerodrome Forecasts (TAFs), flying in thunderstorms, and G-AIRMETs. Both tests were multiple-choice and had 2-4 answer options with one correct answer per question. All questions were drawn from the validated Blickensderfer et al. (2017, 2021) weather interpretation test but were updated to reflect the most-recent weather product presentation style. After truncating the original test with the assistance of meteorologists, flight instructors, and a team of human factors specialists, the questions were separated into two tests. The breakdown of Test 1 and Test 2 is shown in table 3.

Table 3
Test contents and associated weather product scores

Category	Product	Scores *M (SD)*	Num. of Questions	Question Number (from the appendix)	Test
Observation Products	GFA	98.3 (6.5)	4	59, 60, 61, 62	1
	METARs	67.5 (13.2)	8	5, 8, 10, 14, 25, 27, 28, 48	1
	PIREPs	93.3 (13.8)	3	22, 42, 63	1
	Radar	81.7 (13.3)	8	1, 6, 15, 16, 38, 45, 54, 55	1
	Satellite	68.9 (17.7)	6	3, 7, 20, 21, 29, 52	1
	Winds Aloft	75.6 (29.5)	3	9, 32, 33	1
	Station Plots	46.7 (36.4)	4	12, 31, 37, 51	2
Forecast Products	CIP/FIP	84.4 (24.8)	3	39, 44, 56	2
	G-AIRMETs	60.0 (21.4)	5	17, 30, 34, 49, 57	2
	GTG	75.0 (18.9)	4	26, 40, 64, 65	2
	LL SigWx	80.0 (31.6)	2	35, 53	2
	SIGMETs	60.8 (20.5)	8	4, 36, 41, 43, 46, 50, 58, 47	2
	Surface Prog	75.6 (29.5)	3	18, 23, 24	2
	TAFs	51.1 (39.6)	3	11, 13, 19	2
Product Attributes	Flying in Thunderstorms	53.3 (51.6)	1	2	2

Procedure

Participants volunteered for the study by selecting a link that was included in an email sent to the pilot association's mailing list. Participants were first presented with an informed consent form; if they selected "AGREE" then they were given access to the full survey. Participants who selected "DISAGREE" were thanked for their time and the survey closed. Those who participated were randomly assigned to one of the two tests automatically by Qualtrics. Once the survey was opened, the participants first answered the demographics questionnaire, followed by their randomly assigned test. Participants were able to take this survey on the electronic device of their choosing (i.e., a tablet, computer, or phone). Participants were allowed to take the assessment at their own pace and could choose to pause the survey and return within five days to complete it. After completing all parts of this survey, participants were shown a score that was calculated based on their percentage of correct answers for the test they were presented with.

Results

Equivalency of groups, aggregated results, and group differences in pilots' ability to interpret weather information were calculated using the IBM Statistical Package for the Social Sciences (SPSS) version 27. Descriptive statistics are shown in Tables 4 through 6.

Equivalency of Groups

Equivalency of the groups (e.g., participants who took Test 1 versus Test 2) was examined by comparing mean flight hours. An independent-sample t-test was run to determine if there were differences in pilot flight hours between Test 1 (N=15) and Test 2 (N=16). There were three outliers removed from the data after inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. Further inspection of the data, indicated that the identified outliers might be cases of miss input by the participants. The assumption of normality was violated as the dependent variable (Flight Hours) is not normally distributed for Test 2 of the independent variable (Condition) as assessed by the Shapiro-Wilk test ($p < .05$). There was homogeneity of variances for Flight Hours as assessed by Levene's test for equality of variances ($p = .66$). There was not a statistically significant difference in flight hours between pilots who took Test 1 and Test 2, -364.91, 95% CI [-1248.68, 431.44], $t(28) = -.85$, $p = .41$.Thus, there is no significant difference in flight hours between the pilots randomly assigned into the two groups.

Overall Scores Across Tests

The means for percentage correct on Test 1 versus Test 2 are shown in Table 4. An independent-samples t-test was run to determine if there were differences in scores between Test 1 and Test 2. There were no outliers in the data, as assessed by inspection of the boxplot. Scores for each condition were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$), and there was homogeneity of variances, as assessed by Levene's test for equality of variances ($p =.037$). The scores between Test 1 and Test 2 were statistically significant, with pilots who took Test 1 averaging higher scores than Test 2, 13.12, 95% CI [4.29, 21.96], $t(29) = 3.04$, $p = .005$.

Table 4
Descriptive statistics for score (percentage correct) by test

Test 1 M (SD) n=15	Test 2 M (SD) n=16
77.6 (8.3)	64.5 (14.7)

Test 1 Topic Analysis

Test 1 consisted of 32 multiple-choice questions. Six categories of weather products were evaluated in Test 1: GFA, METAR, PIREPs, Radar, Satellite, and Winds aloft. The descriptive statistics for Test 1 individual topics are shown in Table 5.

Table 5
Test 1: Descriptive statistics for correct percentage score by product

Product	*M(SD)* *n=15*
GFA	98.3 (6.5)
METAR	67.5 (13.2)
PIREP	93.3 (13.8)
Radar	81.7 (13.3)
Satellite	68.9 (17.7)
Winds Aloft	75.6 (29.5)
Total	77.6 (8.3)

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in the mean score (percentage correct) among Test 1 topic areas (GFA, METAR, PIREPs, Radar, Satellite, and Winds Aloft). Outliers were present for GFA, METAR, PIREP, Radar, and Winds Aloft as assessed by boxplots. An evaluation of the Shapiro-Wilk test determined the data was not normally distributed ($p < .05$) for each subgroup of Test 1. Mauchly's test of sphericity showed the assumption of sphericity had not been violated, $\chi2(14) = 23.56$, $p = .056$. Scores were significantly different for Product Types, $F(5, 70) = 8.99$, $p < .001$, partial $\eta2 = .39$. This indicated that 39% of the variability in score could be accounted for by differences in subtopic scores. Post hoc analysis with a Bonferroni adjustment revealed that scores for GFA were significantly higher than METARs ($p < 0.001$), Radar ($p = .014$), and Satellite ($p < 0.001$). Satellite was significantly higher than PIREPs ($p = 0.018$), and METAR was significantly higher than Radar ($p = 0.001$).

Test 2 Topic Analysis

Test 2 consisted of 33 multiple-choice questions. Nine areas of interest were evaluated during Test 2: CIP, G-AIRMET, GTG, Low-Level Sig Weather (SigWx), SIGMETs, Station Plot, Surface Prog Chart, TAF, and Thunderstorms. The descriptive statistics for Test 2 are shown in Table 6.

Table 6
Test 2: Descriptive statistics for the score by product.

Product	Total M (SD) *n=16*
CIP	84.4 (24.8)
G-AIRMET	60.0 (21.4)
GTG	75.0 (18.9)
LL SigWx	80.0 (31.6)
SIGMET	60.8 (20.5)
Station Plot	46.7 (36.4)
Surface Prog	75.6 (29.5)
TAF	51.1 (39.6)
Thunderstorm	53.3 (51.6)
Total	64.5 (14.7)

As with Test 1, a one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in scores (percentage correct) among Test 2 topic areas. There were no outliers as assessed by boxplot. An evaluation of the Shapiro-Wilk test determined two subtopics were normally distributed (SIGMET and Station-plot) while the other subtopics (CIP, G-AIRMET, GTG, LL SigWx, SIGMET, Station Plot, Surface Prog, TAF, and Thunderstorms) were not normally distributed, ($p < .05$). Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, $\chi2(35) = 61.18$, $p = .006$. Greenhouse and Geisser (1959) was used to correct the violation. Score (percent correct) was found to be significantly different for Product Types, $F(3.48, 48.79) = 3.05$, $p = .031$, partial $\eta2 = .18$. This indicated that 18% of the variability in score could be accounted for by subtopic. Post hoc analysis with a Bonferroni adjustment revealed no statistically significant difference among individual subcategories for scores on Test 2.

Discussion

Pilot knowledge of aviation weather and aviation weather services is a critical part of ensuring a safe flight. The results from this study indicate that pilots' weather knowledge may be lacking in several key areas. Results of this current study found that pilots generally excelled and struggled to interpret the same weather products as the previous Blickensderfer et al. (2021) study; Station Plots and TAF categories were among the bottom three performing categories for both studies, while the categories Winds Aloft, Surface Prognostic, GTG, and PIREPs all scored above a 70% threshold in both studies. However, in this current study, both RADAR and CIP categories also exceeded the 70% threshold.

The test questions provided in this paper are a tool to help pilots and instructors assess a person's knowledge of weather and weather products by revealing any areas where their weather knowledge may be deficient. Using the questions as part of flight training may provide instructors insight into student knowledge gaps. In turn, a clearer view of students' knowledge can be used to provide targeted training in areas found to be deficient. Additionally, these questions can also highlight areas where individual students excel. In these cases, students may use that information to better focus their study time in other areas.

A study limitation is that this study sampled a subset of current private pilots who were members of a GA high-performance aircraft pilots association with a mean flight time of 2000 hours and averaging over 17 years of flight experience. Therefore these results may not be generalizable to pilots of all certificate and experience levels. Familiarity with the region and experience with regional weather phenomena may or may not impact knowledge of certain topics like thunderstorms and icing. However, these two factors do not impact the validation of the question bank itself, which is the primary goal of this research.

The results from this study and others indicate that pilots' weather knowledge may be lacking in several key areas. The validated test questions are a tool to help pilots and instructors assess their knowledge of weather and weather products and help determine any areas where weather knowledge may be deficient. An understanding of where GA pilots excel and struggle in their weather knowledge can be used to improve weather training and hopefully better equip them with the necessary weather-related skills and knowledge to make safe flight decisions.

Use of the Questions

The question banks, found in the appendices, can be used in three ways:

1. As one test using all the questions (see appendix).
2. Split into the two test banks as described in the measures and results section (Table 3).
3. Using questions that relate to specific topics to perform a targeted evaluation. Table 3 shows the breakdown of test questions found in the appendix by topic. This allows instructors to select questions specific to weather subject areas. Please note that the number of questions per topic will vary and that some topics will have a smaller question set than others.

It is recommended to use an electronic means to deliver the test as it provides the clearest way for weather products and images to be viewed by the test takers. Analysis of the results can be achieved by using the answer key found in the appendix.

Please note that the question bank was made with what were the current versions of FAA Advisory Circulars AC 00-45H and AC 00-6B at the time of publication. Weather products and resources will change and update over time. When using the question bank, be sure to verify that the weather products referenced in the question bank have not been removed or changed.

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Appendix

Due to its length the Appendix hosting all 65 questions can be accessed by following the link below or by scanning the QR code.

View appendix:

Commons.erau.edu/cgi/viewcontent.cgi?article=1016&context=ga-wx-display-interpretation