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A Proposed Taxonomy for General Aviation Pilot Weather Education and Training

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A Proposed Taxonomy for General Aviation Pilot Weather Education and Training

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Introduction

The latest Nall Report, published by the Air Safety Institute of the Aircraft Owners and Pilots Association (AOPA), continues to show a downward trend in the total number of U.S. General Aviation (GA) accidents and fatalities (AOPA, 2018). While this trend includes weather-related accidents, an unacceptably large percentage of these accidents are fatal (known as the lethality rate[1]). Figure 1 shows the weather-related accident trends for 2003-2015, the most recent period for which statistics are available. These data show that while the overall numbers are decreasing, the lethality rate remains steady between 70% - 80%. These trends are a continuing concern for safety-minded organizations such as AOPA, the Federal Aviation Administration (FAA), and the National Transportation Safety Board (NTSB). It is not surprising that these organizations offer weather-related training materials to the GA community through their web sites and live events in an effort to improve pilot weather knowledge and inform safe weather-related aeronautical decision-making.

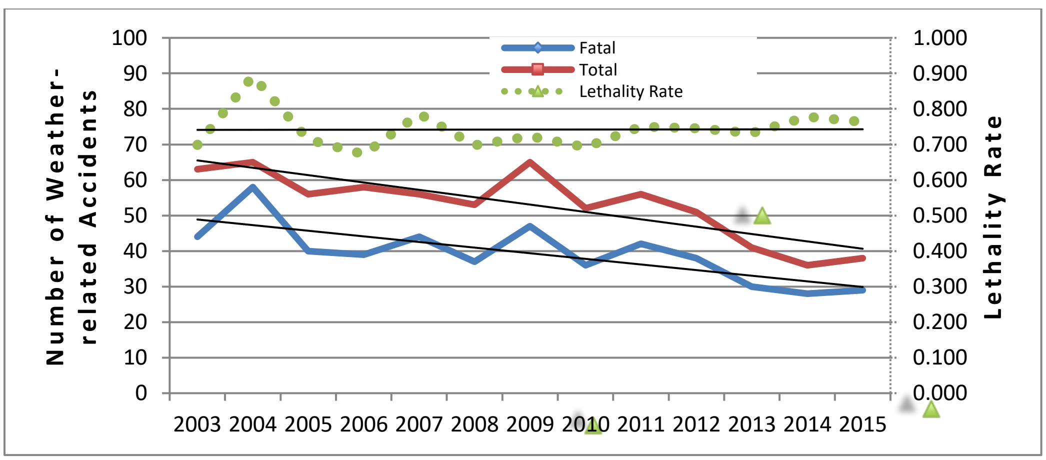

Figure 1. Total numbers of GA weather-related accidents (red curve), fatal weather-related accidents (blue curve), and lethality rate (green curve plotted against right-hand y axis). Linear trend lines for all three curves are shown by thin black line (data derived from Figure 13 in AOPA, 2018 and earlier Nall report data).

[1] The 1997 Nall Report (AOPA, 1997) referred to the "fatal to total accident ratio" in their discussion of weather-related fatalities on p. 7 and put it in terms of a percentage. This is what we refer to as the *lethality rate*.

General Aviation pilots are a very specialized user group of weather product consumers, and the FAA requires various types of weather education and training, and an acceptable level of proficiency on knowledge and practical exams.[2] However, because the GA community is so diverse in terms of demographics, flying activities, experience, and multiple other factors (see, for example, the U.S. Civil Airmen Statistics, available from), it stands to reason that GA pilot weather knowledge can be quite variable (e.g., Burian, 2002). Additionally, when one considers the explosion of aviation-weather related apps for smart phones and tablets over the last 5-10 years, it is not unreasonable to assume that every pilot who uses one of these applications understands all its functionality and its limitations. So, despite revolutionary technological advances in product dissemination, which include the aforementioned apps and near real-time data delivery to the cockpit via satellite-subscription services, the weather-accident lethality rate remains problematic. Additionally, Visual Flight Rules flight into Instrument Meteorological Conditions (VFR into IMC) continues to be the major cause of fatal weather-related accidents,[3] suggesting that GA pilots have unprecedented access to myriad weather data and products, they may not be getting effective training on how to use them.

Basic Research Questions

The research team for this study came together as part of a major FAA-funded research program on Weather Technology In the Cockpit (WTIC). The team consisted of two aviation meteorologists, a certificated flight instructor with a meteorological background (who recently completed a Ph.D. in Aviation program), a human factors psychologist, and two human factors

[2] While there is not a single reference document that lists all required knowledge, the Pilot Handbook of Aeronautical Knowledge (PHAK) (FAA, 2016a) contains dedicated chapters on weather theory and aviation weather services.
[3] A survey of AOPA Nall Reports from 2010-2016 shows that VFR into IMC accounted for 66.3% of fatal weather accidents (reports available from https://www.aopa.org/training-and-safety/air-safety-institute/accident-analysis/joseph-t-nall-report).

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doctoral students. Early in the WTIC study, several of the authors began studying the GA pilot weather education and training process, and the research was mainly focused around two fundamental questions:

1) Are pilots being asked the right types of weather questions on general knowledge exams?
2) Is the weather content available to pilots preparing for their exams adequate and organized?

As we will show later, the answers to these questions pointed to the need for the GA weather taxonomy that was eventually built.

Weather Questions on the General Knowledge Exams

To begin addressing the first research question, in 2011 we obtained access to 649 weather-related test-bank questions that could be used on FAA Private, Instrument, Commercial, and Air Transport general knowledge exams, and categorized them using the cognitive levels defined in the FAA's Aviation Instructor's Handbook (FAA, 2008). To summarize, the handbook defines four cognitive levels (in increasing order of difficulty):

1) Rote – "The ability to repeat something back which was learned, but not understood"
2) Understanding – "To comprehend or grasp the nature or meaning of something"
3) Application – "The act of putting something to use that has been learned and understood"
4) Correlation – "Associating what has been learned, understood, and applied with previous or subsequent learning" (FAA, 2008; Figure 2-10)

The results of our categorization showed that nearly 88% of the questions were at either the rote or understanding levels. This result was consistent with the study of Wiegmann, Talleur, and

Johnson (2008), who found that most weather-related questions available for the Private-pilot written exam were at the rote cognition level with no scenario-based questions, even though the scenario-based technique was used in other parts of the exam relating to weight and balance and cross-country planning. These results also reflected issues related to weather questions on the general knowledge exam that had been identified nearly 20 years earlier. The National Research Council (NRC) report Weather for Those Who Fly (NRC, 1994) and an NTSB report Risk Factors Associated with Weather-Related General Aviation Accidents (NTSB, 2005) had both found that it was possible to answer all aviation weather questions incorrectly on a written airman knowledge test but still pass it. Beyond this, the NTSB (2005) noted that during the required biennial flight review (BFR), "the instructor giving the flight review is free to determine the content; therefore, the BFR may or may not include a demonstration of the weather knowledge and instrument flight skills required for initial certification" (p. 9). Additionally, Burian and Feldman (2009) found that flight instructors typically spent only 10-12 hours on general weather education, and that most overestimated their own aviation weather knowledge. These results support our assertion that GA pilot weather knowledge is quite variable, which can be problematic when attempting to learn new technologies such as WTIC and weather-related apps for handheld devices.

Weather Knowledge Materials in FAA Advisory Circulars

To address the second research question, the team examined the available FAA advisory circulars (ACs) pertaining to weather, since basic knowledge exam materials would come from these publications. We categorized the AC materials into topic areas and noted the publication year to gauge the recency of the information within them. When the study began in 2011, the authors noted that the average age of the ACs was 15.1 years, with the oldest (Aviation Weather,

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AC-06A) published in 1975; today that number is 9.6 years. Table 1 details the currently available FAA weather-related ACs and the year they were published. Since our original survey of the ACs, the FAA has made a substantial effort to update their weather-related ACs, with five ACs having been revised in the last five years, while one was rescinded.

Table 1

Weather-Related FAA Advisory Circulars, Year Published, and Publication "Age"

AC Number	Title	Year Published	Years Since Publication
00-24C	Thunderstorms	2013	6
00-54	Pilot Windshear Guide	1988	31
00-57	Hazardous Mountain Winds and their Visual Indicators	1997	22
00-62	Internet Communications of Aviation Weather and NOTAMS	2002	Canceled in 2013
00-63A	Use of Cockpit Displays and Digital Weather and Aeronautical Information	2014	5
91-74B	Pilot Guide: Flight in Icing Conditions	2015	4
00-30C	Clear Air Turbulence Avoidance	2016	3
00-6B	Aviation Weather	2016	3
00-45H	Aviation Weather Services	2016	3

As the team began to examine the AC documents, we determined the analysis should be done within the context of ultimately being able to employ WTIC products correctly for safe, weather-related aeronautical decision-making. As a result, the team developed three main "domains" of aviation meteorological knowledge towards this goal:

1) *Weather phenomena* (i.e., basic concepts/theory, including that associated with hazards), to the extent that GA pilots use that knowledge to make best use of WTIC products. Weather phenomena include, but are not limited to, topics pertaining to basic

meteorological concepts such as cloud/precipitation formation processes and types, characteristics of fronts, cyclones and anticyclones, and knowledge of the polar and subtropical jet streams. This category also includes the physical effects of various atmospheric phenomena on flight, which is the introduction to weather hazards.

2) *Weather hazard products*, to the extent that GA pilots are educated and trained on those that are most appropriate for in-cockpit usage. Weather hazard products include text-based and graphical products generated by FAA-approved sources which are disseminated and available to airmen to use for flight planning. Examples of these include Meteorological Reports (METARs), Terminal Aerodrome Forecasts (TAFs), Surface Analysis and Weather Depiction charts, Airmen's Meteorological Information (AIRMETs), Significant Meteorological Information (SIGMETs), etc.

3) *Weather hazard product sources and their applications*, which are not the same as '2' because different vendors can offer different versions of a product and there is no guarantee of uniformity and standardization among different vendors. Weather hazard product sources refer specifically to the classification of official product sources as highlighted in AC 00-45-H (FAA, 2016b). This category becomes important when discussing meteorological product sources and issues associated with standardization of product displays such as "graphical METARs" and radar charts. A number of vendors present meteorological information in their products using different types of symbology or color schemes, which can be a source of confusion for users who fly in aircraft that may be equipped with different types of weather-in-the-cockpit systems (Atmospheric Technology Services Company [ATSC], 2010).

We will elaborate on these categories when we present the taxonomy.

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Organization of Relevant Materials and Pilot Ability to "Connect the Dots"

Upon completion of our examination of weather-related ACs, the team returned to the test-bank questions and classified them by the three broad topical categories defined above. The results are shown in Table 2. Not surprisingly, we found that the clear majority of the questions (about 94%) were related to phenomena and hazard products compared to product sources. Of the 37 questions about product sources, none were at the application and correlation levels of learning. These results are disturbing in the sense of required pilot weather knowledge, but also in the lack of attention being given to product sources and their *application*, which are extremely pertinent to the safe and proper use of WTIC products in flight.

Table 2

Total Number of Weather-Related Test-Bank Questions by Topical Category and Cognitive Level

Category / Cognition Level	**Rote**	**Understanding**	**Application**	**Correlation**	**Total**
Weather Phenomena	65	227	42	19	**353**
Weather Hazard Products	94	146	17	2	**259**
Weather Hazard Product Sources	34	3	0	0	**37**
Total	**193**	**376**	**59**	**21**	**649**

In our examination of test-bank questions and official guidance documents, we found little information that allowed pilots to "connect the dots" between the three categories, which is an essential skill for making safe weather-related aeronautical decisions. However, this finding was not new. The NRC (1994) found a poor connection between weather phenomena discussed in then-AC 00-6A (FAA & NWS, 1975) and the hazard products described in then-AC 00-45C (FAA & NWS, 1985). There are two main reasons for this problem. The first reason is the age span of the publications, which has already been discussed. Secondly, and perhaps most importantly, the organization of the ACs totally logical from a meteorological topic point-of-view. For example, turbulence and wind shear are related phenomena, but they have separate ACs describing them. On the flip side, the number one cause of fatal GA weather-related accidents (VFR into IMC) has no AC on it. While the FAA has made a commendable effort to connect basic phenomena in AC 00-6B with hazards and hazard products in AC 00-45H by revising both documents nearly simultaneously, both publications are very large (544 pages combined) and thus challenging to navigate for weather-knowledge study without some type of overarching guidance template. Additionally, AC 00-45H also contains information about product sources (mainly in the first several chapters). There is a need for some type of overarching guidance template for navigating the large amount of material in this and the other weather-related ACs.

When we progress to the Weather Hazard Product Sources and their Application category (the one most relevant to WTIC), we find that AC 00-63A (FAA, 2014) has been published to reflect the changes taking place because of the Next Generation Air Transportation System's implementation of Flight Information Services (FIS) through Automatic Dependent Surveillance-Broadcast (ADS-B). These services consist of those available through the Universal Access Transceiver (UAT), known as FIS–Broadcast (FIS-B), as well as non-FAA FIS systems available through commercial providers. The publication of AC 00-63A was important because its predecessor publication was short and contained limited guidance on data-linked products (including weather) and their proper usage during flight. We also note here the cancellation of AC 00-62, Internet Communications of Aviation Weather and NOTAMS, in 2013. According to the cancellation memo, "This AC is no longer required or maintained. FAA Flight Standards Service (AFS) no longer requires operators to utilize vendors that are approved

Qualified Internet Communications Providers." (FAA, 2013). The rapid change of the commercial market in terms of new products and vendors made the upkeep of such a document nearly impossible.

Despite the above-mentioned documentation updates, we assert that there exists a conceptual "disconnect" between the guidance for Weather Phenomena and Weather Hazard Products. For instance, there are no scenario-based examples that show how knowledge obtained at the phenomena level translates into understanding of hazard products and how they should be employed in planning and execution. Instead, there is ample evidence for a poor understanding of WTIC product sources and their correct and safe *application* in-flight, despite the warnings given in AC 00-63A about the inappropriate use of data-link weather products for tactical avoidance of severe weather. For instance, Latorella and Chamberlain (2004) found that pilots neglected to account for data latencies in real-time weather products such as Next Generation Weather Radar (NEXRAD). In a convective weather situation, such negligence can cause pilots to violate minimum recommended distances from thunderstorms by using NEXRAD as a tactical decision-making tool (Latorella & Chamberlain, 2002, 2004). Beringer and Ball (2004) found similar problems in a study that used simulated weather displays at various resolutions to examine inflight pilot decision-making. Their results showed that pilots who viewed higher resolution weather display actually flew *closer* to simulated convective cells than those using lower resolution displays, violating the minimum distance recommended by the Aeronautical Information Manual (AIM) (FAA, 2019). The consequences of these actions can be deadly, as pointed out by the NTSB in their Safety Alert regarding in-cockpit NEXRAD mosaic imagery (NTSB, 2012). In fact, identifying and communicating hazardous weather in

GA made the NTSB's Most Wanted List in 2014 (see https://www.ntsb.gov/safety/mwl/Pages /mwl7_2014.aspx).

At this point in the study (around 2015-2016), our literature-based research came to the following conclusions:

1) Pilots are being asked weather questions on general knowledge exams that are focused too much at lower cognitive levels and almost solely on weather phenomena and hazard products, and not enough on applying knowledge to hypothetical situations that may be encountered in flight.

2) The weather content available to pilots preparing for their exams is difficult to navigate and should be organized by phenomena, hazard products, and hazard product sources and their application.

To assess the feasibility of making changes to the education and training process, the research team believed it was necessary to develop a taxonomy for pilot weather education and training, which is outlined in the next section. Rather than arbitrarily picking topics from the three knowledge categories, the team took an integrative approach to developing the taxonomy, building upon the results of previous GA pilot education and training studies pertaining to WTIC.

A Weather Taxonomy for Use in GA Pilot Education and Training

The three categories presented above imply a building-block approach to learning about weather, its hazards, the products intended to mitigate the hazards and their proper usage in flight planning and execution. During the evolution of the team's research, concerns raised about the types of questions that should be asked on knowledge exams were reflected by sentiments such as "We don't need to teach them to be meteorologists," referring to worries about just how much weather phenomena knowledge is needed by pilots compared to knowledge about hazards products, sources, and their application. In the end, it was the combination of these issues that pointed to the need for developing a taxonomy that defined terms so that pilots and meteorologists would be on the same page.

A useful definition of *taxonomy* is provided by Hlava (2012):

> A taxonomy is a ‘knowledge organization system,’ a set of words that have been organized to control the use of terms used in a subject field into a ‘vocabulary’ to facilitate the storing and retrieving of items from a repository.

Taxonomies are useful for communities with practitioners from different backgrounds. For example, the Department of Defense’s Modeling, Simulation and Analysis (MS&A) community has an extensive taxonomy that has been continuously evolving for 30 years (e.g., see the MS&A taxonomy discussion in Gustavson, Daehler-Wilking, Blais, & Rutherford, 2011).

Given the unique pilot weather education and training needs, the taxonomy also needed to be flexible enough to account for the means by which the pilot acquires his/her knowledge. This includes both the traditional academic as well as the experiential components. The taxonomy could not simply be a hierarchical list of topics but needed to account for the use of certain unique tools such as simulation and instructor-guided flight training that are part of the pilot’s training experience. Figure 2 shows the taxonomy with its three tiers along with a qualitative estimate of how the knowledge should be obtained. We believe that as one moves from tiers 1 to 2 and on to 3, the topics become more applied, and as a result, the proportion of scenario/ simulation-based training should also change. Additionally, there is a need for traceability in learning-material development as one moves up the tiers. There are results from the literature that support this idea.

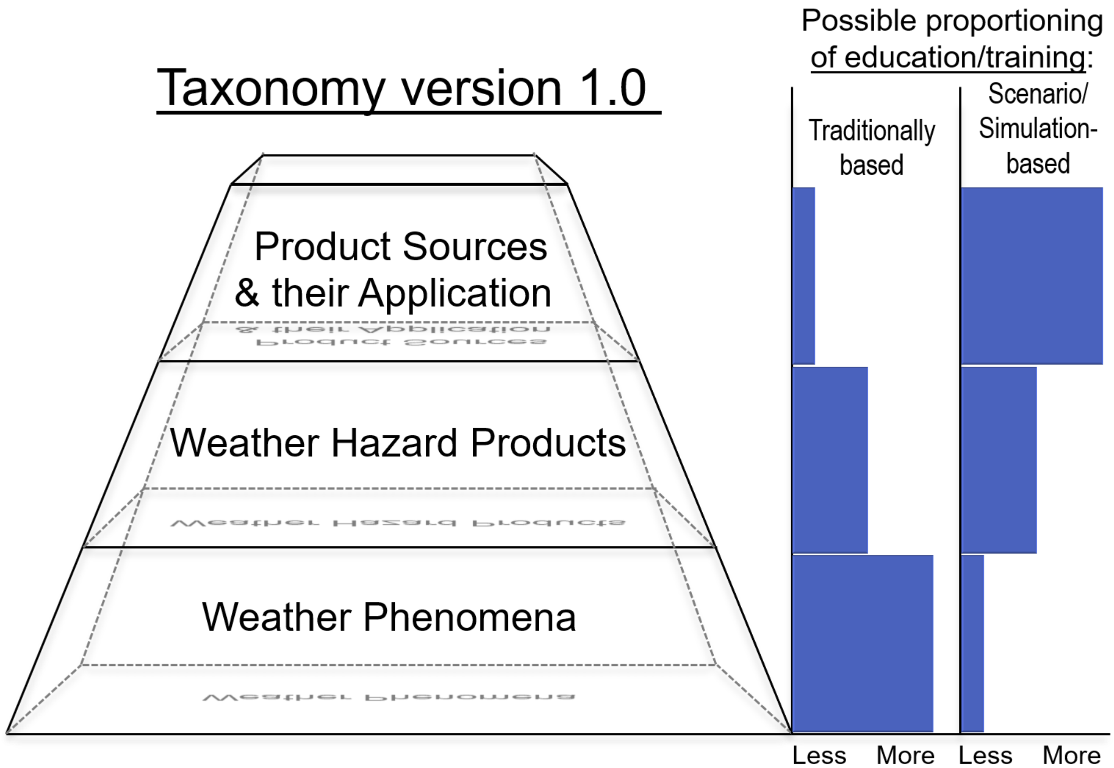

Figure 2. General Aviation pilot weather education and training taxonomy as shown in a building-block approach. Tapering of diagram indicates relative volume of material as one moves up the tiers, while diagram to right suggests proportionality of delivery methods (figure adapted from Lanicci et al., 2017).

The idea of traceability as one moves up the tiering structure is supported by earlier work from Cobbett, Blickensderfer, and Lanicci (2014). Their study developed an education and training module on the use of real-time, in-cockpit NEXRAD products to make informed aeronautical decisions pertaining to convective weather in flight. The module, taught to student pilot subjects in a multi-hour course, included radar basics, the basics of thunderstorms, functions and limitations of NEXRAD, and contained scenarios on its proper use in flight. The instruction included both lecture- and scenario-based elements. The results of the training were evaluated by means of pre- and post-tests that evaluated the students on both basic knowledge and scenario-based materials. The study also included a control group that did not receive the training, for statistical comparison purposes. Results showed that the student pilots receiving the training had statistically significantly higher scores than their control group peers and improved their mean scores on radar knowledge by 14 points on a basic knowledge posttest and 13 points on a scenario-based posttest after receiving the training. These improvements were replicated when the NEXRAD education and training module was taken on the road to three different parts of the country and given to groups of GA pilots with greater ages and experience levels (Blickensderfer et al., 2015).

Table 3 shows a breakdown of each taxonomy tier by sub-tier, and the number of topics contained within each. An example of the challenges associated with developing the taxonomy was the question of how many official weather hazard products should be included in sub-tier 2000, Knowledge of Official Weather Hazard Products. One approach would be to include only products pertaining to specific hazards such as turbulence (e.g., graphic turbulence guidance, AIRMETs) without including upper-level wind analyses from which the location and orientation of the polar jet stream could be determined. We chose to include both types of charts, which inflates the number of topics to 27, the greatest number among any of the three tiers. It should also be pointed out that at any given point in time, the number of topics can change, as new products are introduced and others are eliminated (e.g., King et al., 2017). This would be most noticeable in the third tier, where with the rescission of AC 00-62, sub-tier 3000 could be difficult to determine since there is no longer a list of FAA-approved Qualified Internet Communications Providers. However, we believe that this sub-tier, along with 3100 and 3200, should be continued as a means to continue to determine which apps and product sources are reliable in terms of criteria such as usability, documentation, and reliability.

Table 3

Taxonomy Version 1.0 (Top Level View)

Tier	Weather Phenomena	Number of Topics
1000	Basic meteorological knowledge	14
1100	Knowledge of how meteorological phenomena affect flight performance	14
1200	Knowledge of aviation meteorological hazards	8
	Total	**36**
Tier	**Weather Hazard Products**	**Number of Topics**
2000	Knowledge of official weather hazard products	27*
2100	Analysis and interpretation of different hazard products	8
	Total	**35**
Tier	**Weather Hazard Product Sources and Application**	**Number of Topics**
3000	Knowledge of approved product sources	7
3100	Knowledge of differences between vendor products	1
3200	Knowledge of how/when to use different product sources during different flight phases	5
	Total	**13**

* Includes aviation-weather-specific and general meteorological products.

Table 4 shows a detailed breakdown of sub-tier 1200 into individual topics. Note that the categorization of individual topics has some degree of subjectivity, as illustrated by our inclusion of topic 1203-b, Best Course of Action for Exiting VA (Volcanic Ash) Cloud, under the hazard tier instead of the product source tier. Another example would be our inclusion of topic 1205, Lightning, separately versus placing it under topic 1204, Thunderstorms. The rationale in the lightning example is that triggered lightning may not necessarily occur within an active thunderstorm, although it is likely to appear in an environment with convective clouds. For those wishing to use this taxonomy, modifications may certainly be necessary based on individual user needs. This is simply our best determination based on collective expertise and experience.

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Table 4

Taxonomy Version 1.0 (Detailed View of 1200-Level Topics)

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
1204-b	Downbursts and microbursts
1205	Lightning
1206	Icing
1206-a	Induction versus structural icing
1206-b	Definition of light, moderate, severe icing
1206-c	Impact of super-cooled 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

Potential Applications of the Taxonomy

Presently, Taxonomy V1.0 resides in a Microsoft Excel® spreadsheet with 236 entries, including the tier, sub-tier, and topic headers (Lanicci et al., 2020; spreadsheet available upon request to the lead author). Part of the rationale for this article is to introduce it to the community to obtain feedback as well as explore potential uses for it. A mechanism has been created via the Dropbox™ program to share the spreadsheet with interested users. We believe that there are several potential uses for the taxonomy in its current configuration. These are briefly described below.

Taxonomy V1.0 can be used to examine FAA pilot weather guidance documents, such as the PHAK and the AIM, to determine the proportionality of topics across the three tiers. Specifically, chapters 12 and 13 of the PHAK and sections 1-3 of chapter 7 in the AIM could be analyzed for this purpose. A distribution could be created which can inform us about the proportionality of topics contained within these very important guidance documents among the three tiers.

Taxonomy V1.0 can be used to develop traceable pilot education and training protocols for particularly challenging aviation weather problems, such as VFR into IMC. This problem has received a great deal of attention from a number of several researchers (for example, see the literature review in Keller, Carney, Xie, Major, & Price, 2017). There has also been interest in testing different types of simulation tools for determining their efficacy in helping pilots detect the danger and react to it faster (e.g., Whitehurst, Brown, Rantz, Nicolai, & Bradley, 2019). Therefore, the taxonomy could be used in two ways: 1) to set a baseline for pilot knowledge (i.e., what pilots should know from each of the tiers); and 2) to develop and test protocols that examine both basic as well as practical (scenario-based) knowledge (linking the knowledge tiers).

Taxonomy V1.0 could be used to examine FAA weather training guidance for other parts of the aviation community such as air traffic controllers and flight dispatchers. As before, the taxonomy could help determine proportionality of topics across the three tiers and examine differences between the required knowledge categories between these two groups and between them and pilots. Such knowledge could be used to assess the efficiency of information exchange among these groups and identify and address any potential knowledge gaps. It may be necessary to modify the taxonomy depending on the appropriateness of the topics for these different user groups.

Lastly, Taxonomy V1.0 could be used by other university aviation programs to construct new or modify existing aviation meteorology courses. The taxonomy could be adapted by these programs based on the needs of the students and availability of facilities for simulation and flight training. While these are some suggested uses for the taxonomy, there are no firm plans at present to move forward with any of these at the time of this article's publication.

Conclusion

This article introduced a GA pilot weather taxonomy for organizing education and training materials. The taxonomy, developed as part of the FAA's WTIC research program, focuses on linking three main knowledge tiers (Weather Phenomena, Weather Hazard Products, and Weather Hazard Product Sources and their Application) with the intention of developing protocols that will ultimately lead to correct weather-related aeronautical decision-making in all phases of flight, from planning through execution. As technology advances at a continuing rapid pace, the taxonomy can provide a guiding template for organizing information so that the users of commercial weather products on hand-held applications have adequate background to use these technologies appropriately.

We acknowledge that the taxonomy in its current version has been influenced by our interdisciplinary WTIC research but also by our experiences developing, teaching, and evolving aviation meteorology courses at our home institution. Therefore, it is representative of our perspective and may not be totally translatable to the community in its present form. We recognize the need to share this product with the larger community. We recommend vetting Taxonomy V1.0 in the community to obtain feedback, suggestions, additions/subtractions, etc. We believe that the taxonomy provides a template and organizing construct to help us determine the most appropriate types of education and training for different constituencies in the GA community, from student pilots who are just learning, to those who have been flying for many years. While the taxonomy itself cannot solve all of GA's weather-related problems, we believe that it can help us better identify deficiencies in education and training and point us in the direction towards potential solutions.

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References

Aircraft Owners and Pilots Association (AOPA). (1997). *AOPA Air Safety Foundation 1997 Nall Report – Accident Trends and Factors from 1996*. Frederick, MD. Retrieved from https://www.aopa.org/-/media/Files/AOPA/Home/Training-and-Safety/Nall-Report/97nall.pdf

Aircraft Owners and Pilots Association (AOPA). (2018). *AOPA Air Safety Institute 27th Nall Report*. Frederick, MD. Retrieved from https://www.aopa.org/training-and-safety/air-safety-institute/accident-analysis/joseph-t-nall-report

Atmospheric Technology Services Company (ATSC). (2010). *Capabilities report: Weather technology in the cockpit program*. FAA20101031.1, FAA Weather Technology in the Cockpit, Contract DTFAWA-09-C-00088. Norman, OK.

Beringer, D., & Ball, J. (2004). *The effects of NEXRAD graphical data resolution and direct weather viewing on pilots' judgments of weather severity and their willingness to continue a flight.* DOT/FAA/AM-04/5, Office of Aerospace Medicine, Washington, DC. Retrieved from https://www.faa.gov/data_research/research/med_humanfacs /oamtechreports/2000s/media/0405.pdf

Blickensderfer, E. L., Lanicci, J. M., Vincent, M. J., Thomas, R. L., Smith, M., & Cruit, J. K. (2015). Training general aviation pilots for convective weather situations. *Aerospace Medicine and Human Performance, 86*(10), 881–888. https://doi.org/10.3357/AMHP.4174.2015

Burian, B. K. (2002). *General aviation pilot weather knowledge and training*. FAA Grant #00-G-020 Final Report. Retrieved from http://www.avhf.com/html/Library/Tech_Reports/CFI_Survey_Final_Report.pdf

Burian, B. K., & Feldman, J. (2009). Certified flight instructor weather training: Perspectives and practices. *The International Journal of Aviation Psychology, 19*(3), 217-234. https://doi.org/10.1080/10508410902983870

Cobbett, E. A., Blickensderfer, E. L., & Lanicci, J. (2014). Evaluating an education/training module to foster knowledge of cockpit weather technology. *Aviation, Space, and Environmental Medicine, 85*(10), 1019-25. https://doi.org/10.3357/ASEM.3770.2014

Federal Aviation Administration (FAA). (2008). *Aviation instructor's handbook*. FAA-H-8083-9A. Washington, DC. Retrieved from https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/aviation_instructors_handbook/media/faa-h-8083-9a.pdf

Federal Aviation Administration (FAA). (2013, July 2). *Memorandum entitled ACTION: Cancelation of Advisory Circular (AC) 00-62, Internet communications of aviation weather and NOTAMs.* Washington, DC. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/Cancellation_Memno_AC_00-62.pdf

Federal Aviation Administration (FAA). (2014). *Use of cockpit displays of digital weather and aeronautical information - including change 1 (Advisory Circular 00-63A)*. Washington, DC. Retrieved from https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1024126

Federal Aviation Administration (FAA). (2016a). *Pilot handbook of aeronautical knowledge (PHAK)*. FAA-H-8083-25B. Washington, DC. Retrieved from https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/pilot_handbook.pdf

Federal Aviation Administration (FAA). (2016b). *Aviation Weather Services (Advisory Circular 00-45H)*. Washington, DC. Retrieved from https://www.faa.gov/documentlibrary/media/advisory_circular/ac_00-45h.pdf

Federal Aviation Administration (FAA). (2019). *Aeronautical information manual (AIM)*. Washington, DC. Retrieved from https://www.faa.gov/air_traffic/publications/atpubs/aim_html/index.html

Federal Aviation Administration (FAA) & National Weather Service (NWS). (1975). *Aviation weather for pilots and flight operations personnel (Advisory Circular 00-6A)*. Washington, DC. Retrieved from https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22268

Federal Aviation Administration (FAA) & National Weather Service (NWS). (1985). *Aviation Weather Services: Advisory Circular 00-45C*. Washington, DC.

Gustavson, P., Daehler-Wilking, R., Blais, C., & Rutherford, H. (2011). M&S asset discovery: Services, tools, and metadata. *Proceedings of the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC), Orlando, FL.*

Hlava, M. (2012, March). *What is a taxonomy? Content, document, and knowledge management.* Retrieved from https://www.kmworld.com/Articles/Editorial/What-is-a-Taxonomy-81159.aspx

Keller, J. C., Carney, T., Xie, A., Major, W., & Price, M. (2017). VFR-into-IMC: An analysis of two training protocols on weather-related posttest scores. *Journal of Aviation Technology and Engineering, 7*(1). https://doi.org/10.7771/2159-6670.1150

King, J. M., Ortiz, Y., Guinn, T., Lanicci, J., Blickensderfer, B. L., Thomas, R., & DeFilipis, N. (2017). Assessing general aviation pilots' interpretation of weather products: Traditional and new automated generation products. *Proceedings of the Human Factors and Ergonomics Society 2017 Annual Meeting*. https://doi.org/10.1177/1541931213601489

Lanicci, J. M., Guinn, T., King, J. M., Blickensderfer, E. L., Thomas, R. L., & Ortiz, Y. (2017). A proposed weather taxonomy for general aviation pilot education and training. *18th Conference on Aviation, Range, and Aerospace Meteorology* (American Meteorological Society), Seattle, WA. Retrieved from https://ams.confex.com/ams/97Annual/webprogram/Paper315244.html

Lanicci, J. M., Guinn, T., King, J. M., Blickensderfer, E. L., Thomas, R. L., & Ortiz, Y. (2020). *Taxonomy_v1_(6-24-16)_w_1-28-2020_mod*. Available upon request to lead author.

Latorella, K. A., & Chamberlain, J. P. (2002). Tactical vs. strategic behavior: General aviation piloting in convective weather scenarios. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, 101-105. https://doi.org/10.1177/154193120204600121

Latorella, K. A., & Chamberlain, J. P. (2004). *Decision making in flight with different convective weather information sources: Preliminary results*. NASA Langley Research Center, Hampton, VA. Retrieved from https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040085999.pdf

National Research Council (NRC). (1994). *Toward a new National Weather Service: Weather for those who fly*. Report from National Weather Service Modernization Committee of the Commission on Engineering and Technical Systems. Washington, DC: National Academy Press.

National Transportation Safety Board (NTSB). (2005). *Risk Factors Associated with Weather-Related General Aviation Accidents (Safety Study NTSB/SS-05/01)*. Washington, DC. Retrieved from https://www.ntsb.gov/safety/safety-studies/Documents/SS0501.pdf

National Transportation Safety Board (NTSB). (2012). *NTSB Safety Alert: In-Cockpit NEXRAD mosaic imagery.* SA-017 June 2012, revised December 2015. Retrieved from https://www.ntsb.gov/safety/safety-alerts/Documents/SA_017.pdf

Whitehurst, G. R., Brown, L., Rantz, W. G., Nicolai, D., & Bradley, J. M. (2019). The effect of experiential education on pilots' VFR into IMC decision-making. *Journal of Aviation/Aerospace Education & Research, 28*(2). https://doi.org/10.15394/jaaer.2019.1793

Wiegmann, D. A., Talleur, D. A., & Johnson, C. M. (2008). *Redesigning weather-related training and testing of general aviation pilots: Applying traditional curriculum evaluation and advanced simulation-based methods.* Technical Report HFD-08 1/FAA-08-1.