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General Aviation Weather Encounter Case Studies

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16. Abstract

This study presents a compilation of 24 cases involving general aviation (GA) pilots' weather encounters over the continental U.S. The project team interviewed pilots who had experienced a weather encounter, and we examined their backgrounds, flight experience, and weather encounter details. Results from meteorological data analysis for each weather encounter were consistent with findings of larger GA weather accident studies in terms of the types of hazards encountered and flight phase during which the encounters occurred. Investigation of pilot weather products and the sources from which they were obtained revealed a lack of uniformity of pre-flight data sources and underutilization of available en route flight information services. The team used these results to develop a set of pilot weather education and training recommendations intended to reduce the number and severity of weather encounters.

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INTRODUCTION

Over the last 20 years, nearly 40,000 general aviation (GA) aircraft have been involved in accidents, of which roughly 20% involved fatalities (Shappell & Wiegmann, 2009). Notably, many of those fatal accidents involved encounters with adverse weather (Detwiler et al., 2006; NTSB, 2005; Wiegmann et al., 2005). According to the Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation (2005), about 70% of weather-induced accidents are fatal. Because GA aircraft tend to be smaller, slower, and flown at lower altitudes than transport-category aircraft, they are more vulnerable to hazards posed by the weather. Studies indicate that GA pilots may also be less likely to have access to good weather information (Burian, 2002; Knecht, 2008a, 2008b; Latorella, Lane, & Garland, 2002; Petty & Floyd, 2004). As a result of the differences between GA and transport aviation, weather-related GA accidents have attracted a great deal of attention from governmental agencies such as the National Transportation Safety Board (NTSB), the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and academic researchers.

Most research on weather-related GA accidents has focused on three key areas: 1) identifying the factors associated with weather-related accidents; 2) identifying the pilot decision-making processes that contribute to weather-related accidents; and 3) understanding how new technologies could contribute to improved pilot decision-making (NTSB, 1968, 1974, 2005, 2007; O'Hare & Smitheram, 1995; Wiegmann, Goh, & O'Hare, 2001). The present study focuses on the first two key areas outlined above by analyzing and compiling the results of 24 case studies of GA weather encounters over the continental U.S. The project team used a combination of pilot interviews and a detailed analysis of the atmospheric conditions during the time and location of each weather encounter using archived meteorological data from the National Climatic Data Center. A complementary paper (Shappell et al., 2010) describes the details of the study methodology (i.e., interview template and data compilation) and discusses pilot human factors for the weather encounters. This paper will discuss the methodology for collection and analysis of pertinent weather data for the set of weather encounters, the results of our case analyses, and development of a model for examining weather-related encounters that combines weather and pilot causal factors. We conclude with recommendations for GA pilot education and training on flight weather hazards, the best use of weather information products, and sources for those products.

METHODOLOGY

The study consists of two main parts: pilot interviews and analysis of the weather encounters for each interview case. In the first portion of the study, we interviewed 26 GA pilots who had experienced a weather-related deviation, requested flight assistance, made an emergency declaration, or had an incident over a 25-month period. The roughly one-hour interview was developed using surveys previously employed by NASA and the FAA (Knecht, 2008a, 2008b; NASA, 2007). The interview protocol examined each pilot's background and flight experience, and elicited details of the encounter such as pre-flight preparations (including sources and types of weather products used), weather hazard(s) experienced, and the actions taken by the pilot. Table 1 outlines a brief description of each section of the structured interview.

In the second portion of the study, we attempted to determine the atmospheric conditions during the time and location of each weather encounter. For each weather encounter described in the interview, we accessed archived meteorological data from the National Climatic Data Center (see http://www.ncdc.noaa.gov/oa/land.html#dandp for a link to the various collections of land-based archived data available). We collected relevant aviation routine weather reports (METARs), terminal aerodrome forecasts (TAFs), airmen's meteorological information (AIRMETs), significant meteorological information/advisories (SIGMETs), and appropriate precipitation reflectivity fields from the National Weather Service's Doppler Radar network (NEXRAD). The METARs and TAFs were collected for the departure, destination, and encounter/diversion times and locations in each case. The AIRMETs, SIGMETs, and radar data were collected along the routes and times of each flight and included the encounter times and locations in each case.

During the initial portion of the investigation, we focused our analysis on the METAR data for each case using the following protocol:

1. Examined the METAR available for the departure location/time.

2. Examined the closest METAR available at the location/time of the weather encounter.

Table 1. Structured Interview Outline.

Aircraft Demographics	Pilots were asked standard demographic questions such as what type of aircraft they were flying at the time of the weather encounter and whether they leased, partially, or fully owned the aircraft.
Pilot Demographics	In addition to traditional demographic questions such as education, profession, gender, and age, several items regarding piloting experience and training were asked of the pilots.
Event Information	Pilots were asked to describe their weather encounter in detail. Several additional demographic questions related to the flight were also asked to determine possible human causal factors for the encounter.
Preflight Planning	Of particular interest in this study was the method of preflight weather planning employed by the pilots. Toward these ends, pilots were asked to describe their normal method of preflight planning and whether it was different the day of the weather encounter.
Enroute decision-making	Because all participants encountered adverse weather, several questions were asked regarding their enroute decision-making, especially with regard to utilization of enroute flight services.

Table 2. Flight Phase When Weather Encountered.

Takeoff/Climb	Cruise	Descent/Maneuver	Approach/Landing
1	19	2	2

Table 3. Weather Hazards by Flight Phase.

	Takeoff/Climb	Cruise	Descent/Maneuver	Approach/Landing	Total Encounters
IMC	1	10	1	0	12
Icing	0	9	1	0	10
Non-convective Turbulence	0	1	0	0	1
Convective	0	2	0	2	4
MVFR	0	2	0	0	2

3. Examined the METAR available for the intended destination at the time of departure and the METAR at the actual destination/diversion location at the time of arrival.

Of the 24 cases[1] used in this study, 18 flights took off in visual meteorological conditions (VMC), five took off under marginal visual flight rules (MVFR), and one took off under instrument flight rules (IFR). When the 24 cases were stratified by phase of flight (Table 2), we saw that the majority of these encounters (19) took place during the cruise phase. So while METARs are most useful for examining the terminal weather at departure and destination/diversion locations, they have limited utility for those encounters that took place during the cruise and descent/maneuver phases of the flight. Initially, we collected and analyzed the METARs closest to the encounter time/location to give us a "proxy" for the conditions actually encountered by the pilot. However, using a METAR to represent conditions at cruise altitude (which varied tremendously between cases) violates the purpose of the METAR as an indicator of the weather conditions in the immediate vicinity of the aerodrome. This led us to collect additional data types, which we will describe shortly.

We also developed a distribution of the types of hazards the pilots experienced. In most cases, it was a single hazard, but five cases had multiple hazards. These are summarized by phase of flight in Table 3.

[1]Two cases were discarded because in one interview it came to light that the pilot never actually had a weather encounter (i.e., did not meet our research criteria); in a second case, there was insufficient information upon which to perform a detailed case analysis.

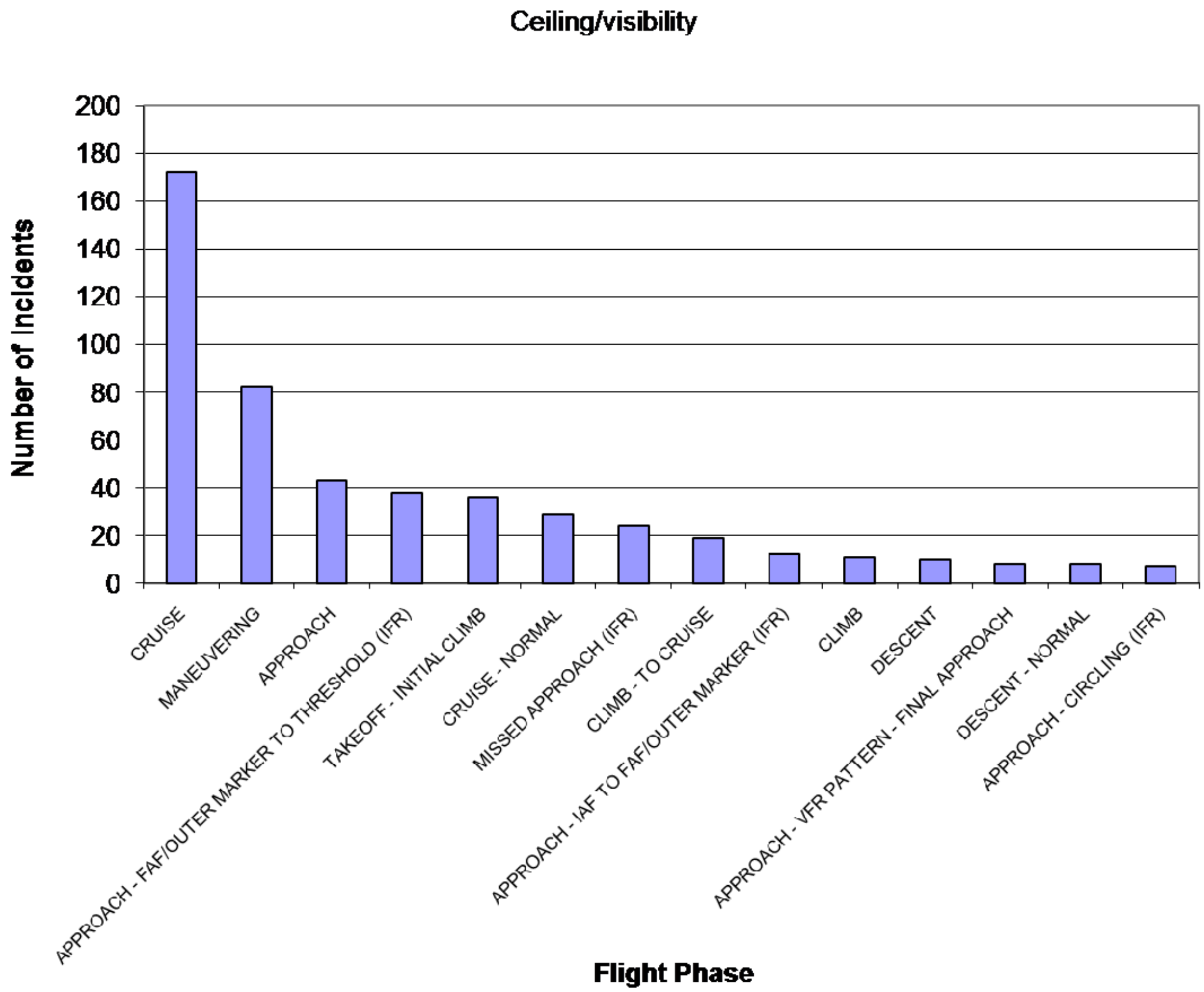


Figure 1. Ceiling/Visibility as causal weather factor stratified by flight phase.

Instrument meteorological conditions (IMC) and icing were the two most frequently encountered hazards by the pilots in our sample, and these occurred predominantly during the cruise phase. Notice that we included a category called MVFR in our dataset to account for two cases in which pilots encountered deteriorating visibility in the cruise phase, which was not technically IFR, yet caused them to make a divert decision. While the small sample size limits any significant statistical analysis, our results are consistent with those of previous studies (e.g., NTSB (2005), see p. 21 and their Figure 6).

The results are also consistent with a separate statistical analysis of GA accidents for the 2000-2006 period retrieved from the NTSB accident/incident database. This statistical analysis was conducted to uncover patterns related to GA weather-related accidents. The methodology was a data mining of the NTSB database and collected the various weather codes used as causal factors into broad categories such as ceiling/visibility, icing, turbulence, convective weather, and non-convective winds. Occurrence frequency statistics and graphs were developed from the accident data. Using this categorical approach, we found that incidents involving ceiling/visibility and icing as causal factors occurred most frequently during the cruise phase of flight (Figures 1 and 2). A Chi-Square statistical significance test applied to the ceiling/visibility and icing datasets indicates that for these weather factors, the number of accidents is not independent of the various phases of flight.

Based on the hazard and flight-phase analysis shown in Table 3, we began investigating additional types of weather information that could give us insights into the atmospheric conditions that occurred at the times and locations of the 24 interview cases.

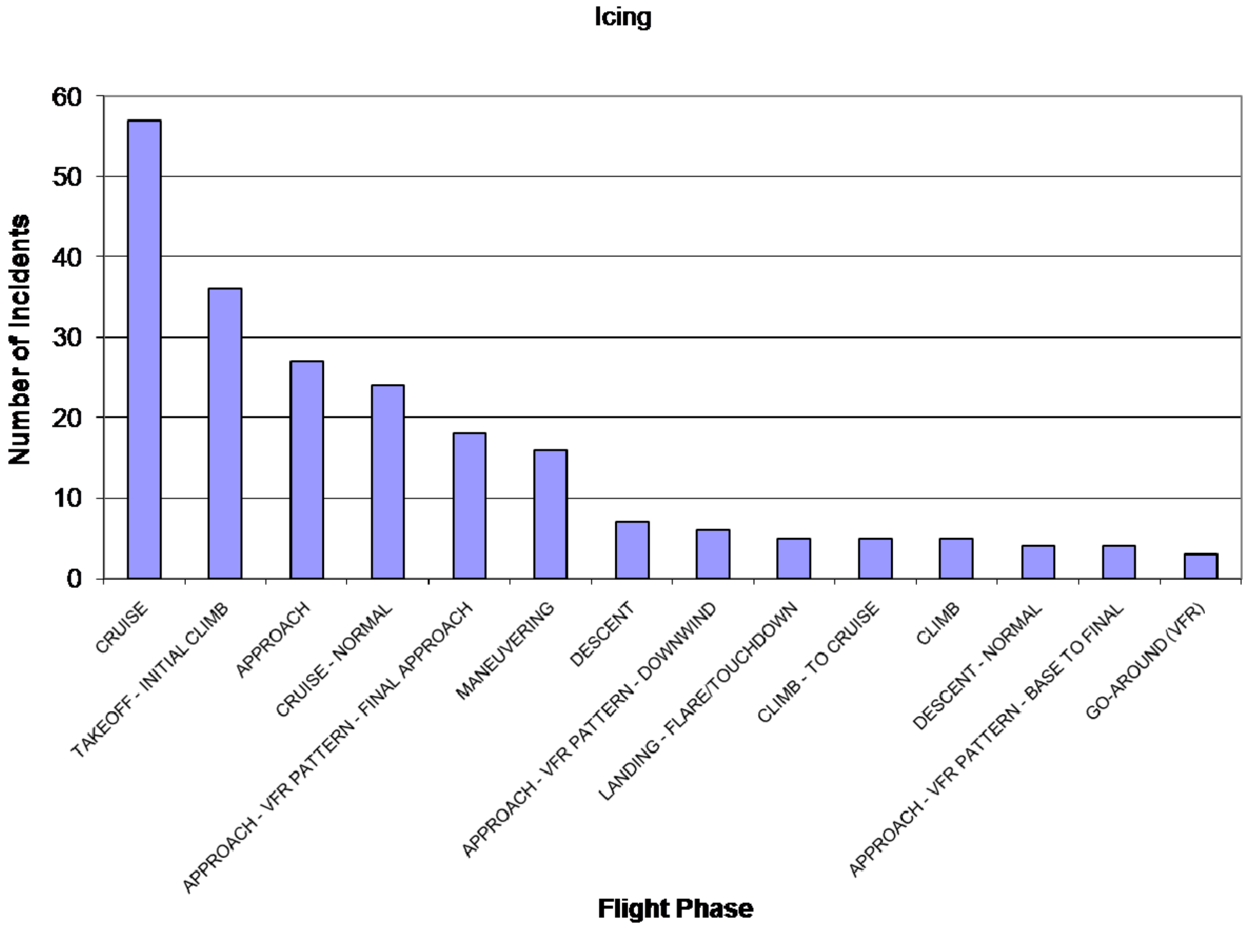


Figure 2. Icing as causal weather factor by flight phase.

We analyzed available AIRMETs and SIGMETs to determine if there were advisories in effect along the route and during the time of each flight.[2] For example, an AIRMET for either IFR or mountain obscuration (MTOS) could be used to infer a higher-than-normal likelihood that a pilot could encounter IMC on the route of flight, since AIRMETs are issued if over 50% of an area is expected to be affected at one time.[3] Additionally, we analyzed Level II NEXRAD base reflectivity data to determine if radar echoes were observed at the time and location of the encounter. These additional data sources serve two purposes: 1) corroboration of the atmospheric conditions along the route and at the time and place of the hazard encounter; and 2) knowledge about the weather information that was available before and during the flight (of which the pilot may or may not have been aware). The presence of radar echoes gives us a near real-time "picture" of conditions over the weather-encounter location. We employed base reflectivity (0.5 degree elevation angle) to account for precipitation occurring at relatively low altitudes, since many of these flights took place at altitudes lower than those of commercial aircraft. This method involves some subjectivity by the researchers, since the altitude of detected precipitation is a function of the distance from the radar, the radar does not sample 100% of a volume scanned, and we did not have exact flight levels and locations for every hazard encountered in the dataset. Despite these limitations, the radar data confirmed the presence of precipitation-producing clouds, implying regions of upward vertical motion (likely to have turbulence), and if air temperatures were between 0°C and -20°C, the potential for aircraft icing.

Once we had established the types of weather data to be collected for each encounter, the task was to determine how to utilize the data to reconstruct the conditions that each pilot experienced during flight. Our approach was to adapt an unpublished model proposed by M. Lenz for addressing weather-related incidents (personal communication, July 6, 2009). The model classified the weather encounter into the following categories:

[2]For icing and turbulence AIRMETs and SIGMETs that would have included pertinent flight levels, we did not make an attempt to verify whether the flight level of the encounter matched the appropriate AIRMET/SIGMET flight level, because we were more interested in the presence of the hazard in the vicinity and time of the encounter.

[3]See http://www.aviationweather.gov/exp/product_overlay/help/p-airmets.html for detailed AIRMET criteria.

Table 4. Weather Categorization for Each of the Flight Hazards Encountered in the 24 Interview Cases.

Hazard/# cases	Obs Network detected Y/N	Wx Product(s) accurate/ inaccurate/ non-existent	AIR/SIGMET issued for time/location	NEXRAD echoes at time/location
IMC - 12 cases	9 - Yes / 3 - No	9 / 0 / 3	9	6
Icing - 10 cases	9 - Yes / 1 - No	9 / 0 / 1	6	6
Non-convective Turbulence - 1 case	0 - Yes / 1 - No	0 / 0 / 1	0	1
Convective Wx - 4 cases (note 1)	4 - Yes / 0 - No	3 / 1 / 0	3	1
"MVFR" - 2 cases (note 2)	2 - Yes / 0 - No	2 / 0 / 0	1	0
Total: 29 cases (note 3)	24 - Yes / 5 - No	23 / 1 / 5	19	14

Note 1 -Two of the four convective weather cases also included turbulence, so these are characterized as Convectively Induced Turbulence

Note 2 – "MVFR" refers to cases where in-flight visibility dropped to within 3-5 miles, so technically not IMC

Note 3 – Total cases > # interview cases because some were multiple hazard encounters

1. Weather hazard was detected/undetected by the observational network
2. Weather hazard product was existent/non-existent
3. Existent weather hazard product was accurate/inaccurate (not applicable if hazard not detected)
4. Pilot obtained/did not obtain existent weather product

We employed all of the data collected to categorize the weather hazard encounter into one of the four categories listed above. These data included the METARs, TAFs, AIR/SIGMETs, NEXRAD echoes, and pilot reports (PIREPs) of the hazard. The following analysis outlines the results of our employment of the weather categories described above through construction of a weather encounter matrix for the 24 cases.

ANALYSIS

Based on the methodology above and the details of the 24 interviews, we produced summary matrix for each weather hazard (Table 4). The table describes whether the hazard was detected by the observational network; whether the hazard product was accurate, inaccurate, or non-existent; the number of cases for which an AIRMET/SIGMET had been issued during the time of and along the route of flight, up to and including the time of the encounter; and whether radar echoes were observed for the encounter time/location, as best as we were able to discern from the interview information. An implicit assumption in this analysis is that the presence of the hazard is indicated by the AIR/SIGMET, METAR/TAF (for those encounters in the non-cruise flight phase), and/or PIREP. While the NEXRAD data were important from the point of view of filling in missing information at the encounter time and location, we consider it to be a secondary product in as much as it is open to interpretation. We produced this matrix for IMC, icing, turbulence, convective weather, and MVFR, along with a discussion of each. Note that because several cases included multiple hazards encountered by the pilot, there are more total encounters than cases.

IMC Encounters

In nine of the 12 IMC encounters, the hazard was detected by the observational network. An AIRMET was in effect for the route/time of flight in nine of 12 cases, and there were radar echoes observed at the encounter location in six of the cases. For the three cases in which the hazard was classified as "not detected" by the observational network, it was the team's opinion that the official products did not capture the hazard, and while NEXRAD echoes were present in two of those cases, it would not have been sufficient for the pilot to realize the IMC hazard was present. Of the 12 IMC cases, five involved multiple hazards.

Icing Encounters

For nine of the 10 icing encounters, a hazard was detected by the observational network. An AIRMET was in effect in six cases, and radar echoes were present in six cases. Four of these cases were also IMC encounters. In the four cases where an AIRMET was not issued, icing PIREPs were reported in three. In the one case where the hazard was not detected, the only evidence the pilot would have had was from his data-linked NEXRAD; this case had AIRMETs out for MTOS, IFR, and moderate turbulence, but not icing.

Non-Convective Turbulence Encounter

Only one non-convective turbulence encounter was reported, and this case was also an IMC encounter. This case did not have an AIRMET along the route/time of flight, and although there were some NEXRAD echoes observed in the vicinity of location of the encounter, the team thought it insufficient to identify the hazard, so we classified it as "not detected" by the observational network.

Convective Weather Encounters

Four cases had a thunderstorm at the time and location of the encounter. Two of these cases also had turbulence, and two had both convective SIGMETs and radar echoes. Two of the convective weather cases were encounters that took place in the approach/landing phase of the flights and were cases in which the pilots landed at the same time that a thunderstorm reached the airfield. Our analysis of these four cases revealed that the hazard was detected in all of them, but in one case the latency of the real-time, data-linked NEXRAD data was an issue (hence the classification as "inaccurate product"). Two of the convective cases offer illustrative lessons about the use of real-time weather data on the flight deck and will be discussed in a later section.

MVFR Encounters

Two cases were encounters where the pilot experienced decreasing visibility that was tending towards IFR but had not yet reached that threshold. In one of these cases, there were both an IFR AIRMET and Convective SIGMET issued for the time and location of the encounter. In the second case, there were no advisories, but NEXRAD echoes were observed at the time and location of the encounter. We chose to classify this case as "hazard detected" and "product accurate" because of the NEXRAD evidence and the presence of cloud layers was predicted by a product known as an area forecast, which we will discuss in the next section.

DISCUSSION

Available Weather Information

As described earlier, one reason for examining data sources in addition to METARs and TAFs is to help compare the information the pilot possessed with the information available during the time of the encounter. The results of the interviews indicated that, in the majority of cases, more data products were available during flight preparation than what the pilot had actually obtained.

Regarding the weather information sources used, statistics gathered from the individual interviews (Figure 3) indicated that pilots regularly consulted the FAA Direct User Access Terminal System (DUATS, 54.5%), the National Weather Service (NWS, 72.7%), or a Flight Service Station (FSS, 77.3%) to obtain weather information during pre-flight planning.

The importance of obtaining updated weather conditions enroute is particularly important in convective weather situations, which develop rapidly and cause problems even if a pilot has access to real-time weather radar in the cockpit. Although the availability of NEXRAD data in the cockpit has the potential to improve a pilot's situational awareness, the user needs to be aware of its limitations (e.g., data latency as long as 7-8 minutes, and incomplete vertical scans, both of which could be critical in situations of rapid thunderstorm cell growth). In such cases, the availability of real-time weather radar data can produce a false sense of security (see, for example, the

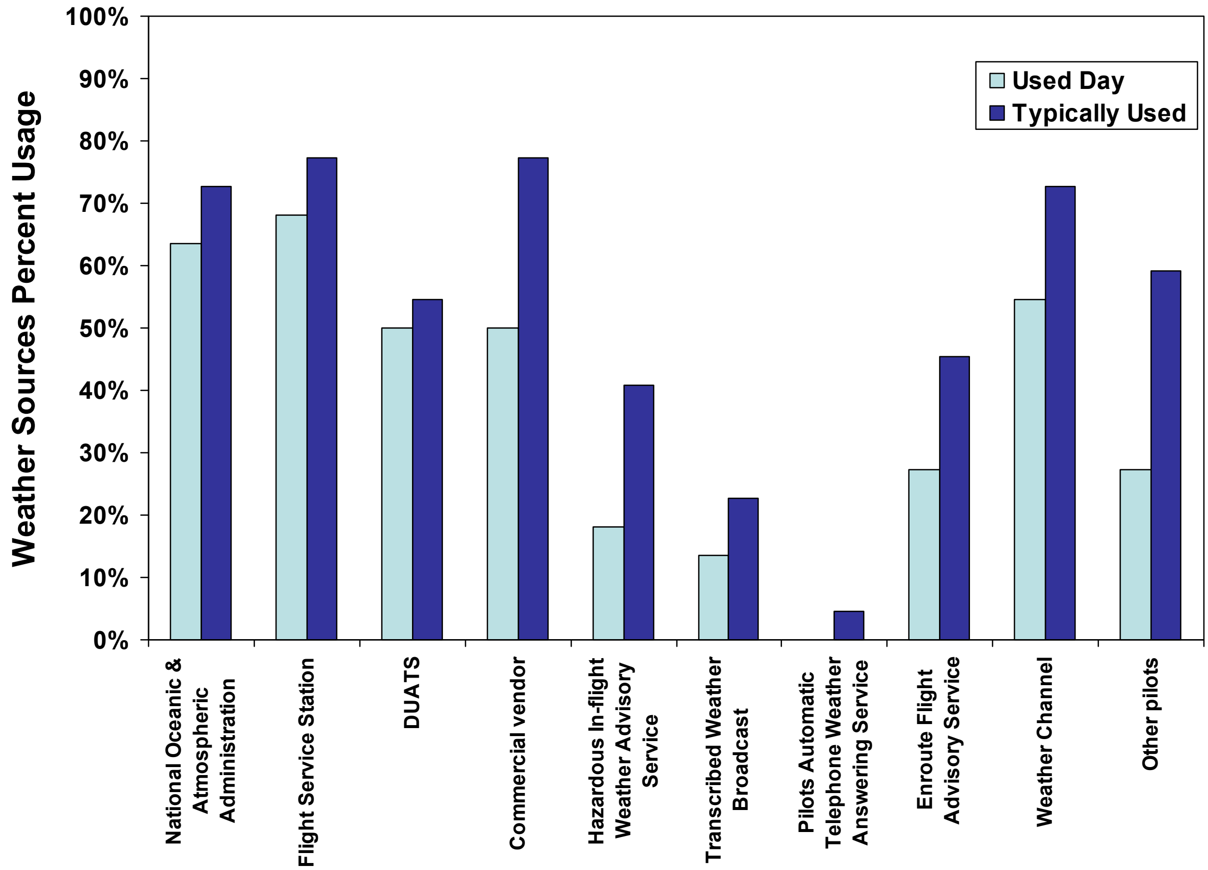
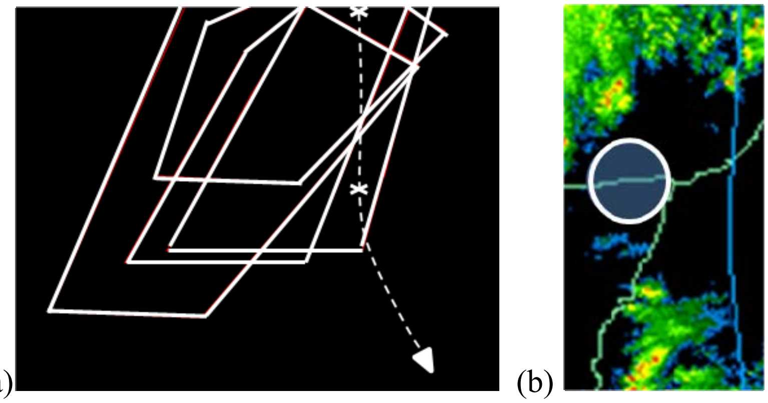
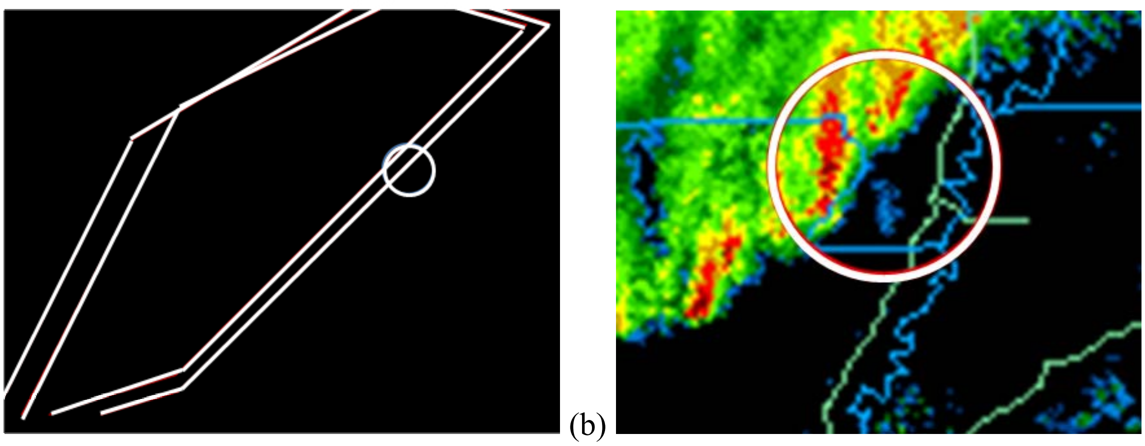


Figure 3. Weather provider sources used by interviewees on the day of encounter (light shading) and routinely (dark shading).



(a) (b)

Figure 4. Panel a: Convective SIGMETs issued for one of our convective encounter cases. Route of flight begins with white 'x' and is shown by white dashed line with arrow. Location of encounter was approximately halfway through the flight and is also indicated with a white 'x.' Panel b: Radar summary (composite reflectivity) for one of the four convective cases in our interview sample. Location of encounter is enclosed by white circle.



(a) (b)

Figure 5. Panel a: Convective SIGMETs issued. The encounter location (shown by white circle) is just outside the eastern SIGMET boundary. We counted this as a "SIGMET = No" case; however, there were AIRMETs issued for IFR and turbulence during this time and location (not shown). Panel b: "Zoom-in" of radar summary (composite reflectivity) with encounter location shown by white circle (note that the horizontal area encompassed by panel 'b' is much smaller than the area shown in panel 'a'). We counted this as a "Radar = Yes" case.

discussion in Beringer & Ball, 2004). Figures 4a and 4b illustrate the Convective SIGMETs and radar summary data from one of the four convective weather cases in our sample. An examination of Figure 4a shows that all four SIGMETs were in effect over a portion of the flight route, but only one was valid for the *actual location* of the weather encounter. That final SIGMET, which included the encounter location, was issued a mere 30 minutes after the time of the weather encounter. However, the radar summary shown in Figure 4b was classified as "Radar = No" because examination of the available data showed that the location of the encounter was very close but not covered by the radar. Another of the convective cases was similar, in that while there was not a Convective SIGMET covering the *exact area* of the encounter, the advisory's eastern boundary was particularly close to the encounter location, except this time there was extensive radar echo coverage in the vicinity (Figure 5). This pilot also had access to near real-time weather radar data in the cockpit but may not have known there was a Convective SIGMET so close to the area in which he was flying. Both of these cases illustrate the difficulties involved with making real-time decisions regarding convective weather avoidance while in flight.

As alluded to earlier, one additional type of aviation weather forecast product was added to the analysis late in the study, primarily to examine the IMC and MVFR cases in more detail. This product was the area forecast (product designator "FA"), a text-based discussion of current and predicted cloud cover, bases, tops, and ceiling/visibility across a geographic region. An example of an FA product is shown in Figure 6. We looked at this product because it includes information applicable to all phases of flight, since it describes cloud cover, bases, and tops. In four of the 12 IMC cases, the FA would have provided additional information to the pilot during pre-flight planning, although it is unknown if it would have prevented the encounter. In the one MVFR case, we believe it would have made a difference, in that it provided evidence of deteriorating conditions at cruise altitude. However, as seen in the example from Figure 6, this completely textual product is verbose and is not easily useable for enroute flight-deck application unless there is a two-pilot crew to minimize "head down" time. Even in a one-pilot configuration, the text product would still have to be read over the radio by a FSS specialist, which is not as efficient as a short glance at a graphical product.

The point of the preceding discussion is that there are additional data sources to be utilized throughout a flight. Additionally, one does not necessarily need real-time, data-linked weather radar data to have good situational awareness of the current and predicted weather. A good example of this last point came from another of our convective cases, in which the weather encounter occurred upon arrival at destination. Investigation of the weather for this case revealed that the destination TAF had been updated multiple times for thunderstorms during the course of the flight, each time with more refined information about the timing and potential wind gusts.

Although flight experience varied among the interviewees, the median for this group was 1,100 total hours (range was from 130 to 20,000). Additionally, all pilots had a basic pilot certification of Airplane Single Engine Land, and were medically certified to fly. Over half (60.0%) held a Class III (private pilot only) medical certificate, with the remaining pilots holding either a Class II (commercial, non-airline duties, and private pilot, 24.0%) or Class I (scheduled airline) medical certificate (16%). Additionally, most of the pilots (76.0%) were instrument rated.

Based on the results of our analyses, we found that the weather hazard had been detected by the observational network during the time of flight in 24 of the 29 hazards encountered. Of these 24, we could find only one case where the resulting weather hazard product could be considered "inaccurate" (due to NEXRAD data latency). If warning signs of potentially harmful weather were present, but the pilots did not expect to be negatively impacted, then

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FAUS42 KKCI 171845
FA2W
MIAC FA 171845
SYNOPSIS AND VFR CLDS/WX
SYNOPSIS VALID UNTIL 181300
CLDS/WX VALID UNTIL 180700...OTLK VALID 180700-181300
NC SC GA FL AND CSTL WTRS E OF 85W
.
SEE AIRMET SIERRA FOR IFR CONDS AND MTN OBSCN.
TS IMPLY SEV OR GTR TURB SEV ICE LLWS AND IFR CONDS.
NON MSL HGTS DENOTED BY AGL OR CIG.
.
SYNOPSIS...HI PRES RDG OVR SWRN VA-SERN NC BY 13Z OVR SERN VA-
CNTRL NC. QUASI STNR FNT XTRM SRN FL AND WTRS MOVG NWD AS WRMFNT
AND BY 13Z CSTL PNHDL-CNTRL PEN-SRN FL WTRS. BY 13Z CDFNT WL MOV
OVR WRN FL PNHDL WTRS.
.
NC
APLCNS...SCT120 BKN CI. 06Z SRN PTN BKN150 TOP FL250. OTLK...VFR
10Z XTRM SRN PTN MVFR CIG SHRASN.
PIEDMONT...SCT-BKN CI. 03Z SCT150 BKN CI. OTLK...VFR.
CSTL PLAINS...SCT CI. BECMG 0305 SCT150 BKN CI OCNL SCT100.
OTLK...VFR.
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Figure 6. Example of Area Forecast product from the National Weather Service's Aviation Weather Center (http://aviationweather.gov/products/fa/).

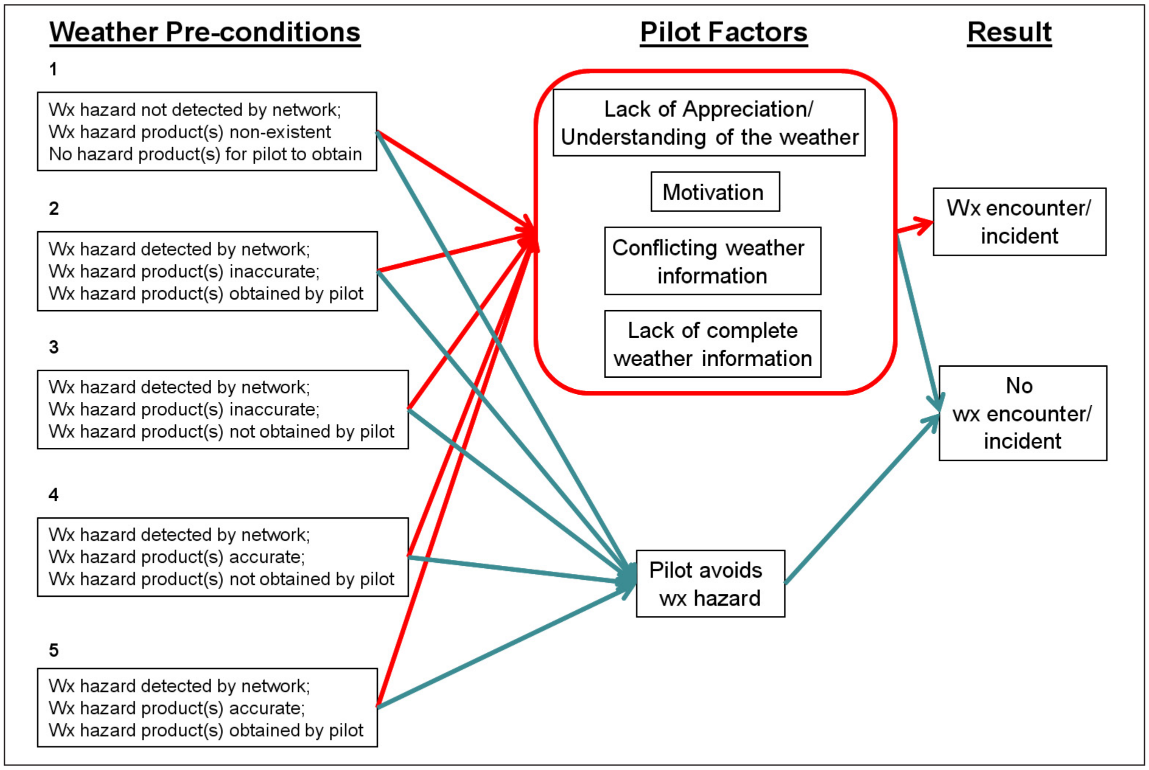

Figure 7. Encounter model developed from this study.

what caused this apparent disconnect? Perhaps the pilots either: 1) did not procure *all* of the appropriate weather information products during preflight preparation and therefore were not *completely* aware of the potential hazards, or 2) procured the appropriate weather information products but misinterpreted the data, leading them to believe that the weather would be less hazardous than it actually was.

To investigate this further, the team developed an integrated encounter model that examined the weather factors described in Table 4 and human causal factors (called Pilot Factors[4] in Figure 7). The model outlines five weather pre-conditions, four pilot factors, and two potential outcomes. Using this model, we first looked at whether the flight weather hazard was detected by the observational network. In this case, detection means that there is sufficient evidence of a flight weather hazard through METARs, TAFs, PIREPs, AIR/SIGMETs, Area Forecasts, and to a lesser degree, the NEXRAD data. Next, we determined if products were available that could capture the location, timing, and intensity of the weather hazard. An inaccurate weather hazard product underestimates severity and/or does not capture the timing or location of the hazard accurately. Just because the hazard is "detected" does not mean that an advisory product would have to be accurate. We then determined if the pilot avoided the weather hazard. A pilot could avoid a weather hazard if he/she knew the location of a hazardous airspace and successfully avoided it or was simply fortunate enough not to encounter it.

Technically, any of these five Weather Pre-conditions can eventually lead to either a weather encounter/incident or no incident, the latter being true if a pilot successfully avoids a weather hazard. The four Pilot Factors were then used to analyze the cause of the weather encounter/incident. It is technically possible for a pilot to experience one of the Pilot Factors and successfully avoid a weather hazard; this information would not be discoverable unless the pilot documented it somehow. In all of our 24 cases, the result was a weather encounter/incident due to one of these four Pilot Factors. The model in Figure 7 is meant to include all of the possible results that could exist.

[4]Shappell et al. (2010) described the process for classifying the 24 interview cases into one of the four pilot factors using a combination of the interview data and narrative summaries of the encounters (see their Discussion, pp.9-12).

Table 5. Weather and Pilot Factor Model Applied to this Study.

Hazard	**Weather Pre-conditions**		**Product Examples**		**Pilot Factors from Interviews**			
Hazard / # cases	Obs Network detected Y/N	Wx Product(s) accurate / inaccurate / non-existent	AIR/SIGMET issued for time / location of encounter	NEXRAD echoes at time / location of encounter	Lack of Apprec / Understand Wx	Motivation	Conflicting Wx Info	Lack of Complete Wx Info
IMC 12 cases	9 – Yes 3 – No	9 / 0 / 3	9	6	5	4	0	1
Icing 10 cases	9 – Yes 1 – No	9 / 0 / 1	6	6	6	1	1	0
Non-convect turbc 1 case	0 – Yes 1 – No	0 / 0 / 1	0	1	0	0	0	1
Convect Wx 4 cases (note 1)	4 – Yes 0 – No	3 / 1 / 0	3	1	4	0	0	0
MVFR 2 cases (note 2)	2 – Yes 0 – No	2 / 0 / 0	1	0	1	1	0	0
Total 29 cases (note 3)	**24 – Yes 5 – No**	**23 / 1 / 5**	**19**	**14**	**16**	**6**	**1**	**2**

Note 1: Two of the four convective cases included turbulence, so these are characterized as convectively induced turbulence
Note 2: "MVFR" refers to cases where in-flight visibility was reduced to 3-5 miles, so not technically IFR
Note 3: Total cases > # of interview cases because some were multiple-hazard encounters

Table 5 expands on the results presented in Table 4 by summarizing the results of our study using the encounter model described in Figure 7. Three important observations can be drawn from the table. First, in over 80% of the cases, the weather hazards were detected by the observational network. Second, in nearly 80% of the cases, aviation weather hazard products, whether AIR/SIGMETs, NEXRAD data, METARs, TAFs, or FAs, were available for the area and time of the encounter. Third, over half of the pilot factors were attributable to the pilot's lack of appreciation for the weather. The results of our analysis using the model suggest that, whatever the reason for the weather encounter, better education and training regarding proper awareness of weather hazards information and increased emphasis on availability and appropriate use of hazards products during different phases of flight may prevent the occurrence of similar weather incidents. This point is discussed in greater detail in the following section.

Weather Education and Training

The training requirements for weather hazards from Title 14 of the Code of Federal Regulations (CFR) part 61.105 states that private pilot applicants "must receive and log ground training from an authorized instructor or complete a home-study course on […] recognition of critical weather situations from the ground and in flight, windshear avoidance, and the procurement and use of aeronautical weather reports and forecasts" (FAA, 2005b). Visual Flight Rules-only pilots are also given some instrument flight training as a precaution, so they can "maintain control of an aircraft while making a course reversal or diversion if they inadvertently enter clouds" (NTSB, 2005). In addition, 14 CFR 61.65 states, "a person who applies for an instrument rating must have received and logged ground training from an authorized instructor or accomplished a home-study course on […] procurement and use of aviation weather reports and forecasts and the elements of forecasting weather trends based on that information and personal observation of weather conditions [and on] recognition of critical weather situations and windshear avoidance" (FAA, 2005a). According to the NTSB (2005), "for instrument-rated pilots, this training is meant to provide the additional knowledge and skills needed for safe flight in IMC."

A valid question to ask, then, is: How does one adequately educate and train a pilot applicant to ensure that the aforementioned requirements are met? There appears to be no standard for educating pilots on meteorology and training them on the proper use of weather products and reliable information sources. In fact, the only hazard specifically discussed in the regulations cited above is wind shear. Regulations require that ground training must be logged, or that a home-study course must be completed (FAA, 2005b), but there are no requirements for the amount of time to be spent on meteorology or what information should be covered. Both the Aeronautical Information Manual (AIM; FAA, 2008) and Aviation Weather Services (Aviation Circular AC 00-45G; FAA, 2010) include descriptions of useful products and sources of information. While both documents detail many of these products, there are no specifics on what is required to be taught. It is unclear whether pilots are sufficiently trained to interpret weather products or if they are taught just enough to pass an examination. Should the latter case be true, then it is possible that after the exam is passed, a pilot may rarely consult some or all of these weather products due to an incomplete understanding of their importance during initial training. Further, the NTSB (2005) pointed out that a pilot can theoretically get all aviation weather questions wrong on an airman knowledge test, yet still pass the exam. The NTSB also 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). Therefore, it is possible that after becoming certified, a pilot may not be required to demonstrate knowledge on some aviation-specific weather information products again.

Regarding weather products and en route sources used, all of the pilots in our study mentioned METARs and TAFs for both the departure and destination locations. However, only a fraction mentioned obtaining services for getting updated information in-flight (also, see Figure 2 in Shappell et al. 2010). It is possible that these pilots may not look at these products regularly, or may not be as familiar with them as they should be. Regardless, it is clear that pilots frequent a variety of sources to procure weather data, in part because "Part 91 regulations do not specify a particular source of weather information for GA pilots" (NTSB, 2005, pp. 11-12). The downside is that, without standardization of products and sources, it is possible that GA pilots may not be receiving the best data available.

CONCLUSIONS AND RECOMMENDATIONS

Although our 24-case study interviews constitute a small sample, we believe that these encounters have highlighted deficiencies in pilot education, training, and skills when confronting various weather conditions. Although we are unable to conduct rigorous statistical tests with the small interview sample size, the results of this study show that there is indeed room for improvement regarding preparation for weather encounters. As such, it is likely representative of deficiencies throughout the GA community. Additionally, the results from the interviews can be combined with those from the data-mining study (Figures 1 and 2) to determine which types of weather information are most critical to GA pilots during different phases of flight.

Another result from the interview portion of the study was the critical role played by air traffic control specialists (ATCSs) in the flight assists. It should be noted that the roles of controllers and management will evolve under the Next Generation Air Transportation System (NextGen), and the GA community needs to be prepared to deal with unexpected weather encounters in a system where ATC may be playing a much different role than they play today.

We suggest that weather education and product training be standardized and taught to pilot applicants. Below, we summarize our recommendations for the content of initial training so that all pilots can have a more thorough understanding of weather hazards before they leave the ground. An appreciation and understanding of these hazards are likely to lead to better pilot decision making and judgment. The summary includes steps that are already being implemented (i.e., maneuvers to take if weather is encountered), as well as steps that are not currently part of the standard procedure.

Summary recommendation: All pilot applicants should receive and log no less than a specified minimum number of hours of ground training focused solely on weather. An authorized instructor, not in-home study courses, should give this ground training. Our recommendations for the content of the training are listed below:

An introduction to in-flight weather hazards should be given, to include, but not be limited to: 1) IMC; 2) convective weather; 3) icing; 4) turbulence; and 5) wind shear. Pilots should be made aware of the significant impact that any of these hazards can have and be trained to avoid them at all costs.

The focus of the ground training should then shift to weather information products that should be consulted during preflight planning. All pilots should be familiar with, and be able to interpret, all of the products emphasized in a suitable publication (e.g., FAA Practical Test Standards; a list of those products is included in the Appendix). It is also recommended that during the BFR, the pilot must demonstrate proficiency in interpreting some of the products in the FAA Practical Test Standards that were emphasized during initial training and certification.

The pilot applicants should also be knowledgeable about accessing the appropriate aviation-specific weather information sources, to include en route services. It is suggested that pilots be introduced to the FAA DUATS and the Aviation Weather Center (http://www.aviationweather.gov) sources as a starting point.

These recommendations are consistent with the guidance stated in Aviation Weather Services (Aviation Circular AC 00-45G; FAA, 2010), section 1.3 and chapter 2.

As we look to the future with NextGen, the role of GA in this new operating environment needs to be considered. From the GA weather perspective, it may be time to explore the possibility of developing specialized GA weather products. Most current aviation weather products are geared towards commercial, high-altitude users. Has the time come to consider the development of an automated GA flight planning tool, perhaps patterned after the templates in the General Aviation Pilot's Guide to Preflight Weather Planning (FAA, 2006)? Is it possible to develop a standard template for GA users that is more sophisticated than current text-based weather products? With the advent of affordable, easy-to-use cockpit weather displays, the GA pilot already has routine access to real-time, sophisticated graphical weather analyses and forecasts on the flight deck. Education, training, and regulatory guidance will need to keep pace with this rapidly developing technology to ensure that it is used correctly and safely by the GA community.

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Appendix A – Sample Weather Products Lists

[Ref: FAA-S-8081-14A With Change 1, Private Pilot Practical Test Standards for Airplane (SEL, MEL, SES, MES), August 2002, Flight Standards Service, Washington, DC 20591]

C. TASK: WEATHER INFORMATION (ASEL and ASES)

REFERENCES: 14 CFR part 91; AC 00-6, AC 00-45, AC 61-23/FAA-H-8083-25, AC 61-84; AIM.

Objective. To determine that the applicant:

1. Exhibits knowledge of the elements related to weather information by analyzing weather reports, charts, and forecasts from various sources with emphasis on— *(product listing italicized by authors)*

a. METAR, TAF, and FA.
b. surface analysis chart.
c. radar summary chart.
d. winds and temperature aloft chart.
e. significant weather prognostic charts.
f. convective outlook chart.
g. AWOS, ASOS, and ATIS reports.

2. Makes a competent "go/no-go" decision based on available weather information.

(Ref: FAA-S-8081-4D, Instrument Rating Practical Test Standards for Airplane, Helicopter, Powered Lift, April 2004, Flight Standards Service, Washington, DC 20591)

I. AREA OF OPERATION: PREFLIGHT PREPARATION

A. TASK: WEATHER INFORMATION

REFERENCES: 14 CFR part 61; AC 00-6, AC 00-45; AIM.

NOTE: Where current weather reports, forecasts, or other pertinent information is not available, this information will be simulated by the examiner in a manner that will adequately measure the applicant's competence.

Objective. To determine that the applicant:

1. Exhibits adequate knowledge of the elements related to aviation weather information by obtaining, reading, and analyzing the applicable items, such as— *(product listing italicized by authors)*

weather reports and forecasts.
pilot and radar reports.
surface analysis charts.
radar summary charts.
significant weather prognostics.
winds and temperatures aloft.
freezing level charts.
stability charts.
severe weather outlook charts.
SIGMETs and AIRMETs.
ATIS reports.

2. Correctly analyzes the assembled weather information pertaining to the proposed route of flight and destination airport, and determines whether an alternate airport is required, and, if required, whether the selected alternate airport meets the regulatory requirement.
1-1 *FAA-S-8081-4D*