Industry Perspective of
Weather Technology in the Cockpit (WTIC) Program
Pilot Industry Survey

Tenny A. Lindholm
The National Center for Atmospheric Research (NCAR)
Research Applications Laboratory (RAL)
University Corporation for Atmospheric Research (UCAR)
Boulder CO 80301

This research is in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed are those of the author and do not necessarily represent the official policy or position of the FAA.

ABSTRACT

This paper presents the results of a Pilot Industry Survey that was developed and conducted by NCAR on behalf of the FAA's Weather Technology in the Cockpit (WTIC) Program Office. The primary goal of the survey was to identify weather information and capability gaps that still need to be addressed for the WTIC Program minimum weather service (MinWxSvc) recommendations for cockpit weather information. We present suggested future research for the WTIC Program as derived from survey results. We also solicit feedback on prioritizing these future research areas, and suggestions for other areas that the survey and subsequent analyses may have missed. The survey results also provide important feedback to weather forecasters and researchers relating to the needs and desires of the airborne flight crew. Pilots represented by the Air Line Pilots Association (ALPA), the National Business Aviation Association (NBAA), and other Part 121 airline groups participated in the survey.

1. Introduction

In 2013, The Federal Aviation Administration (FAA) Weather Technology in the Cockpit (WTIC) program conducted an industry perspective survey of airlines, aircraft manufacturers, weather suppliers and avionic manufacturers on exchanging meteorological information (METI) to / from the aircrew. Since then, a variety of FAA Next Generation (NextGen) enhancements and operational improvements have been incorporated into the national airspace system (NAS), and a number of WTIC program Minimum Weather Service (MinWxSvc) recommendations have been developed and transitioned into operations. The recommendations all relate to incremental improvements in these areas:

- Minimum cockpit meteorological information,
- Minimum performance standards and characteristics of the meteorological information,
- Rendering guidance for the meteorological information on cockpit displays, and
- Enhanced meteorological information and technology training.

This industry perspective research is intended to identify subsequent gaps in cockpit weather technology and information resulting from these changes since the previous study. In addition, this research will obtain feedback and assessments on MinWxSvc recommendations and training that have been developed and transitioned by the WTIC program. The results of this study will be used to scope future WTIC research and potentially develop metrics to assess the benefits of accomplished research.

This study focused on airline and business aviation pilots only. The survey was facilitated by the National Business Aviation Association (NBAA), the Allied Pilots Association (APA), the Southwest Airlines Pilots Association (SWAPA), Independent Pilots Association (IPA), and the Air Line Pilots Association (ALPA). It was administered by the National Center for Atmospheric Research (NCAR) on behalf of the FAA Weather Technology in the Cockpit

(WTIC) Program. Pilots were asked to answer survey questions from their perspective and try to separate their responses from any corporate and/or OPSPEC influences.

To maintain personal confidentiality, answers remained anonymous, and all information was de-identified in this report. All data and analyses were used in aggregate and not attributed to any individual or company. Company proprietary information that was provided was not reported. This information was only available to the FAA and survey team members, who will in turn protected it from disclosure outside the FAA WTIC Program Office.

2.0 Pilot Industry Survey Objectives

Objectives of the Pilot Industry Survey were to identify:

- Gaps, benefits, and impacts associated with weather information on electronic flight bags (EFB) in the cockpit. Identify any operational decisions that pilots are expected to make that are difficult due to a lack of cockpit information.
- Gaps, benefits, and impacts relative to on-route metering and received speed instructions/adjustments versus in-cockpit adverse weather and wind information that may be inconsistent with the on-route metering and speed instructions.
- Impacts of using and availability of Graphical Turbulence Guidance (GTG) and Eddy Dissipation Rate (EDR) for turbulence avoidance.
- Gaps, benefits, and impacts of route availability planning and consistency with cockpit weather information and pilot decision making. For improved departures, how do EFBs influence pilot requests?
- Consistency, impact, changes of flight management systems (FMS) use of wind information and its outputs versus time metering.
- Impact of outcomes from Take-off and Landing Performance Assessments (TALPA) and information (runway condition, braking performance, etc.) needed in the cockpit to make more informed takeoff and landings.
- Necessity for terminal and enroute icing information and any operational issues associated with a lack of that information at this time.
- Gaps, benefits, and impacts associated with weather information in the cockpit and its consistency with aircraft weather radar to make decisions.
- Gaps, benefits, and impacts associated with availability of the weather information when needed.

3.0 Survey Description and Process

The Pilot Industry Survey (Appendix A) used during this study was developed entirely from the above objectives. Questions that address each objective were created by a team of professionals from the following organizations:

- The FAA NextGen WTIC Program Office and technical staff in Washington DC.
- The FAA NextGen Weather Engineering and Evaluation Branch, William J. Hughes Technical Center (WJHTC).
- The Air Line Pilots Association (ALPA) technical staff and pilots.
- The National Business Aviation Association (NBAA) technical staff and pilots.
- The National Center for Atmospheric Research (NCAR) pilot subject matter experts and scientific staff.

The survey began with a section that collected demographic data on the respondents' flight duties and experience, including whether aircraft flown were equipped with accessible Internet on the flight deck. Information was also solicited on the basic capabilities of any available Electronic Flight Bag (EFB) function(s), whether permanently installed on the flight deck or portable devices such as an iPad or tablet computer. We were also interested in what types of weather applications were available for normal use on the flight deck during ground and inflight operations.

This type of information provided a baseline of what capabilities were already available to the pilot on the flight deck when assessing the information gaps that still exist. We anticipated that existing capabilities varied greatly between airlines, aircraft, and type of operation, and so it was important to establish current baselines when assessing gaps in weather information that impact operations.

The survey questions were ported to the Google Forms online tool for administering the survey to pilots. This tool offered the most flexibility for change and survey flow control during development. It also collected response data and offered options for organizing and graphically depicting results in several desired ways. Important to respondents was an ability to use portable devices as well as desktop and laptop computers as pilots are mobile and work in many different environments. The Google Forms tool allowed this, plus permitted total survey flow control to direct the respondents through the survey based on previous answers. All these capabilities minimized the time required by the pilot to complete the survey. We also reduced the number of typed responses as much as possible to make the survey easy to complete.

The Google Forms tool was password protected and completely secure, allowing us to maintain personal privacy and always protect company proprietary information during the administration of the survey and during subsequent analyses.

The entire survey is provided in Appendix A, keeping in mind that the flow of the survey is not apparent unless it is viewed online. Flow control online was automatic and did not require

the respondent to manually "go to" a particular question or section based on how he/she answered a question.

4.0 Survey Results

The following sections describe and analyze the results of both the multi-selection questions on the survey and those questions which required written responses. The first section summarizes pilot experience and operational environment. Then we baseline the equipage, capabilities, and weather information access relative to current weather information use during ground and inflight operations. Finally, responsive to the WTIC objectives, we identify gaps that still exist in terms of both information content and adequate decision support.

NOTE: In general, throughout this section, comments from pilots were included to illustrate their actual reaction to questions on the survey. Most responses were brief and direct. Some pilots took the time to fully explain their positions regarding the issues posed by the survey. These comments are included in their entirety with quotes to indicate that they were not edited. The many brief responses were summarized in some cases and are not direct quotes.

a. Summary of Pilot Operational Environment

Over 200 pilots responded to the survey, most of whom flew domestic Part 121 operations. We received considerable feedback on all aspects of domestic weather information use and availability during preflight and inflight. 90% of the respondents flew scheduled passenger trips; the remainder flew either cargo, corporate, or charter operations. Respondents flew literally every Boeing and Airbus airliner common to both passenger and cargo operations today, plus many corporate and regional aircraft currently in use.

b. Summary of Pilot Internet Access and Capability

Of the pilots who responded, more than half of them indicated that they had Internet access on the flight deck. Almost all Internet access was company-provided, and pilots indicated that they were able (in theory) to access weather updates via the Internet inflight. Some operational limits and constraints are discussed later in this report.

Of those with Internet access either on the ground and/or inflight, 90% of the pilots used portable EFB devices for weather information access. The rest had installed EFBs on the flight deck, used personal devices, or had no EFB capability. A few only had access to weather information on the ground via a GATELINK-type hard connection while at the gate.

c. Summary of Pilot Access to Inflight Weather Updates (EFB and/or other sources)

This section baselines weather access, both for preflight and inflight operations, based on whether the pilot does or does not have Internet and weather updates inflight. It should be noted that preflight weather sources are similar for all pilots independent of inflight update capability,

and most have access to the Internet at the gate, in the terminal, or even away from the airport prior to showing for a flight.

1) WITHOUT ACCESS TO INFLIGHT WEATHER UPDATES (VIA EFB OR SIMILAR DEVICES)

For pilots without Internet and weather update access on the flight deck, weather information is obtained via "legacy" sources such as text and voice communications from dispatch, ATC, and other aircraft. Nearly 90% of the pilots had airborne weather radar systems available for convection and turbulence information.

Preflight weather (textual format) is used for METAR/TAF and PIREPS at departure, destination, and alternate airports. *AviationWeather.gov* (AWC), WSI and JEPP FLIGHT PLAN PRO were mentioned as useful tools during preflight. For those pilots who commented on these sources of preflight weather information:

> Preflight weather information is obviously limited in the airports we receive information for, and the fact that weather changes can occur quickly can limit its usefulness. Once enroute, we have no way of updating preflight weather outside of contacting FSS, ATC, or company dispatchers.

"Legacy" weather sources were sometimes available via Multi-Function Control and Display Unit (MCDU) text messages from AOC or ATC while airborne, and this information served to supplement the weather obtained during preflight. Voice communication with other aircraft and real-time PIREPs were stated as an essential source of real-time updates of turbulence and convective information, usually in the form of action taken to avoid these hazards (for example, a climb or descent to avoid an airspace volume with turbulence). A serious limitation of this source of information is frequency congestion, especially when the weather is bad. In summary, almost all responses stated that:

> All these [legacy] sources are usually not accurate [exception: real-time voice updates] by the time they get to us. Except for onboard weather radar, which has its own limitations.

This assessment was shared by many pilots who stated that airborne weather radar was range-limited, as little as 80nm, and at times was limited due to attenuation. Attenuation often limited pilot visibility of hazardous weather beyond the leading edge of a line of storms or precipitation. Further, some airborne weather radars only displayed a 45-degree arc in front of the aircraft which limited awareness of hazardous weather beyond +/- 20 degrees either side of current heading.

A common observation as stated by one pilot on textual updates:

> "AOC Uplink weather (ACARS messaging with dispatch) is not terribly useful because a textual description of a weather system does not paint a great picture. For

example, on a flight to Ecuador my dispatcher sent me a SIGMET with about 20 points that marked the boundaries. I spent about 20 minutes plotting all of the points, only to then figure out that the SIGMET did not cover any of my route but did extend 2000 miles all the way down to southern Chile. This would have been so much easier to figure out graphically."

The use of Internet either in the terminal or via GATELINK (if available at the gate) is mentioned as a valuable tool for updating weather prior to pushback (as described by one pilot):

"I update the Jepp Flight Deck Pro wx before takeoff as a reference. On-board weather radar is used enroute along with ATC guidance. However, EFB updating at the gate with no updating after pushback is not good, in some cases not used at all. But it serves as another reference to be compared with visual and radar information."

Another useful tool to supplement the on-board weather radar is the Stormscope (lightning detection) system, if equipped. This system highlights the most intense part of convection shown on an airborne radar display. However, most commercial aircraft are not equipped with the Stormscope system.

2) WITH ACCESS TO INFLIGHT WEATHER UPDATES (VIA EFB OR SIMILAR DEVICES)

We saw a significant improvement in pilot capability to merge weather information with decision-making when pilots had access to timely weather updates inflight. 92% of the pilots used their company-provided portable EFB to access weather information during all phases of flight (departure, enroute, descent/approach). Pilots identified several company-provided and/or commercial applications used for obtaining inflight updates of aeronautical and weather information, given that Internet was available on the flight deck. Either through these applications or independently, pilots with Internet access also used many of the same "legacy" sources as those without a company-provided Internet.

Flight Information Services (FIS) via Automatic Dependent Surveillance-Broadcast (ADS-B) remains a very important source of weather information. The Internet connection facilitates updating this information as needed. Below are summaries of many responses regarding use of FIS in conjunction with the airborne weather radar:

ADS-B: NEXRAD (accurate with delay. Winds Aloft, SIGMETs AIRMETs, METARs, TAFs. All these are very accurate. Weather radar: Accurate but range limited.

FIS via Garmin MX20 - this gives us a slightly outdated satellite radar picture (10-20 mins) that allows us to see the bigger picture. It also provides the ability to pull up METAR and TAFs from along the route,

NEXRAD composite depictions are identified by most pilots who have an Internet connection as the most valuable, regardless of application(s) used. Below is a direct quote which catches the general feelings of most pilots:

> "Having radar depicted on our EFB's showing where the thunderstorms are is INVALUABLE to us. Unfortunately, the Wi-Fi on our aircraft is extremely unreliable. WE NEED TO BE ABLE TO SEE WHERE THE THUNDERSTORMS ARE ON OUR IPADS. PERIOD. Can't stress it enough."

Two important points are emphasized in this and similar comments throughout the pilot responses. First, pilots are seeking information about the "big picture" which the NEXRAD composite provides. Second, although most pilots have access to the Internet on the flight deck, and the capability (in theory) to update weather information inflight, more than 40 of the respondents claim that the Wi-fi provided is unreliable and sometimes does not work at all. International flyers universally say that the Internet is not available during some portions of the flight. Both points will be covered later in this report.

Another important point that suggests additional research is some applications available to pilots are difficult to use and understand. Plus, in most cases, the information is not presented relative to the aircraft's flight trajectory, which adds workload when the pilot is required to relate text or graphics to his/her location and planned route of flight. This comment summarizes the problems pilots encounter even though Wi-fi, well-intentioned applications, update capabilities, and (presumably) training are provided:

> "Our WSI product is WAY too complicated to use and the layers functions easily allow you to mistakenly remove weather for other layers and miss important information. It doesn't update unless we are over the domestic U. S., and even then our Internet service is sketchy at best (literally a 50% chance of working). In short, we are getting way too much information we don't need. I need accurate trend information for the big picture…. Thunderstorms, low vis and ceilings, winds, and volcanic ash. And none of this information is complete until I know the aircraft's direction of flow, which I feel is critical to the weather information itself and operating the aircraft safely."

d. Operational Decisions Impacted by Lack of Cockpit Weather Information

Pilots agree that there are just a few weather hazards that govern how their flights are conducted in a safe manner:

- Convection, and associated hazards like turbulence, icing, lightning.
- Other types of turbulence, such as windshear, clear-air, convective-induced, wake, mountain wave.
- Inflight icing, in particular in the terminal area and enroute during Extended-range Twin-engine Operational Performance Standards (ETOPs) operations.

- Volcanic ash.

Enroute winds are also important for route and fuel planning considerations. Terminal ceiling, visibility, and any other weather conditions that affect destination and alternate planning are also critical.

This section attempts to identify those decisions a pilot is expected to make but has difficulty due to a lack of updated weather information, with a focus on the above safety and operational considerations. Written comments from the pilots tell us that they need to understand the "big picture" to most effectively support their strategic decision-making. For most, it is not good enough to be given routings, altitudes, clearances, diversions, etc., without understanding the reasons for these actions when they come from ATC and/or AOC. These concerns reiterate the need for collaborative decision-making between the cockpit, ATC, and AOC. It also means all players in the "triad" need to share the same information at the same time. The most obvious example is the stated need for NEXRAD composite information with trend projections, even with its inherent limitation caused by delay and lack of vertical extent information. This product allows the pilot to get a better picture of what a tactical avoidance maneuver might do to his, or ATC's, strategic plan.

Pilots want the actual weather information, not decision support that tells them what to do. They also want to know what ATC is planning and what it is based on. They want to be in charge. A big caveat, as described by several pilots, is there are times when pure decision-support is necessary. An example is a low-level windshear or microburst alert, either of which requires immediate actions by the pilot. Where pure decision-support is required or appropriate should be an area of active research.

e. Information and Capabilities Needed to Lessen Impacts

Above all, satisfying information gaps must focus on the decisions required; must support the cockpit, ATC, and AOC at the same time; and must not fall into the "nice to have" category to have the most impact. Here are summaries of comments made by pilots who commented on this issue; direct quotes are also included as indicated:

- Pilots need EFB apps that are user friendly, easy to use, and have high glance value. "I do not have time to manipulate the app, manage overlays, and interpret complex displays."
- Some pilots stated a need for international coverage. "Especially Latin America, over the Gulf of Mexico and Caribbean, oceanic convective activity. Need Internet weather onboard."
- "Improvement in Wi-fi reliability, to include availability on the ground and below 10,000 feet."
- Pilots need strategic information to support decision-making at greater distances, to include animated graphics, trend projections (motion, growth, decay), and vertical extent

of hazard information. Some pilots suggested that weather depiction charts via the Internet would help the need for strategic information. "I want to plan! Big picture and forecast along my route of flight. No wifi, no planning!"

- Some pilots requested international ATIS information on apps to support flights in the Caribbean, Alaska, and Canada.
- "Graphical SIGMETs, please!"
- A few responses stated that ATIS information for nearby airports was difficult to access when D-ATIS was not included on inflight sources. This was important in busy terminal areas when planning for a possible diversion.
- Given a working Wi-fi and Internet access, weather updates inflight are not very valuable if the actual nowcasts and forecasts are not updated up to four hours. Pilots stated that forecasting should continue to focus on updates as frequently as possible. However, there is a point where decisions must be made and acted upon, so there is a tradeoff when frequent updates drive different decisions. This should be an active research area—when does frequently updated information become counterproductive for all players in the "triad"?
- More than 40 responses from the pilots described the limitations of their airborne weather radar systems—range, attenuation, forward visibility angle (+/- 45 degrees). Manufacturers and airlines are actively working on improving some of these limitations.

f. Information Gap Impact to Efficient Traffic Flow Control

Many comments describe a lack of visibility on why ATC and AOC select routes and diversions during preflight and enroute. Pilots seem to need knowledge on why and what information drives routing decisions. Here are some anecdotal examples pilots provided in the survey responses:

- "ATC will recommend a turn to the North when our radar and delayed EFB looks far better to the South. I was an air traffic controller before flying [Part] 121 and also know the limitations of ATC WX products. But will say current ATC does an outstanding job helping us with WX decisions!"
- Routing out of MSY was to go North (tstms tops 50k+) due to perception that we could not go more than 50nm offshore (South) enrt to IAH. ATC "said" they were painting a 'hole' but CHIDD [Chicago Departure Control] agreed no hole existed. We flew South to 162nm limit."
- "ATC often tries to vector us into areas that our onboard weather radar shows to be unsafe. This usually occurs in the terminal are where things are constantly changing, and changing rapidly."
- "Clearances that route the flight directly through or across a line of level 3-4 thunderstorms, with no explanation or expectation of reroutes."

- "ATC has access to way better weather data than we do. Unfortunately, they do not have vertical development. so sometimes they will report returns that are below the aircraft and do not require deviation."
- "ATC often routes us in ways we don't expect, like to a different entry quarter of a major airport. This puts us at risk of diverting due to inadequate fuel."
- "I was given recommendations to deviate right when I could see with onboard radar and with eyes out the window that the storms had already blown far enough away such that no deviation was necessary. We did not deviate, and we had a smooth ride."

Some of these issues are unavoidable and occur simply because pilots have both an out-the-window view and real-time tactical information from their airborne weather radar, and controllers' information is inherently delayed. Others may be addressed by continuing to enhance collaborative decision-making by ensuring that ATC, AOC, and the cockpit share the same weather information as it relates to trajectory decisions. How best to do this is an active research area.

g. Turbulence Mitigation and Avoidance Gaps and Impacts

Turbulence—convective-induced and clear-air—is the most operationally significant weather hazard for pilots and operators for both safety and cost concerns. It is also the most frequently occurring hazard and the most difficult to predict. It is dynamic to the point of even challenging the usefulness of real-time pilot reports. Most of the time, turbulence is operationally handled through mitigation—alerting crew and passengers, and/or altitude changes. Other than turbulence associated with thunderstorms, it is difficult to pinpoint and horizontally avoid. Preflight sources of information assist in planning a trajectory that minimizes the chances of an encounter. Primary enroute turbulence information (as identified by pilots) focuses on real-time updates because preflight information may not be relevant a few hours after departure.

The above result echoes pilot written comments on what type of merged information they desire to best mitigate or avoid areas of turbulence. They desire a 3-dimensional graphic so that the best avoidance strategy is immediately apparent—that is, either a climb or descent. A merged product would include the following, accounting for the dynamic nature of most forms of turbulence:

- A model-based forecast that updates frequently, and provides short-term nowcasts, that also
- Assimilates a constant flow of filtered voice PIREPs and automated, objective measures of turbulence as reported by aircraft (currently, eddy dissipation rate [edr]}

Most of the pilots are familiar with the above paradigm as some carriers have been using such a product for several years. Some weather vendors are also providing such a product that updates as frequently as every 30 minutes. Pilots also indicate that raw edr data would be useful, displayed ASAP after being reported by other nearby aircraft.

h. Departure and Arrival Gaps and Impacts

Weather information impacts in the terminal area for arrival and departure are mostly related to timeliness and ease of access, as these are busy phases of flight. Most critical information, such as low-level windshear or microburst alerts, are communicated immediately by ATC, or ATIS and AOC if trend or forecast information is available. Other arrival and departure information must be readily available without too much effort and should not conflict with what the pilot sees from other sources. Some examples were provided by pilots in their survey responses:

- "Pilots need accurate real-time wind data AT the runway. Wind information from a weather station located miles across ATL (Atlanta Hartsfield Airport) is useless. We want wind information at the threshold, which is why we value PIREPs from immediately landing aircraft."
- A few pilots stated that ATIS information for nearby airports was difficult to access when D-ATIS was not included on inflight sources. This was important in busy terminal areas when planning for a possible diversion.
- "When a terminal area controller vectors me towards a weather system I would not fly through, he almost always has a plan to turn me away in time to keep us safe, however, this information is oftentimes not shared with pilots unless they ask."
- "It's really difficult to get a picture of the entire airspace. While the airborne weather radar gives a good look at the airspace that you [immediately] plan to occupy, it gives no guidance on other airspace sectors. For example, if you're on the north downwind for an airport, you can't precisely tell if there is less convective activity on the south downwind for that airport."
- "By that point [that is, entry into the terminal area], the only thing that would be helpful would be able to get a changing ATIS via an inflight source without having to listen to the broadcast. Workload and frequency congestion make ATIS monitoring difficult when weather conditions are challenging."
- "We need real-time convection, turbulence, icing, LLWAS TDWR, D-ATIS, anything that relates to terminal area and runways in use so to be able to plan for runway changes or approach holding and fixes."

i. TALPA Gaps and Impacts

Pilots report that TALPA information describing field conditions (FICON) during inclement weather is reported fairly well. However, pilots suggested several ways to improve the description and reporting of field conditions:

- "There seems to be a consistency problem when reporting runway condition and types of contamination (runway condition, or RCC). RCC codes might be generated using a surface vehicle, which translates readings to a unique code. This code does not easily translate to pilot action or mitigation strategy."

- Pilots suggest that braking action reports come from aircraft, NOT the airport manager (sic) which is at least 5-10 minutes old. "Quicker and more consistent dissemination of information from previously landing aircraft, specifically via the controllers, specifically approach control (vs tower), since this would allow more time to make decisions and mitigation strategy."
- "We need RCC and braking reports PRINTED or DISPLAYED. Listening to ATIS is not effective when cluttered with these codes. Comm 2 is blocked anytime com 1 is receiving. Other airport frequencies bleed over. All the time these people think I would be distracted looking at an iPad is actually wasted 10X trying to obtain with the damn radio..."

j. Inflight Icing Gaps and Impacts

Because most of the respondents of the survey were Part 121 pilots flying well-equipped aircraft, few comments addressed the inflight icing hazard. Decision support for ground deicing operations is well-understood and tested, providing hold-over times and strategies that assure contaminant-free takeoffs. Two pilots suggested a need for ground icing and field condition information beyond those gaps that were covered in the TALPA section.

International pilots reiterated the need for accessible inflight icing information to support ETOPS operations. Flight routings for ETOPS trips usually incorporate that information during AOC flight planning; however, should a diversion possibility arise during ETOPS, that information needs to be readily available to pilots. It apparently is not.

k. Problems with Inconsistency of Weather Information (from voice, onboard sources, data link sources)

Nearly half of the pilots reported inconsistencies between different sources of similar weather information (for example, airborne weather radar and EFB information). Over 30% of pilots indicated that these inconsistencies contributed to situational awareness confusion. Several instances of inconsistent weather information have already been presented. Simply, with more information from different sources, the potential for inconsistency goes up. One pilot's comment describes what others' feelings were about dealing with disparate information:

> "Perhaps a better word than "confusion" would be "conflict" - as in "which electronic source are you going to follow?" There are nuanced differences between JeppFDPro, WSI, and SkyNet. As such, sometimes one crewmember favors the data provided by one over the other. This is mainly in instances of determining which altitude(s) might be smoother than others." Other comments provided instances of inconsistent information used to support other decisions, such as routing around convection.

Training and understanding of the consequences of disparate weather information as it is used for decision support should be addressed in further research. This problem potentially can get worse as more sources of weather information become available.

Other comments are provided to further illustrate how inconsistent weather information affects decision-making (these are direct quotes):

- "Skypath and WSI often show turbulence differently."
- "Until we realized some of the weather information we were getting was not real-time, it was stale, we made deviation decisions based on this information that was not always the best, i.e., unintended turbulence encounters."
- "Internet weather was showing heavy rain approaching the airport, however the rain was actually over the airport at that time."
- "Of course. It has killed people. Multiple times. That is why it is critical to have both sources. They each have severe limitations and adequately cover the gaps of each other."
- "Storms are moving and we are trying to make decisions based on hours old WSI picture when it doesn't compare to current radar. In the case of a MAX aircraft or manual radar picture I've often had difficulty rationalizing the difference between what I expect to be there and the radar display. Results in substandard decisions."
- "When determining landing legality based off a TAF. When sources differ it makes dispatching legality ambiguous.
- "Despite numerous admonitions from the industry, I have witnessed more than one pilot get too involved in what the NEXRAD picture shows rather than looking at the onboard radar for tactical navigation around storms."
- "It does for less experienced crew members, until they experience what reality actually is. Newer pilots need to be educated about these topics. Current training in this area is not consistent and depends upon the initiative of the crewmember to self-educate."
- "Even with the negative, positive for having more weather sources: BUT needs to be trained or through experience."
- "Should we deviate or not? Climb or descend? Too many times to mention them all."
- "The inability to "see" changing weather beyond 80 nm ahead has led to unnecessary diversions, late diversions with fuel emergencies, and extended reroutes without adequate fuel."
- "Some pilots I fly with try to rely on NEXRAD information for short range weather information. It makes them feel uneasy to trust the onboard weather radar when NEXRAD is painting a grim picture."
- Anecdotal insight: "A rapidly building embedded cell is impossible to see with your eyes, but can easily be identified by the on board radar. Similarly, a cell that is over or near a large city can be extremely difficult to identify without NEXRAD or other data to support the information. Also, during descent it's very difficult to discern ground returns from storm returns, especially without a ground map overly. Often times a city on the shoreline looks very much like a storm return with strong attenuation behind it

> due to no returns from the water. This is completely avoided by satellite weather data. Just today, the EFB weather showed us the general picture of what we were transiting through on a stormy day from New York to S. Carolina. It helped us plan for turbulence ahead of the distance our onboard radar sees and allowed us to inform the flight attendants further ahead of what we could using just onboard radar."

In general, redundancy is good. However, effective training on proper use and interpretation seems to be needed. A pilot provides us one more example of anecdotal use of multiple sources of the same information, developed through training and/or experience:

> "EFB provides a trend…intensities/direction and speed, tops of storms and turbulence …an idea of what to expect…albeit old data from departure time…it also collocates the weather with known navaids/waypoints on the route…whereas onboard radar becomes an exercise in dead reckoning outside the weather….and once inside the weather is of a very reduced value in navigating through or around varying intensities of precipitation…"

L Latency and Availability Gaps and Impacts

Most weather information provided by inflight updates has an associated latency, and that will continue to be unavoidable. Delays associated with sensing, processing and communication will always be there. Some latencies, especially those associated with radar composite products, are at least 15 minutes. Turbulence information products that assimilate edr and PIREP data strive to be closer to real-time. Airborne weather radar, seat-of-the-pants sensing, voice (ATC and pilot) reports, and out-the-window updates are the only real-time sources available. Other sources supplement and extend awareness with differing latencies.

Pilots know this but realize, once again, that training and experience are needed to properly integrate the differing lag times with limitations for effective decision-making.

m. Value of Interplane (party-line) Communications

There is no question—almost all the pilots stated air-to-air communication (party-line) is important to obtain and/or confirm weather conditions, particularly turbulence. The increased use of digital communications will not affect the use of the party-line. Airlines have established a common air-to-air VHF frequency for voice interplane communications, and presumably individual airlines have done the same. Discussions on AOC frequencies also occur. One comment below is a good summary of how party-line integrates with other sources of information:

> "What is more important, voice or EFB: Both are important. Voice communications allow for the ability to ask multiple questions if data is not understood or get more clarifying information. But data information displayed on an EFB with a flight plan overlay make it simpler to understand if a weather event/PIREP will be near my aircraft's route of flight."

Another comment:

> "I feel the "party lines" are most useful for determining which altitudes are better rides than others. It's also beneficial when a chunk of wx looks absolutely awful, someone braves it, and then reports back that it looks to be far more turbulent than it actually is."

5.0 Summary and Conclusions

a. Gaps and Limitations of Current Cockpit Weather Information

The data indicate that the following infrastructure and equipage limits exist, impacting the full realization of uplink weather information benefits:

- Over 40 pilots reported that Wi-fi on the flight deck is sporadic and is not dependable. Some were commuter pilots flying smaller, presumably less-capable aircraft that may not have a Wi-fi capability. The majority of the negative comments came from pilots flying more capable, larger commercial aircraft (not regional or general aviation aircraft). The potential impact to the overall WTIC capability is that pilots are still reliant on preflight information plus whatever voice or textual updates they can access from AOC, ATC, and other aircraft.
- Pilots who presumably have dependable Wi-fi and connected EFBs are then faced with applications that are difficult to use and access weather information that is inconsistent either due to latency or content inconsistencies from different sources.
- Related to the previous point, pilot training and experience are factors in pilots having difficulty with integrating inconsistent, latent information into their decision-making process, usually when the weather is bad and workload is high.
- Improvements in weather forecasting, including content, timeliness, and frequency of updates, are needed as reported by 30% of the pilots. Most mentioned was more frequent updates of turbulence information. Pilots requested 4-D graphics to better relate to decision-support in their 4-D environment. 4-D graphics include the time dimension, which can be graphically displayed using past-present-future looping to show movement and growth trends. A time stamp is not sufficient, although it still is necessary.
- Over 60% of the respondents desire background knowledge of why trajectories are planned or changed due to weather by ATC or AOC. This was stated in several different ways as illustrated by anecdotal insights included in this report. The implication is that decision support tools must include access to the basis for recommended courses of action. Pilots "want to plan" and need the big picture view.
- Pilots do need winds aloft and temperature information for fuel and flight planning, to include information above and below current flight level. However, the method of depiction could be improved. If winds are ingested into flight management systems,

gridded wind vectors might be appropriate. If wind information is presented to the pilot, it should be in the form of a "wind factor," or effective wind component (+/-) over a flight segment.

- Radar composite products should always include motion and cloud-top information.

b. Prioritization of Future Research Opportunities

Future WTIC Program research opportunities were derived from the June 2022 survey results. These suggested areas of future research were presented to the Friends and Partners of Aviation Weather (FPAW) Spring 2023 Meeting. This group represents virtually all stakeholders in the field of aviation weather, from users to information researchers and providers, to FAA regulatory agencies and operational testers. Attendees gave further input that helped validate and prioritize these derived research opportunities. Further input from several FPAW attendees, including pilots and representatives from Part 121 airlines, said that the survey results adequately captured their thoughts on the positive impacts of inflight weather information updates. Areas of future research that were presented did address those gaps and issues still negatively impacting the capability. One industry member (weather radar manufacturer) asked for more information on limitations of airborne weather radars and adequacy of pilot training. Several other attendees representing flight safety and general aviation commented that, from their perspectives, access to full capabilities such as SIRIUS-XM is more important than full Internet access. Other comments suggest that UAS requirements for inflight weather updates and use need to be identified. Finally, one comment suggested that meteorologists need to be trained to think like pilots, not the other way around. This comment just reinforces the theme that is a common one—the format and function of weather information and access should relate to the 4-dimensional flight profile to have the most rapid and effective impact on pilot decision-making.

A proposed prioritization of WTIC research opportunities as validated at the FPAW 2023 Spring Meeting follows:

- First, pilots *require* completely dependable access to Internet sources of weather information. Wi-fi is the current tool used for access. Future research is needed to identify *the* tool for access that is always available so that pilots are not forced to revert back to preflight information or voice/text updates.
- Research is needed to refine complex applications pilots are currently using that come from their airlines, corporate flight departments, and commercial weather providers. Overlay confusion and functional complexity are common complaints. When the weather is bad, pilots need simple access to the information they need, and graphics that relate to the aircraft's trajectory are the best way to present that information. This suggests establishing application performance standards that are common across all weather applications.
- Related, even though Wi-fi (that is, Internet access), well-intentioned applications, update capabilities, and many sources of information are available, flight crew training (in absence of a great deal of experience) is needed to safely use these capabilities in an

optimal way. Research is needed to define and create effective training. This further validates the need for a continuing task and decision analysis for all stakeholders that can refine the precise information needed to support each task and decision. Then, make that information easily accessible.

- Given Internet access, weather updates inflight are not very valuable if the actual nowcasts and forecasts are not updated frequently. Pilots stated that forecasting should continue to focus on updates as frequently as possible. However, there is a point where decisions must be made and acted upon, so there is a tradeoff when frequent updates drive different decisions. This should be an active research area—when does frequently updated information become counterproductive?
- Pilots across the board want the actual weather information, not decision support that tells them what to do. They also want to know what ATC is planning and what it is based on. There are exceptions when pure decision-support is necessary. An example is a low-level windshear or microburst alert, either of which requires immediate and specific responses from the pilot. Where pure decision-support is required or appropriate should be an area of active research.
- Related, many issues of integrating different sources of information are unavoidable and occur simply because pilots have both an out-the-window view and real-time tactical information from their airborne weather radar, and other information is inherently delayed. Problems may be addressed by continuing to enhance collaborative decision-making by ensuring that ATC, AOC, and the cockpit share the same weather information as it relates to trajectory decisions. How best to do this is an active research area.
- Research, rapid prototyping, and demonstration of a capability to graphically project a given weather hazard along an aircraft planned flight route. This potential product would also include the details of the hazard and decision support to help avoid or mitigate the hazard.
- Pilots desire an improved way of depicting edr information, perhaps merged with model-based nowcasts that update very frequently and are presented graphically along an aircraft flight trajectory. A major air carrier does this in concept; however, pilots are suggesting that there is room for improvement.
- There is a need for a capability to submit PIREPS via an application vs. voice. “We're on our iPad already looking at weather and working our flight plans. It seems very antiquated and tedious to submit a voice PIREP when a MUCH more detailed one could be only 5 or so clicks away.”

APPENDIX A

FAA Weather Technology in the Cockpit (WTIC) Pilot Industry Survey

Dear Participant:

Background: In 2013, The Federal Aviation Administration (FAA) Weather Technology in the Cockpit (WTIC) program conducted an industry perspective survey of airlines, aircraft manufacturers, weather suppliers and avionic manufacturers on exchanging meteorological information (METI) to / from the aircrew. Since then, a variety of FAA Next Generation (NextGen) enhancements and operational improvements have been incorporated into the national airspace system (NAS), and a number of WTIC program Minimum Weather Service (MinWxSvc) recommendations have been developed and transitioned into operations. The recommendations all relate to incremental improvements in these areas:

- Minimum cockpit meteorological information,
- Minimum performance standards and characteristics of the meteorological information,
- Rendering guidance for the meteorological information on cockpit displays, and
- Enhanced meteorological information and technology training.

Purpose of This Study: This new industry perspective research is intended to identify subsequent gaps in cockpit weather technology and information resulting from these changes since the previous study. In addition, this research will obtain feedback and assessments on MinWxSvc recommendations and training that have been developed and transitioned by the WTIC program. The results of this study will be used to scope future WTIC research and potentially develop metrics to assess the benefits of accomplished research. This study focuses on airline and business aviation pilots only.

The survey is facilitated by the National Business Aviation Association (NBAA), the Allied Pilots Association (APA), the Southwest Airlines Pilots Association (SWAPA), Independent Pilots Association (IPA), and the Air Line Pilots Association (ALPA). It is administered by the National Center for Atmospheric Research (NCAR) on behalf of the FAA Weather Technology in the Cockpit (WTIC) Program. Please, consider your answers to these questions from a pilot’s perspective, and try to separate your responses from any corporate and/or OPSPEC influences.

Personal Confidentiality: Your answers will remain anonymous and all information will be de-identified. All data and analyses will only be used in aggregate and not attributed to any individual or company.

Company Proprietary Information: If there is any proprietary information you would like to share with the FAA but not other individuals, you may identify that information on the survey. That information will be made available only to the FAA and survey team members, who will in turn protect it from disclosure outside the FAA WTIC Program Office. Proprietary information identified by you will not appear in any publicly available versions of the FAA's final report.

Points of Contact:

FAA: Mr. Eldridge Frazier, Lead Engineer, Weather Technology in the Cockpit, 202.267.2790, eldridge.frazier@faa.gov

NCAR: Mr. Tenny Lindholm, Project Manager at the National Center for Atmospheric Research (NCAR) Research Applications Laboratory (RAL), 303-246-3590, lindholm@ucar.edu

NBAA: Mr. John Kosak, Program Manager, Weather | Air Traffic Services
National Business Aviation Association, (202) 308-0561, jkosak@nbaa.org

ALPA: Mr. Mark Phaneuf, Senior Staff Engineer, Air Line Pilots Association, International, 703-689-4202, mark.phaneuf@alpa.org

* Required response

What air carrier do you currently fly for (if none, please respond "None")?*

Your answer

Do you primarily fly domestic or international routes?*

- Domestic
- International

If you answered Domestic above, do you mostly fly CONUS, Alaska, or Hawaii?

- CONUS
- Alaska
- Hawaii

Are you primarily an*

- FAR Part 91 pilot?
- FAR Part 121 pilot?
- FAR Part 135 pilot?

- Other:

Do you primarily fly cargo, passenger, or other types of operations (please identify below)?*

- Cargo
- Passenger
- Other:

What aircraft type(s) (e.g., B737, A320) do you currently fly (include make, model, series)?*

Your answer

Do you have Internet access in the cockpit?*

- Yes
- No

If Internet is not available...

How do you access weather updates inflight? Please check all that apply, then identify the information you obtain from that source and tell us if that information is adequate for weather situational awareness.*

- ADS-B
- AOC uplink or voice
- ATC uplink or voice
- "Party line," or voice from other aircraft
- Airborne weather radar
- I use preflight weather information only (without inflight updates)
- Other. Please describe below

Your answer

For each source checked above, identify the weather information obtained and its adequacy for weather situation awareness.

Your answer

When updating weather information in the TERMINAL AREA environment using the above selected sources, what information is most important to you?*

Your answer

To support decision-making in the TERMINAL AREA, what weather information gaps exist when using the above selected sources? For example, what weather information is not available, and/or needs improvement given no Internet access? If none, please answer "N/A." The term "gap" refers to the difference between the current state of the weather information and the desired state as it relates to supporting pilot situational awareness.*

Your answer

When updating weather information in the ENROUTE environment using the above selected sources, what information is most important to you?*

Your answer

To support decision-making ENROUTE, what weather information gaps exist when using the above selected sources? For example, what weather information is not available, and/or needs improvement given no Internet access? If none, please answer "N/A." The term "gap" refers to the difference between the current state of the weather information and the desired state as it relates to supporting pilot situational awareness.*

Your answer

If Internet is available...

Is Internet access company provided?*

- Yes
- No

Are you able to access inflight weather updates from your Internet?*

- Yes
- No

If you are able to access inflight weather updates...

Do you use an Electronic Flight Bag (EFB) that can connect to the Internet for inflight weather updates? Please select all that apply.*

NOTE: For the purposes of this survey," EFB" is defined as any portable or installed device (to include tablet) used to access flight-related information.

- Yes, a company provided portable EFB

- Yes, installed equipment (hard mounted or Original Equipment Manufacturer [OEM] installed equipment)
- Yes, a personal device
- Yes, but my EFB can only access weather updates on the ground
- No, I do not use an EFB

If you have a connected EFB...

What application(s) on your EFB do you use to access weather information? Examples might be: ForeFlight, WSI Pilot Brief Optima, Jepp FlightDeck Pro, Sky Path, Delta Airlines Flight Weather Viewer. If you are uncertain, please answer "Unknown." If you do not use an EFB, please answer "N/A."*

Your answer

Do you use a personally installed application (such as ForeFlight or SiriusXM Aviation)? Please identify the application you use, or answer "N/A" if none.*

Your answer

During which phases of flight do you use your EFB to access weather information? Please check all that apply.*

- Preflight
- Pushback/Departure
- Enroute
- Descent/Arrival
- None of the above. I do not use my EFB.

Do you use any of these other sources (in addition to your EFB) to access weather information inflight? Please check all that apply.*

- ADS-B
- AOC, voice or uplink
- ATC, voice or uplink
- Airborne weather radar
- Voice from other aircraft ("party line" or direct communication)
- None
- Other:

What weather information will be beneficial to you for decision making strategies for each phase of flight (with or without an EFB)?

a. Preflight:

Your answer

b. Pushback/Taxi:
Your answer

c. Enroute:
Your answer

d. Descent/Arrival:
Your answer

Are there any phases of flight where there are gaps, or areas of improvement needed, in weather information available to you? The term "gap" refers to the difference between the current state of the weather information and the desired state as it relates to supporting pilot situational awareness.

a. Preflight:
Your answer

b. Pushback/Taxi:
Your answer

c. Enroute:
Your answer

d. Descent/Arrival:
Your answer

Questions for all capabilities...

Are you aware of any inconsistencies between different sources of similar cockpit weather information (e.g. onboard weather radar versus EFB)?*

- No.
- Yes. Please specify below.

Your answer

Have these inconsistencies created weather situation awareness confusion? If "yes," please explain below.*

- No
- Yes. Please explain below.

Your answer

Is there a benefit to you of having multiple sources / displays of weather information in the cockpit (e.g. onboard weather radar and EFB)?*

- No
- Yes. Please provide an example below.

Your answer

Do frequent inflight weather updates ever create uncertainty with ATC instructions that might be based on different sources of weather information (for example, reroutes, RTAs, crossing restrictions, metering, etc.)?*

- No, ATC instructions are consistent with what I would expect given my weather updates.
- Yes, I have seen situations where ATC instructions are not consistent with what I would expect given my weather updates. Please provide an example below.

Your answer

The increased use of data communications like ACARS and/or automated uplinks/downlinks of information via the EFBs may decrease the sharing of weather reports via voice PIREPs and the "party line." How often do you depend on the "party line" or voice PIREPs to support weather avoidance decisions (for example, every flight or less frequent)?*

Your answer

Are "party line" and other voice communications about hazardous weather more useful for decision support than updates via the Internet?*

Your answer

This and the next two questions relate to turbulence weather information. What sources of turbulence information do you use for flight planning?*

Your answer

What turbulence information do you use for inflight tactical turbulence notifications?*

Your answer

What additional information about hazardous turbulence conditions would improve your ability to notify the cabin or avoid these hazards?*

Your answer

What type of product would you prefer for inflight turbulence guidance that provides location, altitude, and severity?*

- A product that graphically shows turbulence as it is reported by other aircraft
- A product that graphically depicts turbulence forecasts and short-term nowcasts
- Both of the above

Consider the Takeoff and Landing Performance Assessment (TALPA) process and information. Which of the TALPA information types are available to you on the flight deck? Check all that apply.*

- Runway condition code (RwyCC)
- Braking action
- Expected runway conditions (contaminate type and depth)
- Pilot braking action reports

Please identify any other types of information that, if provided, could assist you with takeoff and landing performance and safety. For example, increased time/directional resolution of winds when braking action is reduced; liquid water equivalent of snowfall;... If "none," please so state.*

Your answer

APPENDIX B

Acronyms

ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance Service-Broadcast
AOC	Airline Operations Center (Dispatch)
ATC	Air Traffic Control
ATIS	Automated Terminal Information Service
AWC	Aviation Weather Center
edr	Eddy Dissipation Rate
EFB	Electronic Flight Bag
ETOPS	Extended-range Twin-engine Operational Performance Standards
FICON	Field Conditions
FIS	Flight Information Services
FMS	Flight Management System
GATELINK	SITA wireless connectivity at the airport gate
GTG	Graphical Turbulence Guidance
LLWAS	Low-level Windshear Alert System
MCDU	Multi-Function Control and Display Unit
PIREP	Pilot Report
RCC	Runway Condition Code
SIGMET	Significant Meteorological hazards
TAF	Terminal Aerodrome Forecast

TALPA	Take-off and Landing Performance Assessments
TDWR	Terminal Doppler Weather Radar
WTIC	Weather Technology in the Cockpit