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Airport Wind Observations Architectural Analysis

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16. Abstract

The analysis presented here identifies potential shortfalls in the current wind information architecture, and offers recommendations for improvements that would serve the Federal Aviation Administration (FAA) in the context of Next-Generation Air Transportation System (NextGen) enabled concepts. The methodology relied on interviews and discussions with stakeholders, review of existing problem reports and operational logs, search and review of documentation related to wind sensors and operational policy, and analysis of airport wind sensor data. An immediate action to follow up on this architectural analysis would be to initiate a systematic process for evaluating and prioritizing the relative cost/benefit tradeoffs at individual airports.

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EXECUTIVE SUMMARY

Wind information is a critical element for ensuring safe aviation operations, particularly while performing low altitude takeoff and landing procedures. Across the National Airspace System (NAS), supporting wind observations are currently collected across a multitude of different sensor platforms whose configuration varies substantially from airport to airport, largely dependent upon airport physical size, traffic volume, and hazardous wind shear exposure. For more than a decade, chronic concerns from air traffic controllers and pilots have emerged regarding the consistency and reliability of wind information at a number of locations.

The analysis presented here identifies potential shortfalls in the current wind information architecture, and offers recommendations for improvements that would serve the Federal Aviation Administration (FAA) in the context of Next-Generation Air Transportation System (NextGen) enabled concepts. The methodology relied on interviews and discussions with stakeholders, review of existing problem reports and operational logs, search and review of documentation related to wind sensors and operational policy, and analysis of airport wind sensor data. An immediate action to follow up on this architectural analysis would be to initiate a systematic process for evaluating and prioritizing the relative cost/benefit tradeoffs at individual airports.

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1. INTRODUCTION

Airport terminal wind information is critical for ensuring safe operation of aircraft during takeoff and landing operations and for managing airport runway configurations. The headwind/tailwind component affects aircraft vertical control, takeoff/landing distance, and in-trail separation, and the crosswind component affects lateral control of the aircraft, most importantly during takeoff, approach, and landing. Crosswinds can also be an impacting factor for aircraft control during taxiing and ramp operations. Aircraft manufacturers provide wind performance thresholds for safe operations, and airlines establish policies for their pilots that define wind component limits for takeoff and landing. Aircraft wind requirements generally vary by aircraft size and design, and may be adjusted for specific runway conditions. During the period 2010–2017, National Transportation Safety Board (NTSB) incident logs cite wind as a contributing factor in 1545 (14%) of 11,203 total reports (largely involving general aviation) of aircraft accidents and incidents across the NAS (Table 1).

The rapid expansion of commercial aviation and associated airport construction after the Second World War was accompanied by a proliferation of airport wind/weather sensor deployment that would continue throughout the latter half of the 20th Century. In addition to improving technology, the need for detection of dangerous wind shear led to further expansion of wind sensor deployment and information availability. By the end of the century, ground-based systems for providing wind information deployed at more than one thousand airports across the National Airspace System (NAS) were comprised of a multitude of different technologies, sensor types, processing algorithms, runway coverage strategies, information distribution channels, and display nodes. New systems and sensors for acquiring and distributing wind information from aircraft have further expanded the availability of wind information in the 21st Century.

Over the last ten years, a number of field reports have emerged citing issues related to incomplete, erroneous, or inconsistent wind reports being used to support operations. Lack of wind gust information conveyed to the pilot of Continental Flight 1404 in December 2008 was cited as a contributing cause to the plane's runway excursion on departure, causes injuries to 4 crew members and 43 passengers. In subsequent years, there were many issues cited relating to the availability of multiple wind reports at individual airports, with discrepancies observed between simultaneous observations. Of particular note is a series of problem reports issued out of Detroit Wayne Airport (DTW) in the 2011–2013 period, citing inconsistencies in reported winds that were causing confusion amongst controllers and pilots, particularly with regard to determining whether conditions were within acceptable operational limits for landing. A concurrent Federal Aviation Administration (FAA) investigation into the issues cited a number of causes, including wind shear on the airport complex, differences in gust value processing between sensor types, wind direction variability owing to light wind speeds, and sensor interference from roosting birds. Later reports of erroneous winds were found to be caused by faulty sensor mechanics. Similar issues of wind report inconsistency followed the DTW problem reports, with multiple instances noted at Charlotte (CLT) and Dulles (IAD), and reports of erroneous winds owing to aging sensors at other airports. Multiple wind sensing shortfalls were reported during 2015 at the three major New York area airports, citing issues related to inconsistent wind reports and sensor citing deficiencies, and expression of concern that the shortfalls represented a safety risk.

Discussion with an experienced representative from the National Air Traffic Control Association (NATCA) indicated that widespread concerns about airport wind information date back to a working group assembled in 2001–02. Among the continuing issues of concern are the limitation of wind data from a single airport location, deficient sensor siting, variability of sensor heights from anemometer-based wind shear detection systems, and inconsistency of simultaneous reports from multiple sensors. A general concern is that the wind information provided to the pilot is not reliably representative of the wind conditions at the runway threshold (end of physical runway) at the aircraft altitude during a takeoff or landing operation, and do not routinely meet International Civil Aviation Organization (ICAO) standards. ICAO guidelines recommend a uniform height of 10 m (32 ft), and deployment of multiple sensors where topography or prevalent weather conditions cause significant difference in surface wind at various sections of the runway [1].

The FAA has recognized concerns from the user community regarding potential shortfalls in providing wind information to support operations, and has initiated efforts to resolve some of the cited issues. In particular, the current Surface Weather System (SWS) Program seeks to mitigate the issue of multiple algorithms across different platforms being used for computing sustained and wind gust values by installing wind sensor upgrades that use a common processing logic. Simultaneously, the upgraded sensors are comprised of sonic anemometers that reduce the mechanical failure risk associated with legacy prop-and-vane systems. Furthermore, as part of this upgrade process, the SWS program is using this opportunity to consider targeted sensor site relocation to reduce the number of sensors that are subject to compromised data quality due to siting issues. In all, more than 200 SWS sensor upgrades will have been installed by the end of 2018.

The Weather Observation Improvements (WOI) program within the FAA manages the evolution of the existing aviation weather observation sensor networks to one that provides the optimal quantity and quality of ground, air, and space-based sensors. A consistent and effective aviation weather sensor network is fundamental to NextGen. Of primary focus is the surface weather sensor network in the terminal environment. A comprehensive list of weather observation shortfalls is continuously refined and prioritized based on feedback from key stakeholders and user groups. The program uses this information to explore potential NextGen-enabled concepts and to mitigate high priority shortfalls.

In this regard, the WOI seeks to address observation improvements associated with airport terminal area winds, which includes the outstanding concerns expressed herein. The broader goal is to establish a terminal wind observation architecture to support the long-terms goals of the FAA NextGen system. This will be achieved through an analysis of the current architecture for wind data acquisition and information delivery, identification of existing shortfalls, analysis of solution space, recommendations for improvement, and transfer of technology necessary to ensure appropriate improvements.

This architectural analysis represents a key step in that process. It includes a survey of existing wind sensing infrastructure and capability across the NAS, and an outline of wind information requirements driven by the manner in which wind information is currently used to support terminal operations. (It should be noted that distinctions between commercial and general aviation exist in this regard.) In the context of this existing framework, outstanding potential shortfalls in the way that wind information is acquired, processed, distributed, and applied are identified through 1) discussions and interviews with operational stakeholders, 2) a review of existing problem reports and logs, 3) a search and review of documentation that governs wind information acquisition and policy for use, and 4) a sample review of airport wind data to corroborate and characterize some of the specific issues that have been raised by stakeholders. A listing and description of the solution space for addressing shortfalls is also presented.

This initial analysis would benefit from a subsequent comprehensive effort to more closely identify airport-specific issues and solutions across the NAS with the goal of prioritizing follow-on action for addressing shortfalls as part of the NextGen weather observation improvement objective.

Table 1. Number of Citations of Wind as a Contributing Factor in NTSB Aircraft Accident and Incident Reports from 2010–2017

CONTRIBUTING CAUSE	No.		IMPACT EFFECT	No.
Gusts	514		Effect on operation	614
Crosswind	407		Contributed to outcome	278
Tailwind	259		Response/compensation	244
Downdraft	74		Ability to respond/compensate	155
High wind	69		Effect on equipment	137
Sudden wind shift	57		Decision related to condition	49
Variable wind	56		Not specified	46
General	53		Awareness of condition	23
Wind shear	29		Accuracy of related information	3
Dust devil/whirlwind	15		Availability of related information	2
Updraft	9		Timing of the related information	2
Microburst	4		Compliance with procedure	1
			Effect on personnel	1

2. TERMINAL AREA WIND INFORMATION SOURCES

2.1 OVERVIEW

This section provides a descriptive summary of the various wind information sources currently in service across the NAS, in order to establish a baseline for understanding potential systemic shortfalls and opportunities for improvement. The FAA requires each airport in the NAS to have both a primary and backup weather observation capability [2]. As such, all airports have a minimum of two ground-based wind information sources. In general, the wind-sensing component of the widespread national network of automated surface weather stations provides one of the wind sources (either primary or backup) to more than 1500 U.S. airports across the NAS. The number and type of additional wind sources at an individual airport is largely dependent upon the physical airport size and the number of operations serviced, but also takes into account relative exposure to wind hazards or complexity of the local terrain that affects wind dynamics. Large hub airports that handle many hundreds of thousands of takeoff and landing operations per year typically have more than two wind sources, including both anemometer and radar based systems. Mid-sized airports will typically have a second sensor that is owned and maintained by the FAA. Smaller airports often contract out to a private service the responsibility of maintaining a backup wind sensor source. In total, most of the airport terminal wind information used to support aviation operations in the NAS is acquired through one or more of these sources:

1) Wind information available as a component of a broader weather sensor suite:
    a. Automated Surface Observing System (ASOS)
    b. Automated Weather Observing System (AWOS)
2) F-420 Series wind sensors
3) Low Level Windshear Alert System (LLWAS)
4) Wind Measuring Equipment (WME)
5) Stand Alone Weather System (SAWS)
6) Surface Weather System (SWS)*
7) Wind socks
8) Wind data derived from radar-based systems:
    a. WSR-88D Next-Generation Weather Radar (NEXRAD)
    b. Terminal Doppler Weather Radar (TDWR)
    c. Weather Systems Processor (WSP)
    d. Integrated Terminal Weather System (ITWS)
9) Aircraft-derived wind information

[*] The FAA is in the process of replacing all existing F420 Series and WME cup-and-vane sensors with wireless sonic SWS anemometers. Full upgrade is expected by the end of 2018.

The most widely available wind information distributed across the NAS is acquired from one of the two primary surface weather observing systems (ASOS and AWOS), which provide the wind data contained in the weather message routinely broadcast to pilots. This network of sensors is jointly owned and operated by the National Weather Service (NWS), FAA, and Department of Defense (DoD). These surface weather sensing suites are located at more than 1500 U.S. airport terminals, including very small, non-hub airports (Figure 1).

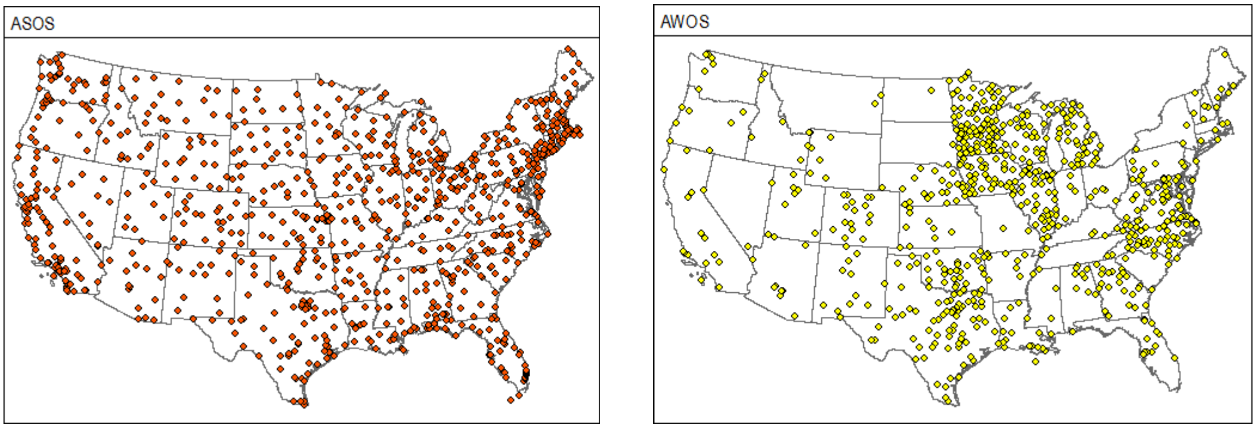


Figure 1. ASOS and AWOS surface weather station distribution in CONUS.

In addition to the densely distributed ASOS/AWOS systems, the FAA has deployed and maintains nearly 850 wind sensors (F-420, SAWS, LLWAS, and WME) across more than 450 Class B, C, and D airports. Airports with LLWAS or WME typically designate a sensor from those sources as the primary or designated "airport" wind, intended to define a wind report generally representative of wind conditions across the airport runway complex. The F-420 and SAWS sensors may be designated as either primary or backup (relative to ASOS/AWOS) at the discretion of the local air traffic operations manager. Deployment of several sensors at a single airport (most notably LLWAS, which is primarily intended for wind shear detection) also allows runway-specific wind information to augment the primary airport wind. Wind information from radar-based systems (most notably TDWR, distributed to users via the ITWS system) is also available at 49 airport terminal locations. The distribution of Continental United States (CONUS) airports across the NAS equipped with FAA-owned wind sensors (in addition to ASOS/AWOS) is shown in Figure 2.

The remaining paragraphs in this section provide capsule summaries of the various wind information sources, including background history on deployment and general characteristics of the data provided.

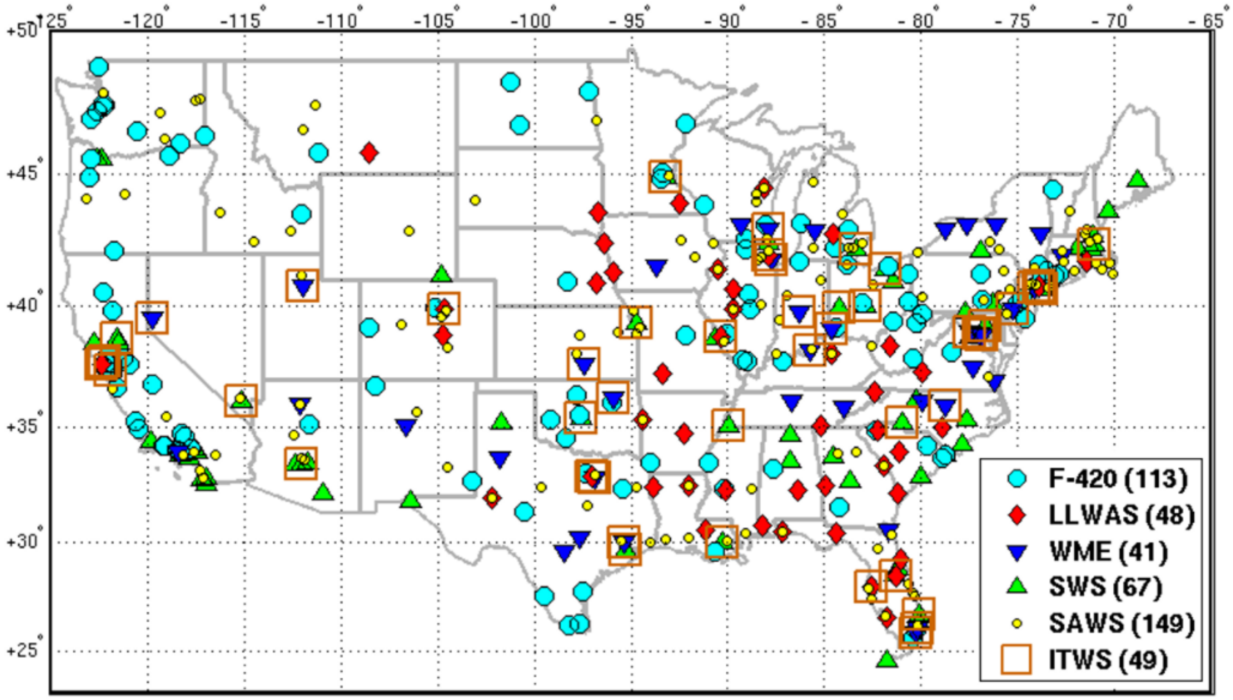


Figure 2. FAA sensor sources (CONUS only) for providing designated airport wind.

2.2 SURFACE WEATHER OBSERVING SYSTEMS

2.2.1 Background

The most prevalent source of surface wind information at airports within the National Airspace System is via automated weather sensing systems. The earliest such system in the era of automation was the AWOS, which served as the primary source of weather observations from the 1960s into the early 1990s. Early AWOS systems included only those weather elements that could be measured directly at the site location: temperature, dew point, wind (speed and direction), and atmospheric pressure. By the 1980s, technological advances allowed for automated measurements of sky condition (cloud amount and height), visibility, and present weather (precipitation and fog). A major effort to upgrade and unify the nation's surface weather observation network took place from 1991–2004 through development and deployment of the ASOS system (Figure 3) at more than 900 locations across the United States, primarily at airports. Development and deployment was jointly funded by the NWS, the FAA, and the DoD. ASOS remains the primary source of surface weather information at most airports today, though many variants of AWOS still exist at smaller airports, including some variations that were conversions of other systems, such as the Automated Weather Sensor System (AWSS).

2.2.2 General Characteristics

Most towered airports in the United States are served by a single automated surface weather observing system, predominantly ASOS and AWOS. The NWS has established specific guidelines for siting these systems and for characteristics of their component sensors in order to assure commonality and interchangeability of weather information among various federal and military organizations, and to ensure that the resultant observations are representative of the meteorological conditions affecting aviation operations. In particular, guidelines recommend that the wind sensing subsystem be adjacent to the primary runway at a distance of 1000 to 3000 feet down the runway from threshold, with a distance from the runway centerline between 500 and 1000 feet [3]. Specific adjustments are considered based on local elevation differences and runway instrumentation. Wind sensor height is specified to be 30 to 33 feet above the average ground level within a radius of 500 feet. It is desired that all obstructions (e.g., vegetation, buildings, etc.) be at least 15 feet lower than the height of the sensor within the 500-foot radius of the sensor, and no greater than 10 feet above the sensor at distances from 500 to 1000 feet. An object is considered a sheltering obstruction if the distance between the sensor and the object is less than ten times the height of the object and the lateral angle from the sensor to the ends of the object exceeds 10 degrees.

A wind speed and direction measurement is made once every second. A 2-minute running average of wind speed is updated internally every 5 seconds, and reported once per minute. Wind gust information is computed by comparing 5-second averages (of the 1-second samples) to the 2-minute average wind, and appended to the 1-minute report if appropriate thresholds are met within the wind gust algorithm. Wind direction is computed as a 2-minute average of 5-second average wind directions, reported once per minute.

One-minute reports of wind speed (including gust) and direction are made available for reporting the 1) ASOS/AWOS One-Minute-Observation (OMO), 2) the computer-generated voice messages (i.e., the ground-to-air radio and telephone dial-in message), and 3) the hourly Meteorological Aviation Report (METAR) and METAR intra-hourly Special Aviation Weather Report (SPECI).

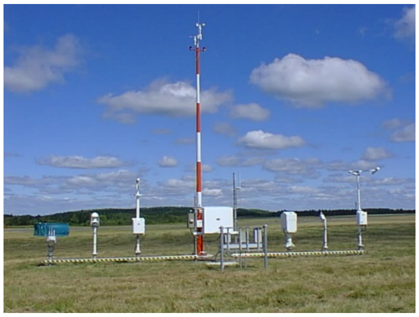


Figure 3. ASOS sensor suite, with cup-and-vane anemometer on 10 meter pole.

2.3 F-420 SERIES ANEMOMETERS

2.3.1 Background

Pre-dating the automation era, one of the earliest systematic deployments of electronic wind sensing in the NAS was the F-420 series of cup and vane anemometers, which were installed beginning in the late 1950s. While later years saw deployment of newer generation surface weather sensing suites and anemometer-based wind shear detection systems at the nation's medium-large airports, many of the small–medium sized airports continued to be serviced by the legacy F-420 systems up until the present day. These legacy sensors are currently in the process of being replaced as part of a widespread FAA wind sensor upgrade effort expected to be completed by the end of 2018.

2.3.2 General Characteristics

The F-420 provides analog output of wind speed and direction to a dedicated display. A local weather observer uses visual/mental averaging to estimate wind speed direction during a 1-minute period in order to report an hourly observation at the top of each hour.

2.4 LOW LEVEL WINDSHEAR ALERT SYSTEM

2.4.1 Background

Additional sources of wind information in the terminal airspace emerged beginning in the 1970s through the deployment of sensors designed to detect hazardous wind shear. The first such system was the anemometer-based LLWAS. LLWAS uses wind measurements from multiple sensors situated on tall poles (typically ~150 feet above ground level (AGL), sited sufficiently high to avoid obstruction) at various locations within the terminal area. Measurements are taken every 10 seconds and sent to a central processer, where algorithms examine wind differences to determine the presence and magnitude of hazardous shear.

The first generation of LLWAS systems was installed at 110 FAA towered airports between 1977 and 1987. Wind shear was detected by examining the vector difference between a centrally located sensor (Center Field, or CF) and five remotely situated sensors around the airport runway or runway complex. Between 1988 and 1991, LLWAS systems were upgraded with improved software and hardware (LLWAS-2) to improve wind shear detection and reduce false alarms. Coincident with the advent of radar-based wind shear detection systems in the 1990s, LLWAS underwent a series of modifications associated with algorithmic and sensor upgrades. The first major modification was LLWAS Network Expansion (LLWAS-NE) which increased the number of wind sensors at an airport by extending coverage up to 3 miles beyond runway thresholds. A second major modification called LLWAS Relocation/Sustainment (LLWAS-RS) involved upgrade of sensors and some site relocations at a number of airports. At other airports (of the original 110 locations), the LLWAS system was decommissioned because it was considered redundant with recently deployed radar-based systems, or because the impact was not considered cost effective. There are currently 49 remaining LLWAS sites of either the NE or RS variety, of which 9 are co-located and integrated with radar-based wind shear detection systems.

2.4.2 General Characteristics

The configuration of wind sensors comprising an LLWAS network is designed such that the station geometry provides adequate coverage for detection of wind shear that may impact a runway or airspace extending up to 3 miles beyond a runway threshold. (Runway thresholds are boundaries that define the beginning and end of the designated space for landing and takeoff under non-emergency conditions.) As such, the number and location of individual LLWAS anemometers at an airport are dependent upon airport runway layout configuration and size. To provide appropriate station geometry, stations are typically located along either side of a runway (and runway extension), with a typical distance of 1 to 2 miles between neighboring stations. The number of LLWAS anemometers at an airport ranges from as few as six at smaller, single runway airports to as many as 31 (at Denver International Airport). In the original version of LLWAS, one of the sensors within an airport's station network was designated as "Center Field" or "CF", in that it was a centrally located sensor whose wind was compared against that of the other "remote" sensors in order to identify wind shear. LLWAS-CF is used for deriving the "airport wind" or "AW", which designates a single sensor as providing a wind observation that is most representative of the runway complex area. Furthermore, at airports whose LLWAS system has been decommissioned, the former Center Field sensor has been retained to continue providing the designated airport wind. The anemometer equipage at this station is referred to as the airport Wind Measuring Equipment (WME), distinguishing it from ASOS/AWOS, which also typically provides a centrally located airport wind observation.

LLWAS siting guidelines require that the station anemometer is installed at a sufficient height to ensure that wind measurements are unaffected by nearby obstructions which may cause sheltering or channeling of wind which could mask wind shear detection capability. As such, the network anemometers are not constrained to a single prescribed height, unlike ASOS/AWOS anemometers, which are uniformly situated at ~32 feet AGL. Generally, LLWAS anemometers are installed on taller poles, with a typical height of ~150 feet AGL.

In order to provide timely detection of wind shear, LLWAS winds are reported at 10-second intervals (comprised of an approximately 8-second sample). At the designated LLWAS-CF sensor, a 2-minute average wind and wind gust (analogous to ASOS/AWOS) is also computed every 10 seconds. Additionally, at the remote LLWAS sensors, a 30-second average is computed (derived from the 10-second winds) in order to provide a more stable "threshold wind" intended to be representative of wind conditions closer to proximate runway thresholds. The threshold wind does not include gust information.

2.5 WIND MEASURING EQUIPMENT

2.5.1 Background

Widespread deployment of radar-based wind shear detection systems in the 1990s led to decommissioning of more than half of the original 110 LLWAS airport installations. However, the Center Field sensor within each of these decommissioned networks was retained and assigned the nomenclature WME, and continued to provide the 2-minute average and gust wind information. The general policy at most of these airports is that the WME be routinely designated as the Airport Wind, with the implication that, as a centrally located wind measurement, it is generally representative of the wind conditions at that airport. This is significant in that it has widely become the default wind observation reported by air traffic controllers upon establishing voice communication with pilots during the approach procedure. It is also important to note that the presence of a WME, in addition to the airport surface weather sensing system (ASOS/AWOS or their equivalents) allows for a second centrally located wind observation within an airport. This creates an opportunity for both redundancy and potential discrepancy in establishing a single representative airport wind report.

2.5.2 General Characteristics

The WME wind maintains the characteristics of its previous incarnation as the LLWAS CF wind, providing a 2-minute average wind and wind gust updated every 10 seconds, originating at a generally centralized airport location at a height sufficient to avoid the influence of obstructions.

2.6 STAND ALONE WEATHER SYSTEM (SAWS)

2.6.1 Background

The SAWS was introduced by the FAA in 2001 and, similar to the F-420 Series and as its name implies, is a standalone weather system with its own sensors and displays, not integrated with other systems. Deployment was targeted to upgrade aging weather sensors and provide an FAA-owned backup to ASOS/AWOS at Service Level C airports.

2.6.2 General Characteristics

The SAWS consists of a sensor unit, a control and display unit which receives telemetered data and distributes it to as many as 7 displays, and a matrix style display that is both daylight readable but also suitable for darker environments. It is the first FAA weather station to employ an ultrasonic anemometer. The sensor system provides wind speed and direction, temperature, and barometric pressure.

Wind speed and direction are measured every second and averaged every three seconds. The 3-second average is displayed as an instantaneous wind. Running average is calculated from the 3-second averages, with a user-selected running average option of 15, 30, 60, or 120 seconds.

2.7 SURFACE WEATHER SYSTEM

2.7.1 Background

As a major FAA sustainment effort, the SWS was designed to replace the aging cup and vane anemometers used in the WME and F-420 systems with ultrasonic wind measurement sensors. Additionally, the wind processing algorithm within SWS provides uniformity between the two existing sensor variations, and is more consistent with the processing used to compute ASOS/AWOS sustained wind and gust values. The SWS platform is wireless, and allows for networked communication between multiple platforms.

The replacement process began in 2017 and is expected to be completed by the end of 2018. As part of this effort, an attempt is made to improve sensor pole siting at existing locations where local obstructions are known to diminish data quality, and in some instances install tilt-down poles for easier maintenance. In addition to providing wind information, the SWS sensor suite also includes measurements of temperature, humidity, and pressure.

2.7.2 General Characteristics

The SWS wind algorithm processing provides 2-minute sustained wind and wind gust values consistent with those provided by ASOS/AWOS. In instances where a single airport may have multiple SWS sensors, the more centrally located sensor provides a 2-minute average and gust information, with additional sensors providing 30-second wind values analogous to that provided by LLWAS.

2.8 WINDSOCKS

2.8.1 Background

Windsocks are conical fabric tubes whose physical response to wind conditions provide an immediate indication of local wind speed and direction. They were amongst the earliest mechanisms for determining airport wind conditions for supporting aviation operations, and continue to be prevalent at airports of all sizes due to their simplicity, immediate response as a visual indicator to pilots, and low operation and maintenance requirements. Airports will typically have multiple windsocks to provide visual wind information at the threshold of each runway.

2.8.2 General Characteristics

Per FAA standards, a properly functioning windsock will orient itself directionally in a wind speed of at least 3 knots. At higher speeds, the elevation of the sock angle or the length of extended sock is proportional to wind speed, with the sock becoming fully extended at 15 knots. Socks are often colored in alternating bands to indicate wind increments of 3 knots (Figure 4).

Figure 4. Windsock.

2.9 RADAR-DERIVED WIND INFORMATION

2.9.1 Background

Upgrade of the U.S. weather radar network and development of radar-based wind shear detection introduced new sources of wind information for aviation applications during the 1980s and 1990s. The WSR-88D radar system network was deployed in the late 1980s as part of a tri-agency effort (NWS, FAA, DoD) to replace the aging WSR-57 radars as the nation's primary operational weather radar. These S-band Doppler radars provide radial velocity data that are analyzed algorithmically for signatures of wind hazards associated with convective weather, such as mesocyclones and tornadoes. This was followed in the 1990s by deployment of 45 FAA C-band TDWR, specifically designed to provide high fidelity radial wind measurements in the vicinity of major airport terminals that have relatively high exposure to wind shear. In parallel, the WSP was implemented as a lower cost alternative to TDWR at medium traffic airports, wherein existing aircraft surveillance radars were modified to provide lower fidelity wind information that was suitable for providing some level of wind shear detection capability. Later in the decade saw FAA deployment of the ITWS, which consolidated the myriad of weather information sources in the terminal airspace, which includes TDWR, ASR-9 surveillance radar weather channel data, WSR-88D, LLWAS, ASOS/AWOS, and wind observations derived from aircraft.

2.9.2 General Characteristics

Basic wind information from the WSR-88D is presented to the user community in the form of radial velocity imagery. The radial component of the wind direction (with respect to the radar location) is displayed on plan-view maps for each radar tilt angle. A separate product provides a graphical indication of velocity spectrum width, which is essentially proportional to radial wind variance. Radial velocity information is also used to detect signatures associated with convective weather mesocyclones and tornado vortex signatures, which are also displayed graphically with visual icons. A Principal User Interface (PUP) is available to National Weather Service and DoD personnel for direct viewing of WSR-88D products. Most other users may view products via public Internet distribution.

TDWR radars also provide high fidelity pencil-beam radial velocity information. In addition, they provide graphical representation of the location and movement of convective outflow gust fronts, as well as location of hazardous wind shear in the form of microburst alerts. These products have been integrated into the ITWS display interface, which is now the primary mechanism for distribution of radar-derived weather information to control tower cabs. Additionally, ITWS uses the TDWR radial velocity information and wind information from ground sensors and aircraft to produce a Terminal Winds product. This product provides wind speed and direction vertical profiles on a 2 km grid surrounding the terminal air space at 1000-foot vertical increments.

2.10 AIRCRAFT-DERIVED WINDS

2.10.1 Background

Aircraft meteorological observations have been around since the early part of the 20th century, pre-dating our current weather balloon sounding system by decades. The original aircraft were military biplanes that flew designated trajectories to gather information. By 1950, the International Civil Aviation Organization had established Standards and Recommended Practices related to meteorology that included a section on aircraft based observations. Around 1980, weather-observing equipment began to be installed in aircraft and those observations were automatically reported by some airlines via datalink. Over the next few decades, the number of participating aircraft grew rapidly into a system integrated into both aviation operations and weather forecasting.

2.10.2 General Characteristics

Aircraft-derived wind observations are winds computed from measurements made onboard an aircraft. These aircraft-derived observations are computed from a combination of information that is part of the aircraft functioning and specialized equipment for making these measurements. Standards for these observations are set by the World Meteorological Organization (WMO), which has over 180 member countries participating. Although some aircraft can measure wind, most wind observations are derived from the innate aircraft systems using location, flight heading, and actual heading to estimate the experienced wind.

According to WMO guidelines, the frequency of reporting should be tied to flight phase, with increased frequency during take-off and landing. A typical scenario might be every 20 seconds for the first/last few minutes, every minute between this point and cruise altitude, then infrequently (7 to 60 minute frequency) while en route. These are the ideal reporting frequencies, but are not required, so actual flight profiles may have significantly fewer observations. For these profiles, wind direction is reported in terms of degrees true north rounded to the nearest whole degree. Wind speeds can be reported in either km/hour or knots, rounded to the nearest 2 km/hour or 1kt. There is also required a quality flag to indicate when the roll angle of the aircraft is 5 degrees or more (which invalidates the wind measurement). The result is a series of wind vectors of expected quality similar to those derived from radiosondes, with expected uncertainties of 2 to 3 m/s.

Wind information is primarily transmitted via the Aircraft Communications Addressing and Reporting System (ACARS), a datalink system introduced by Aeronautical Radio, Incorporated (ARINC) in 1978. More recently, these aircraft observations have been transmitted via a Mode S datalink, wherein a ground system interrogates an appropriately equipped aircraft, requesting information from which wind observations can be derived. The frequency of these reports is about one every 5 to 10 seconds. Uncertainties of wind direction when compared to a numerical weather prediction model are 10 to 15 degrees and 2–2.5 m/s for wind speeds.

3. ACQUISITION AND DISTRIBUTION OF WIND INFORMATION

3.1 OVERVIEW

This section describes the primary distribution mechanisms for making terminal wind information available to air traffic controllers and pilots. Information to air traffic controllers is largely distributed via displays situated in the control tower cab, the configuration of which depends on local wind sensor equipage, which in turn is largely dependent upon airport physical size and number of operations. Information distributed to pilots will vary by the size/equipage of aircraft, with many of the differences associated with the distinction between commercial and general aviation operations. Figure 5 shows a superset of the various wind data sources, control tower cab display nodes, and communications links for conveying wind information to pilots.

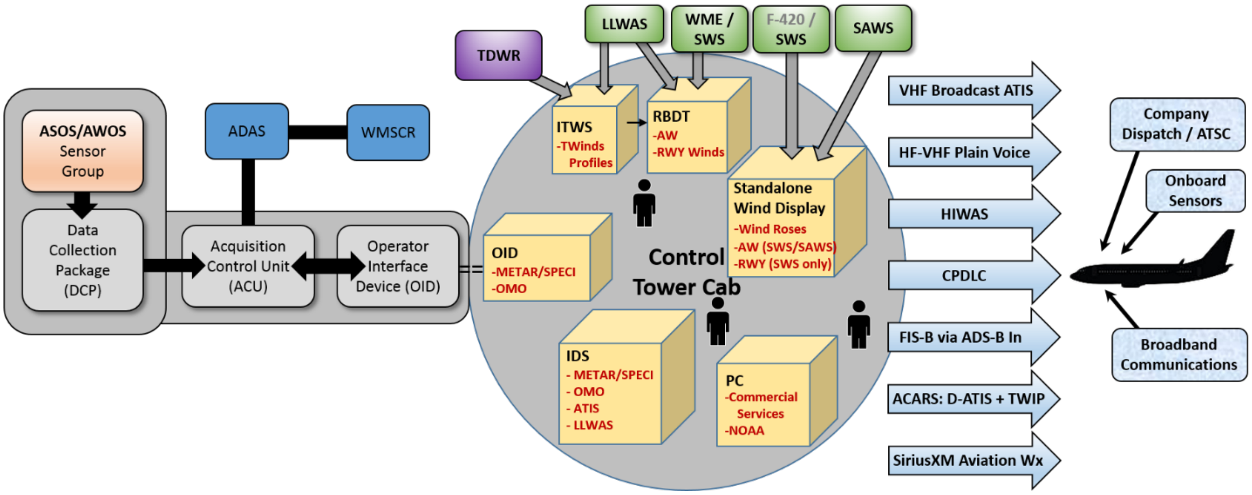


Figure 5. Mechanisms for distribution of wind information to air traffic control tower cab and pilots.
Note: due to the wide variability between sites, details of data exchange between the tower systems are not shown in this diagram.

For the purposes of this discussion, seven general configurations for acquiring and distributing wind information are identified:

1) *Configuration 1:* Large airports with significant wind shear exposure that are within coverage range of a TDWR radar and are also equipped with an LLWAS network of anemometers. [Currently 9 airports]

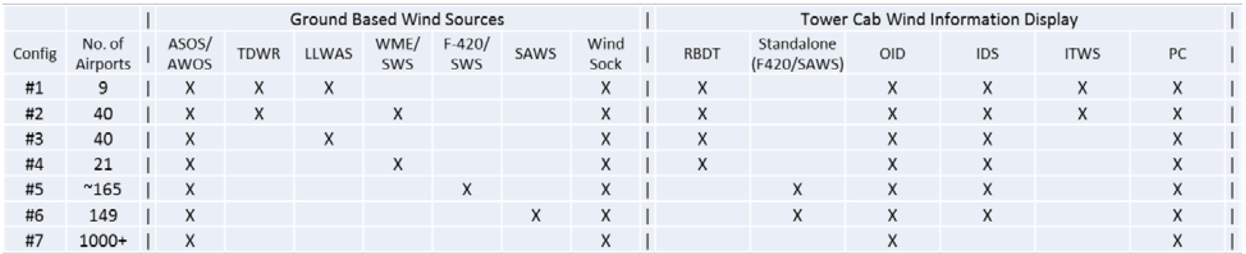
2) *Configuration 2:* Large airports within coverage range of a TDWR radar, with an FAA airport wind provided by a WME. [Currently 40 airports]
3) *Configuration 3:* Large airport outside of TDWR radar coverage but equipped with an LLWAS sensor network for wind shear detection [Currently 40 airports]
4) *Configuration 4:* Medium to large airports for which a previously deployed LLWAS has been decommissioned, where a WME has been retained for providing an FAA airport wind measurement. (The existing WME sensor at these airports is being replaced by a current generation SWS sensor.) [Currently 21 airports]
5) *Configuration 5:* Small to medium airports serviced by a legacy F-420 series sensor, which is being replaced by the current generation SWS sensor system (including display). [Currently approximately 165 airports]
6) *Configuration 6:* Small to medium airports serviced by the SAWS. [Currently 149 airports]
7) *Configuration 7:* Small airports whose primary local wind observation source is from an ASOS/AWOS surface weather station. [Currently more than 1000 airports]

The wind information displays in an airport control tower cab is essentially determined by the sensor equipage associated with each of these configurations. Figure 5 shows the six primary display mechanisms, which include:

1) A Ribbon Display Terminal (RBDT), initially designed for displaying runway-specific wind shear information.
2) A standalone (not integrated into another system) display unit which shows an analog (or digitized analogy rendering) wind dial presentation (sometimes referred to as “wind rose”), originally designed and implemented for cabs at airports serviced by F-420 wind sensors, currently being replaced by SWS system displays. This type of wind rose display was also adopted for deployment of SAWS.
3) The Operator Interface Device (OID), primarily intended for editing and distribution of ASOS/AWOS data
4) The FAA Information Display System (IDS), for viewing a wide variety of aviation-related information including wind and weather.
5) The ITWS display, which serves as the primary interface for TDWR radar information.
6) A Personal Computer (PC) with display monitor, for general Internet access.

Table 2 below summaries the sensors and display nodes associated with each of the seven general configurations. A more detailed description of each distribution mechanism is provided in 3.2. Communication links for conveying wind and weather information to pilots are described in 3.3.

Table 2. Typical Configurations of Wind Sensing Equipment and Associated Mechanisms for Distribution of Wind Information to Users



		Ground Based Wind Sources							Tower Cab Wind Information Display					
Config	No. of Airports	ASOS/ AWOS	TDWR	LLWAS	WME/ SWS	F-420/ SWS	SAWS	Wind Sock	RBDT	Standalone (F420/SAWS)	OID	IDS	ITWS	PC
#1	9	X	X	X				X	X		X	X	X	X
#2	40	X	X		X			X	X		X	X	X	X
#3	40	X		X				X	X		X	X		X
#4	21	X			X			X	X		X	X		X
#5	~165	X				X		X		X	X	X		X
#6	149	X					X	X		X	X	X		X
#7	1000+	X						X			X			X

3.2 WIND INFORMATION AVAILABLE IN TERMINAL CONTROL TOWER CABS

3.2.1 Ribbon Display Terminal

The Ribbon Display Terminal (abbreviated RBDT, and typically referred to as simply the “ribbon display”) is the primary device for delivery of wind information to the control tower cab at medium to large commercial airports with ground-based wind shear system protection. (See Figure 6.) Ribbon displays were largely intended for standardized presentation of runway-specific wind shear alert information derived from either LLWAS or TDWR (or both); they also provide a key distribution mechanism for individual airport wind observations.

The top line of the ribbon display is designated for displaying the so-called “airport wind”, abbreviated as AW. This wind is intended as the single FAA wind observation designated by default as representative of local terminal area near-surface wind conditions relevant to aircraft operations. It includes a 2-minute average wind speed and direction updated every 10 seconds, and a calculated wind gust. The source of this wind depends upon the local airport sensing equipage. For airports serviced by LLWAS, the airport wind source is the 2-minute average of the 10-second wind values measured from what is typically the most centrally located LLWAS wind sensor on the airport, formerly referred to as the Center Field. For airports where a previously existing LLWAS system has been decommissioned, the source is the so-called WME, which is the former LLWAS-CF sensor.

The remaining lines of the ribbon display provide runway-specific wind shear and wind information. For airports with wind shear detection capability provided by either LLWAS or TDWR, or an integrated LLWAS-TDWR system, these subsequent display lines provide runway-specific alert information when wind shear has been detected, indicating the type and strength of shear. When there are no active wind shear alerts on a runway, these display lines at airports equipped with LLWAS sensors provide what are referred to as “runway threshold winds”. These runway-specific winds are derived from the wind observations measured at the LLWAS sensor nearest to the end of each runway. They are comprised of a 30-second average of 10-second LLWAS wind measurements. Runway threshold winds do not include gust information.

Figure 6. Ribbon Display Terminal (RBDT).

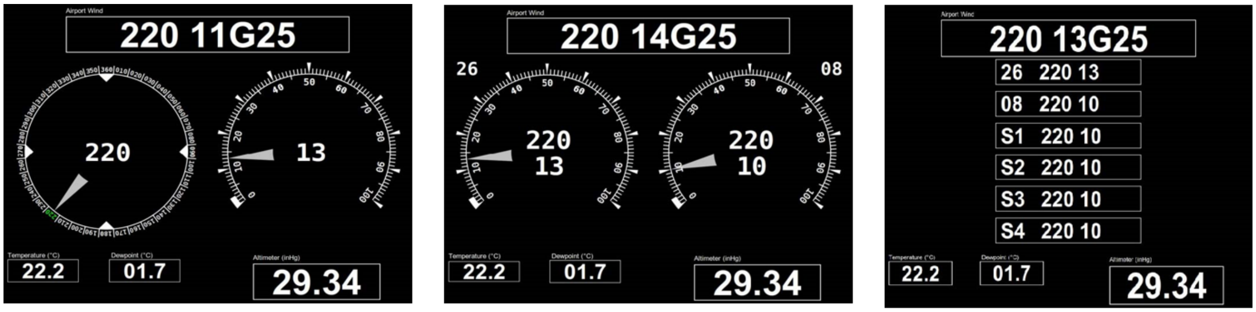
3.2.2 Standalone Weather Display Units

3.2.2.1 F420 Display / SWS Weather Display

More than 150 small-medium size airports that are not equipped with LLWAS or WME are serviced by legacy F-420 series wind sensors. These sensors are associated with a dedicated display for viewing wind information Values are presented to the users in an analog dial format, with separate dials or "wind roses" for wind speed and wind direction. No computed average (equivalent to those on the ribbon display) are available. In order to report an hourly observation at the top of each hour, a local weather observer uses visual/mental averaging to estimate wind speed direction during a 1-minute period.

All of the F-420 sensors and displays will be replaced by the SWS system by the end of 2018. The SWS Display (Figure 7) retains a digitized version of the analog dial representation for showing continuous current wind speed and direction values, plus a digital representation of a 2-minute average wind and wind gust (consistent with WME, LLWAS-CF, and ASOS). The display also includes temperature, dew point, and altimeter pressure information (Figure 7-A).

The look of the SWS Display is modified for airports with more than one SWS sensor. For airports with two sensors, the display shows two side-by-side wind direction dials, with the wind speed and direction displayed digitally inside the dial, with the airport wind speed and gust shown above, and temperature, dew point, and altimeter shown below (Figure 7-B). For airports with more than two SWS sensors, the display is more analogous to the ribbon display at LLWAS airports, showing the airport wind 2-minute average speed and gust, plus individual wind speed (30-second average) and direction for each sensor, which may also receive a runway-specific designation (Figure 7-C).



(A) (B) (C)

Figure 7. SWS display options, for airports with A) a single SWS sensor, B) two SWS sensors, and C) three or more SWS sensors.

3.2.2.2 SAWS Display Unit

SAWS wind and weather information is delivered to a standalone display unit (Figure 8). Consistent with the F-420 display concept, it presents instantaneous wind direction on an analog-format wind dial (or rose), with a digital representation of instantaneous wind speed. It also shows a five-character representation of a time-averaged wind speed/direction, with user-selected averaging period options of 15, 30, 60, and 120 seconds. Also displayed are temperature, dew point, and atmospheric pressure.

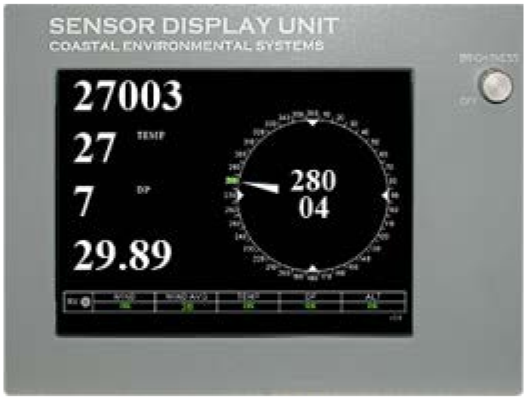


Figure 8. Stand Alone Weather System (SAWS) Display Unit.

3.2.3 ASOS/AWOS Operator Interface Device

The extensive network of surface weather observing stations jointly owned by the FAA and NWS (most typically ASOS or AWOS) provides the most prevalent source of wind information across the NAS, with sensor deployment across a much broader spectrum of airport sizes compared to the medium-to-large airports that are equipped with FAA-owned LLWAS, WME, or F420 wind sensors. In all, more than 1500 such stations provide wind and weather information used to support aviation operations across the NAS. These sensors also serve as the backbone of U.S. weather information supplied for global weather information distribution to support the ICAO. As such, these weather systems are associated with an extensive acquisition, processing, and distribution mechanism for which an overview is provided here, as depicted in Figure 5.

The ASOS and AWOS systems are comprised of a sensor group for collecting a myriad of weather information that includes temperature, humidity, air pressure, wind, cloud amount and height, horizontal visibility, and precipitation (type, intensity, and accumulated amount). Raw measurements are continually gathered by a collocated Data Collection Platform (DCP), and then transmitted to the Acquisition Control Unit (ACU), which is the central processing unit for formatting, quality control, storage, and archiving. A number of formats are automatically generated by the ACU, which include:

1) The hourly METAR, also referred to as Aviation Routine Weather Reports
2) Aviation Selected SPECI, which are intra-hourly updates of the hourly METAR, generated whenever a prescribed aviation-critical threshold is crossed
3) One Minute Observation (OMO) data
4) Standard Hydrometeorological Exchange Format (SHEF) messages
5) Auxiliary and Maintenance data
6) Daily and Monthly Summary messages

The ACU makes the data available to users through a variety of outlets. These include the Weather Message and Switching Center Replacement (WMSCR), which makes the data available via the Automated Weather Observation System Data Acquisition System (ADAS), computer-generated voice available to pilots, and general aviation dial-in telephone lines.

A key outlet of the ACU is the OID, shown in Figure 9. Multiple OIDs at different locations may be associated with a single ACU, e.g., at the local NWS office and a local airport tower cab. The OID allows users, often NWS personnel (or their contractors), to make manual modifications to the messages generated automatically by the ACU prior to further distribution. These modifications may include back-up or augmented data, or corrections to the original automated message. It is important to note that, although the ASOS message (METAR/SPECI or OMO) may be accessed and viewed on the OID screen workspace, it is often not located in a convenient location for viewing within the cab space, or routinely viewed as a primary display device. The OID ultimately distributes weather (including wind) information to nodes in the tower cab.

Figure 9. ASOS/AWOS Operator Interface Device (OID).

3.2.4 FAA Information Display System

The FAA IDS in an ATC tower cab receives and makes available to users the various sources of locally acquired wind/weather data, including LLWAS if available, and the METAR/SPECI and OMO formatted data for use by controllers at operational positions such Ground, Local, and Flight Data (Figure 10). The IDS also ingests and makes available non-weather operational information, and is a complete data display, data integrator, and data sharing platform. It is common for each primary position within the tower cab to have a dedicated ID.

The IDS display is essentially panel-formatted, meaning that the user can select various panels of information separated by type, which can be displayed simultaneously. For instance, an operator may select a panel that provides METAR/SPECI weather observations or one that displays the OMO ASOS format, or both. Of course, other panels containing non-weather information may also be displayed. It is worthy to note that, because of its availability at each controller position, this is often the primary mechanism for viewing ASOS wind information in the tower cab, rather than via a separate device specifically intended exclusively for wind/weather-related information, such as the ribbon display or other standalone wind display units.

The IDS also serves as the key interface for the Automatic Terminal Information System (ATIS). ATIS is a continuous broadcast of recorded aeronautical information system that is accessible in the terminal airspace of busier airports. In addition to information relevant to runway operations, the ATIS broadcast is a key source of weather information to pilots on approach.

The recorded ATIS broadcast is updated at fixed intervals or when there is a significant change in information. Regarding weather, the ATIS broadcasts the ASOS/AWOS METAR/SPECI observation. This means that the wind information provided via the ATIS broadcast is routinely updated hourly, or when there is a significant change to an aviation-related weather parameter. For a wind-only change to trigger the update, the requirement is a wind shift of at least 45 degrees in less than 15 minutes with a wind speed of at least 10 knots throughout the shift. The faster-update OMO winds available from ASOS/AWOS are not routinely included in the ATIS broadcast.

03/17/98 11:46:01

Status Info Pg 03/17 11:24

ALTIMETER 30.05

WINDS 290 10G14

ATIS D

APPROACH ILS

FANS 250-310

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KDMO 180853Z 29007KT 3SM -RA BR
BKN035 OVC060 18/17 A3005 RMK AO2
SLP124 P0004 60039 T01780167 53016
$=
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PIREPS

MOD CHOP AT 30 REPORTED BY MD88 ON FINAL RWY 26L

SEVERE TURB. REPORTED BY B757 35 NE OF MCI @ FL270

NOTAMS

TXWY "C" CLSD APCH END RWY 27 UFN FOR CONSTRUCTION.

GROUND DELAYS

ORD DFW ATL LGA SFO BOS

RVR

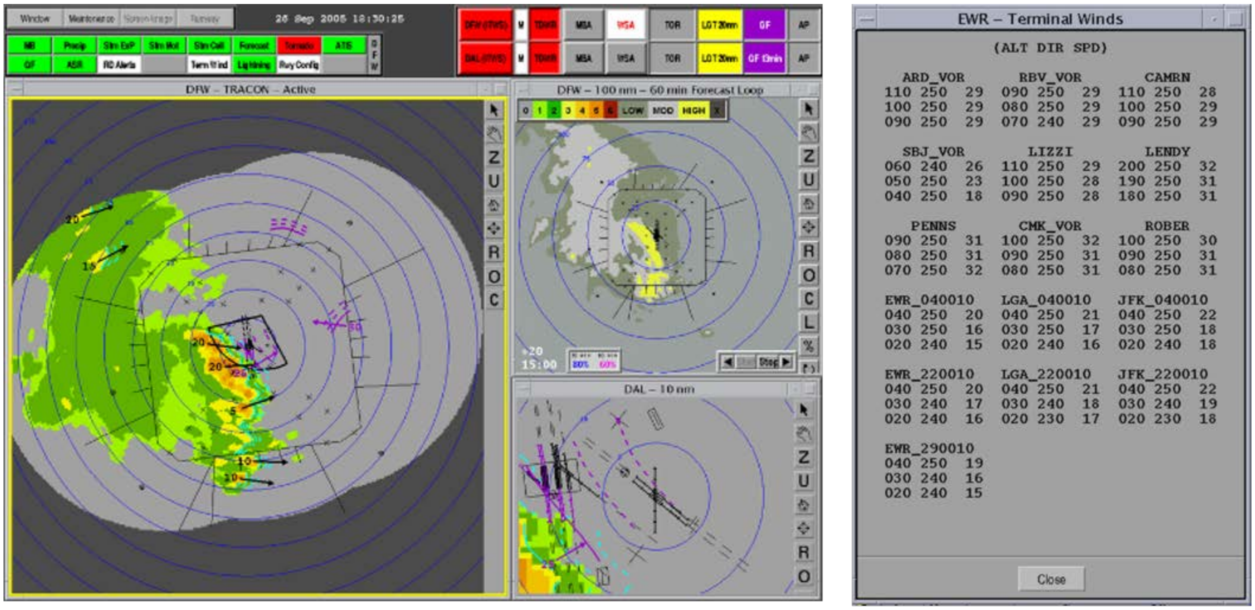
RWY	TD	MP	RO	E	C
26L	1900+	2100+	2300+	0	N
27R	2300+	2100+	1900+	0	N
09L	1900+	2100+	2300+	0	N
08R	2300+	2100+	1900+	0	N

Figure 10. FAA Information Display System (IDS).

3.2.5 Integrated Terminal Weather System

Radar-derived weather information, most notably from TDWR, is made available in the tower cab through the ITWS display, which integrates data from a number of sources in the terminal area. Most graphical products provide depictions of convective weather, precipitation intensity motion, precipitation type, wind shear information, and lightning. Displays of convective weather location and intensity may be overlain with location and movement of gust fronts, which represent wind shift boundaries associated with convective outflow (Figure 11A).

ITWS also acquires data from non-radar sources, such as ASOS, LLWAS, and aircraft derived wind measurements. Coupled with radar radial velocity information, these data are used to create a Terminal Winds Product, which is a local scale analysis of wind conditions in the terminal area at 2 km horizontal spacing and 1000 foot vertical spacing. From this analysis, wind profiles for atmospheric layers at expected flight altitudes at key air traffic locations, (e.g., arrival fixes and markers) are delivered in a text product format (Figure 11B). Additionally, the ITWS display allows a pop-up window which replicates the ribbon display information described in 3.2.1.



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(ALT DIR SPD)

  ARD_VOR        RBV_VOR        CAMRN
110 250  29   090 250  29   110 250  28
100 250  29   080 250  29   100 250  29
090 250  29   070 240  29   090 250  29

  SBJ_VOR         LIZZI         LENDY
060 240  26   110 250  29   200 250  32
050 250  23   100 250  28   190 250  31
040 250  18   090 250  28   180 250  31

   PENNS         CMK_VOR        ROBER
090 250  31   100 250  32   100 250  30
080 250  31   090 250  31   090 250  31
070 250  32   080 250  31   080 250  31

EWR_040010    LGA_040010    JFK_040010
040 250  20   040 250  21   040 250  22
030 250  16   030 250  17   030 250  18
020 240  15   020 240  16   020 240  18

EWR_220010    LGA_220010    JFK_220010
040 250  20   040 250  21   040 250  22
030 240  17   030 240  18   030 240  19
020 240  16   020 230  17   020 230  18

EWR_290010
040 250  19
030 240  16
020 240  15
```

(A) (B)

Figure 11. ITWS display panels. A) Convective weather display showing location and movement of gust fronts in purple. B) Terminal Winds product, showing wind information at three flight levels at 16 different fix locations.

3.2.6 Personal Computer/Internet Access

In addition to FAA-specific data delivery and display mechanisms, tower cabs are often equipped with a general purpose PC that can be used to access publicly available information via the Internet. This includes wind and weather information from private commercial vendors, or from a host of aviation weather products provided by NOAA, most notably those generated at the FAA Aviation Weather Center.

3.3 WIND INFORMATION AVAILABLE TO PILOTS

3.3.1 ATIS VHF Broadcast

Automatic Terminal Information Service is a continuous recorded broadcast of the latest airport weather and aeronautical information. Voice synthesized audio is available through published very high frequency (VHF) radio frequencies to reduce controller-pilot radio chatter. Weather information includes the most current METAR observation and remarks along with any airport hazard such as wind shear or microburst alerts.

3.3.2 HF-VHF Plain Voice

Terminal and en route weather information is conveyed verbally between air traffic control and pilots through high frequency (HF) and very high frequency voice communications. Pilot reports (PIREPs) of cloud height, visibility, wind, airspeed losses/gains, thunderstorms, turbulence, and icing, are often provided and requested through plain voice transmission.

3.3.3 Hazardous Inflight Weather Advisory Service

The Hazardous Inflight Weather Advisory Service (HIWAS) provides continuous recorded weather forecasts broadcast to airborne pilots over selected very high frequency omnidirectional radio (VOR) frequencies. Information includes Airmen’s Meteorological Information (AIRMETS), Significant Meteorological Information (SIGMETS), Convective SIGMETS, Center Weather Advisories (CWAs), severe Alert Weather Watches (AWWs) and urgent PIREPS.

3.3.4 Controller-Pilot Direct Link Communications

Controller-Pilot Direct Link Communications (CPDLC) is a two-way aeronautical data-link through which air traffic controllers and pilots can transmit non-urgent strategic text messages to/from aircraft as an alternative to voice communications. Messages are displayed on a flight deck visual display and may include weather and weather deviation requests.

3.3.5 Flight Information Services-Broadcast via ADS-B

Flight information Services-Broadcast (FIS-B) via ADS-B is a method of disseminating meteorological and aeronautical information to displays in a cockpit. FIS-B is a ground based data-link service provided through the Automatic Dependent Surveillance-Broadcast (ADS-B) Universal Access Transceiver network. The free advisory service is used by general aviation pilots to obtain METARs, Terminal Aerodrome Forecasts (TAFs), winds aloft, NEXRAD precipitation maps, AIRMETs, SIGMETs, etc.

3.3.6 ACARS: Digital ATIS and TWIP

Data-Link ATIS (D-ATIS) is a text-based, digitally transmitted version of the ATIS audio broadcast. It is accessed via a data-link service such as the Aircraft Communications Addressing and Reporting System. D-ATIS may be used outside the standard operating range of conventional VHF ATIS. Terminal Weather Information for Pilots (TWIP) is accessed via ACARS and consists of text messages and character graphic maps describing precipitation and wind shear hazards at TDWR-ITWS supported airports. TWIP is transmitted every 1 to 10 minutes.

3.3.7 Company Dispatch and Air Traffic System Control

Certified airline company dispatchers and air traffic system controllers communicate weather information directly to their pilots via HF, VHF, and Satellite Communications (SATCOM) radio. Publicly available and proprietary information is also disseminated from airline operations control centers (AOC) or system operation centers (SOC) through data-link service. Weather forecasts created by AOC/SOC meteorologists are legally authorized for flight planning purposes and flight following.

3.3.8 Onboard Sensors

Standard sensors and instruments installed on commercial or general aviation aircraft can detect and derive atmospheric wind, temperature, humidity, and pressure information. Data are used in-flight for situational awareness and may be transmitted to ground for assimilation into national models. On-board weather radar is used to detect or predict precipitation, convection, turbulence, and icing. Mode-S Enhanced Surveillance (EHS) enables interrogation of specific aircraft registers to extract or derive aircraft wind speed, direction, and temperature. Mode S EHS is widely available to provide immediate access to aircraft-derived observations through onboard sensors and Global Positioning System (GPS). The update rate is every 4.8–12 seconds and encompasses from near the surface to typical cruise altitudes. Aircraft-derived weather observations are the most important input for wind and temperature forecast accuracy.

3.3.9 Broadband Communications

High-speed internet access is available aboard many aircraft through various commercial wireless and satellite communications providers. Cockpit internet connectivity and in-flight Wi-Fi provides laptop computers and tablets (e.g., iPads or “Electronic Flight Bags”) direct access to all forms of near real-time weather data similar to ground-based users.

3.3.10 SiriusXM Aviation Weather

SiriusXM Aviation Weather is a popular subscription based service available through satellite downlink and is unidirectional and broadcast, that is, does not need to be requested. Products may be viewed on a laptop, tablet, ForeFlight application, etc., and are published at fixed periods; for example, icing every 15 minutes and NEXRAD data every 5 minutes. Over 40 elements are available including METARs, TAFs, graphical winds, echo tops, and turbulence.

4. WIND INFORMATION USE AND REQUIREMENTS

Wind information to support aircraft operations within the NAS is primarily used to address two important considerations: 1) aircraft control for ensuring safe operations, and 2) air traffic flow control to optimize system efficiency, particularly in the context of terminal and en route capacity constraints. Terminal area wind observations are most relevant to the former and are the focus of this analysis, whereas the latter is more dependent on wind forecasts, ranging in time horizons from a few minutes to many hours.

Regarding aircraft control for ensuring safety, wind information can be further broken down into a headwind/tailwind component that affects vertical control, takeoff/landing distance, and in-trail separation, and a crosswind component that affects lateral control of the aircraft, most importantly during takeoff, approach, and landing. Crosswinds can also be an impacting factor for aircraft control during taxiing operations. From an airport management perspective, wind information also plays an important role in selecting airport runway configurations to ensure continued safe and efficient operations.

Allowable thresholds for departure and arrival headwind/tailwind and crosswind components vary by aircraft size/type, runway length, and runway condition (dry or wet). The maximum tailwind component for both types of operation on a dry runway surface with no significant limitation in runway length is typically 10–15 knots. A 10-knot threshold is more typical for smaller general aviation aircraft, whereas the higher 15-knot limit might apply to the largest commercial jets. Reduction from these maximum limits would be made in accordance with the aforementioned considerations for specific airframe and runway length/conditions.

Manufacturers publish crosswind limits specific to each aircraft, which are associated with a "maximum demonstrated crosswind landing" that essentially set an upper limit on allowable crosswind. These limits will be largely dependent on aircraft size (and may vary for runway condition), with commercial jets ranging from 20–40 knots for takeoff and 30–45 knots for landing. Limits for smaller general aircraft are more typically in the 15–20 knot range. Most commercial airlines establish a crosswind threshold for departure and arrival operations that is lower than the allowable manufacturer limit. In addition to takeoff and landing operations not being allowed when these thresholds are exceeded, departure of commercial aircraft will be delayed or cancelled if there is an expected exceedance at the destination airport at the anticipated time of arrival, based on wind forecasts (primarily as indicated in the TAF). The ultimate decision to take off or land, of course, also requires that crosswind conditions not exceed safe levels as assessed by the pilot under the circumstances associated with each individual operation, which may be a lower threshold than prescribed allowable limits established by airline policy. This of course holds true for general aviation pilots who are not bound to commercial airline operational policies.

In this section, the use of wind information and the corresponding information requirements are examined by phase of flight, making distinctions between that associated with pre-flight planning and takeoff operations, and approach/landing operations. Additional considerations associated with airport surface taxiing are also included. Note that many of the specifics are more relevant to air carrier operations as compared to general aviation.

4.1 PRE-FLIGHT PLANNING AND TAKEOFF

4.1.1 General Considerations for Wind and Weather

The pre-flight planning and takeoff operations phases require consideration of wind (and other weather) conditions which will impact both the local takeoff operation at the originating airport, and the anticipated conditions impacting the approach/landing operation at the destination airport at the expected time of arrival. A key concern for takeoff is ensuring that the winds are within thresholds to ensure an acceptable runway ground roll distance, given aircraft loading and other factors. This is largely determined by the headwind/tailwind component along the path of the takeoff operation, also taking into account the specific aircraft type, runway length, runway conditions, and other impacting weather (e.g., air density). A crosswind threshold is also established to ensure lateral aircraft control. Since headwind conditions support greater takeoff and landing performance (in terms of a shorter ground roll), the operating configuration of an airport (i.e., the selection of runways and flight orientation designated for takeoff and arrival operations) is largely chosen to run operations into a headwind to the greatest extent possible. Re-configuration of an airport in response to changing wind conditions can be a disruptive process to air traffic flow, so air traffic managers use wind forecasts to anticipate such changes in order to minimize the disruptive impact.

Consideration for wind conditions as they impact the required amount of runway to be used during takeoff or landing is a primary component to the operational sequence associated with flight operations. Depending on the aircraft type, the current winds are typically entered into the Flight Management System to determine appropriate thrust and flap settings, or in a general aviation application are used by the pilot in reference to aircraft performance charts to ensure adequate runway length is available to perform the takeoff or landing.

Pre-flight planning also considers anticipated wind and other weather conditions at the destination airport at the expected time of arrival. Headwind/tailwind and crosswind requirements for approach and landing procedures (discussed in 4.2), analogous to those for takeoff, must be met in order to allow landing. These requirements also take into account runway length, runway condition, air density, etc. Additional requirements associated with cloud ceiling and visibility conditions that determine the operational throughput of the destination airport are also taken into consideration during pre-flight planning. If anticipated wind/weather conditions are marginal for supporting approach and landing, or threaten full operating capacity, provisions are made during the pre-flight planning phase. These provisions may include carrying additional fuel and/or filing for an alternate airport.

4.1.2 Timeline of Pre-flight Planning and Takeoff

A summary of preflight planning and takeoff actions and requirements for air carrier operations is presented in Table 3. Planning with respect to weather conditions begins approximately one hour prior to anticipated departure. Forecast wind/weather information is applied (by airline flight dispatchers) to determine route and fueling requirements, largely in response to flight level wind conditions between airports. This wind information is primarily derived from numerical weather prediction models. Expectations of wind/weather conditions at the destination airport at the time of arrival is routinely derived from TAFs generated by the NWS regional forecast offices. Forecast support and guidance is also provided by the FAA's Aviation Weather Center (AWC). Failure of expected weather conditions to meet or exceed specific thresholds requires filing for an alternate destination. Requirements include ceiling/visibility conditions (nominally at least 1000 feet and 3 miles, though this may vary by airport and aircraft instrumentation), a destination runway free of precipitation, and crosswind conditions not to exceed an aircraft-dependent threshold as described in 4.1.1. At this stage of planning, the pilot has reviewed both the expected conditions at the destination, and observed weather at the local (originating) airport. The current local conditions are obtained through the ATIS broadcast, which provides the most recent METAR (hourly) or SPECI (special intra-hourly) weather observation acquired by the local ASOS (or AWOS, where equipped). This information is used as input to automated system algorithms, which determine aircraft load and balance, and expected takeoff performance.

During the passenger boarding phase of pre-flight, 15–40 minutes prior to departure, the expected runway for clearance is identified, for which runway distance for aborted takeoff is determined and climb-out weight can be calculated. Any newly available wind/weather information is provided to the flight planning and load/performance algorithms, which may require adjustments to routing, fueling requirements, and loaded aircraft weight limit. The primary algorithms for establishing load requirements are the Electronic Weight Balancing System (EWBS) and the Takeoff Performance System (TPS). METAR/SPECI reports continue to be the source of local wind estimates at this point, so that any change to wind information would be associated with either a new hourly weather observation, or a special observation triggered by a change in aviation-impacting weather conditions for the local airport. The wind threshold for initiating a SPECI observation is a wind direction change of 45 degrees or more in less than 15 minutes while maintaining a wind speed of at least 10 knots throughout the directional shift. (Note that this threshold is significantly higher than that which might impact headwind/tailwind component as it relates to lift, and corresponding weight limits.) Other triggering weather elements are significant changes to visibility, runway visual range, convective activity, freezing/frozen precipitation, and cloud ceiling height. With regard to a weather observation change resulting in decreased headwind, a downwardly adjusted weight limit at this point would require reduction of passengers and/or baggage.

The pre-flight closeout takes place with the final boarding of passengers. This is typically the final opportunity for adjustments to passenger allowance, cargo, and fueling to meet runway length and climb performance requirements, with most recently updated wind information (METAR/ATIS) run through the performance algorithms. Once loading closeout is confirmed with dispatch, the pilot will request pushback and proceed to taxi out. Monitoring of wind conditions continues throughout taxi to departure runway.

While taxiing or awaiting final clearance for departure, the pilot may have the opportunity to view the airport windsock, depending on proximity from the departure runway. If the windsock gives an indication of significantly less headwind component than from the recently monitored wind values or the wind reported upon final clearance, s/he may be prepared to add thrust upon takeoff, or balk at the current weight allowance and request a modification. (The latter would be a rare occurrence.) Unlike the previous wind reports monitored up until this point in the operational timeline, final takeoff clearance is typically accompanied by a voice report of the “airport wind” delivered by the tower controller. This airport wind report is usually the final wind information received by the pilot prior to takeoff.

The notion of a designated airport wind was mentioned previously in sections 2 and 3, and is critical to understanding the use of terminal area wind information to support operations. As stated previously, the FAA requires each airport to have both a primary and backup wind source. Larger airports may have many additional wind observations available from anemometer and/or radar-based wind shear detection systems. With multiple sources available at all airports, the selection of the source designated to provide the airport wind is the responsibility of air traffic management (more specifically, a control tower supervisor). At the largest airports with LLWAS or WME, the default airport wind is typically the wind observation appearing on the top line of the ribbon display, which is the 2-minute average wind (and gust) from the LLWAS-CF or WME sensor. These wind observations are updated each minute. Furthermore, at LLWAS airports where runway-specific wind information is available from sensors extending along each runway, the controller has the option of providing this wind (updated every 30 seconds, but with no gust information) to the pilot for takeoff clearance if s/he feels it is more representative for that operation than the designated airport wind, particularly if there is a significant difference between the two. In any case, the pilot is not made aware of the source of the wind report delivered with final clearance.

At airports equipped with FAA-owned F-420 Series wind sensors (or their replacement SWS sensors) or SAWS system sensors, air traffic management has the option to designate the primary airport wind from one of those sources, or from the local surface weather station (ASOS/AWOS) wind sensing subsystem. The two key factors in selecting a source are reliability of the observation, and maintenance considerations. If one of the two sources is better situated in terms of either location on the airport or clearance from potential obstructions, it will typically be the key factor in the choice. If siting is essentially equivalent, the decision may be affected by the maintenance reliability of the sensor equipment, either in terms of equipment reliability, or facility in securing maintenance support in the event of a faulty sensor. A similar choice is made at smaller airports, where equipment maintenance of the non-ASOS/AWOS sensor is provided via a local service contract.

The key takeaways with regard to the wind report delivered to the pilot for final clearance are: 1) the source wind for final takeoff clearance may originate from a number of possible sources at the discretion of air traffic control, and 2) this wind source will typically be from a different source (that is updated every 30- or 60-seconds) than the ATIS wind that the pilot has been receiving earlier in the pre-flight phase, namely the hourly METAR wind or intra-hourly SPECI wind, both measured from ASOS/AWOS.

Table 3. Summary of Sequential Pre-flight Planning and Takeoff Actions and Requirements

	Time Before Departure	Actions	Wind/Weather Sources	Requirements / Considerations
Obtain dispatch release	60 minutes	1. Dispatch plans route and fuel requirements 2. Pilot obtains wx forecast for destination 3. Pilot obtains wx at origin 4. Pilot sends wx information to dispatch for initial Electronic Weight Balancing System (EWBS) / Takeoff Performance System (TPS) calculations	TAF, METAR, SPECI (via digital ATIS broadcast through ACARS) Company weather briefing/proprietary models	1. Check for ETA +/- 1 hour 2. Ceiling 3. Visibility 4. Runway braking 5. Accumulation of water/snow/ice on runway 6. Crosswind
Load aircraft, update plans	15–40 minutes	1. Expected runway for departure clearance (from dispatch) entered by pilot into EWBS/TPS. 2. Update EWBS/TPS based on any new wx info, additional fueling for diversion, alternate routings, etc. 3. May decide weight adjustments are needed; bump passengers or bags	Same	1. Runway distance for aborted takeoff. 2. Climb-out weight 3. Tailwind
Closeout	~3 minutes	1. Passengers loaded 2. Cargo loaded 3. Fuel loaded and communicated for final run of EWBS/TPS 4. Request pushback	Same	1. Final weight for passenger, cargo, fuel 2. Expected runway confirmed 3. Runway length and climb performance must meet requirements
Pushback to taxi (ramp)		Note: Aircraft now under ramp control (may be airline or other non-FAA responsibility)		
Taxi		Under active ATC ground control 1. Monitor ATC for runway, wind information 2. Re-calculate EWBS/TPS if necessary to see if wind changes require thrust or flap setting changes	METAR, SPECI	
Clear for departure	Departure roll	1. Takeoff clearance communication includes runway and current winds from ATC	Local current (recent minute) wind observation from primary airport wind sensor [See text for details]	Headwind/tailwind and crosswind requirements meet runway length, climb performance, and crosswind tolerance requirements

4.2 APPROACH AND LANDING

4.2.1 General Considerations for Wind and Weather

Primary weather considerations during the aircraft approach and landing phase are visibility, precipitation, and wind. Visibility during arrival affects allowable spacing between arriving aircraft and landing requirements associated with aircraft and runway instrumentation. Visibility limitations may be caused by low level (extending to the ground) presence of fog, haze, or precipitation, or presence of a cloud ceiling below critical operational levels. Nominal critical thresholds determining aircraft spacing and requirements for instrument landing are 3 miles horizontal visibility and 1000-foot ceiling. The presence of precipitation is also a consideration for aircraft performance during approach and landing/braking as it influences runway friction during wet conditions.

As with takeoff operations, the important role of wind during approach and landing is its impact on stabilizing aircraft control. Rapid changes in headwind/tailwind (and associated gustiness) affect an aircraft's ability to maintain proper airspeed, pitch, and altitude on approach, which becomes increasingly critical with descending altitude. Changes in crosswind impact an aircraft's roll and yaw as the pilot attempts to maintain stable lateral navigation. Of course, much of the approach guidance is automated on larger commercial aircraft, with aircraft having prescribed tolerances (typically established by the aircraft manufacturer) which vary with aircraft size and design. Exceedance of tolerance limits can result in a missed approach or go-around, with failure to navigate properly during approach potentially leading to excess or insufficient airspeed, landing beyond or short of intended touchdown point, runway excursion, or missed runway with catastrophic impact.

4.2.2 Timeline of Approach and Landing

A summary of approach and landing actions and requirements is presented in Table 4. During en route navigation to the start of descent, pilots will typically receive updates through their airline operations center or digital ATIS, so the primary source of wind is from the hourly METAR or intra-hourly SPECI. Pilots may also receive PIREPS from dispatch, transmitted via ACARS. At approximately 40 nm from the destination airport, contact will be made with Approach Control, from which the pilot will receive wind information (per METAR), PIREPS, and an indication of the expected landing runway. PIREPS may include information about runway wind gain/loss.

Inside of 10 miles from the airport and at an altitude of ~1500–3000 ft AGL (depending on type of aircraft, route, airport size, etc.), the aircraft will be handed off to tower control. A tower controller will make voice contact with the pilot during which s/he will routinely report the current local airport winds, as well as other information such as runway confirmation, relevant PIREPS, or wind shear alert notification. This may be the point at which the pilot receives the final clearance to land, or landing clearance may be conveyed on subsequent voice contact during approach. Any subsequent voice contact would also typically include a report of current airport wind conditions. Unlike the ATIS reports (sourced from the hourly METAR or intra-hourly SPECI), wind conditions reported by voice from the tower controller are typically taken from one of the wind systems which provide a more frequent wind observation update (e.g., every minute). This is analogous to the discussion of airport wind for departure clearance discussed in 4.1.2. At larger airports, this is typically the so-called airport wind from the top line of the ribbon display (sourced from either WME or LLWAS-CF) or from a ribbon display runway threshold wind (sourced from LLWAS). For other airports, the more frequently updated wind source could be from the F-420 (or its SWS replacement), the standalone SWS replacements for WME, the standalone SAWS display, or the 1-minute ASOS observation acquired from either the OID or IDS.

Conveyance of wind information from the tower controller to pilot has critical influence on operability and the ultimate disposition of the scheduled landing procedure. Voice wind reports from the tower are used to determine compliance with allowable crosswind and tailwind thresholds for approach and landing, and for pilot assessment of risk to aircraft control during the landing procedure due to the potential for loss of airspeed or lift, high airspeed variation, or departure from the intended path due to excessive variability in aircraft attitude. Failure to meet established wind component requirements (headwind/tailwind/crosswind) or presence of wind conditions that the pilot determines to be unsafe for landing will result in a missed approach, with a subsequent go-around procedure or continuation to alternate airport. Missed approaches put additional workload on air traffic controllers and managers, and may affect an airport's ability to meet arrival demand. They are also costly to airlines in terms of additional fuel burn, flight schedules, and crew scheduling.

Table 4. Summary of Sequential Approach and Landing Actions and Requirements

	Location from Touchdown	Actions	Wind/Weather Sources	Requirements / Considerations
En route	To start of descent	1. Flight Management System (FMS) updates 2. Destination situational awareness updates	TAF, METAR, SPECI (via digital ATIS broadcast through ACARS, PIREPS)	
Approach Control (1)	~40 nm	1. Pilot confirms latest received ATIS 2. Approach control provides winds, PIREPS, expected runway	TAF, METAR, SPECI PIREPS (especially gain/loss information)	
Approach Control (2)/ Handoff to Tower Control	2–10 nm; 1500–3000 ft altitude	1. Clearance to land, including runway, current winds, relevant PIREPS. [Pilot refusal based on unsuitable conditions triggers removal from arrival pattern or missed approach.] 2. Wind Shear or Microburst alerts trigger pilot to initiate escape	Local current (recent minute) wind observation from primary airport wind sensor [See text for details]	Crosswinds, tailwinds within legal limits and company operational policy.
Final approach/landing	Under 1000 feet AGL	1. Pilot accepts or refuses final landing clearance 2. Visually acquire runway for VFR landing 3. Align with runway (decrab), flare, and touch down	None	No loss of control due to: 1. Loss of airspeed or lift 2. High airspeed variation 3. High vertical airspeed/turbulence 4. Departure from intended approach path due to excessive roll, pitch, yaw

5. POTENTIAL SHORTFALLS

5.1 METHODOLOGY AND SOURCES

This section identifies potential shortfalls in the current paradigm for acquiring, processing, distributing, and the ultimate practical use of wind information to support terminal area operations. With the proliferation of wind/weather system deployment over the last several decades, airport wind information has been a topic of discussion for many years, including formation of a working group in the 2000–2001 period. In the years since then, there have been episodic reports and anecdotes of wind report inaccuracies and inconsistencies. The shortfall analysis here attempts to consolidate historical issues with more recent input from stakeholders in order to characterize potential existing systematic inadequacies, and opportunities for improvement. This is done in the context of understanding the current paradigm for acquisition, distribution and use of wind information presented in Sections 2 through 4. In total, this shortfall analysis relied on these key sources:

- **Discussions and interviews with stakeholders**
    - Experienced representative from National Air Traffic Control Association (NATCA)
    - Comments from documented interview notes with Newark Liberty International Airport (EWR) and John F. Kennedy International Airport (JFK) Tower Operations personnel (2012, 2015, 2016) and New York Terminal Radar Approach Control (TRACON) (2012)
    - Pilots: Large commercial jets, regional commercial jets, private general aviation
    - The FAA Weather Sensors and Display System group (AJW-1444) at the Program Support Facility (PSF) responsible for deployment, maintenance, and data quality assurance for FAA weather/wind sensor systems
    - National Transportation Safety Board (NTSB) responsible for accident investigation, including causality from wind-related issues
    - Interview with New York Area NWS Science and Operation Officer (SOO), responsible for investigating shortfalls in providing wind information and forecasts to user community
- **Review of existing problem reports and operational logs**
    - Extensive FAA investigation of wind reporting discrepancies at DTW (2008)
    - FAA investigation report of wind-reporting discrepancies reported at CLT and IAD, (2012)
    - NTSB incident log from 2010–2017, citing cases with wind as contributing factor
    - White paper documentation of terminal wind sensing shortfalls at the New York area airports (EWR, JFK, LaGuardia Airport (LGA))
- **Documentation search and review**
    - Air traffic control Standard Operating Procedures (SOP): LGA, EWR, JFK, New York N90 TRACON, Chicago TRACON
    - FAA Aeronautical Information Manual
    - FAA Order JO 6560.20C: Siting Criteria for Automated Weather Observing Systems

  - FAA Order 6560.21A: Siting Guidelines for LLWAS
  - FAA Order JO 7110.65W: Air Traffic Control Procedures
  - FAA Order JO 7900.5D: Surface Weather Observing
  - Wind sensing commentary documentation from FAA Terminal Requirements, AJT-2C1
  - Department of Commerce (DOC) Plan for Meteorological Services and Supporting Research (2017)
  - Technical papers on representativeness of wind observations at airports
- **Analysis of airport wind sensor data**
  - ASOS and WME wind sensors at EWR
  - LLWAS data from 8-sensor network at LGA

5.2 GENERAL SOURCES OF POTENTIAL WIND REPORT ERROR

Wind observations in the terminal area are intended to inform pilots of the expected wind conditions that the aircraft will be exposed to during takeoff and landing, such that s/he may ensure safe navigation or abort the intended operation if conditions warrant. The most critical area is the flight path airspace from the point of liftoff/touchdown to the area extending just beyond the runway threshold (end of concrete). Ideally, the pilot desires a representation of the wind condition on a time/space measurement scale relevant to its impact on the airframe, and at the time that the aircraft will be in that airspace.

A historical limitation to providing the most desirable wind information is the obvious practical restriction of siting a wind sensor in the departure path or arrival glide slope near the runway threshold. (A new opportunity in this regard is emerging with the advent of aircraft wind observations and developing communication technology and infrastructure; this is included in later discussion.) Instead, there has been an attempt to site wind sensors as close to the optimal location as practically possible. This introduces a risk that the wind measurement is not representative of the critical impact location at the runway threshold.

In this context, there are four general categories of possible impediments to providing the appropriate wind information to pilots:

1. **Observation uncertainty:** A wind measurement is essentially an estimate of mass transport rate through an area or volume. As a fluid, the nature of atmospheric flow is variable, with variation of motion occurring on multiple space and time scales. It is important to select a measurement time scale appropriate to reflect impact on an airframe for the duration that the airframe is expected to be exposed to the wind. The time must be sufficiently long to smooth out short term fluctuations that do not affect aircraft performance, but short enough to be responsive to significant changes in the wind. Within the U.S. NAS, the standard time average has been established at two minutes, with a reporting interval capability of one minute. (In Europe, a longer 10-minute average is standard.) There are also attempts to report gustiness variation using algorithmic logic intended to capture variations from the sustained wind that are significant to impact aircraft navigation. The presumption is that this choice of measurement provides the most relevant quantified

characterization of the wind with regard to aircraft navigation. It is also presumed that the local measurement is of unobstructed free flow of air as would be experienced by an aircraft, unaffected by undue local channeling or blocking of wind by upstream obstacles such as buildings or vegetation growth. These upstream obstacles could also introduce frictional affects that would create an underestimate of free air flow.

2. **Spatial translation error:** Since ground-based wind sensors cannot be situated in the actual path of the aircraft, the nearest available wind observation is presumed to be representative of the flight area of interest, i.e., near the runway threshold at the aircraft altitude. This requires an assumption regarding the horizontal uniformity of wind over the distance between the sensor and flight path. This assumption requires that the local influences of the wind at the two locations be similar (e.g., free of nearby obstructions, and subject to similar surface roughness), and that the dynamic forcing of wind at the locations be similar, e.g., not differentially influenced at the micro/meso scale (1 to tens of km) by regional terrain, nearby bodies of water, variation of elevation, etc. Both of these assumptions (similar local environment and similar dynamic forcing) are likely to decrease in reliability with increasing distance between sensor location and area of interest, with the possibility of introducing spatial translation error.

3. **Temporal translation error:** To ensure navigation control, pilots want to know anticipated wind conditions at the time the aircraft is in the vicinity of the runway threshold. Since the most recent wind report prior to takeoff or touchdown is conveyed by tower control at the time of final clearance, there is an elapse of time before the takeoff or touchdown maneuver takes place. In this sense, the wind report acts as a short-term forecast, with the presumption that short-term wind conditions will prevail. This is true much of the time, but not always, and represents another risk of introducing error. This risk is even greater with a similar presumption that the wind received from ATIS on entering the local TRACON is expected to prevail for the remainder of the flight, especially since the ATIS wind (METAR) may already be nearly an hour stale at the time of receipt by the pilot.

4. **Deficiency in conveyance, interpretation, or application:** Non-uniformity and variation of redundancy in available airport wind data sources across the NAS poses the risk for miscommunication, or requires discernment on the part of controllers in selecting among multiple wind source alternatives. Policies for disseminating wind also exhibit some variation that is dependent upon airport size.

5.3 DESCRIPTIVE LISTING OF POTENTIAL SHORTFALLS

The listing of shortfalls described here is not sequenced by priority. Rather, the listing order generally follows the categorization of potential error source categories described above, starting with local sensor observation errors, to space and time translation errors, to shortfalls associated with conveyance, interpretation, or application of the wind information.

Shortfall #1: **Sensor observation may not be representative of local wind conditions (at the sensor site) due to upwind obstruction or other influences.**

Typical obstructions are from nearby buildings or vegetation canopies, or irregular terrain. Either the impact could be to create drag that would underestimate the local wind, or cause channeling that would cause an overestimate. Other influences may be nearby activity that would intermittently influence the local wind flow, such as proximity to a heavily travelled high-speed roadway or taxiing aircraft. An example of this are the WME and ASOS sensor locations alongside the New Jersey Turnpike at Newark Liberty International Airport. Some airports have also reported intermittent bird roosting on sensors causing erroneous data.

Sensor location siting is usually done with great care to meet FAA wind sensing guidelines (e.g., Orders JO6560.20C and 6560.21A) which are specific about ensuring unobstructed flow in the vicinity of wind sensors, but some airports have limited viable alternatives. In other instances, initially well-sited sensors are impacted by new construction or vegetation growth that was not present at the time of initial siting and installation.

Shortfall #2: **LLWAS/WME wind sensing equipment may be on poles with heights that differ from international standards, and/or from each other.**

LLWAS sensors are often located at variable heights in excess of 100 ft AGL, well above the standard 10 m (32 ft), as the sensor network was deployed to meet the requirements of a specified anemometer-based wind detection system. Most of the wind sensors for other (non-LLWAS) platforms comply with the 10 m standard. This can lead to inconsistency in the wind observations within an airport terminal, potentially causing confusion or lack of confidence in determining which report is more representative of conditions at the runway threshold of interest.

Shortfall #3: **Runway threshold winds do not include gust information.**

Essentially all other reported wind observations besides the runway threshold winds provided by LLWAS included gust information in addition to sustained wind. Gust information is considered desirable to support stable navigation of takeoff and landing operations.

Shortfall #4: **Data quality of local observation may be compromised due to electro/mechanical failure.**

This is an inevitable risk associated with any sensing system. Mitigating actions are preventive maintenance, timely detection of compromised performance, and responsive corrective maintenance. The process for ensuring data quality of LLWAS sensors is fairly standardized, with data samples sent regularly to AJ-1444 for quality assurance analysis. However, policies for preventive maintenance and processes for failure detection may vary by sensor source/type, airport, and responsible party (FAA, NWS, private contractor, etc.).

<u>Shortfall #5:</u> Wind reports from different sensor types may be inconsistent due to different processing algorithms for computing sustained wind and gusts.

As described previously, airports are required to have both a primary and backup wind source, with potentially different processing algorithms. This potential risk is largely being addressed through FAA installation of the SWS to replace WME and F-420 wind sensors, which apply the same basic processing for computing sustained wind and gusts, and are also consistent with ASOS processing. This current plan does not include modification of the LLWAS sensors.

<u>Shortfall #6:</u> Wind reports provided to pilots via ATIS (typically ASOS hourly METAR or SPECI) may not be representative of current conditions due to latency.

The wind report received by the pilot from ATIS may be have been observed up to an hour earlier than the time of receipt, due to the reporting frequency of METAR. A 2013 ICAO study group on meteorological observations indicated that inclusion of intra-hourly SPECI report does not sufficiently address this issue, owing to the large range of tolerance before an additional special report is required [4]. There may be up to an additional time of 45 minutes between the receipt of the report and actual touchdown. (Of course, the pilot will have received an updated report from the tower control tower prior to that.)

<u>Shortfall #7:</u> Wind reported via voice contact with tower controller (as part of the takeoff or landing clearance message) may differ from recently communicated wind to pilot from ATIS broadcast due to different wind sensor sources. The report for the former is typically from WME, F-420, SWS, or SAWS, which all are updated at one-minute intervals.

This has been a significant source of consternation across the NAS as reported anecdotally and as documented formally in problem reports submitted by air traffic controllers. Instances of missed approaches have been identified as due to this cause, as pilots anticipating a wind within tolerance may receive a subsequent wind report out of tolerance. The wind discrepancy may result from the difference in the observation time, observation location, or location height. This situation also creates diminished confidence in both the wind reports and the short-term wind forecasts provided by aviation forecasters. This has specifically been identified as an issue in the wind difference reported by the WME and ASOS at a number of airports. The general concern of determining the appropriate use of multiple wind sensors within a touchdown zone was a topic of discussion for the 2010 ICAO study group on meteorological observations and forecasts [5].

It would be beneficial to examine more carefully these types of reported discrepancies to better characterize their frequency and probable cause. Toward this end, the analysis presented here included a cursory look at an example of the discrepancies that were reported between the WME and ASOS winds at Newark Liberty International Airport (EWR), using data available from 2014–2016. Figure 12 shows the difference in wind speeds (2-minute average) at one-minute intervals over the three year period, where these differences are seen to occur both clustered in time and sporadically. A closer look at of some sample periods of higher frequency indicated that the differences were often associated with either synoptic scale or convective mesoscale features causing wind gustiness that created a challenge in quantifying the ambient wind, even when considering only the sustained (2-minute average) values. However, a scatterplot of the difference (Figure 13) indicates there is clearly a systematic bias in wind speed reporting between the two sensors, with ASOS showing a tendency toward higher winds. A corresponding look at differences in wind direction over the data period is summarized in Table 5. In general, this type of quantitative examination of specific sensors should be extended to other airports and sensor platforms to better understand the characteristics of reported wind sensor discrepancies, and the degree to which wind conditions over a terminal area (i.e., at different runway thresholds) at an individual airport may vary spatially due to either local environmental effects (e.g., obstructions, terrain, etc.) or local variability in wind/weather forcing dynamics. (Note the relevance to the next item in this list.) Availability of LLWAS sensor data at multiple locations on larger airport complexes would be useful in this regard.

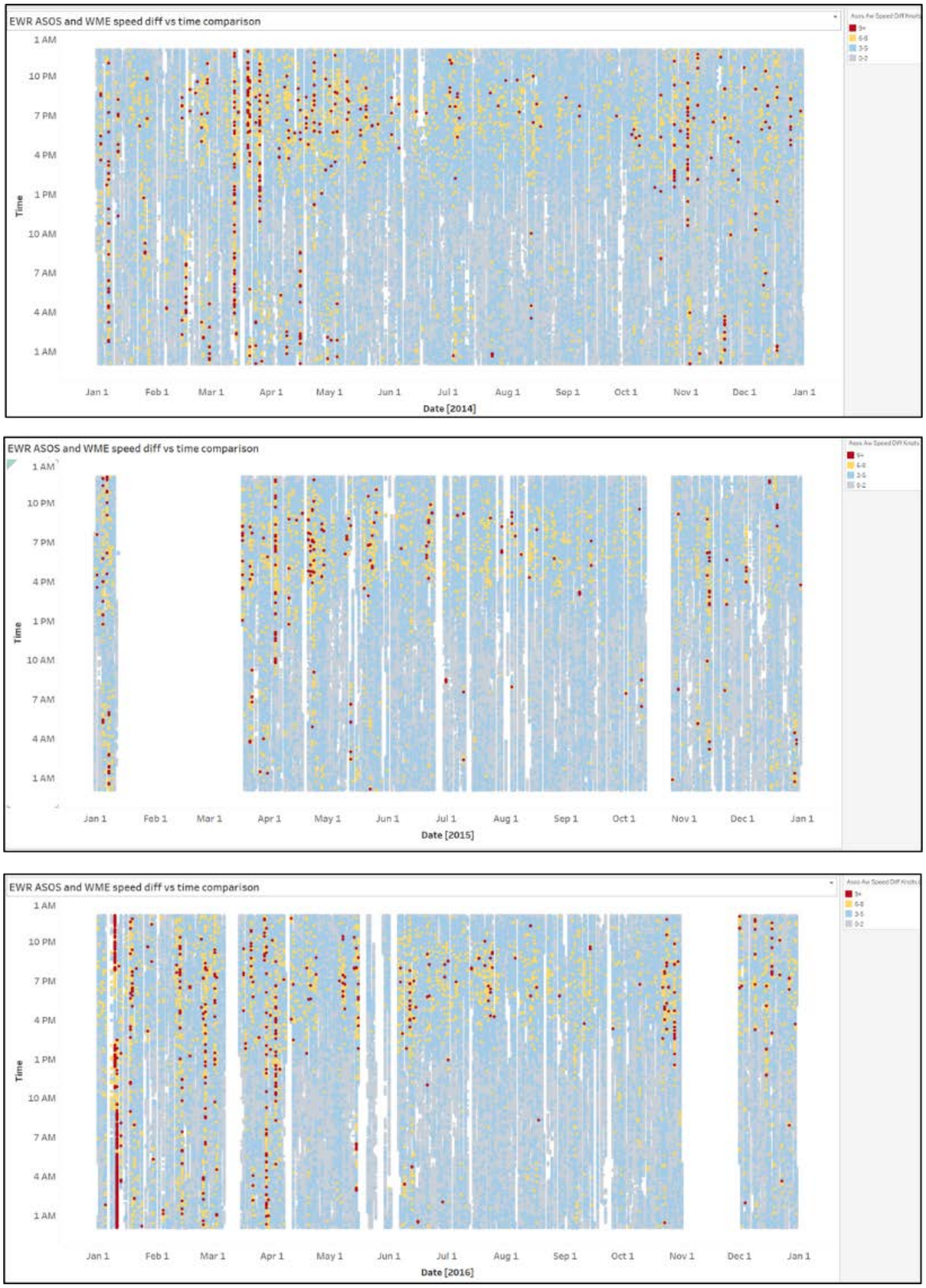


Figure 12. Wind speed difference between ASOS and WME wind observations over 3 years (2014–2016) at EWR. Horizontal axis shows date, vertical axis shows time of day (GMT). Each colored dot represents the difference at each minute between the 2-minute average values observed by each system. White space represents missing data.

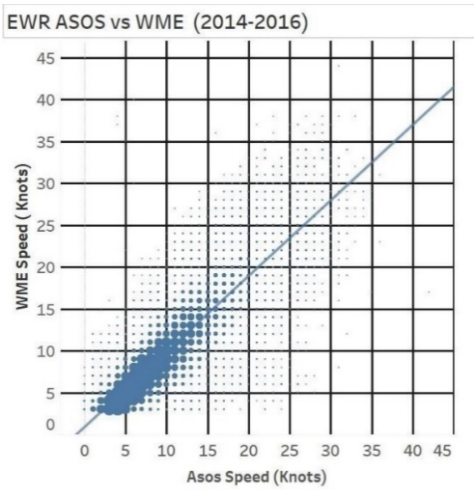
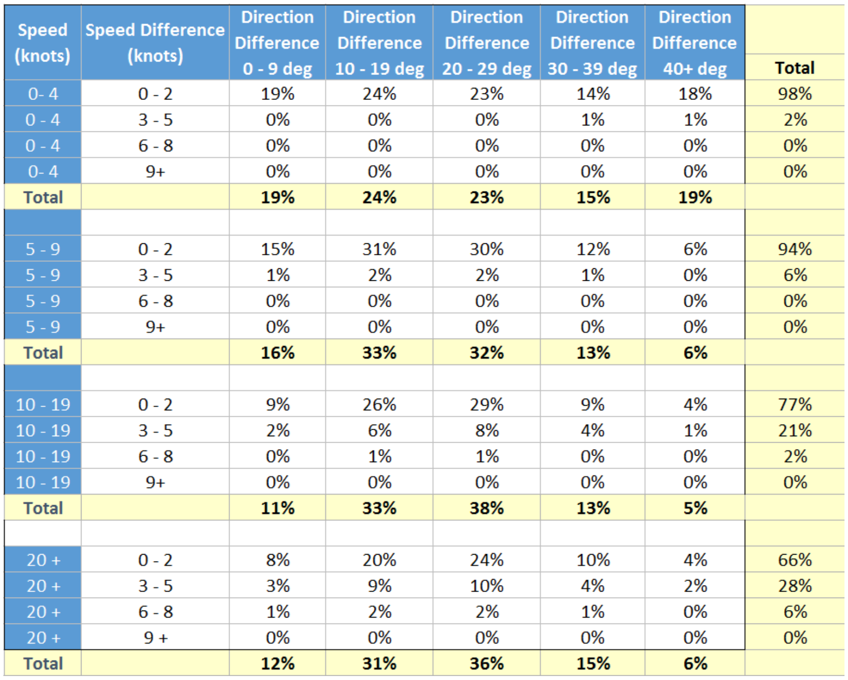


Figure 13. Scatterplot comparing ASOS and WME wind observations (2-minute averages each minute) at EWR during 2014–2016

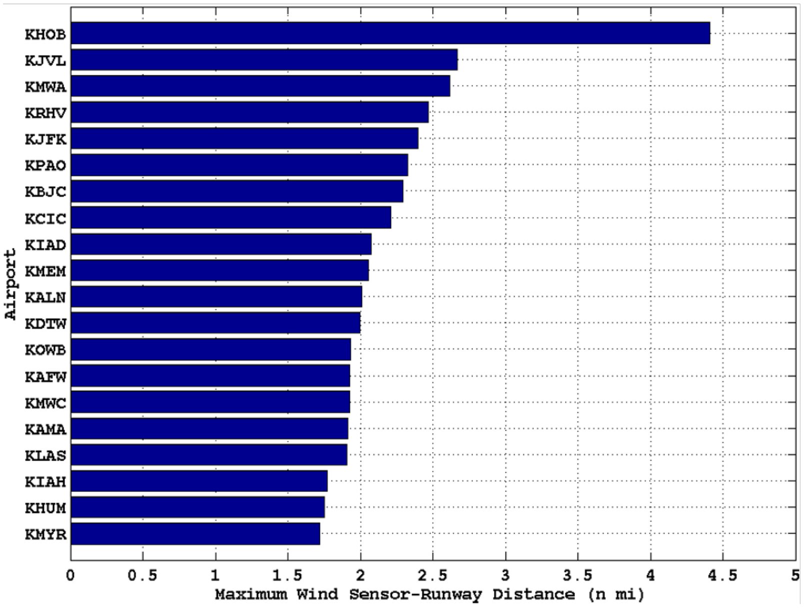
Table 5. Difference in Wind Direction Observations by ASOS and WME at EWR (2014–2016), Segregated by Wind Speed Category



Speed (knots)	Speed Difference (knots)	Direction Difference 0 - 9 deg	Direction Difference 10 - 19 deg	Direction Difference 20 - 29 deg	Direction Difference 30 - 39 deg	Direction Difference 40+ deg	Total
0- 4	0 - 2	19%	24%	23%	14%	18%	98%
0 - 4	3 - 5	0%	0%	0%	1%	1%	2%
0 - 4	6 - 8	0%	0%	0%	0%	0%	0%
0- 4	9+	0%	0%	0%	0%	0%	0%
Total		**19%**	**24%**	**23%**	**15%**	**19%**	
5 - 9	0 - 2	15%	31%	30%	12%	6%	94%
5 - 9	3 - 5	1%	2%	2%	1%	0%	6%
5 - 9	6 - 8	0%	0%	0%	0%	0%	0%
5 - 9	9+	0%	0%	0%	0%	0%	0%
Total		**16%**	**33%**	**32%**	**13%**	**6%**	
10 - 19	0 - 2	9%	26%	29%	9%	4%	77%
10 - 19	3 - 5	2%	6%	8%	4%	1%	21%
10 - 19	6 - 8	0%	1%	1%	0%	0%	2%
10 - 19	9+	0%	0%	0%	0%	0%	0%
Total		**11%**	**33%**	**38%**	**13%**	**5%**	
20 +	0 - 2	8%	20%	24%	10%	4%	66%
20 +	3 - 5	3%	9%	10%	4%	2%	28%
20 +	6 - 8	1%	2%	2%	1%	0%	6%
20 +	9 +	0%	0%	0%	0%	0%	0%
Total		**12%**	**31%**	**36%**	**15%**	**6%**	

<u>Shortfall #8:</u> Wind report for runway threshold may not be representative due to spatial translation from observation location.

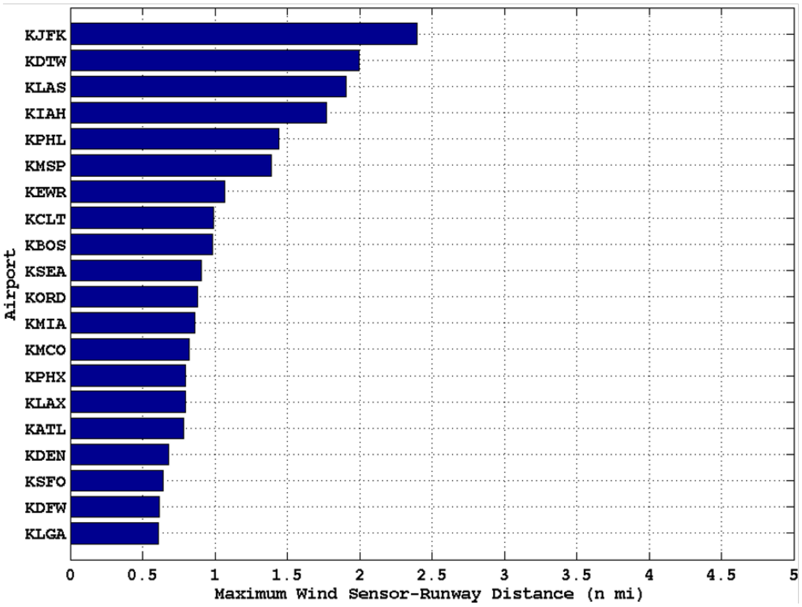
As discussed, this factor largely depends on the homogeneity of conditions between the two locations. A second cause would be encroachment of a local wind shift (e.g., from a convective gust front or synoptic scale front) at one of the two locations. For either cause, the occurrence of spatial translation differences is likely to have some correlation with the distance between the observation location and the location of operational interest. The maximum distance between any runway threshold on an airport and the location of its nearest wind reporting sensor varies significantly across the NAS, ranging from 0.2 n mi at Grand Canyon National Airport (KGCN) to 4.4 n mi at Lea County Airport (KHOB) in New Mexico, and depends largely on both airport size and the number of sensors on the airport. The median such distance is approximately 0.7 n mi. Note: Lea County Airport is something of an outlier in this regard; airports with the top twenty longest maximum distances shown in Figure 14. The maximum distance between a runway threshold and its nearest wind sensor at the 20 busiest NAS airports is shown in Figure 15.



AIRPORT IDs, Annual Operations (thousands)

HOB	Lee County Regional, NM	8
JVL	South Wisconsin Regional, WI	33
MWA	Veterans Airport of S. Illinois, IL	51
RHV	Reid-Hill San Jose, CA	163
JFK	Kennedy International, NY	453
PAO	Palo Alto Airport, CA	149
BJC	Rocky Mountain Metro, CO	166
CIC	Chico Municipal, CA	38
IAD	Washington Dulles, DC	294
MEM	Memphis Int'l, TN	223
ALN	St. Louis Regional, MO	30
DTW	Detroit-Wayne Metro, MI	395
OWB	Owensboro-Davies, KY	18
AFW	Fort Wayne Alliance, TX	112
MCW	Lawrence Timmerman, WI	28
AMA	Amarillo Int'l, TX	61
LAS	Las Vegas McCarran, NV	543
IAH	Bush Houston Intercont'l, TX	450
HUM	Houma-Terrebonne, LA	57
MYR	Myrtle Beach Int'l, SC	122

Figure 14. Maximum distance between a runway threshold and its nearest sensor, for airports with largest maximum distances among 264 CONUS airports.

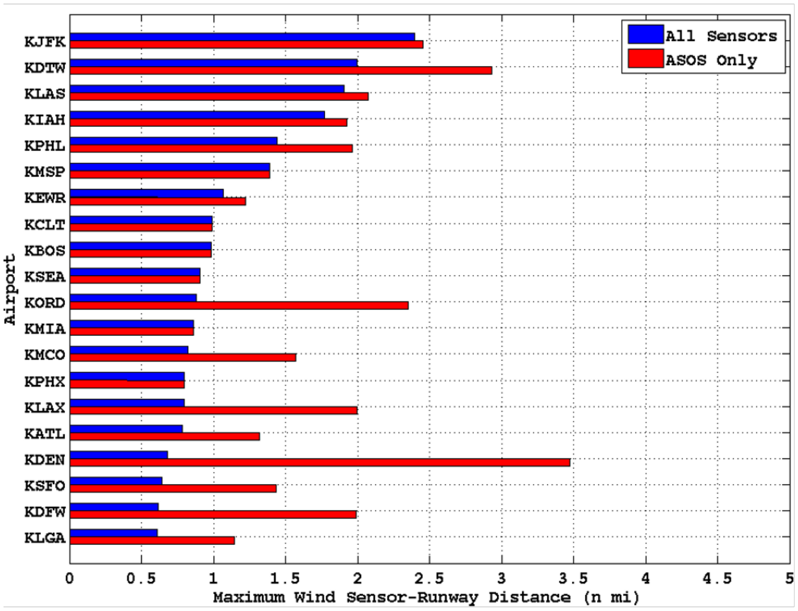


AIRPORT IDs, Annual Operations (thousands)

JFK	Kennedy International, NY	453
DTW	Detroit Metro Wayne, MI	395
LAS	Las Vegas McCarran, NV	543
IAH	Bush Houston Intercont'l, TX	450
PHL	Philadelphia Int'l, PA	370
MSP	Minneapolis - St. Paul Int'l, MN	416
EWR	Newark Liberty Int'l, NJ	444
CLT	Charlotte/Douglas, NC	554
BOS	Boston Logan Int'l, MA	406
SEA	Seattle-Tacoma Int'l, WA	416
ORD	Chicago O'Hare Int'l, IL	867
MIA	Miami Int'l, FL	413
MCO	Orlando Int'l, FL	338
PHX	Phoenix Sky Harbor, AZ	431
LAX	Los Angeles Int'l, CA	700
ATL	Atlanta Hartsfield, GA	879
DEN	Denver Int'l, CO	582
SFO	San Francisco Int'l, CA	460
DFW	Dallas - Fort Worth Int'l, TX	654
LGA	LaGuardia Airport, NY	366

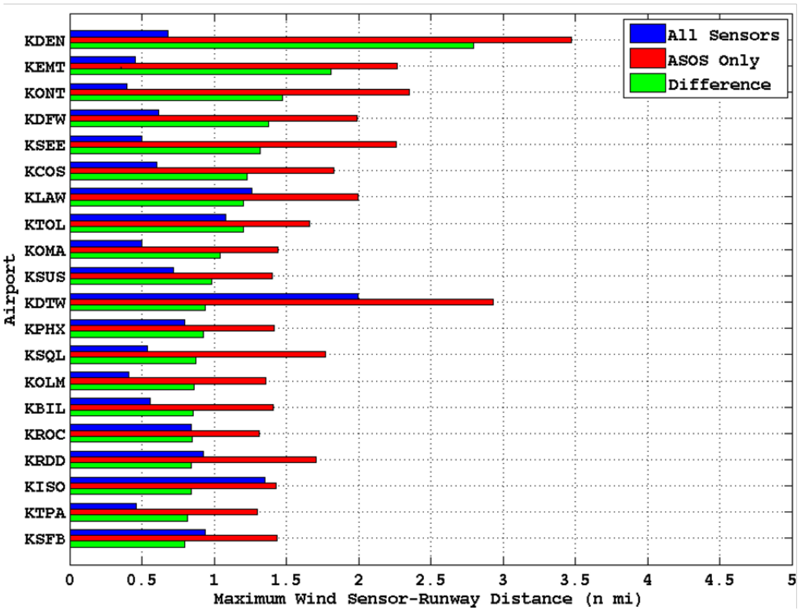
Figure 15. Maximum distance between a runway threshold and its nearest sensor, for airports with largest maximum distances among 264 CONUS airports.

This issue relates to the concern raised in Shortfall #7, regarding potential discrepancies between recorded ATIS broadcast winds (ASOS, via METAR) and tower controller voice reports of wind, typically derived from a more frequently updated source. In addition to potential discrepancy due to latency, differences may also result from the distance between source locations. The physical distance between ASOS and an airport's primary wind sensor (e.g., WME, LLWAS, SWS, etc.) varies from airport to airport, with greater distances increasing the potential for wind report differences. Furthermore, more extensive wind sensor coverage (e.g., from LLWAS) at some airports increases the likelihood that there will be a disparity between the runway-to-nearest-sensor distance and the runway-to-ASOS distance. Figure 16 is an extension of Figure 15, comparing the maximum distance between a runway threshold and its nearest wind sensor with the maximum distance to the ASOS sensor, at the 20 busiest airports. The difference between these "nearest sensor" distances lends some insight as to which airports are more susceptible to ATIS/voice discrepancies. The most impacted airports are those with LLWAS, which provides runway-specific coverage. This is most evident at Denver International Airport (DEN), which has a very large airport footprint that is covered by a network of 31 LLWAS sensors. Figure 17 shows a similar metric for a broader pool of 264 NAS airports, showing the top 20 airports whose maximum runway-to-sensor distance exhibits the largest difference when compared to the maximum runway threshold distance to the ASOS wind sensor.



AIRPORT IDs, Annual Operations (thousands)		
JFK	Kennedy International, NY	453
DTW	Detroit Metro Wayne, MI	395
LAS	Las Vegas McCarran, NV	543
IAH	Bush Houston Intercont'l, TX	450
PHL	Philadelphia Int'l, PA	370
MSP	Minneapolis - St. Paul Int'l, MN	416
EWR	Newark Liberty Int'l, NJ	444
CLT	Charlotte/Douglas, NC	554
BOS	Boston Logan Int'l, MA	406
SEA	Seattle-Tacoma Int'l, WA	416
ORD	Chicago O'Hare Int'l, IL	867
MIA	Miami Int'l, FL	413
MCO	Orlando Int'l, FL	338
PHX	Phoenix Sky Harbor, AZ	431
LAX	Los Angeles Int'l, CA	700
ATL	Atlanta Hartsfield, GA	879
DEN	Denver Int'l, CO	582
SFO	San Francisco Int'l, CA	460
DFW	Dallas - Fort Worth Int'l, TX	654
LGA	LaGuardia Airport, NY	366

Figure 16. Maximum distance between a runway threshold and nearest wind sensor (blue) at 20 busiest U.S. airports, compared to maximum runway threshold distance from ASOS (red).



AIRPORT IDs, Annual Operations (thousands)		
DEN	Denver Int'l, CO	582
EMT	San Gabriel Valley Airport, CA	83
ONT	Ontario Int'l, CA	97
DFW	Dallas - Fort Worth Int'l, TX	654
SEE	San Diego Gillespie Field, CA	221
COS	Colorado Springs Municipal, CA	135
LAW	Lawton - Fort Sill Regional, OK	27
OMA	Omaha Eppley Airfield, OK	96
SUS	Spirit of St. Louis Airport, MO	98
DTW	Detroit Wayne Metro, MI	395
PHX	Phoenix Sky Harbor, AZ	431
SQL	San Carlos Airport, CA	104
OLM	Olympia Regional, WA	40
BIL	Billings Logan Int'l, MT	83
ROC	Greater Rochester Int'l, NY	87
RDD	Redding Municipal, CA	96
ISO	Kingston Regional Jetport, NC	22
TPA	Tampa Int'l, FL	195
SFB	Orlando Sanford Int'l, FL	306

Figure 17. Maximum distance between a runway threshold and nearest wind sensor (blue), compared to maximum runway threshold distance from ASOS (red), at 264 CONUS airports across NAS. Green bar indicates maximum distance differences comparing all sensors versus ASOS sensor only.

Shortfall #9: Multiple wind source options for communicating wind to pilots relies on discretion of controller in selecting representative wind. Pilots are not currently made aware of wind information source.

Similar to the previous issue of different winds being reported by ATIS and tower control, this is most likely to be an issue at airports with LLWAS systems. These airports have a 2-minute airport wind derived from LLWAS-CF and 30-second LLWAS winds associated with each runway threshold, in addition to the wind provided by ASOS. Tower controllers have the authority to exercise discretion in selecting the appropriate source for each operation.

Shortfall #10: A formal process for collecting, prioritizing, and resolving wind observation issues is not in place.

As noted earlier in this report, issues related to wind observation system performance have been raised through a range of channels. However, there is no formal process in place to regularly survey and prioritize potential issues. Having such a process would aid in ensuring that latent problems do not persist, as well as facilitate tracking the impact of changes in observation equipment and processes over time.

6. SOLUTION SPACE FOR POTENTIAL IMPROVEMENT

This section identifies opportunities for follow-on efforts to address the shortfalls listed in the previous section. These are presented as a “solution space” for action that will lead to improvement in the NAS wind information infrastructure, in that they are developed taking into account the existing wind sensing network capability, and with consideration for practicality within the current framework of data acquisition, distribution, and use. It also reflects that there is no attempt for prioritization yet, as this needs to be done in the context of available resources and other competing investments within FAA.

Recommendation #1: Add additional wind sensors at some airport runway ends, where a benefit/cost evaluation suggests that this is appropriate in the context of other FAA investments in NAS improvements.

Limitation of available resources would require that FAA be selective in this determination. AJW-1444 is already aware of some potential coverage deficiencies, particularly at airports where local wind flow is substantially affected by local terrain, or local weather influences tend to create variability of the wind flow across the terminal airspace. Initial action in this direction would be to perform a more structured analysis of runway coverage deficiencies across the NAS, taking into account distance from threshold to nearest wind sensor, and local effects that are likely to influence the representativeness of wind measured at a distance from the runway threshold. Wind information deficiencies at individual airports would have to be weighed against impact across the NAS, using factors such as traffic volume or hub dependency for connecting flights in order to generate a prioritized list for new sensor deployment.

It should be noted here that the newly procured SWS sensors provide an opportunity to expand the existing wind-sensing network by exploiting their capability to operate wirelessly within a network. One of the major challenges in adding new sensors is the cost and difficulty of identifying unobtrusive site locations with necessary power and communication capability. Toward this end, AJW-1444 has performed some initial testing of deploying SWS sensors on ILS equipment platforms. Additional testing would require to ensure non-interfering radio capability.

Recommendation #2: Move existing sensors to either: 1) improve upon current locations where measurement quality is degraded by local environmental influences, or 2) improve airport wind information at certain runway ends, without significantly affecting existing uses of that sensor such as for wind shear detection.

The first action is mostly relevant to airports with only a primary or secondary sensor, where one or two observations are relied upon to provide coverage for all runways. The FAA is already making improvement in this area as they are performing some relocations as part of the deployment activity to replace WME and F-420 with SWS. This action is more likely to be practical for locations where the local environment influence has changed since the initial installation, e.g., via building construction or tree growth. The second action is more relevant to airports with LLWAS, which have an additional network of sensors for which a preferred location of some members may provide an improvement. However, it is unlikely that there is much opportunity for improvement here, since the LLWAS-NE sensors were originally sited with runway proximity as a consideration, and any relocations have the potential of disrupting wind shear detection capability as the associated algorithms require some presumption about the spacing and configuration of sensors within the network.

<u>Recommendation #3:</u> For problematic sensor locations for which relocation is not feasible, make algorithmic adjustments to the wind observation based on known performance issues.

Some measurement deficiencies are systematic and quantifiable, particularly those associated with obstruction or surface roughness issues from particular upwind directions, or are associated with non-standard sensor pole height (required to provide clearance from obstructions). In these instances, a sufficiently long record of observations can provide quantifiable characteristics in wind behavior to which correction factors can be applied.

<u>Recommendation #4:</u> Include gust information in current runway winds observation derived from LLWAS.

The LLWAS data platform has the capability to make a gust computation. The current limitation may be associated with display restrictions. This should be a candidate for reconsideration and modification.

<u>Recommendation #5:</u> Review the procedures for providing wind information to pilots, and make modifications that reduce the risk of inconsistent or stale information.

As described earlier, the conveyance of wind information for final clearance with a different source than that used in the ATIS broadcast has resulted in instances of reduced pilot confidence in terminal wind information and, in some cases, led to alteration of takeoff or landing procedures when the clearance wind unexpectedly fails to meet prescribed performance criteria. This is compounded by the increased likelihood of a “stale” wind observation in the ATIS message, which relies on the hourly METAR report.

An intuitively obvious potential solution would be to use the more frequently updated clearance wind in the ATIS broadcast. However, two factors have contributed to the resistance of this change. First, there is a current data quality control step that requires that the weather observation submitted to ATIS be manually reviewed by a certified observer. More frequent updates (e.g., every minute rather than the hourly METAR or intra-hourly SPECI) has been cited as potentially introducing an unacceptable workload in this regard. Secondly, the higher frequency update would also require frequent re-recordings of the ATIS message, which includes operational information in addition to weather.

Following a series of wind information complaints in this regard, this procedure has been modified at DTW in recent years to allow inclusion of the clearance wind instead of the METAR wind in the ATIS broadcast. Their experiences should be reviewed for consideration of this modification to take place across either at other selected locations or widely across the entire NAS. Contemporary technology for voice recognition may also aid in more frequent automated update of the broadcast ATIS message. The wind information provide in ATIS may also be improved with an indication of potential wind shift risk prior to touchdown or takeoff. (See Recommendation #7 in this regard.)

In a similar vein, the policy and process for selecting the airport wind conveyed to the pilot for final landing clearance should also be reviewed. As described earlier, each airport in the NAS is required to have a primary and backup wind source. Additionally, airports with LLWAS also have runway-specific wind information. Current policy gives the tower controller authority to use discretion in selecting the wind source for providing final clearance. A possible consideration is to standardize this selection for each airport.

Recommendation #6: Use wind measurements from other systems to complement surface anemometer measurements.

Two candidate wind sources in this regard are aircraft wind measurements and Doppler radar. These existing sources present an opportunity to provide timely wind information directly along the flight path, which has been a historical shortcoming of ground based anemometer systems.

There has been increased attention in recent years on making better operational use of wind measurements derived from aircraft. (Refer to 2.10 for details.) Aircraft equipage for providing this information continues to increase in the active fleet, with concurrent ongoing research using Mode S EHS to produce real-time wind estimates and new work developing requirements to extend a similar capability into future ADS-B systems. An appealing operational concept is automated passive receipt of wind information from the preceding aircraft in the cockpit of a trailing aircraft presented via display or automated voice, which would provide a timely wind observation in a relevant location of interest such as on short final or over the approach threshold.

Another source of wind information that may not be fully exploited operationally in the terminal airspace is Doppler radar measurements from existing weather systems, such as TDWR, ITWS, WSR-88D, and ASR (refer back to 2.9). The use of this information is primarily limited to detection of wind shear or other hazardous wind (and weather) signatures. The exception is the ITWS Terminal Wind product that provides selected vertical wind profile segments at key operational locations within the local TRACON airspace, with a vertical resolution of 1000 feet. This concept could be expanded to provide lower altitude wind information specifically at runway threshold locations.

Recommendation #7: Introduce short-term wind forecast information into the wind observation domain.

As described earlier, terminal wind observations are, in effect, currently used as short-term forecasts owing to the latency between the time of the observation and the actual aircraft navigation through the takeoff or landing airspace of interest. It is presumed that the observed conditions will persist throughout completion of the operation; any unanticipated abrupt change poses a safety risk. In some sense, knowing the risk of a wind change during execution of a low altitude procedure may be as important as knowing the current wind. Existing wind shear detection systems, particularly the radar-based system mentioned previously, already generated short term predictions of anticipated terminal area wind shifts, such as the ITWS gust front product which predicts location of wind shifts (including post-shift speed and direction) out to 20 minutes. There is additional ongoing research in short term wind forecasting that melds observational wind data (from anemometers, radar data, aircraft, etc.) with numerical weather prediction forecasts and statistical forecast predictions. Inclusion of this information, perhaps in the form of a notation of wind shift risk in the conveyed observation, provides an opportunity to augment the current paradigm.

Recommendation #8: Ensure reliable data quality of existing sensors by improving or streamlining mechanisms for monitoring and detecting degraded performance, and policies and processes for timely corrective maintenance.

The variety of different wind sensor platforms and ownership (FAA, NWS, private contractors) poses a challenge in providing consistent preventive maintenance, data quality monitoring, timely fault detection, and corrective maintenance. The ongoing upgrade to SWS sensors is a positive step in this direction in that it improves uniformity across the FAA wind sensor fleet, and includes more reliable ultrasonic technology (not prone to mechanical failures) and communication capability. A separate process is in place for LLWAS data in which monthly samples are sent to AJW-1444 for data quality review. A review of current processes and policies for the various platforms would likely add value by identifying shortfalls or raising visibility on known deficiencies. It is also recommended that a stakeholder forum, such as the Collaborative Decision Making (CDM) Weather Evaluation Team (WET), serve as a formal focal point for collecting user issues and prioritizing potential solutions. The WET (or another identified forum) should be charged with periodically soliciting concerns from airline, traffic management, and other community members and elevating those concerns to the FAA for resolution.

Recommendation #9: Re-evaluate current wind observation guidelines and translate them into specific requirements that encompass sensor characteristics, deployment location, processing methods, and data dissemination.

Existing guidelines for airport wind observation equipment and data processing are dated and incomplete. As a result it may be difficult to determine whether a given airport warrants changes in equipment characteristics, siting, processing, or data dissemination. An effort to translate findings from recent analyses of wind observation system performance into specific quantified requirements would facilitate making future investment decisions.

Recommendation #10: Develop a flexible analysis tool that can be used to evaluate cost/benefit tradeoffs of candidate wind observation deployments against established requirements.

Assessment of wind observation system performance currently requires a suite of ad hoc data collection and analysis. A flexible analysis tool, containing validated models of sensor performance, wind dynamics, and processing effects, would aid in assessing whether existing implementations are adequate and/or exploring possible solutions to identified observation problems. This tool could be used, for example, to evaluate the relative benefit of locating a given type of sensor in a given position relative to other sensors and the runways. A unified tool would also aid in ensuring consistent analysis and decision-making is applied across the NAS.

7. SUMMARY

Wind information is a critical element for ensuring safe aviation operations, particularly while performing low altitude takeoff and landing procedures. Across the NAS, supporting wind observations are currently collected by a multitude of different sensor platforms whose configuration varies substantially from airport to airport, largely dependent upon airport physical size, traffic volume, and hazardous wind shear exposure. For more than a decade, chronic concerns from air traffic controllers and pilots have emerged regarding the consistency and reliability of wind information at a number of locations.

The analysis presented here identifies potential shortfalls in the current wind information architecture, and offers recommendations for improvements that would serve the FAA in the context of NextGen-enabled concepts. The methodology relied on interviews and discussions with stakeholders, review of existing problem reports and operational logs, search and review of documentation related to wind sensors and operational policy, and analysis of airport wind sensor data.

The analysis revealed ten specific shortfalls:

1. Sensor observation may not be representative of local wind conditions (at the sensor site) due to upwind obstruction or other influences.
2. LLWAS/WME wind sensing equipment may be on poles with heights that differ from international standards, and/or from each other.
3. Runway threshold winds do not include gust information.
4. Data quality of local observation may be compromised due to electro/mechanical failure.
5. Wind reports from different sensor types may be inconsistent due to different processing algorithms for computing sustained wind and gusts.
6. Wind reports provided to pilots via ATIS (typically ASOS hourly METAR or SPECI) may not be representative of current conditions due to latency.
7. Wind reported via voice contact with tower controller (required as part of the takeoff or landing clearance message) may differ from recently communicated wind to pilot from ATIS broadcast due to different wind sensor sources. The report for the former is typically from WME, F-420, SWS, or SAWS, which all are updated at one-minute intervals.
8. Wind report for runway threshold may not be representative due to spatial translation from observation location.
9. Multiple wind source options for communicating wind to pilots relies on discretion of controller in selecting representative wind. Pilots are not currently made aware of wind information source.
10. A formal process for collecting, prioritizing, and resolving wind observation issues is not in place.

Ten recommendations for action are offered to address shortfalls and provide an improved wind information infrastructure to support NextGen-enabled concepts:

1. Add additional wind sensors at some airport runway ends, where a benefit/cost evaluation suggests that this is appropriate in the context of other FAA investments in NAS improvements.
2. Move existing sensors to either: 1) improve upon current locations where measurement quality is degraded by local environmental influences, or 2) improve airport wind information at certain runway ends, without significantly affecting existing uses of that sensor such as for wind shear detection.
3. For problematic sensor locations for which relocation is not feasible, make algorithmic adjustments to the wind observation based on known performance issues.
4. Include gust information in current runway winds observation derived from LLWAS.
5. Review the procedures for providing wind information to pilots, and make modifications that reduce the risk of inconsistent or stale information.
6. Use wind measurements from other systems to complement surface anemometer measurements.
7. Introduce short-term wind forecast information into the wind observation domain.
8. Ensure reliable data quality of existing sensors by improving or streamlining mechanisms for monitoring and detecting degraded performance, and policies and processes for timely corrective maintenance.
9. Re-evaluate current wind observation guidelines and translate them into specific requirements that encompass sensor characteristics, deployment location, processing methods, and data dissemination.
10. Develop a flexible analysis tool that can be used to evaluate cost/benefit tradeoffs of candidate wind observation deployments against established requirements.

An immediate action to follow up on this architectural analysis would be to initiate a systematic process for evaluating and prioritizing the relative cost/benefit tradeoffs at individual airports.

GLOSSARY

ACARS	Aircraft Communications Addressing and Reporting System
ACU	Acquisition Control Unit
ADAS	Automated Weather Observation System Data Acquisition System
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AIRMETS	Airmen’s Meteorological Information
AOC	Airline Operations Control Centers
ARINC	Aeronautical Radio, Incorporated
ASOS	Automated Surface Observing System
ATIS	Automatic Terminal Information System
AW	Airport Wind
AWC	Aviation Weather Center
AWOS	Automated Weather Observing System
AWSS	Automated Weather Sensor System
AWWs	Alert Weather Watches
CDM	Collaborative Decision Making
CF	Center Field
CLT	Charlotte
CONUS	Continental United States
CPDLC	Controller-Pilot Direct Link Communications
CWAs	Center Weather Advisories
D-ATIS	Data-Link ATIS
DCP	Data Collection Platform
DEN	Denver International Airport
DOC	Department of Commerce
DTW	Detroit Wayne Airport
EHS	Enhanced Surveillance
EWBS	Electronic Weight Balancing System
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
FIS-B	Flight Information Services-Broadcast
GPS	Global Positioning System
HF	High Frequency
HIWAS	Hazardous Inflight Weather Advisory Service
IAD	Dulles
ICAO	International Civil Aviation Organization
IDS	Information Display System

ITWS	Integrated Terminal Weather System
JFK	John F. Kennedy International Airport
KGCN	Grand Canyon National Airport
KHOB	Lea County Airport
LGA	LaGuardia Airport
LLWAS	Low Level Windshear Alert System
METAR	Meteorological Aviation Report
NAS	National Airspace System
NATCA	National Air Traffic Control Association
NE	Network Expansion
NEXRAD	Next-Generation Weather Radar
NextGen	Next-Generation Air Transportation System
NTSB	National Transportation Safety Board
NWS	National Weather Service
OID	Operator Interface Device
OMO	One-Minute-Observation
PC	Personal Computer
PIREPs	Pilot Reports
PSF	Program Support Facility
PUP	Principal User Interface
RBDT	Ribbon Display Terminal
RS	Relocation/Sustainment
SATCOM	Satellite Communications
SAWS	Stand Alone Weather System
SHEF	Standard Hydrometeorological Exchange Format
SIGMETS	Significant Meteorological Information
SOC	System Operation Centers
SOO	Science and Operation Officer
SOP	Standard Operating Procedures
SPECI	Special Aviation Weather Report
SWS	Surface Weather System
TAFs	Terminal Aerodrome Forecasts
TDWR	Terminal Doppler Weather Radar
TPS	Takeoff Performance System
TRACON	Terminal Radar Approach Control
TWIP	Terminal Weather Information for Pilots
VHF	Very High Frequency
VOR	Very high frequency Omnidirectional Radio
WET	Weather Evaluation Team
WME	Wind Measuring Equipment
WMO	World Meteorological Organization

WMSCR	Weather Message and Switching Center Replacement
WOI	Weather Observation Improvements
WSP	Weather Systems Processor

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[3] FAA, *FAA Order JO 6560.20C, Siting Criteria for Automated Weather Observing Systems,* 2017, pp. 2–3.

[4] ICAO, *AMOFSG/10-SN No. 14: The Provision of Crosswind and Tailwind Information*, 2013, p. 9.

[5] ICAO, *AMOSFG/8-SN No. 42: Wind Reporting at Touchdown Zone with Multiple Anemometers*, 2010.