Distribution of Aviation Weather Hazard Information: Low Altitude Wind Shear*

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1. Aviation Weather Hazard Information Distribution

Weather Hazard Information distribution is a necessary component for a successful system of weather hazard avoidance for aviation. It is a very important component, but not the only one. In order to be successful, a complete set of components must be included in the system:

- Accurate Conceptual Model (Appropriate models of the physical process responsible for generating the hazard)
- Production Infrastructure (System of tools (hardware, software and manpower); the raw data feeds necessary for production of the hazard information and a standardized message format.)
- Quality Control Infrastructure (System of tools (hardware, software and manpower) & data feeds necessary for identifying and correcting erroneous information immediately)
- Distribution Infrastructure (A method to relay, in a timely manner, only the information pertinent to the specific user)
- Policies and Procedures (There must be clearly defined expectations of actions required of the users and recipients of the hazard information)
- Training (The users and recipients as well as individuals responsible for production and quality control of the information must receive initial and recurrent training regarding actions required)

ICAO in their Annex 3, Chapter 7 titled, SIGMET Information, Aerodrome Warnings and Wind Shear Warnings [ICAO 1998], describes in part one such system for weather hazard avoidance. ICAO does a good job defining the necessary production infrastructure. ICAO especially has been successful in defining the standardized message format. The format for SIGMETs is described in detail in Annex 3. But, an international organization such as ICAO is limited in its scope of influence. Quality control of the SIGMET product and the distribution of the SIGMET is, in large part, beyond ICAO's control. In addition, the actual weather hazard avoidance policies, procedures and training must be accomplished internally by each individual commercial aviation operator.

Since each component listed above is directly dependent on the other five for a successful weather hazard avoidance system, Northwest Airlines (NWA) has chosen to attempt to address all six components of the system internally with use of the NWA Turbulence Plot System (TPS) [Fahey et. al. 2000].

2. Low Altitude Wind Shear Hazard Alerting

There is a long history of interest and forecasting of wind shear at NWA. NWA began reporting and forecasting wind shear in 1962 [Ruble, 1986, Sowa, 1974]. Originally, the focus at NWA was on low altitude frontal wind shear. The ability to clearly identify wind shear associated with convection was dramatically increased with the introduction of Doppler weather radar technology in the 1980's. As early as 1993, as part of a data link test program, NWA was coordinating with MIT Lincoln Laboratory and uplinking wind shear alerts generated by the FAA's Orlando, Florida Terminal Doppler Weather Radar (TDWR) to NWA aircraft. The FAA's currently deployed Terminal Weather Information for Pilots (TWIP) was the final result (see section 3.1).

NWA has integrated the TWIP alerts into the TPS. This was done by NWA to address the convective wind shear hazard. Prior, the more general TPS thunderstorm alert was used to warn of downbursts and gust fronts. TWIP provides a significant improvement in alerting capability since, of all the weather conditions, convective induced wind shear poses the greatest potential risk to commercial jet aircraft.

The airflow in a downburst fans out as it nears the ground, causing a wind divergence. Conversely, the airflow along a gust front converges. Usually, a divergence is associated with an aircraft experiencing a loss of headwind and a convergence is associated with a gain in headwind.

FAA wind shear alerts specifically use the following convention: if the estimated loss is between

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15 and 30 knots, over 4 km of flight, the event is labeled a "wind shear with loss," and if the estimated loss is 30 knots or greater, over 4 km, the event is labeled a "microburst". The hazard is considered greatly reduced for a downburst over spatially larger events, as the shear is less abrupt. In an area where convergence is detected, alerts are labeled “wind shear with gain” as long as the gain is 15 knots or greater.

NWA continues to manually issue TPS alerts for terrain induced and warm and cold front induced shear. Gusty winds and inversion generated wind shear are considered a low to nil risk to commercial jet aircraft and are not included in the NWA TPS alerts.

2.1 Current Low Altitude Wind Shear Alerting Systems

There are two primary ground based wind shear alert generation systems. The Terminal Doppler Weather Radar (TDWR) (Dasey, et al., 1996, Troxel, et al., 1996), and the Low Level Wind shear Alert System (LLWAS) (Wilson, and Gramzow, 1991). The coverage of both of these systems is nominally from the runway out 3 nmi, although in practice it is not always possible to site the LLAWS anemometers to give full 3 mile coverage. Both systems issue loss and gain alerts. There are two TDWR data processing tasks used to detect wind shear. One detects wind shear with loss (microbursts) and the other detects wind shear with gain (gust fronts). TDWR data quality issues can lead to false alerts or missed alerts (Isaminger et al., 1996). In this paper, only the latest LLWAS system (network expansion) is discussed, as earlier LLWAS systems do not issue microburst alerts. LLWAS NE examines the wind from pairs and triples of stations to detect wind shear. The LLWAS system is designed to be robust to sensor noise of 20% of wind speed. When due to sensor failure, or very gusty wind conditions, the noise in the input wind measurements rises above this level LLWAS may issue false alerts. Another sensor issue that can lead to false LLWAS alerts is sensor sheltering or partial sensor blockage in high winds. The LLWAS system has the ability to ignore wind measurements from certain sensors when the wind is from a direction associated with sheltering, but this feature is not currently used.

Both TDWR and LLWAS provide valuable and generally accurate wind shear warnings, although either systems at times will miss issuing a warning, or will issue false alerts. False wind shear level alerts may be nuisance wind shear alerts in that there is wind shear present, but it is weak or transient, or they may be outright incorrect. Because microburst alerts generally lead to a pilot decision to not land or take off, false microburst alerts have important consequences. Generally, both TDWR and LLWAS are not incorrect in the same conditions. For this reason, at the eight airports that have both systems (ATL, DEN, DFW, MCO, MSY, ORD, STL & TPA) they are combined into a single system. The integration/merging algorithm attempts to reduce false alerts and increase the accuracy of the loss or gain estimate by dropping weak wind shear alerts issued by only one system, by downgrading weak microburst alerts issued by only one system, and by averaging alerts if issued by both systems. Which alerts are "weak" is defined by site adaptation parameters. Strong microburst alerts issued by a single system are not dropped in order to reduce the possibility of not alerting for a valid “strong" alert.

2.2 Alert System Accuracy

The TDWR microburst algorithm has demonstrated a probability of detection well in excess of 90% and a false alarm rate of approximately 6%. Virtually all false TDWR loss alerts are in the 15 – 25 knot category. The TDWR gust front algorithm (Machine Intelligent Gust **F**ront Algorithm (MIGFA)) has a probability of detection of approximately 85% - 95% for events of 20 knots or more, but there is evidence that the false alarm rate may be near 20%. These false alerts are generally weak, in the 15 to 20 knot range, but may persist for an extended period of time as the gust front traverses the airport. Unlike the microburst algorithm, MIGFA does not require the presence of a reflectivity signature aloft to validate the detection, therefore, many of these alerts occur when convective activity is not present in the terminal area. However, due to the nature of the gust front phenomena, not all alerts generated without associated convective activity can be considered false. Outflow boundaries and cold fronts may occur at significant distances away from any associated activity. The frequency of this occurrence is not known, but individual cases are being investigated by the FAA/AOS-250 as TDWR basedata become available. An analysis of MIGFA performance is currently under way in an attempt to reduce the false alarm rate. In comparison, the previous TDWR gust front algorithm (GF88) had a false alarm rate near 10% and a probability of detection rate of less than 50%. Both NWA studies reported herein, concentrated on false alerts of 30 knots and greater. As mentioned above, the majority of the TDWR false alerts are less than 30 knots and therefore were not evaluated.

LLWAS has demonstrated a loss alert detection and false alert rate similar to the TDWR. However, LLWAS issues more of its false alerts above the 30-knot microburst threshold. The two most common causes of false LLWAS alerts are gusty winds where real, but transient, pockets of wind shear give rise to false alerts, and poor quality wind measurements due to sensor failures or sensor sheltering. The LLWAS system can also alert over a region larger than the actual event.

Studies in Orlando in the summers of 1991 and 1992, and in Denver in 1992 and 1993, show that integrating a TDWR and an LLWAS-NE can help reduce false alerts and improve wind shear detection in the convective weather season; these studies do not address performance in other weather regimes. In contrast, both NWA studies were conducted in the winter half of the year.

Integrated Liquid-water (VIL) is a planned TDWR product used to determine if the conditions are favorable to microburst generation. In a new version of TDWR, not yet released, VIL is used to verify TDWR microburst detections: if the VIL is low in the location of the detection, the detection is discarded. A prototype version of the Integration algorithm incorporating this test to eliminate false LLWAS microburst alerts in clear air conditions is being tested. While the VIL test is expected to reduce the number of false loss alerts in clear air, it will not help with false gust front alerts. Since LLWAS often does not provide full detection out 3 nmi from the runways, integration can not remove false MIGFA alerts from the ends of the runway corridors. The original TDWR gust front algorithm provided a poor detection capability. Because of this, the integration algorithm does not require TDWR confirmation for LLWAS-NE generated gust front alerts. Now that MIGFA has been fielded at all TDWR sites, it is believed that the improved gust front detection performance will allow for verification of LLWAS NE gust front alerts with those generated by TDWR, to reduce false LLWAS gain alerts. A study is currently underway to determine the optimum algorithm parameters to accomplish this. Several issues such as data quality, time resolution and minimum detectable wind shear length must be investigated first. It is anticipated that these parameters may aid in filtering out "nuisance" LLWAS-NE false alarms on gusty wind days.

3. Terminal Weather Information for Pilots (TWIP)

3.1 TWIP Program History

TWIP grew out of a desire to provide pilots with the same TDWR-based, meteorological alerting information displayed to Air Traffic Controllers. By augmenting the software that is part of the TDWR control and display unit located in every TRACON served by a TDWR, a datalink-based hazard notification service is provided via the ACARS datalink used by the majority of passenger-carrying airlines. Such a notification service assures that aircrews are aware of potential hazards to flight prior to contacting the tower/approach controller.

The initial, FAA-sponsored demonstration of TWIP occurred in 1993 at the ITWS testbed operated by MIT Lincoln Laboratory in Orlando, FL. By 1997, the demonstration had been expanded to include ground installations at Boston, Charlotte, Washington-National, Chicago, Memphis, Dallas-Fort Worth, Atlanta, and Denver and participation from more than six airlines in an extended evaluation of TWIP. The TWIP software specification was completed by MIT Lincoln Laboratory in 1995. Raytheon, under a subcontract to MIT Lincoln Laboratory, subsequently developed and tested the TWIP software. Raytheon then delivered a build of TDWR software augmented with TWIP functionality for Formal Qualification Testing in December 1996. FAA accepted the software in early 1997, completed (in collaboration with ARINC) the necessary network and communications upgrades at the first of the 45 TWIP sites during early 1997. At the time of the 1st NWA study, Fall 1998, 26 of the 45 initial planned TWIP airport sites were producing alerts (ATL, BOS, CLT, CMH, DAL, DAY, DCA, DEN, DFW, HOU, IAH, ICT, MCI, MCO, MEM, MKE, MSP, MSY, OKC, ORD, PBI, PHL, RDU, STL, TPA and TUL), At the time of the 2nd NWA study in early 2000, 3 additional airport sites had been added (BWI, IAD, MIA). After completion of the 2nd NWA study, in June 2000, one additional site was added (DTW) bringing the total active TWIP airports to 30.

3.2 TWIP Message Distribution Methods

There are two methods for disseminating TWIP alerts: Request/Reply and Send/Cancel. TWIP messages from each site are generated every minute in active weather, and every 10 minutes otherwise, and stored in a central database. Crews using the request/reply method obtain copies of the most recent message for a given site by generating a request via the ACARS Management Unit (MU). Upon receipt of the request, the ARINC-hosted database returns the current TWIP message for display on the MU. Although this protocol provides the crew with complete control over the timing of the TWIP messaging, no provision is made to alert them of changes in the weather situation after receiving a TWIP message.

The send/cancel method utilizes an airline's own distribution software. For crews receiving a TWIP message via send/cancel method, alerts are automatically sent to the aircraft whenever there is a significant change, for better or worse, in the meteorological hazard at a particular airport. Typically, airlines using this method stipulate that messages are forwarded to aircraft that are within a certain range of the departure or destination airport. Arrival of the automated messages at the aircraft triggers aural and visual cues in the cockpit, which signal the crew to retrieve and read the queued TWIP message. Since automatic broadcast of messages occur without regard for the workload of the crew, they represent a potential nuisance if uplinks are not screened to minimize nuisance alerting. To minimize this problem, TWIP applies certain criteria to assure that as few messages as possible are generated to represent an accurate picture of the most severe hazard currently impacting the airport.

The choice of which type of access method to use is made by each participating airline. NWA currently employs the send/cancel method of distributing the TWIP alerts. This is consistent with the distribution method by NWA for all weather hazards included in NWA’s TPS. Only aircraft within 40 minutes of Estimated Time of Arrival (ETA), or departing aircraft between out (brakes released at the gate) and off (wheels off the runway) receive alerts. As a quality control measure, all alerts containing both “No Storms Within 15nm” and shears less than 30kts are not uplinked but are available in a NWA database for dispatcher and meteorologist information.

4. 1998-2000 Accuracy Case Studies and Proposed Improvements

Two studies were conducted at NWA. In the first study, conducted in Oct. through Nov. 1998, all examples of questionable wind shear and microburst alerts issued through the TWIP system were manually collected by NWA dispatchers and meteorologists.

Forty-three examples were identified; 17 of which were alerts of 30kts or greater. All 17 were deemed false alerts.

The second, more rigorous, study, conducted Jan.-May 2000, captured all alerts coming through TWIP containing “No Storms Within 15 NM." An automated daily report was generated from the TWIP folder in the NWA archived weather database. During the Jan. through May 2000 study period there were a total of 1369 send/cancel wind shear alerts generated which contained the statement “No Storms Within 15nm”. Of those 1396 alerts, 91 of them contained shears greater than or equal to 30kts. These 91 alerts were studied in detail, since these are the alerts that are uplinked to the flight crews. Of these 91 alerts, 19 alerts were deemed valid, and 72 alerts were deemed false. Unfortunately, these 72 alerts were uplinked to NWA flight crews.

4.1 False Alert of 30kts or greater

There were 25 cases of blatantly false gust front alerts during the Jan. thru May 2000 study. These blatantly false alerts were traced to a software bug in the MIGFA algorithm. At the time of writing, TDWR Software Build 11.0, containing a fix for this bug, is planned to be released on 07 July 2000, and each TDWR site has 60 days for installation.

There were 22 examples of false alerts generated from the LLWAS NE system in gusty winds (see Table 1). Twenty of the 22 alerts were generated at locations where the LLWAS NE generated alerts are integrated with the TDWR alerts. The 2 alerts at Miami (MIA) on 15 Jan. are the only exceptions. It is assumed that those 20 alerts were generated by the LLWAS NE system. Currently integration software is designed to cross check LLWAS NE generated alerts with the TDWR alert only when the loss is between 30Kts and 32.5Kts; gain alerts are not cross checked. In other words, a “35Kt LOSS” LLWAS NE generated alert is passed directly though TWIP even if there is no collaborating TDWR generated alert. If the maximum microburst value for cross checking is increased to at least 35kts it is expected that all eight 35kt LOSS alerts would be reduced to 25 knots, or less than microburst strength. It is assumed that the seven 40kt LOSS alerts would still be directly passed through without cross checking. If a VIL test, discussed above, were added, it is also expected these alerts would be removed or down graded. Due to a lack of information, the authors are unable to explain and thus unable to suggest corrections for the four 30Kt GAINs from MIA, MSY & TPA; two 30Kt Losses at DEN and the one 50Kt GAIN from DFW.

In 10 cases there is evidence of meteorological conditions favorable for possible wind shear, such as a METAR indicated wind shift, although with an indicated shear much below the magnitude contained in the alert, or a METAR indicated convection and/or virga in the vicinity, although with no significant wind shift.

Table 1: False LLWAS alerts in gusty wind conditions

Date	Start Time	Stn	Magnitude	Current Wx Wind	Gusts
15-Jan-00	1249	MIA	30ktGAIN	17KT	23KT
15-Jan-00	1404	MIA	30ktGAIN	16KT	22KT
10-Jan-00	2033	ORD	35ktLOSS	18KT	25KT
10-Jan-00	2115	ORD	40ktLOSS	13KT	20KT
24-Feb-00	2213	MSY	30ktGAIN	12KT	18KT
8-Mar-00	731	DEN	40ktLOSS	22KT	32KT
8-Mar-00	401	DEN	40ktLOSS	14KT	26KT
9-Mar-00	852	ORD	40ktLOSS	16KT	24KT
9-Mar-00	934	ORD	35ktLOSS	16KT	24KT
9-Mar-00	1229	ORD	40ktLOSS	21KT	28KT
9-Mar-00	1333	ORD	35ktLOSS	21KT	28KT
7-Apr-00	142	DFW	50ktGAIN	24KT	32KT
8-Apr-00	303	TPA	30ktGAIN	16KT	22KT
20-Apr-00	2027	STL	35ktLOSS	26KT	32KT
9-May-00	2136	ORD	40ktLOSS	17KT	22KT
10-May-00	2251	DEN	35ktLOSS	22KT	29KT
12-May-00	1642	DEN	35ktLOSS	21KT	32KT
12-May-00	1713	DEN	30ktLOSS	27KT	34KT
16-May-00	2156	DEN	35ktLOSS	21KT	28KT
16-May-00	2224	DEN	40ktLOSS	21KT	28KT
16-May-00	2245	DEN	30ktLOSS	26KT	30KT
16-May-00	2317	DEN	35ktLOSS	27KT	31KT

In the case of three false alerts, a FAA official from the NWA-Certificate Management Office was riding on the flight deck performing an inspection. The aircraft departed MSP at approximately 1235Z 03 May 2000. During taxing for takeoff, a 30kt GAIN alert was uplinked to the flight crew. In the previous hour two 35kt gain alerts had also been generated. The Operations Inspector subsequently reported that the climbout of MSP was uneventful with no shear experienced. Post analysis of wind and temperature profiles obtained from the MPX (Chanhassen MN) radiosonde released at 12Z that day, indicated a temperature inversion between the surface and the first mandatory level, 925 mb. Wind velocity at 925 mb was approximately 240 degrees at 30kts vs. surface wind reported 12Z & 13Z, 210 at 10-13kts. No proposed resolution identified.

There were 12 other alerts deemed false where an explanation of the cause is not possible.

4.2 False Alerts less than 30Kts

In addition to the details regarding the study of the 91 alerts with shear of 30kts or greater, note should also be taken of the problem of frequent false alerts for shears less than 30kts. The biggest risk with these type of false alerts is that Air Traffic user's confidence in the system may be eroded.

Example 1: 06-07 Mayí00 DFW 61 false alerts

During a 31 hour period 61 TWIP message were generated. All 61 were for “20Kt LOSS”. During this entire 31 hour period, no precipitation was reported. The wind direction varied by only 40 degrees (160 to 200), but winds gusted consistently during the period (20 to 35 kts).

Example 2: 18-19 Marí00 ATL 42 false alerts, all with 20kt loss.

Example 3: 08 Apr 00 MSY 39 false alerts, all with 20Kt loss.

The proposed explanation for these events is that in all of 142 cases the LLWAS NE algorithm triggered on pockets of divergence in the gusty winds. Not all LLWAS NE alerts require confirmation with a TDWR alert. In the integration algorithm, there is a cut-off for weak wind shear alerts with loss. Only weak wind shear alerts are removed. That cut-off is currently set at 17.5 knots. Since before rounding, the 20 knot alerts range from 17.5 knots to 22.5 knots, if the cut-off is raised to 20 knots, approximately half of the 20 knot false alerts would be cancelled, and if the cut-off is raised to 22.5 knots, all 20 knots LLWAS alerts without a companion TDWR alert would be cancelled. Raising the weak wind shear filtering threshold and introducing the new Integration VIL test would potentially eliminate all 142 of these nuisance alerts.

4.3 Other False Alerts

A significant event was noted by NWA dispatchers and meteorologists outside of the two study periods. On 26 June 2000 Orlando FL (MCO) false 45 knot alerts were generated every 20-21 minutes for 9 hours. Part of the TDWR system went into maintenance mode and continuously generated the same alert. The TDWR Software Build 11.0 includes an automatic process for rebooting the DFU to eliminate this problem.

4.4 Valid Alerts and Frontal Shear

During the Jan to May 2000 NWA study, of the 19 alerts deemed valid, 7 were associated with a cold front or a trough.

In these 7 cases it is assumed that the alerts were generated, even though no storms were detected, when the TDWR algorithms identified the convergence area, very near the surface, associated with the cold front or trough. It is noteworthy that the alert was generated, in best case, 10 minutes before, to worst case, 12 minutes after the METAR reported the wind shift associated with the cold front passage. NWA continues to produce cold front shear alerts manually with the goal of an average 1-hour advance notice.

NWA has procedures, developed in the 1960's, for forecasting both warm front and cold front shear (D. F. SOWA, 1974). It is of great interest to NWA whether the FAA wind shear alert systems feeding TWIP have the potential to issue alerts during frontal induced wind shear events in general and warm front shears specifically. No examples of alerts due to a warm front induced low altitude wind shear could be found during the Jan.–May 2000 study. The current assumption used by NWA is that the TDWR as well as LLWAS based detection systems are unable to identify warm front induced low altitude wind shear, when the warm front surface is aloft, over the airport station in question. NWA will continue to produce warm front shear alerts manually until proven otherwise.

5. Conclusion and Recommendations

The successful avoidance of aviation weather hazards requires a concerted effort encompassing all aspects of the problem: accurate conceptual model of the hazard; tools for hazard alert production; real-time quality control of the alerts to ensure accuracy; distribution of timely and pertinent alerts to the users; clearly defined and implemented procedures for alert use, and recurrent training for all users.

With regard to the wind shear hazard and the TWIP product specifically, there are 3 area that are recommended to receive additional attention: Tools for Hazard Alert Production, Quality Control, and Training.

5.1 Tools for Hazard Alert Production

Continued efforts to fine tune the tools used to produce wind shear alerts is recommended as the number one priority. It is assumed that the blatantly false gust front alerts (50Kt to 95Kt gain alerts) will be eliminated with the introduction of TDWR software build 11.0. It is recommended that the gust front alerts be monitored to ensure that these false alert no longer occur.

At sites where both LLWAS NE and TDWR provide inputs to alert generation, additional cross checking should be implemented. It is recommended that a study be undertaken regarding the benefits of increasing the “weak wind shear” and “weak microburst” thresholds above the current 17.5kt and 32.5kt levels respectively. Representatives from the FAA, industry and research community should jointly decide if benefits out weigh risks. If benefits out weigh risks changes should be implemented.

Shears induced by synoptic scale fronts, especially warm frontal shear have the potential to pose a significant hazard to aviation. A study of the capability of automated system capabilities to detect frontal shears should be initiated.

It is also recommended that work continue on development of new tools, for example Vertically Integrated Liquid (VIL). Integration of METAR reports is another potential source of information for tool development.

5.2 Quality Control

The users report their perception that there is currently no organization with procedures or staff to immediately address alerts of questionable accuracy. They further report that confidence in the accuracy of the entire system has been undermined resulting in examples of valid alerts being ignored. It is recommended that representatives from FAA, industry and research community evaluate if this perception is valid. If so, a system for real-time quality control be implemented.

5.3 Training

The users report their perception that ATC personnel, specifically at towers, have limited awareness of the TWIP program. Air Safety Reports site examples where flight crews have received TWIP alerts and tower personnel were either unaware of the alert or unaware that flight crews had access to this information directly. Similarly, awareness of the TWIP system on the part of pilots and dispatchers is important to be further emphasized. In general, the commonality of understanding and awareness of the alerts by all users: air traffic controllers, flight dispatchers and pilots should be emphasized.

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