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Hazard Evaluation and Operational Cockpit Display of Ground-Measured Windshear Data

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Information transfer issues associated with the dissemination of windshear alerts from the ground are studied. Two of these issues are specifically addressed: the effectiveness of different cockpit presentations of ground-measured information and assessment of the windshear hazard from ground-based measurements. Information transfer and presentation issues have been explored through pilot surveys and a part-task Boeing 767 "glass cockpit" simulation. The survey produced an information base for study of crew-centered windshear alert design, whereas the part-task simulations provided useful data about modes of cockpit information presentation for both windshear alert and ATC clearance delivery. Graphical map displays have been observed to be exceptionally efficient for presentation of position-critical alerts, and some problems with text displays have been identified. Problems associated with hazard assessment of ground-measured windshear information have also been identified.

I. Introduction

LOW-ALTITUDE windshear is the leading weather-related cause of fatal aviation accidents in the U.S. Since 1964, there have been 26 accidents attributed to windshear resulting in over 500 fatalities.[1,2] Low-altitude windshear can take several forms, including macroscopic forms such as cold-warm gustfronts down to the small, intense downdrafts known as microbursts. Microbursts are particularly dangerous and difficult to detect due to their small size, short duration, and occurrence under both heavy precipitation and virtually dry conditions. For these reasons, the real-time detection of windshear hazards is a very active field of research. Also, the advent of digital ground-to-air datalinks and electronic flight instrumentation opens up many options for implementation of windshear alerts in the terminal area environment. Study is required to determine the best content, format, timing, and cockpit presentation of windshear alerts in the modern ATC environment to best inform the flight crew without significantly increasing crew workload.

II. Ground-Based Windshear Detection and Warning

A. Ground-Based Detection Technology

Ground-based windshear detection will play a large role in near-term windshear alerting and avoidance systems. The currently operational Low-Level Windshear Alert System (LLWAS), networks of anemometers around an airport and its approaches, are being expanded at some airports and are more capable of detecting windshears that impact the ground within the network boundaries. More importantly, ground-based Doppler weather radar systems such as Terminal Doppler Weather Radar (TDWR) and Doppler processing of ASR-9 radar data are becoming available and are capable of locating and measuring windshear events throughout the terminal area. These systems will provide the core data for near-term windshear alerting systems. Airborne predictive (look-ahead) sensors currently in the R&D phase—such as infrared radiometers, airborne Doppler radars, and lidars—will supplement ground-derived data as they become available and economically feasible. Airborne in situ or reactive windshear sensing, provided through comparison of airspeed measurements with inertial accelerometer measurements, is a currently available technology that can provide flight crews with warning once windshear penetration has occurred.

B. Integrated Ground-Based Systems

Assuming the near-term (early 1990s) deployment of both ground-based Doppler weather radars and the Mode-S ground-to-air digital datalink, possible paths of information flow are illustrated in Fig. 1. In this environment, data from LLWAS and TDWR sensors can be combined with pilot reports (PIREPs) to form the current windshear database. These PIREPs may be verbal or reported automatically by an airborne inertial sensor over the digital datalink. This data then can be processed to varying degrees and transmitted to the aircraft via voice communications or digital datalink. Several issues are raised by this implementation. One of these is the degree of data processing done; this can range from transmission of essentially raw data (as in the original LLWAS implementation, for example) or complete processing of the data into an executive decision to close the runway. One consideration is purely operational: what should be the distribution of decision-making responsibility between the pilot and the ATC controller? Another consideration is technical: given the available weather information, what is the (quantitative) hazard posed by the current weather situation to a particular aircraft or aircraft type?

Another of these issues is the "crew interface," the procedure and method used to inform the crew of a hazard. An essential difficulty in presenting windshear information is the need for alerts during descent and final approach, which are high workload phases of flight. For this reason, design of the crew interface is critical; a poor interface will result in loss of information or increased crew workload. The advent of electronic cockpits and digital ground-to-air datalink opens up a variety of options for implementation of the crew interface. Some issues to be examined include information content, message format, and mode of presentation.

C. Research Focus

The specific focus of this research has been the evaluation, transmission, and presentation of ground-based Doppler

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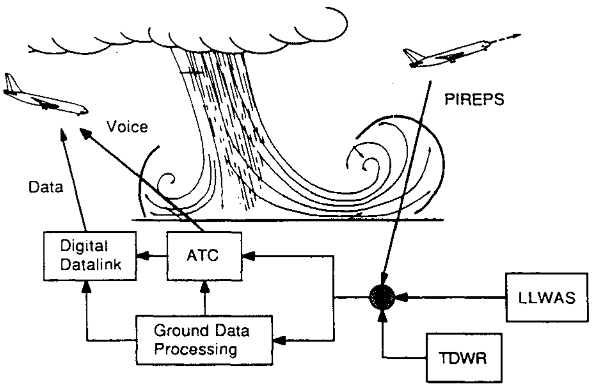


Fig. 1 Integrated ground-based windshear alerting system.

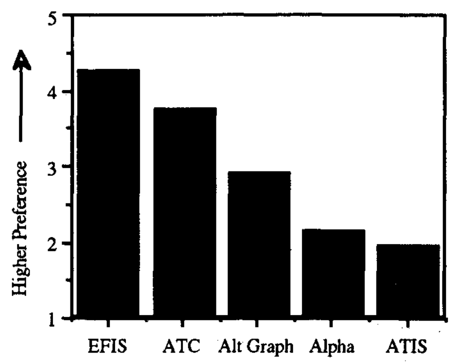


Fig. 2 Pilot rankings of possible relay/presentation modes for ground-generated wind shear alerts.

weather radar derived information through a limited bandwidth digital datalink (Mode-S). The first issue studied is the content and cockpit presentation of uplinked windshear alerts. User input was solicited through pilot opinion surveys and then used to design a part-task simulation experiment. The primary results deal with the use of electronic instrumentation for presentation of uplinked information, specifically the relative merits and disadvantages of voice, alphanumeric (textual), and graphical modes of presentation. In this context, *voice* or *verbal* mode refers to standard ATC radio communications, *alphanumeric* or *textual* mode refers to presentation (on some electronic or paper device) of the literal text of a message, and *graphical* mode refers to a combined pictorial/text presentation of the alert information on some electronic map or map-like display. Alphanumeric and graphical presentations presuppose the existence of a ground-to-air digital datalink.

The second issue examined is the evaluation of ground-measured windshear data to determine a hazard index. This hazard index should both be able to accurately quantify the windshear hazard present and be used to generate a meaningful alert for the flight crew. Overwarning must be minimized, since a large number of false or nuisance alerts can disrupt airport operations and damage pilot confidence in the alerting system. Preliminary analysis has identified some of the issues and problems involved, and further work is in progress.

III. Crew Interface Issues

A. Pilot Opinion Surveys

To obtain user input on both current windshear alert systems and requirements for future systems, a pilot opinion survey was conducted. With the cooperation of the Airline Pilots Association and United Airlines, responses were collected from 51 line pilots of transport category aircraft with autoflight systems (Boeing 757, 767, 747-400). Significantly, 51% of the respondents have had what they considered to be a hazardous windshear encounter; most of these occurred at Denver-Stapleton airport, a UAL hub and an area noted for heavy microburst activity during the summer months. It should also be noted, however, that pilots who have had a hazardous windshear encounter may have been more likely to respond to the survey. Some general results are the following:

1) Most of the pilots (90%) agreed that "microbursts pose a major safety hazard to transport category aircraft."

2) Only 15% of the respondents agreed that "currently available windshear alert data is sufficient for safe operation in the terminal area," while 44% disagreed.

3) *All but one* (98%) of the pilots felt that "a system to provide aircrews with better and more timely windshear alerts is *necessary*."

These responses clearly indicate that pilots are dissatisfied with current windshear alert data and would be receptive to improvements. The pilots were also asked to rate the usefulness of currently available windshear data. Significantly, PIREPs and visual clues were rated more useful for windshear avoidance than LLWAS. However, neither PIREPs or visual information are always available. This emphasizes the need for improved remote detection and advance warning and the importance of good PIREP collection and distribution. A digital datalink would be very useful in this application.

Another set of questions dealt specifically with the use of a ground-to-air datalink and an EFIS to display windshear (specifically microburst) alerts. Responses indicated that pilots are receptive to graphic displays (Fig. 2). The specific suggestion of integrating windshear information with an EFIS moving map display was strongly supported, ranking 4.3 out of 5. Also of interest was the high preference for ATC voice alerts (3.9/5), which is likely a result of a practiced ability to interpret radio communications. Display of wind shear alerts on some alternate graphical display (other than the EFIS moving map) was also ranked above alphanumeric displays and ATIS. Comments indicated that the low ranking of ATIS was due to the long time between updates.

Due to time limitations of VHF verbal communications and bit limitations of digital datalinks, the amount of information space available for a given alert is limited. For this reason, message content is critical. Thus, a question dealing with the message content of microburst alerts was included. The responses indicated that location and intensity of microbursts are clearly the most important items of information. Size, microburst movement, and intensity trends are of secondary importance. Ranking of this information allows design of alerts that fit within the message length constraints and still retain enough information to be useful. In this case, the data indicates that the message must include location and intensity. Later comments from the part-task simulation experiment subjects indicated that size would be desirable also, since it is in some sense related to the intensity.

The survey also addressed timing of microburst alerts. There was no consensus as to in what phase of flight (i.e., when during the descent and approach) alerts should be given; the most common response was "as soon as detected." This topic needs to be further examined, since the high workload environment during terminal area operations makes timing of the warning crucial.

A codistributed survey was specifically concerned with use of a Flight Management Computer (FMC) in concert with an EFIS and was intended to evaluate crew acceptance and use patterns of these automated systems. Regardless of flight hours with the FMC, pilots expressed a decided preference for automated aircraft over nonautomated ones, with an overall mean of 82%. In general, crews were enthusiastic about the EFIS, which supported the preference for graphical alerts expressed during the windshear survey. The complete findings from this survey are presented in Ref. 3.

B. Flight Simulator Study

The purpose of the part-task simulator study was to compare message presentation modes—verbal, alphanumeric, and graphical as defined in Sec. II. C—on a modern "glass cockpit" aircraft. This was done for both uplinked microburst windshear alerts and for ATC clearance amendments in the terminal area.

Simulator Design

The Boeing 757/767 class of aircraft with its Electronic Flight Instrumentation System (EFIS) was (approximately) simulated (Fig. 3). The primary instrumentation was displayed on an IRIS 2400T color graphics workstation. It included a good fidelity representation of the EFIS displays, including the EHSI and the Electronic Attitude Director Indicator (EADI). Airspeed and altitude were displayed as moving tapes (as in the 747-400 aircraft), and a vertical speed indicator was also included. A window for display of alphanumeric wind shear alerts was provided. A low-priority tracking sidetask was included for workload adjustment and monitoring. The EHSI display was controlled through an external control panel that allowed the pilot to change EHSI modes (MAP or ILS) and the display range and to suppress unwanted off-route information.

The Control Display Unit (CDU) for data entry into the FMC was simulated with an IBM/XT computer. It provided the necessary subset of the FMC functions required for the simulation. Non-FMC control of the aircraft was performed through an autopilot panel, similar to the glareshield panel on the 757/767. The standard autothrottle and autoflight systems were available, including FMC-programmed lateral and vertical path guidance and the various capture ("select") and hold modes for airspeed, heading, vertical speed, and altitude guidance.

An ATC workstation was located in a separate area. The controller received live audio and video of the simulation area, which were recorded. The controller monitored the experiment, controlled the timing of ATC clearances and windshear alerts, and communicated with the pilot through a voice link.

This experiment was concerned with cognitive decision-making issues rather than the details of pilot performance. Therefore, controls and instruments not related to the particular cognitive task at hand were not simulated. The lack of a copilot and imposition of a sidetask compensated for the workload loss. The subjects generally agreed that the simulation was accurate for the tasks they were asked to perform. Also, no windshear dynamics were included, in that the data of interest was the go/no-go decision and whether or not penetration occurred. The major advantages of the part-task simulator are the ease of setup and operation and the flexibility of the electronic displays. Alphanumeric and graphical message formats are easy to implement and change.

Scenario Design

Nine descent and approach scenarios into the Denver-Stapleton airport were devised. The Denver terminal area was selected for two reasons: 1) the high incidence of dry microburst activity observed there, and 2) the large number of possible descent profile and landing runway combinations. The inclusion of both ATC amendments and microburst alerts in the same scenario was useful in preventing the subject from anticipating repeated windshear alerts.

Each scenario was divided into two phases. The aircraft started at the outer limit of the terminal area with an initial flight plan, which was preprogrammed into the FMC. During descent, three amendments that required reprogramming of the FMC for compliance were given. Of these, one was "unacceptable," implying that the pilot should have taken some corrective action such as requesting clarification or a new routing. The pilot was unaware that any of the amendments were going to be unacceptable.

The second phase of the scenario began when the aircraft was vectored onto the final approach course. Windshear alerts could occur after this point. Microbursts were positioned either as a *threat* on the approach path or as a *nonthreat* on the approach or departure end of another runway. In addition, microbursts were sometimes positioned on the missed approach path. The alert was given either close in (at the outer marker, 6 to 9 n.mi. from touchdown) or further out (20 n.mi., with a second message at 10 n.mi. from the runway threshold). The microburst alerts always contained warnings for all possible approach runways, not only the one being used by the simulated aircraft. This was to measure the pilot's ability to discriminate between threatening and nonthreatening situations.

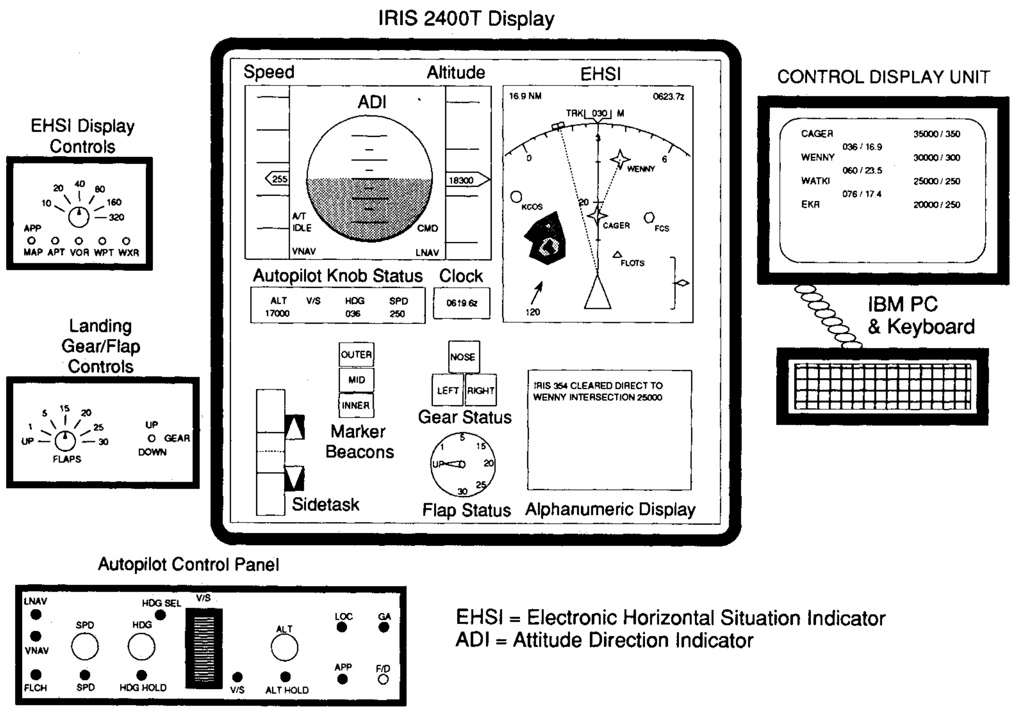


Fig. 3 Boeing 757/767 part-task simulator.

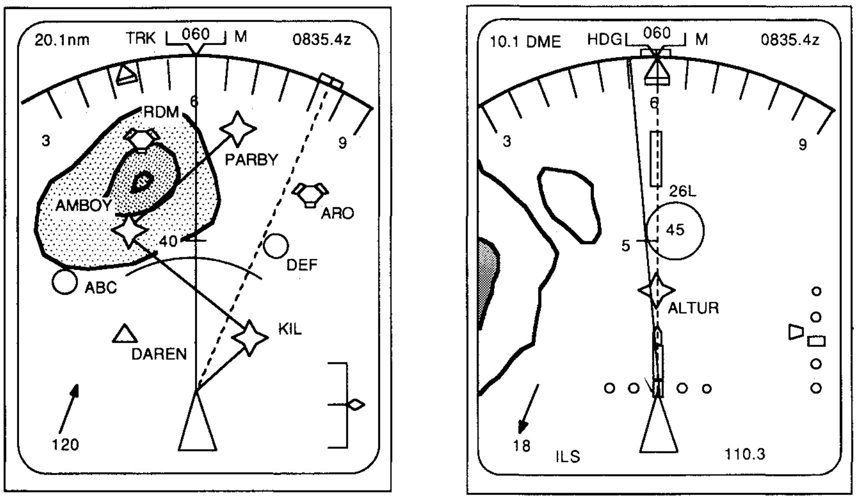


Fig. 4 Boeing 757/767 EHSI display modes: MAP (left) and ILS (right).

The nine scenarios were divided into three sets of three by presentation mode. In each block, all amendments and windshear alerts were given in the assigned mode: verbal, alphanumeric, or graphical. Verbal clearance amendments were given according to current ATC operating procedures. Alphanumeric clearance amendments were activated remotely by the controller, generating an audible alert. The text of the message appeared on the CDU screen when called up by the pilot. In the graphical mode, activated clearance amendments appeared on the EHSI as an alternate route (dashed white line). These could be accepted or rejected with a single CDU keystroke. Pilots were not required to read back text or graphical amendments.

Verbal microburst alerts were given as radio messages by the controller. Text microburst alerts appeared in an alphanumeric window just below the EHSI display. The following is a typical verbal or text alert: "IRIS 354, Microburst Alert. Expect four-zero knot loss, 2 mile final approach runway one-seven-left." Graphical microburst alerts appeared in the appropriate location on the EHSI map (in both MAP and ILS mode) as flashing white circles with the intensity (headwind-to-tailwind divergence value in knots) drawn inside them. An example is shown on the ILS mode display in Fig. 4. Verbal cues were given (i.e., "IRIS 354, Microburst alert.") in all modes, so that the method and time of initial notification were kept constant. This would not be true of an actual cockpit, where an automated audible alert would most likely be used. Over the subjects tested, all scenario blocks were tested in all the modes, and the order in which the subject encountered the modes was rotated. This process was used to attenuate learning and scenario-dependent effects.

With the approval of the Air Line Pilots' Association, eight active 757/767 line pilots volunteered for the experiment. The subjects were all male; five were captains, and three were first officers. The pilots ranged in age from 30 to 59 years, with a mean of 47 years. In addition, several other pilots of varying experience assisted in the development of the simulator and the scenarios.

Experimental Procedure

At the start of the session, the pilot was asked to complete the first stage of a NASA-designed workload evaluation,[4] which asked him to prioritize the different types of workload for the specific task of flying a 757/767 aircraft. Next, the features of the simulator were demonstrated. A sample scenario was used to demonstrate all of the three modes for both phases of flight. When the subject became comfortable with the operation of the simulator, the test scenarios began. At the start of each scenario, the pilot was given an initial clearance into Denver-Stapleton and had all the necessary charts to make the approach. Each of the nine scenarios lasted from 20 to 35 min. During the flights, one of the experimenters served as the ATC controller and one remained in the cockpit with the pilot to answer questions about physical operation of the simulator. After each scenario the pilot completed a separate subjective workload evaluation sheet for the descent phase (the clearance amendment task) and for the approach phase (when microburst alerts were given). After all of the scenarios, there was a debriefing session in which the pilot's impressions of the simulator and the presentation modes were solicited.

Results

Three forms of numerical data—pilot performance, workload, and preference—were taken. The measure of pilot performance for the microburst alerts was the percentage of "correct decisions" made in each presentation mode. An incorrect decision was scored for either 1) avoidance action taken when none was necessary, or 2) no avoidance action was taken in a clearly hazardous situation. The fewest incorrect decisions (8%) were made with graphical microburst alerts, the next fewest (17%) with verbal alerts, and the most (27%) were made with text alerts. This indicates that text alerts may actually degrade performance relative to verbal alerts, likely due to the greater comprehension time associated with reading the text message. It is also important to note that pilots are very experienced and comfortable with verbal radio communications. The positional information contained in the graphical mode actually led several pilots to request and program nonstandard missed approach procedures in advance to avoid the windshear areas completely. When the pilots were given the information in the other modes, this was generally not observed.

The NASA Task Load Index[4] was selected to assess workload for both tasks in each of the modes. This scale divides workload into six components: mental demand, physical demand, temporal demand, effort, frustration, and performance. The ratings were made along a continuum from "very low" to "very high." Weightings for each of the aforementioned six factors are obtained individually for each subject through a paired comparison task during subject orientation. The weights are simply the number of times a particular component was chosen to be a more important contributor to workload.

The overall workload ratings for each mode are plotted in Fig. 5. For both tasks, workload for the graphical mode was significantly lower than the workload for the verbal and textual modes. The six subscale ratings all showed a similar trend. The appearance of greater workload induced by the textual condition is not a significant effect.

Pilot comments and subjective evaluations of the presentation modes were obtained through loosely structured post-

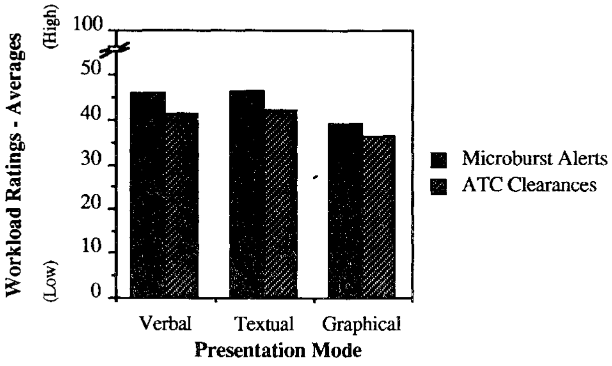


Fig. 5 Part-task simulation results—subject workload by mode.

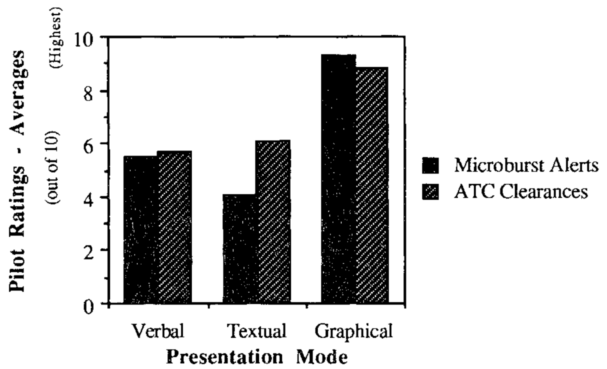


Fig. 6 Part-task simulation results—pilot preference by mode.

experiment interviews. In their evaluation of the modes, pilots overwhelmingly preferred the graphical mode of communication (Fig. 6), which is consistent with the survey results. For the windshear alerts, the text mode was consistently rated less desirable than the verbal mode. This was not the case for clearance amendments. Although the text and verbal modes seemed to be equally desirable from the averaged ratings, in fact, some pilots greatly preferred the text mode over the verbal, while others preferred the exact opposite (hence the midrange average value). All pilots indicated that they were comfortable with current verbal procedures, though, so they did not feel that the advantages of the text mode were significant.

Some further observations were taken from the experimenters' notes and pilots' comments. First, textual alerts given in time-critical situations, such as final approach, were thought to require too much head-down time. Second, digitally transmitted information in either mode, textual or graphical, leads to a loss of voice inflection information. Since controllers sometimes use voice inflection to distinguish urgent alerts from normal communications, this is in some sense a loss of information. Third, digitally transmitted information, if directed to specific aircraft, prevents pilots from hearing instructions given to other aircraft in the terminal area ("party-line" information). Some pilots stated that hearing the communications to other aircraft in the vicinity gave them a better understanding of the overall situation and enabled them to be better prepared when an alert arrived. Other pilots indicated that they could do without the information.

To obtain the benefits of graphical messages, the detailed format of such messages must be carefully designed to present only the necessary information in clear fashion without clutter or data overload. In the case of windshear alerts, the pilots identified this minimum presentation to be a simple symbol showing location, approximate size, and intensity. The proposed Mode-S datalink, for example, allows 48 bits of useful information every 4 to 12 seconds in surveillance mode. This minimum alert presentation can likely be expressed in 24 bits or less, allowing two messages per scan. Therefore, the Mode-S link can possibly be used to display and track several microbursts, while keeping up with the 1 minute update rate achieved by TDWR in the current configuration.

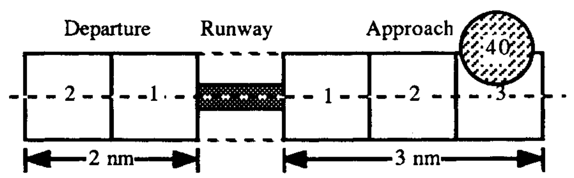
IV. Hazard Assessment

The successful implementation of ground-measured windshear alerts requires an effective way of quantifying the windshear hazard. This hazard criterion must provide an accurate estimate of the danger to approaching and departing aircraft that can be easily interpreted by the flight crew. To maintain pilot confidence in a ground-based windshear avoidance system, an alert must correlate with what the aircraft is experiencing or will experience. Otherwise, even an accurate measurement can be perceived as a false alarm.

The alerting criterion used in the recent TDWR operational evaluations at Denver-Stapelton and Kansas City International airports (and in current testing, as well) is based on horizontal wind measurements. When a change in low-altitude horizontal winds above a threshold is measured (radial from the radar), the area is marked and quantified by the maximum radial shear measured within it. If this area is within the segments identified in Fig. 7, an alert is issued.[5,6]

One problem with this system is that a microburst that occurs in one of the boxes may in one case never encroach on the flight path and in another be right on the center of it. In either case, the same alert is issued. This means that approaching or departing aircraft may fly through the center of a microburst or almost entirely miss it, experiencing the entire event or nothing at all. This could be perceived as a false alarm by the pilot, although the windshear is present and may even be fairly close to his position. A recent report about the 1988 TDWR Operational Evaluation indicates that this could be a major issue.[7] Data was collected from 111 pilots who landed or took off during alert periods. (Since the microburst alerting software changed over the course of the 1988 Operational Evaluation, the pilot responses included in this calculation were those pilots who not only were alerted but also would have been alerted by the final version of the warning algorithm. The earlier version of the algorithm produced more alerts than the final one.) Of this group, 34% indicated that "nothing was encountered," whereas another 31% reported something like "nothing much was encountered." A "nuisance alarm" rate this high can unnecessarily disrupt airport operations as well as damage pilot confidence in the windshear alert system.

A portion of this problem may also stem from the intensity quantity used. The windshear quantity used in the alerts is derived from the maximum change in radial velocity over the area of shear. This number is reported in the alert as an X ". . . knot airspeed loss." In reality, for an axisymmetric microburst, this number represents about an $X/2$ airspeed gain followed by an X knot loss. This is not a reporting error, but crews should be aware that the quantity being measured is the maximum horizontal wind change over the shear and that the maximum airspeed loss relative to the reference airspeed before penetration is approximately one-half of the reported value.



The alert corresponding to the 40 knot microburst pictured above might be:"United 226, Denver tower, threshold wind one six zero at six, expect a forty knot loss on three mile final."

Fig. 7 Windshear reporting zones for approach and departure: 1988 TDWR operational evaluation.

A more fundamental difficulty in using wind change or "airspeed loss" as the hazard criterion is that the hazard due to a microburst windfield is primarily a function of horizontal wind gradient and downdraft velocity rather than overall horizontal windshear. The critical danger is loss of aircraft total energy, which can be usefully defined as the sum of air-mass relative kinetic energy and potential energy measured with respect to ground level. The impact of the immediate windfield on the aircraft's rate of energy loss has been quantified by some researchers[8] as "*F*-factor"

$$F \equiv \frac{\dot{W}_x}{g} - \frac{W_h}{V} \tag{1}$$

where $\dot{W}_x$ is horizontal wind velocity (tailwind positive), g is gravitational acceleration, W_h is vertical wind velocity (updraft positive), and V is aircraft airspeed.

This quantity indicates the loss of climb rate (or effective excess thrust-to-weight ratio) due to the immediate windfield. It is clear, through examination of the windshear hazard in energy terms, that the energy loss the aircraft experiences can take the form of either airspeed or altitude loss. The proportion of these is a function of the control strategy employed. Therefore, F is a more compelling measure of the potential performance loss due to a microburst than total divergence.

Wind change, however, is convenient for intensity measurement since it can be measured directly by a ground-based Doppler radar. There are several problems with using ground-based radar measurements to estimate F. One is the inability to directly measure vertical wind velocity. A second relates to altitude variance. Microburst windfields can vary strongly over the lowest 1000 ft above ground level (AGL). A radar scan beam used for microburst detection has a finite beamwidth on the order of 0.5–1 deg. For a radar situated several miles from the airport (typical for TDWR), this implies that the radial velocity measurements are a weighted average over the lowest 500–1000 ft AGL. This makes estimation of peak horizontal shear more difficult.

A third difficulty is microburst asymmetry. For divergence estimating purposes, the asymmetry ratio of a microburst can be defined as the ratio of shear in the direction of maximum divergence to shear in the direction of minimum divergence. One study of Colorado microbursts[9] indicated an average asymmetry ratio of greater than 2 with extreme cases greater than 5; asymmetries of up to 5.5 were also measured in Oklahoma downbursts.[10] This indicates that a single Doppler measurement of one radial microburst slice (not aligned with the flight path) can significantly over or underestimate the shear along the flight path.

The problem is then estimation of F given the measurement limitations. The TDWR measurement of radial velocity also contains an estimate of microburst size (diameter along the radial slice), as well as the locations of other microbursts that may interact with the local wind field of global knowledge to identify and estimate F using characteristics. The reflectivity field is also known. The microburst itself can be modeled either with a suitable fluid dynamic model of microburst winds and/or measured statistics of naturally occurring microbursts. It should then be possible to combine the measured data with the microburst models to estimate the peak downdraft, peak horizontal shear, and hence the peak F that could be encountered within the microburst. Provided this problem can be solved, use of estimated F-factor as a hazard criterion for alert generation could reduce overwarning.

Another way to reduce "nuisance alerts," specifically in the case of microbursts laterally displaced with respect to the flight path, could be accomplished by modifications of the alert format. One possible change (proposed in Ref. 7) is to add the words "left," "right," or "center" to the alert to indicate the microburst position relative to the flight path.

Independent of changes in the hazard criterion or the alert format, the detrimental effects of nuisance alerts could be reduced by clarifying the actual meaning of the currently employed alert to flight crews. The possibility of a microburst being to the side of the flight path should be discussed, and the meaning of the microburst wind change value should be explained. Crews should also be aware of the measurement limitations of the sensing system.

V. Conclusions

A pilot opinion survey and a flight simulator experiment have been performed to examine issues related to dissemination of ground-measured windshear information to flight crews with and without a digital datalink. Survey results indicated that the currently available windshear avoidance information is not sufficient and that a better system is highly desirable. A preference for graphically presented microburst alerts was expressed, and some specific questions about the makeup and timing of microburst alerts were answered.

Simulation experimental results indicated that presentation of windshear alerts as graphical symbols on a moving-map display is significantly more effective than verbal alerts. Pilot performance improved, and pilot workload decreased. Both the survey results and comments from the simulation subjects indicated a strong pilot preference for graphical presentations. Presentation of windshear alerts as text on an electronic display proved inferior to standard verbal communications in terms of workload increase, pilot performance, and pilot preference. In the time-critical situation of windshear alerts, it was apparent that textual messages were more subject to misinterpretation than were verbal ones.

It is critical to the implementation of a ground-based windshear alerting system to quantify the windshear hazard both accurately and clearly. Overwarning can unnecessarily disrupt airport operations as well as damage pilot confidence in the windshear alert system. The system used in the 1988 TDWR Operational Evaluation was shown to result in a significant number of nuisance alerts, for which the pilots reported experiencing little or no windshear.[8] To address this problem, it is proposed that 1) a better method of assessing the windshear hazard be developed, and that 2) flight crews be better educated about the meaning of ground-generated windshear alerts.

The current method of generating windshear alerts from TDWR information has been examined, and some causes of overwarning have been identified. These causes fall into two groups: 1) the alert generation methodology, and 2) difficulties in quantifying microburst hazard from the available measurements.

Educating flight crews about the meaning of ground-generated alerts is equally as important as good hazard assessment. Some possible pilot errors in interpretation of the current alert format have been identified. By better informing flight crews about the details of the alerts and the limitations of the sensor system, the inevitable "nuisance alerts" that will be issued will not damage crew confidence in the system.

Acknowledgments

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