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10.5 STUDY OF NETWORK EXPANSION LLWAS (LLWAS-NE) FAULT IDENTIFICATION AND SYSTEM WARNING OPTIMIZATION THROUGH JOINT USE OF LLWAS-NE AND TDWR DATA *†

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1. INTRODUCTION

Low level wind shear has been identified as an aviation hazard which has caused or contributed to a significant number of aircraft accidents (Soffer, 1990). To protect aircraft from hazardous wind shear, the Federal Aviation Administration (FAA) developed a system called the Low Level Wind Shear Alert System (LLWAS), containing a collection of anemometers as well as data processing logic (Wilson and Gramzow, 1991). The LLWAS has undergone several advancements in both design and algorithmic computation. The latest deployment, known as the Network Expansion Low Level Wind Shear Alert System (LLWAS-NE), consists of additional sensors to the original LLWAS network, providing better coverage of the airfield. In addition, the LLWAS-NE is capable of providing runway-oriented wind shear and microburst alerts with loss and gain values. The alerts from LLWAS-NE will be integrated with those from the Terminal Doppler Weather Radar (TDWR) and the Integrated Terminal Weather System (ITWS) at locations where all systems are available (Cole, 1992; Cole and Todd, 1994).

An analysis was undertaken at Orlando (MCO) and Dallas/Ft. Worth (DFW) International Airports to assess the accuracy of wind shear alerts produced by LLWAS-NE and the TDWR/LLWAS-NE integration algorithm. Identifying improvements that can be made to either system is important, as LLWAS-NE alert information is anticipated to be integrated with ITWS in an ITWS/LLWAS-NE integration algorithm. As currently specified, the ITWS/LLWAS-NE integration algorithm will work the same as the TDWR/LLWAS-NE version. The ITWS/LLWAS-NE algorithm is an area where additional work is necessary to ascertain if the integration parameters should be modified to account for performance differences between the ITWS and TDWR algorithms. We suggest that ongoing assessment of the LLWAS-NE should use both LLWAS-NE data and TDWR base data, when possible. Comparing both data sets also will facilitate optimization of LLWAS-NE parameters used in the computation of the alerts.

2. BACKGROUND

The LLWAS system is being developed in four phases which reflect the operational deployments (Wilson and Cole, 1993). The original LLWAS system (LLWAS I) was developed in 1976 and consisted of a centerfield sensor as well as five other sensors placed along the periphery of the airport (Soffer, 1990). The basic LLWAS I configuration was installed at 110 FAA towered airports between 1977 and 1987, with the primary function of detecting large-scale events which were conducive to wind shear. LLWAS I had no microburst detection capability and had excessive false wind shear alerts.

The LLWAS II deployment consisted of software and hardware upgrades to the existing LLWAS I, which improved the probability of wind shear detection. Also, wind shear detection capability at centerfield was added as well as reduction of the false wind shear alert rate (Soffer, 1990). Between 1988 and 1991, all of the LLWAS I systems were upgraded to be LLWAS II compliant. The improvements in the wind shear detection algorithm increased the safety at airports equipped with this system.

Even before the LLWAS II deployment, it was clear that additional wind shear protection was needed off the airport; namely, on the final approach and departure corridors. The need for additional wind shear protection lead to the

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development of the LLWAS III system, also referred to as LLWAS-NE. The LLWAS-NE system consists of additional sensors placed near the airport along both arrival and departure corridors as well as a major software upgrade to include microburst detection capability (Wilson and Cole, 1993). All of the LLWAS-NE deployments are taking place at airports which currently have a TDWR. The TDWR/LLWAS-NE integration algorithm merges alerts from both systems to improve aviation safety. Installation of the LLWAS-NE systems is nearing completion across the country. The final phase of LLWAS deployment (LLWAS IV) will take place over the next few years. A full system hardware upgrade is anticipated. Additionally, LLWAS-NE alerts will eventually be integrated with ITWS after this system is deployed.

3. CASE STUDIES

An analysis was undertaken at MCO and DFW to assess wind shear and microburst alerts produced by the following alerting systems: LLWAS-NE, integrated TDWR/LLWAS-NE, and ITWS. The runway-oriented alerts generated by each system were archived and the TDWR base data were examined to generate single-Doppler radar truth. The loss or gain value for each Area Noted For Attention (ARENA) on the arrival and departure corridors was determined by the change in velocity along the flight path. Since the vertical velocity of a wind shear event decreases as the flight path nears the surface (final approach or initial departure), gain events are associated with an increase in air speed and loss events are associated with a decrease in air speed. For gain events, the maximum horizontal distance was limited to 2 kilometers, while loss events could extend over a distance of 4 kilometers. In the case of runways which were not oriented parallel to the radial viewing angle, the event was allowed to extend beyond the ARENA to calculate the velocity difference. No attempt was made to use the LLWAS-NE wind information in determining the truth for an ARENA. Thus, it is possible that the truth could be over- or underestimated for an asymmetric event.

3.1 Orlando

Investigation into the MCO wind shear alerts began after the LLWAS-NE system issued a loss alert for a gust frontal passage. Alert data from all three systems were archived and compared to a single Doppler radar in an effort to determine the cause of the discrepancies. The MCO Airway Facilities (AF) technicians performed several tests on the LLWAS-NE network but found no major problem with the system or individual sensors. Interestingly, the LLWAS-NE loss alerts were always issued for the same location. By careful comparison of TDWR base data with LLWAS-NE alert data, we were able to identify an LLWAS-NE overspeed problem in one of the sensors (#14). Pilot reports (PIREPs) were extremely helpful in verifying the accuracy or inaccuracy of alerts in real time. A hardware malfunction was found in sensor #14's Remote Control Assembly (RCA) (the main portion of the electronics package). If the wind speed increased above approximately 20 knots, the sensor would begin to report wind speed values 10 to 20 knots higher than the surrounding sensors, as shown in Figure 1.

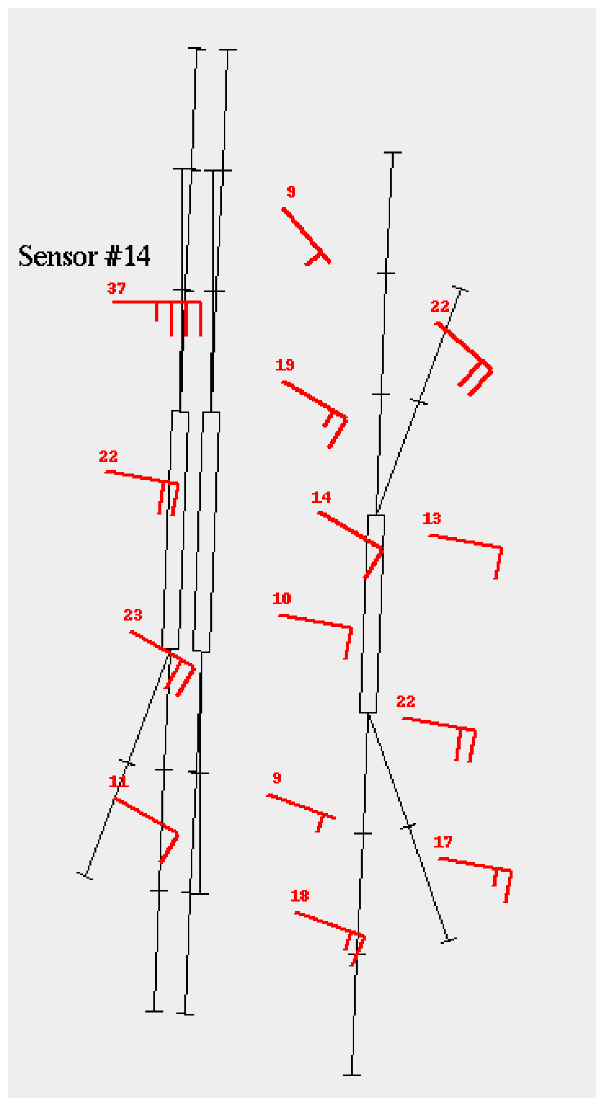

Figure 1. Example of overspeed problem in sensor #14.

The wind shear induced between sensor 14 and the surrounding sensors was enough to trigger wind shear loss alerts and a few microburst alerts. In effect, the LLWAS-NE system treated the situation as a wind shear over one of the runways and issued loss alerts for the appropriate ARENAs. The RCA was replaced which eliminated the LLWAS-NE alerting problem. Since the replacement, the LLWAS-NE received an upgrade in the monitoring software. The new software will allow AF to identify sensor failure in a timely manner.

While analyzing the LLWAS-NE alerts versus the TDWR base data, it became obvious there were discrepancies for events which could not be attributed to a sensor malfunction. Based on an examination of the LLWAS-NE parameter set, a hypothesis was formulated to account for the additional alert discrepancies. This hypothesis was that the conservative nature of the parameter set contributed significantly to the alert discrepancies. For this analysis, a sensor problem was defined as a loss alert for a gain event, and a parameter problem was defined by a loss alert on an ARENA with little or no actual velocity differential according to the TDWR base data. As shown in Table 1, the conservative nature of the parameters accounted for one-half of the false alerts on a minute-by-minute basis during select cases over the summer of 1997. In terms of overwarning (an alert that is 10 knots over the truth), the parameters were much more likely to cause an alert discrepancy than a sensor problem. The table is presented to identify possible failure mechanisms for microburst alerts in Orlando rather than to quantify the overall

TABLE 1.
LLWAS-NE Failure Mechanisms
for Microburst Alerts in Orlando, FL

	Sensor Problems		Parameter Problems	
Date	**False Alerts**	**Over-warning**	**False Alerts**	**Over-warning**
970522	0	0	4	41
970612	0	0	0	0
970702	1	0	1	0
970711	0	0	0	0
970715	5	0	0	0
970716	3	2	3	0
970806	3	0	4	20
Total	12	2	12	70

LLWAS-NE performance. While this was a relatively small sample, it provides the impetus for analyzing LLWAS-NE alerts from other sites to ascertain if this scenario is unique to MCO.

3.2 Dallas

Alert data also were collected at DFW from ITWS, the integrated TDWR/LLWAS-NE system, and LLWAS-NE to determine the performance of these systems in a different environment. In particular, we were interested in assessing the impact of the conservative LLWAS-NE parameters at a more complex airport in terms of runway orientation. Results from DFW will be presented within the oral presentation.

4. ALERT INTEGRATION

Alert integration algorithms help maximize safety by increasing the accuracy of detecting aviation weather hazards. The current TDWR/LLWAS-NE integration algorithm was developed on the notion that both systems have correctly identified a valid wind shear event but are getting varying results due to the different measurement methods (Cole and Todd, 1994). If both systems are measuring the wind shear event correctly, the current approach is adequate. However, if one system provides inaccurate alerts due to a hardware fault (as was the case at MCO), a much greater use of overall domain information seems necessary. At the present time, the integrated TDWR/LLWAS-NE integration algorithm does not perform a validation check on LLWAS-NE alerts. The use of TDWR storm cell information or ITWS vertically integrated liquid water (VIL) information in the integration algorithm could be used to invalidate potential LLWAS-NE false microburst alerts by either reducing the alert to wind shear strength or removing it entirely. The inclusion of a storm cell or VIL test to validate the integrated alert could have mitigated the severity of the MCO sensor overspeed problem.

The following suggestions would facilitate LLWAS-NE fault identification and system optimization:

1) Continue to assess LLWAS-NE performance by comparing LLWAS-NE alerts with TDWR base data when possible. Based on the MCO experience, comparisons of alerts generated by each system should utilize TDWR base data either in real time or recorded cases.

2) Couple TDWR and/or ITWS alert information with LLWAS-NE alert information to determine the overall performance of the integration

algorithm. A direct comparison of each alerting system could provide information on strengths and possible weaknesses in each system. If one alerting system is performing better than another, then the integration algorithm could be modified to enhance the overall performance (see above).

3) Identify possible site-adaptable parameters which could be modified to enhance the LLWAS-NE alerting algorithm.

The LLWAS-NE algorithm uses a combination of triangles and edges to determine the loss or gain along each of the ARENAs. To account for sensor malfunctions, the parameter set is quite conservative, i.e., the maximum station-to-station distance for event validation is 5 km. As shown in Figure 2 (sensors 2, 7, and 12), this allows for triangles and edges to be associated with an ARENA even if there is only a small fraction of overlap. The net effect of this conservative parameter set is for events to be associated with runway segments with little or no actual loss. A definitive study should be undertaken to determine the most effective setting for this parameter at MCO and other sites where TDWR may make such conservative parameter settings unnecessary. We could envision a modification to the current LLWAS-NE algorithm that uses the more conservative parameter for a stand-alone LLWAS or as a back-up if the TDWR goes out of service and a more aggressive parameter when integrated with either TDWR or ITWS. In the case of an integrated system, the radar-based alerts should be accurate enough to allow for less confirmation from LLWAS-NE.

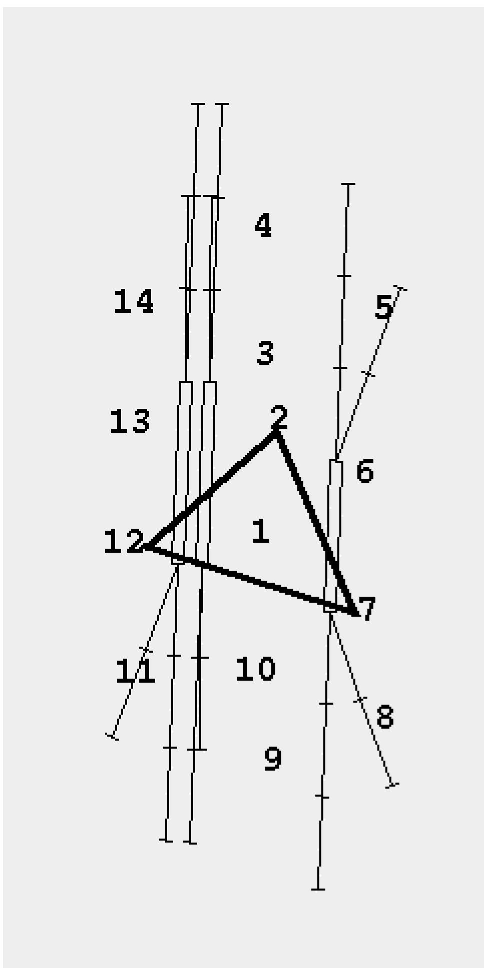

Figure 2. Example of the conservative parameter setting for the MCO LLWAS-NE.

5. CONCLUSIONS/FUTURE WORK

We have discussed the evolution of wind shear protection at FAA airports from LLWAS I through LLWAS-NE. Further advancement in aviation weather hazard detection was provided by the TDWR. In the near future, an additional step in aviation safety will take place with the deployment of ITWS. Alert information generated by each system uses different algorithms and detection schemes. Therefore, it is possible that alerts between each system could differ slightly but should still be very similar. To maximize aviation safety, alerts from LLWAS-NE will be integrated with both the TDWR and ITWS (depending upon the system used at each airport). Current integration logic assumes that each system has correctly measured a valid wind shear event but could get varying results due to different detection schemes. If the systems are measuring the event correctly, the current approach is adequate. However, if one system has sensor failures, a much greater use of overall domain information seems necessary. An introduction of TDWR storm cell or ITWS VIL into the integration algorithm as a validation check for LLWAS-NE microburst alerts is a suggestion. The validation check could help prevent false alarms or overwarnings caused by sensor failure in the LLWAS-NE system. Additionally, comparisons of LLWAS-NE alert information to TDWR base data could be undertaken to validate wind shear detection accuracy. Finally, by comparing Doppler data to LLWAS-NE alerts, it may be possible to adjust site adaptable parameters to enhance the performance of LLWAS-NE and integration algorithms.

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