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METEOROLOGICAL SUPPORT OF THE WEATHER SYSTEMS PROCESSOR (WSP) OPERATION

Ilana Steinhorn *
Weather Processors and Sensors, FAA, Oklahoma City

1. INTRODUCTION

The Weather Systems Processor (WSP) is the wind shear detection and alert system currently used by Air Traffic Control at 34 airports nationwide, most of them of medium traffic capacity. Less costly than the Terminal Doppler Weather Radar (TDWR), the WSP was developed and enhanced by MIT Lincoln Laboratory, and was built by Northrop-Grumman, as an add-on modification to the Airport Surveillance Radar ASR-9. Commissioned from August 2002 to April 2005, the fielded WSP systems are each maintained by its FAA trained specialists and are also supported nationwide by the Weather Processors and Sensors branch of the National Airways Systems (NAS) Engineering, an Oklahoma City division of the FAA Air Traffic Organization.

Meteorological support is an integral part of the extensive direct hardware and software/firmware engineering support provided by the WSP team to airport facilities that includes, among other duties: documentations of technical maintenance books, second level engineering field support, development and modification of site-specific adaptation files, software corrections and improvements, and system re-hosting.

This presentation deals with some of the aspects associated with the WSP system, from the perspective of the WSP support meteorologists, and is based on actual data from various sites.

* *Corresponding author's address:* Ilana Steinhorn, Mike Monroney Aeronautical Center, Weather Processors and Sensors Branch (ATO-W AJW-14A). P.O. Box 25082, Oklahoma City, OK. 73125; e-mail: Ilana.ctr.steinhorn@faa.gov

2. THE WSP SYSTEM

The WSP provides alerts to Air Traffic Control (ATC) of hazardous low altitude wind shear conditions. Yet unlike the TDWR, that has its own pencil beam radar transmitter and receiver and is a stand alone 3-dimensional detection system, the WSP uses the faster ASR-9 fan beam's two dimensional signals and Doppler capability. These and the fact that it is located closer to the runways make its products and capability somewhat different from those of the TDWR. Review of ground-based wind shear detection systems is given by Keohan (2007). Comprehensive descriptions of WSP and ASR-9 capabilities and of the performance of the WSP test systems may be found in various reports and articles, most by MIT Lincoln Laboratory scientists and engineers, such as: Weber and Stone (1994), Newell (2000), Sheretz et al. (2000), and Weber (2002).

2.1. *The WSP Products and Algorithms*

The WSP products include: detection of microburst events within 15 nmi of the airport, detection of gust fronts and forecasts of time of their airport impact and wind shift, wind shear and microburst alerts depending on the runway configurations, mapping of precipitation intensity with reduced clutter caused by anomalous propagation, and thunderstorm cell location and movement.

At most sites, the WSP has replaced the Low Level Wind Shear Alerting System (LLWAS) anemometer network system, but uses a center field sensor ("Airport Wind") for wind speed, direction, and gust information. The LLWAS-2 system in Albuquerque (ABQ), NM has been integrated with the radar-based products to enhance the WSP ability to detect gust fronts, especially those whose strong velocities are not aligned with the radar line of sight (Frankel and Pughe, 2003).

The WSP major weather algorithms are the AMDA, for microburst detection (Newell and Cullen, 1993), and MIGFA, for gust front detection (Troxel and Pughe, 2000). They are built to accommodate two types of weather environments, “wet” and “dry”, where the dry is more sensitive to wind shear events with limited precipitation. Other important algorithms include the Storm Motion and Storm Extrapolated Position and the Alert Generation algorithms (Newell, 2000 and various internal MIT reports). Before input into these algorithms, the radar signals are processed to suppress anomalous propagation clutter (Cullen, 1996).

2.2. *The WSP at Work*

The WSP commissioned systems work automatically, with periodic maintenance and monitoring provided on site by trained FAA system specialists. Using the WSP, the controllers at the airport and at the corresponding TRACON are better able to dynamically adjust the traffic flow to avoid thunderstorms on approach and departure corridors and wind shear hazards on the active ARENAs (AREa Noted for Attention that includes the runways and their extended 3 or 2 miles of approach and departure, respectfully). Once alerts are issued, controllers relay by voice the appropriate messages to pilots.

Specifically, at each site, the controllers receive on their individual alphanumeric Ribbon Display Terminals (RDTs) runway-specific information, which includes the type, location, and intensity of hazardous wind shear events that impact the active ARENAs (Figure 1).

Figure 1: Ribbon Display Terminal (RDT) used by air traffic controllers indicating time, Airport Wind (AW), active runways for arrivals (A) and departures (D) and microburst alert (MBA) on the 07D runway.

Alerts include “GF” (Gust Front) accompanied by a text and a number specifying the predicted impact time in minutes; “WSA” (Wind Shear Alert) accompanied by a number and a +/- sign, for airspeed gain of at least 15 kts due to gust front or airspeed loss between 15 and 30 kts due to microburst; and “MBA” (MicroBurst Alert) accompanied by a number 30 or greater and a - sign, for airspeed loss due to higher intensity microbursts. In addition, the RDTs produce audible alarms. The center field wind speed, direction and gust also appear, as received from a sensor located at the center of the field.

A color Geographic Situation Display (GSD) is used by the controllers’ supervisor to view color graphic images and symbols of precipitation, storms, and wind shear events and alerts, and to control the desired runway configurations (Figure 2).

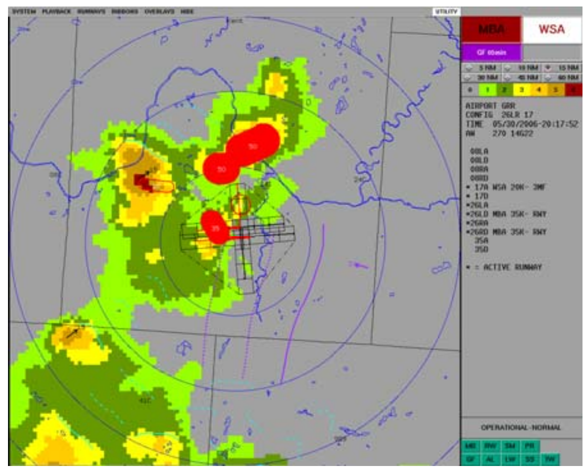

Figure 2: Geographic Situation Display (GSD) used by air traffic supervisors in Grand Rapids (GRR), MI shows convective storm activities on 30 May, 2006. While departure on 17D and arrival on both left and right 26 are still clear of hazards,, arrival on 17A and departure on both 26D are associated with Wind Shear Alert (WSA) and MicroBurst Alert (MBA), respectively. In addition, a gust front is approaching from the east and the alert “GF in 05 min” enables potential timely modification of runway configurations.

The FAA system specialists have the capability to control and monitor the system using the Maintenance Data Terminal (MDT). A Base Data Display (BDD) exhibiting velocity and precipitation patterns of both the high and low receiving beams, and various components of the AMDA and MIGFA algorithms, is used for system certification and optimization.

3. METEOROLOGICAL SUPPORT OF WSP

Meteorological support for the WSP includes evaluation of site data to determine system performance and testing of the meteorological algorithms. This is done often in response to requests from the site, and for each modification, enhancement or upgrade of the system. Often such evaluation leads to uncovering other aspects such as hardware configuration and maintenance issues, software bugs and information issues. Select aspects of the meteorological support are presented below, concentrating on the detection performance of the meteorological algorithms.

3.1. *Data Types and Availability*

Data collection is done at the sites when the need arises and not on a regular basis. The product files are recorded usually as viewed on the TRACON GSD. Tapes of recorded data plus any available pilot, controllers and technicians reports or comments are the source of information available to the second-level team for analyzing and assessing the meteorological conditions and the health of the system.

Product data files are available for the past 14-16 days, with the possibility of manual archiving for a longer period of time, while base data files are stored on the system for 20 hours, with the possibility of real-time recording in 7-days intervals. Analysis of the data, along with PIREPS, controllers' logs, technicians' comments and the National Weather Service (NWS) meteorological records (when available), may provide information about several aspects, including: well-being of the software and hardware of the WSP system, performance of the meteorological algorithms, prevailing meteorological conditions at the particular site, non-meteorological phenomena that mimic wind shear, and behavior of the radar-WSP interface.

3.2. *Precipitation Mapping and Storm Motion*

Precipitation mapping is the basic product of the WSP. The WSP may still be usable when other products are missing, but only when precipitation is unavailable is the WSP flagged by RedX. The major advantage over the original ASR-9 precipitation mapping is the elimination of most anomalous propagation (AP) clutter. Additional advantage is the color display which is available for use by the controllers' supervisor (Figure 2). The precipitation intensity is divided into 6-level scheme based on the NWS's recommendation. In addition, the WSP calculates and displays storm direction and cells movements over the full 60 nmi instrumented range of the ASR-9, which help keep aircraft away from thunderstorms and enhance safety.

Comments received from the sites about the precipitation and storm color displays are usually positive. These products also received above average performance ratings in studies that involved controllers' comments (Weber 2007, ATO FAA 2007). With WSP, the supervisor can modify his/her display to show precipitation above a certain level of his choice, while being able to distinguish between storms and cells of different intensity. This capability will be vastly reduced should a 4-level precipitation presentation replace the existing, more accurate, 6-level one. Any improvement would likely be concentrated about the way to make the displays more accessible to controllers who at this time are supposed to rely on the RDTs information only.

Questions sometimes arise regarding the 6-level divisions of the precipitation intensity. The divisions between the levels are somewhat different from the NEXRAD precipitation divisions, which may cause the precipitation images to look somewhat different. Also, the WSP mapping, while similar to the original ASR-9 display, has in addition a precipitation threshold, meaning that WSP does not display precipitation level equivalent to reflectivity of 18 dBZ and lower. This sometimes limits the ability to observe snow. Most non-meteorological echoes, such as those associated with insects and birds, also have low reflectivity values and therefore cannot be displayed on the GSD.

Product and base data files received are routinely examined by observing precipitation patterns. Because of the precipitation threshold, basic analysis has to rely on base data for cases of "clear" days. Precipitation analysis also helps with the detection of non-meteorological phenomena, electro-magnetic interference, and some hardware related issues.

3.3. *Missed Detections*

When reports on suspected missed detection are received, it is expected that an immediate recording of base data has been done, before the stored data are deleted from the system. With these and with product files and controllers' logs it is usually possible to assess the situation. While the WSP is not expected to detect all cases, it is very important to determine whether the WSP behaves as designed, or a problem exists.

Reports of missed detection often occur when there are Pilot Reports (PIREPS) of wind shear. Many aircraft are now equipped with "reactive" or sometimes "predictive" on-board wind shear detection equipment. These systems either report wind shear to assist the pilot in recovery, or they provide warning that the aircraft is about to approach wind shear. Both systems are different from the WSP which is a ground based radar system. Usually only suspected missed or false detection is reported to the WSP support team, while perceived correct detection is seldom mentioned. Therefore it is impossible to judge the degree of agreement between the systems.

Judging by a case by case analysis, it is apparent that most missed-detection reports by pilots concern wind shear below 15 kts per 4 km, usually 10 kts. This is a relatively low wind shear that the WSP, like the TDWR, do not report by design. It should be noted that the WSP is able to detect wind shear of 10 kts. However the probability of detection of this low intensity wind shear is smaller than that of stronger wind shear, plus the probability of its false detection may be higher.

Other concerns involve a comparison between the WSP and the LLWAS systems, often addressed in the early stages of WSP deployment. In most cases no data were provided for examination. In the one case of several months' worth of data in Tucson (TUS), AZ during 2005, it was determined that both systems alerted at the same time.

There also seems to be some expectation for the WSP to detect other wind related phenomena, besides microbursts and gust fronts. Examples are dust devils, low level turbulence, and sudden wind gust. Sometimes microbursts are indeed detected when dust whirls exist, but generally dust whirls do not signify microbursts over 15 kts, and in low humidity they cannot be detected by the WSP. Turbulence also is not part of the WSP products, and wind gust may only be reported as detected by the separated center field wind sensor with its 2 minutes continuous averaging data.

One should also consider the difference in the WSP system between "detection" and "alert". WSP may detect wind shear events and report them on the GSD as either purple lines (gust front) or round, red shapes (microbursts). WSP issues a gust front alert if it is within the airport gust front impact zone, but it only provides WSA if the gust front actually hits an active segment of an ARENA. With microbursts, there is some weighting done to ensure the microburst is strong enough over the active ARENA. Microburst shapes that appear as stronger (filled red shapes) may produce either MBA or WSA or no alert at all depending on their location. Therefore it is important to correctly adjust the runway configurations on the GSD to reflect the actual configuration in use.

There are only a few examined cases where it appears that the WSP did not detect a real and strong enough wind shear. This happened when the wind shear involved a very shallow layer near the ground. The radar has a wide elevation fan beam so that phenomena confined near the ground will fill a smaller fraction of the beam. The result is averaged data that mask some of these conditions. Cases like this occurred in Grand Rapids (GRR), MI on 4 April 2007 and in Austin (AUS), TX on 31 May 2007. It should be noted that in most weather situations there is a difference between the receiving high and low beams that helps in the detection.

3.4 *False Detections*

False detections may reduce the users' confidence in the system. Controllers are obligated to report WSP alerts to pilots at all time, and in some sites suspected false alarms occur more often than is desired. Examining the WSP data, PIREPS, and meteorological conditions of reported false alert cases, reveal distinctive repeated patterns:

False alerts do not get reported when there is convection activity with precipitation at the airport or in its vicinity. During such activity, all WSP alerts are presumed as correct. All cases reported as false are associated with little precipitation or with clear days.

Most reports concern false alerts. However the description below refers to false detections. As stated above, detections may or may not result in alerts. From a meteorological point of view, it is important to verify the accuracy of the detections which depend on many factors. The alert algorithms depend on fixed criteria for each site parameters, such as the location and strength of the shear in relation to the gust front impact zone or the active ARENAs segments. So far these seem to work properly at all times.

Rare cases of false detection are associated with a shallow layer of air around the ground having different properties from the layer above it: In GRR, the same day that WSP did not detect wind shear (see above) it detected a false gust front that was close to the ground but did not reach the surface. This is because being based on fan beam radar signals the WSP could not distinguish signals from a too shallow layer near the ground and integrated them with those coming from upper levels. In Windsor Locks (BDL), CT in September 2007, WSP issued gust front alerts with the approach of a storm, while the Airport Wind remained calm. In this case it was possible either that the gust front was located above the ground or that the gust front did not pass near the location of the center field sensor.

False wind shear events in AUS on 13 and 14 January 2006 were attributed to uncommon weather system that was associated with humid cool air moving above the shallow surface air which was moving at the opposite direction. The WSP system, based on a fan beam signals, viewed both layers as one, therefore WSP interpreted the vertical shear as if it were horizontal, resulting in a false detection.

More regular false alerts were reported in TUS, prompting an extensive data collection and analysis. As a site in a dry location, the algorithms in TUS system are set to be more sensitive than in most locations which are considered as wet. Yet in addition it was found that the false detections were largely due to emissions from a nearby power plant. Correction for AMDA algorithm by Bob Frankel of MIT took into consideration the fact that these microbursts were stationary and in relatively low reflectivity. With this correction, the behavior of the WSP system became much more satisfactory.

Other local false detections, mostly of gust fronts, are associated with electromagnetic interference (EMI) from large ships. The WSP identifies the strong velocity, low reflectivity EMI signature as a thin line wind shear. Similar but weaker velocity signatures are correctly identified as clutter. In Honolulu (HNL), HI false gust front (GF) and wind shear alerts (WSA) accompany the arrival of large aircraft carrier vessels. The vast majority of EMI cases in HNL and in Norfolk (ORF), VA however do not result in false detection, and only few of the detections cause alerts

Many of the false detection cases occur during early morning hours in the Fall and Spring seasons. Usually the sky is clear at the time. Occasionally small false clouds are seen as a low-level precipitation (Figure 3). In all cases it appears to be a strong "bird signature", seen on the WSP Base Data Display (BDD) as sudden increase in reflectivity with movement away from a centralized point. The growing, "blooming", circle itself often moves (Figure 4). This behavior, when interpreted by the WSP, mimics convective cells and their associated microbursts. Occasionally two or more such false cells appear, separated by several minutes, suggesting several different groups or species of birds leaving their roost. Occasionally false gust fronts appear instead of a microburst.

The seasonal occurrence during Fall and Spring seasons may be associated with the birds' seasonal migration. The bird signature appears under stable meteorological conditions, when light wind and temperature inversion occur. As in most WSP sites there was no attempt to actually find the birds, the term "bird signature" is used here to designate only certain radar reflectivity and velocity patterns. Bird signatures do not always generate wind shear events.

Besides the seasonal migration, regular roosting behavior is associated with known bats activity in AUS which occasionally produces alerts around sunset. Bats activity is also observed in TUS but it seldom produces alerting microbursts or gust fronts.

Less than a third of the WSP sites suffer from seasonal sunrise microburst false alerts. Since WSP does not observe higher altitudes, it cannot distinguish between the birds (or other) mimicking activity that is close to the ground and the microbursts that have higher-level wind components.

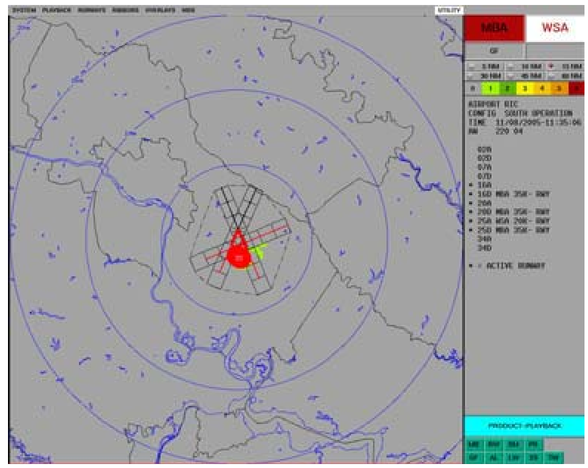

Figure 3: Bird activity as seen during product playback. A GSD image at Richmond (RIC), VA on 8 Nov 2005 at 11:36 UDT, shows WSA and MBA due to a strong false microbursts that lasted 15 minutest. There was also a small false cloud.

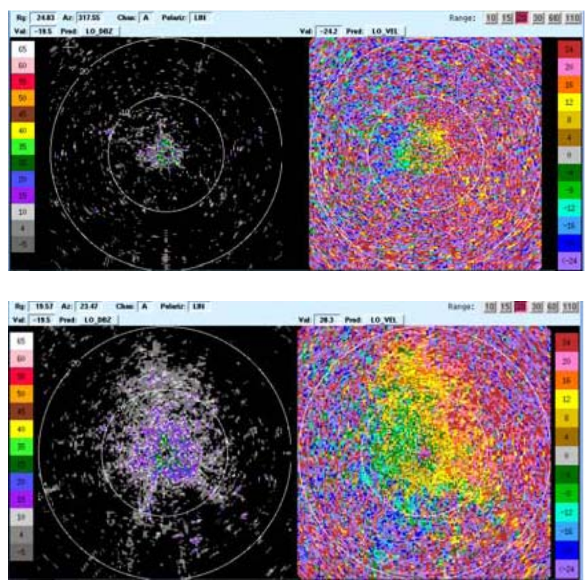

Figure 4: Bird signature of the event shown in Figure 3, as seen in base data images of reflectivity (left) and velocity (right): The upper image shows earlier stages of the "blooming" before the onset of the false microburst. The lower image shows the "blooming" in its peak 14 minutes later.

Yet possible future criteria for distinguishing between these phenomena include the regularity of the time of day (twilight/sunrise) and the associated low reflectivity. Additional criteria are being examined before applying a correction to the AMDA algorithm, to avoid missed detections, although so far there have been no reports on low reflectivity convection activity during twilight/sunrise at any site.

3.5. *Probabilities of Detection and of False Alarm*

The Probability of Detection (POD) and Probability of False Alert (PFA) are regarded as measures of the usefulness of the WSP system. Controllers' satisfaction from the system is largely affected by their perception of the actual POD and PFA (ATO-FAA, 2007).

The POD and PFA statistics refers to the detection of wind shear events. It does not refer to other wind-related phenomena such as turbulence or dust devils, which the WSP is not designed to detect. The POD and PFA values also depend on the type of the events and their strength.

The scientific truth studies and the calculated statistics of probabilities of detection and false alarms were performed by MIT Lincoln Laboratory throughout the operational testing of the system (Weber et al., 1996). The WSP systems were operating at 4 places (Huntsville, AL, Kansas City, KS, Orlando, FL and Albuquerque, NM), and a truth radar and/or anemometer network were used to compare their performance. The statistics differentiate between types of wind shear (gain, loss), intensity (in kts per 4 km), and place (test sites). More studies and statistics were later performed in Albuquerque (ABQ), NM and Austin (AUS), TX with the prototype WSP, and with the production systems in connection with the enhanced WSP system (Frankel and Pughe, 2003).

When scientifically comparing the stated PODs and PFAs versus the actual, one should remember that the commissioned WSP is optimized for two average types of climate termed "wet" and "dry", and that the sets of algorithms parameters are fixed for these two types with some automatic seasonal variability. Because of the diversity of the 34 operational sites, it is likely that the actual PODs and PFAs are different for each site. However, scientific calculations of the PODs and PFAs for each site, based on comparison to the performance of a truth radar, are not feasible. Subjective calculations could have been done based on a systematic and comprehensive data collection and analysis, but this would have required much more resources than are currently available.

What remains is the perception of WSP performance with regard to wind shear detection. Based on the data received, there is no reason to suggest vast differences between the "promised" POD values and the "actual" ones, and the WSP seems to properly detect wind shear within its capability. However the PFA values may be larger in some sites than they were in the prototypes. Although bird and bats signatures were detected (Isaminger, 1992, and Echels, personal communication), they apparently did not pose major concern at those sites. As stated above, seasonal false alarms above the stated PFA values affect about third of the WSP systems and are under investigation for a possible correction.

3.6 *When the System Benefits are Evident*

The WSP "We Solve Problems" support team is generally pleased with the feedback received from the sites regarding the very few hardware and software interruptions and the benefits of the system during convective weather activity. Most data received fall into the categories of perceived missed or false alerts; however site technicians are encouraged to share interesting cases, when time allows. The team is also asked occasionally to help create presentations for educational purpose. Product and base data animated images show how the WSP is used to select hazard-free runways, while storms are present at other parts of the airport. These indicate that the WSP does fulfill its purpose to help direct air traffic safely to and from airports during severe weather.

4. CONCLUSIONS

The WSP has been commissioned for several years. Analysis based on recorded data and reports from operational sites indicates that the WSP properly detects wind shear events, within the capabilities and limitations of its design. In some airports however it issues seasonal false alarms during sunrise or sunset that may be associated with birds' activity. WSP capability is affected by its use of fan radar signals which may result in missed detection. This may happen under certain, relatively rare, meteorological conditions. Controllers and pilots expectations from the WSP performance should take into consideration the types of hazards it is designed to detect, and its intended alerts compared to those issued by aircraft wind shear detection systems.

5. ACKNOWLEDGEMENT

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6. REFERENCES

ATO, FAA, 2007: WSP Human Factors Assessment Report: Identification of WSP Benefits Gaps, ATO-Terminal Human Factors, Draft.

Cullen, J.A., 1996: Anomalous Propagation Ground Clutter Suppression with the ASR-9 Weather Systems Processor, MIT Lincoln Laboratory, Project Report ATC-244.

Cullen, J.A., B. Excels, B. Frankel, C. Rolfe, and S. Trowel, 2003: Enhancements to the WSP algorithms Version 2.0, MIT Lincoln Laboratory, Draft.

Fahey, T.H. , C. M. Shun, A. Angered, J. Asano, and T. Nguyen, 2006: Low Altitude Wind Shear Hazards: Ground Based Detection and Commercial Aviation User Needs, 12^{th} Conf. on Aviation, Range & Aerospace Meteorology, Amer. Meteor. Soc., Atlanta, GA.

Frankel, B. and W.L. Pughe, 2003: Anemometer-Based Algorithms for the WSP, MIT Lincoln laboratory, Draft.

Isaminger, M.A., 1992: Birds Mimicking microbursts on 2 June 1990 in Orlando, Florida, MIT Lincoln Laboratory, Project Report ATC-184.

Keohan Christopher 2007: Ground-based wind shear detection systems have become vital to safe operations, ICAO Journal, Vol. 2.

Newell, O.J., 2000: ASR-9 Weather Systems Processor Software Overview, MIT Lincoln Laboratory, Project Report ATC-264.

Newell, O.J. and J.A. Cullen, 1993: ASR-9 Microburst Detection Algorithm (AMDA) for the WSP, MIT Lincoln Laboratory, Project Report ATC-197.

Sheretz, F., J. Farr, and M, Weber, 2000: Learning from Incidents - What the Machine Can Learn, ISASI 2000 Conf., Bunratty, Ireland.

Troxel, S.W and W.L. Pughe, 2000: Machine Intelligent Gust Front Algorithm (MIGFA) for the WSP, MIT Lincoln Laboratory, Project Report ATC-274.

Weber, M.E., 2002: WSP Signal Processing Algorithms, MIT Lincoln Laboratory, Project Report ATC-255.

Weber, M.E., J.A. Cullen, S.W. Troxel, and C.A. Meuse, 1996: ASR-9 Weather System Processor (WSP): Wind Shear Algorithms Performance Assessment, MIT Lincoln Laboratory, Project Report ATC-247.

Weber, M.E. and M.L. Stone, 1994: Low altitude wind shear detection using Airport Surveillance Radars, IEEE National Radar Conference, Atlanta, GA.

Weber, M.E., J.Y.N. Cho, M. Robinson, and J.E. Evans, 2007: Analysis of Operational Alternatives to the Terminal Doppler Weather Radar (TDWR), MIT Lincoln laboratory, Project Report ATC-332.