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A QUICK LOOK REPORT FOR THE 1990 DEMONSTRATION & OPERATIONAL TEST AND EVALUATION OF AN INTEGRATED WIND SHEAR AND GUST FRONT DETECTION AND WARNING SYSTEM: BASED ON THE INTEGRATION OF A FUNCTIONAL PROTOTYPE, TERMINAL DOPPLER WEATHER RADAR (TDWR) WITH THE OPERATIONAL LOW-LEVEL WIND SHEAR ALERT SYSTEM AT THE STAPLETON INTERNATIONAL AIRPORT, DENVER, CO

FINAL DRAFT

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Author:

PATRICK MARTIN, ACN-240

Principal Contributors:

ERIC HESS, TAI LEE,
BAXTER STRETCHER, of ACN-240
and
THE PROJECT DIRECTOR & MEMBERS OF STAFF
of
THE NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
RESEARCH APPLICATIONS PROGRAM

ACN-240
PRIMARY SURVEILLANCE SYSTEMS BRANCH

COMMUNICATION/NAVIGATION/SURVEILLANCE DIVISION
FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

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EXECUTIVE SUMMARY

This Quick Look, report was prepared in response to the FAA Program Manager's request to provide an FAA Technical Center (FAATC) oversight for demonstration and operational test and evaluation of the integrated, Terminal Doppler Weather Radar (TDWR)/Low-Level Wind Shear Alert System (LLWAS), Wind Shear Detection and Warning System, which occurred at the Denver CO, Stapleton, International Airport, during the period 1 June thru 7 September 1990.

This oversight process was requested in order to assure that ongoing changes in the Stapleton International Airport's integrated TDWR/LLWAS System, during the period from 1989 thru 1990, have, in fact, improved the System's performance and acceptance by the Airport's Air Traffic Control Specialists (ATCS).

Following the 1989/90 changes to the integrated TDWR/LLWAS System, the 1990 tests and demonstration were conducted from 1 June through 7 September, 1990. Operations were conducted for 13 weeks, seven days per week from 1200 to 1900 local time. Wind shear alerts from the integrated TDWR/LLWAS System and other TDWR weather products were provided to the Stapleton, International Airport's Air Traffic Control Tower/TRACON and the FAA Northwest Mountain (NM) Region, Air Route Traffic Control Center (ARTCC), Center Weather Service Unit (CWSU). A special benefit which accrued from the tests and demonstrations was the wind shear alert coverage provided to Stapleton International Airport during the 1990 summer, convective season.

The most important objective of the 1990 tests was to demonstrate an advanced technique and improved methodology for combining data from the TDWR and the LLWAS in order to generate an integrated wind shear product that was both timely and more accurate than the products produced by either stand-alone system. The wind shear information was displayed to the ATCS Supervisors on geographic situation displays (GSD) and the runways, approach and departure corridors' wind shear alerts were provided to the Supervisors and the ATC Tower Controllers on alphanumeric, Ribbon Display Terminals (RDT). The wind shear alert information on the RDTs was read directly to the pilots approaching and departing the airport. Other weather products displayed on the GSD included: gust front detection; windshift location prediction; precipitation in the NWS standard six (6) levels; operational LLWAS network winds; Storm Motion products; and 30 minute Nowcast products (from 17 June to 28 July).

The overall effort was planned and executed by the National Center for Atmospheric Research (NCAR) of Boulder, CO. under the sponsorship of the FAA, Weather Radar Branch, ANR-150. The technical data collection was accomplished by NCAR personnel. The completed data analysis and technical evaluation will be available in an NCAR Summary Report, which will be submitted to the FAA, Weather Radar Branch, ANR-150 by February 15, 1991.

The DOT Volpe National Transportation Systems Center (VNTSC) will provide an analysis of pertinent voice and written pilot questionnaires, in order to evaluate the performance of the integrated TDWR/LLWAS products. TSC will prepare a separate Final Report for the FAA, Weather Radar Branch, ANR-150.

As part of the FAA oversight program, questionnaires were prepared and administered to ATC Tower/TRACON ATCS personnel. The preparation of the ATCS Questionnaires and the subsequent data analysis, which appears in this report, was accomplished by FAATC, ACN-240. Appendix C., contains a complete summary of the Questionnaires' grouped responses and the written comments furnished by the ATC Controllers and Supervisors.

The following bullet is a summary of the preliminary, technical appraisal of the integrated TDWR/LLWAS System and its related weather products. This summary was furnished by the NCAR Project Director with the stipulation that the data is from a preliminary quantitative evaluation. The completed analysis and technical evaluation will be available in an NCAR Summary Report, which will be submitted to the FAA, Weather Radar Branch, by February 15, 1991.

*** The preliminary analysis of five cases (microburst and/or windshear-with-loss events), during the 1990 tests and demonstrations, has shown that the integrated TDWR/LLWAS weather product performed extremely well, generating a Probability Of Detection (POD) in excess of 90 percent and a False Alarm Ratio (FAR) of less than five (5) percent in the region within five nautical miles of the airport. ***

The conclusions which were derived from the FAATC (ACN-240) oversight of the testing and operational demonstration of the integrated TDWR/LLWAS and the Human Factors evaluation by ACN-240 can be summarized as follows:

The prototype, integrated TDWR/LLWAS System's concepts and algorithms, as tested and to the extent that the criteria has been studied, were operationally satisfactory; however, changes in the Gust Front, Storm Motion, and Nowcast weather products; the GSDs' software and the production RDTs' hardware/software, as described in the SUMMARY OF RESULTS Section, are desirable for improved service use.

This report also contains a RECOMMENDATIONS Section, which endorses the implementation of suggested changes in the integrated TDWR/LLWAS System's weather products and encourages the continuation of the testing and demonstrations of the integrated System at the Stapleton International Airport.

INTRODUCTION

PURPOSE.

The purpose of this report is to provide a Quick Look at the results of the demonstration and operational test and evaluation of the integrated, Terminal Doppler Weather Radar (TDWR)/Low-Level Wind Shear Alert System (LLWAS), Wind Shear Detection and Warning System, which occurred at the Denver CO, Stapleton, International Airport, during the period 1 June thru 7 September 1990.

The overall effort was planned and executed by the National Center for Atmospheric Research (NCAR) of Boulder, CO. under the sponsorship of the FAA, Weather Radar Branch, ANR-150. The hardware and software components of the TDWR system were assembled, modified, operated and maintained by NCAR personnel. The integrated TDWR/LLWAS system description and the definitions for the TDWR/LLWAS weather products were prepared by NCAR personnel. The technical data collection was accomplished by NCAR personnel. The completed data analysis and technical evaluation will be available in an NCAR Summary Report, which will be submitted to the FAA, Weather Radar Branch, ANR-150, by February 15, 1991.

The DOT Volpe National Transportation Systems Center (VNTSC) will provide an analysis of pertinent voice and written pilot questionnaires, in order to evaluate the performance of the integrated TDWR/LLWAS products. In addition, VNTSC will provide an analysis of the voice data tapes of the ATC Tower's communications channels for those periods when Microburst and/or Gust Front Advisories were issued and provide an evaluation of the issued Advisories relative to the pilot reported wind shear encounters. TSC will prepare a separate Final Report for the FAA, Weather Radar Branch, ANR-150.

As part of the FAA oversight program, questionnaires were prepared and administered to ATC Tower and TRACON ATCS personnel. The preparation of the ATCS Questionnaires and the subsequent data analysis, which appears in this report, was accomplished by FAA Technical Center, ACN-240.

PROGRAM BACKGROUND AND OPERATIONAL CONCEPTS.

The primary mission of the integrated TDWR/LLWAS System is to enhance the safety of air travel through the timely detection and reporting of hazardous wind shear in and near the terminal approach and departure zones of an airport. A survey has indicated that between 1975 and 1985 wind related events were a factor in 149 accidents claiming 465 lives. Specific sources of the hazardous wind shear which are to be detected are microbursts and gust fronts. The secondary mission of the System is to improve the management of air traffic in the terminal area through the forecast of precipitation, and ultimately the detection of other hazardous weather phenomena including turbulence and tornadoes.

The integrated TDWR/LLWAS System is one project in the National Airspace System (NAS) Plan. The plan's goal is the modernization and improvement of the Government systems supporting aviation commerce in the United States. In the end-state of the NAS Plan, the integrated TDWR/LLWAS System will send weather product information to Air Traffic Control (ATC) computers and the Tower Control Computer Complexes (TCCC).

The end-state users of the integrated TDWR/LLWAS System outputs are pilots, ATCS and their Supervisors. The fielded Systems will automatically monitor an airport's terminal area and generate hazardous weather products to be furnished to the end-state users. The hazardous weather advisories/warnings will be provided on Ribbon Display Terminals (RDT), in a simple, structured format, which does not require interpretation by the user.

In addition, weather data from the integrated TDWR/LLWAS System will appear on color-graphic, Geographical Situation Displays (GSD) which will show the current locations of hazardous weather (e.g. wind shear event locations and regions of heavy precipitation), as well as, wind shifts, which may impact the airport in the next 20 minutes. This situation display information will enable the ATCS Supervisors in the Tower and TRACON to better determine and coordinate runway changes.

DISCUSSION

TEST PLAN PHILOSOPHY AND OVERVIEW.

The 1990 tests and demonstration were an extension to the 1989 tests and demonstration at Stapleton International Airport. Following the 1989/90 changes to the integrated TDWR/LLWAS System, the objectives of the 1990 tests and demonstration were to verify projected increases in the probability of Microburst (MB) and Gust Front (GF) detection, a lowering of the MB and GF false alarm rates and, in general, to demonstrate and test improved, integrated TDWR/LLWAS weather products at the Denver, CO, Stapleton International Airport.

The integrated TDWR/LLWAS System tests and demonstration at the Stapleton International Airport provided microburst and wind shear alerts similar to the airport's commissioned, network expansion LLWAS. During the daily, test periods (June 1 thru September 7), sensor data output from the LLWAS was combined with the TDWR (Mile High Radar) data in a software, integration algorithm and the output weather products were displayed on the RDTs and Geographic Situation Displays (GSD) stations at the ATC Tower and TRACON test sites. A duplicate GSD terminal was available at the FAA Northwest Mountain (NM) Region, Air Route Traffic Control Center (ARTCC), Center Weather Service Unit (CWSU). In order to asses the integrated TDWR/LLWAS warning function, alert messages were substituted for the LLWAS only, alert messages from 1200 to 1900 Local time. During these hours, the primary alert sensor was the integrated TDWR/LLWAS system; however, if necessary, the Tower Cab, ATCS Supervisor could immediately switch the RDTs to the normal, commissioned LLWAS configuration.

In addition to the primary, integrated TDWR/LLWAS products; namely, the Microbursts and Gust Fronts products, six(6) levels of precipitation, LLWAS wind vectors, and Storm Motion (also referred to as Storm Cell Tracking), were available at the GSD stations throughout the test period. A daily, Nowcast product was issued from 17 June through 28 July and appeared on the GSDs. The first Nowcast for each day was issued at 1230 Local Time.

During the tests and demonstrations, the source of the wind shear alarms was the integrated TDWR/LLWAS System; however, the routine data (center field and threshold winds, etc.) from the LLWAS continued to be presented on the ATC Tower's LLWAS, Ribbon Display Terminals i.e., the LLWAS data passed through the interface equipment into the TDWR system (in one direction from LLWAS to TDWR). The commissioned LLWAS system was independently operated at all times.

TDWR/LLWAS TEST BED.

The TDWR/LLWAS Test Bed was established as part of a continuing program to study Low Altitude Wind Shear events. In 1988, scientists and engineers from the Massachusetts Institute of Technology, Lincoln Laboratory (MIT/LL) and the National Center for Atmospheric Research (NCAR) participated in demonstrations and operational testing of a complete, prototype TDWR detection and warning system. This TDWR system provided a high degree of reliability, timeliness and accuracy in the detection and warning of hazardous wind shear events. The success of that effort allowed the FAA to initiate the procurement of the first 47 operational TDWR systems.

In 1989 the test bed hardware was modified to its present configuration. A description of the major components of the integrated TDWR/LLWAS System and the NCAR Operations Center follows:

THE PROTOTYPE TDWR SYSTEM. The location of the TDWR test bed radar (Mile High Radar) is shown in Figure 1. This radar, which is functionally similar to a TDWR, is physically located at a site in Adams County, CO, approximately 17 km (11 mi) northeast of Stapleton International Airport at Latitude 39^{O} 52' 42.5" N; Longitude 104^{O} 45' 28.4" W with a radar feedhorn height of 5262 ft above MSL.

Using previously developed Doppler weather radar algorithms and components of the Raytheon prototype NEXRAD System, the test bed, TDWR System (Mile High Radar) had essentially the same sensitivity, data scanning and product generation features as the TDWR Systems, which are being procured by the FAA; however, the MHR is a 10-cm, S-Band Doppler radar system. It utilizes a parabolic center-feed antenna which has a diameter of approximately 27 feet. A pulse pair Doppler processing scheme was used with a data resolution of 225 meters in both the velocity and reflectivity fields. Improvements to the MHR instituted for 1989/90 included clutter residue reduction. A description of the MHR radar performance parameters is provided in Appendix A.

In addition to the demonstration and testing of the integrated TDWR/LLWAS, operation of the MHR provided wind shear alert coverage to Stapleton International Airport during the 1990 summer, convective season.

Denver Terminal Doppler Weather Radar (TDWR) Geographical Setting

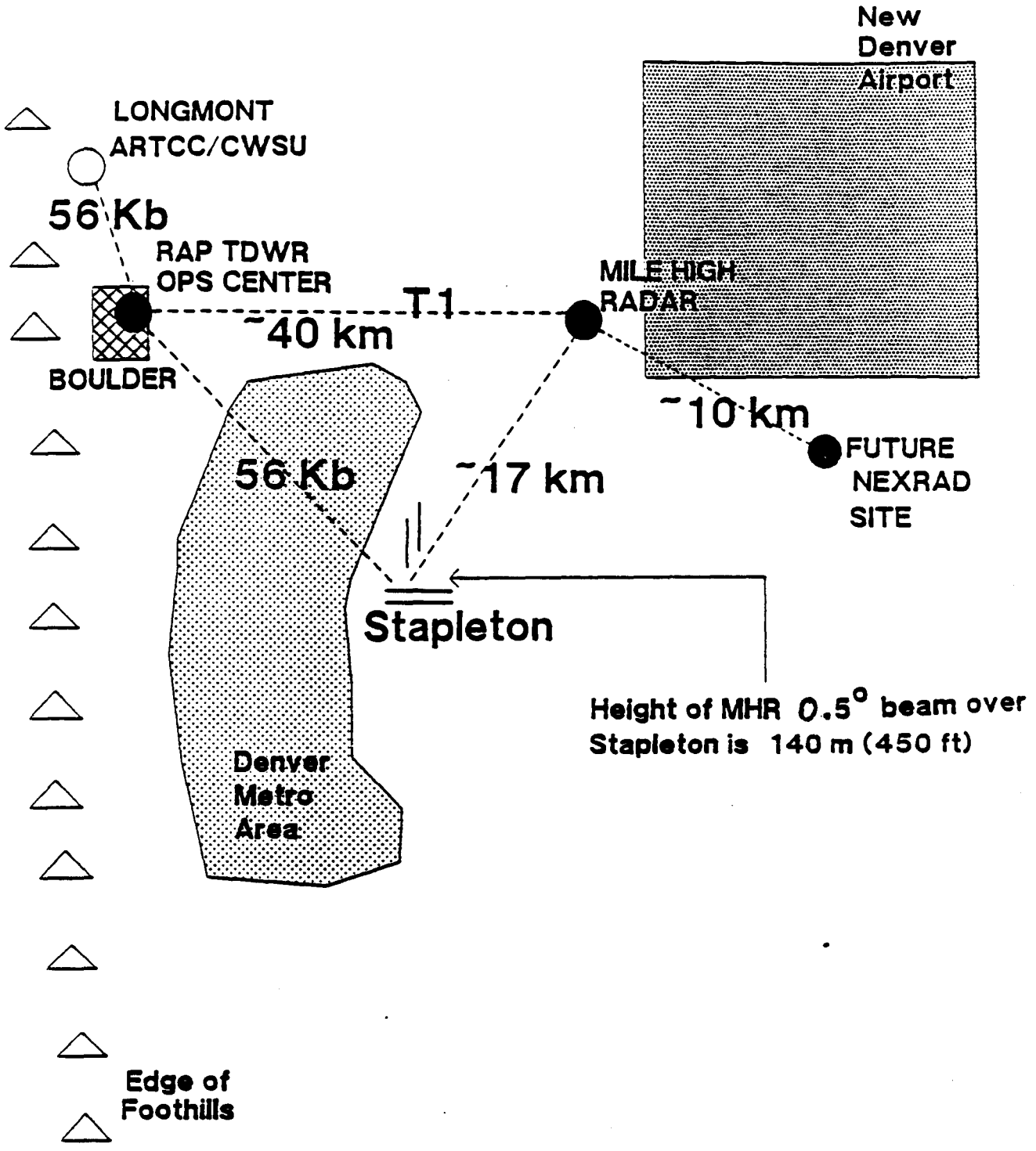


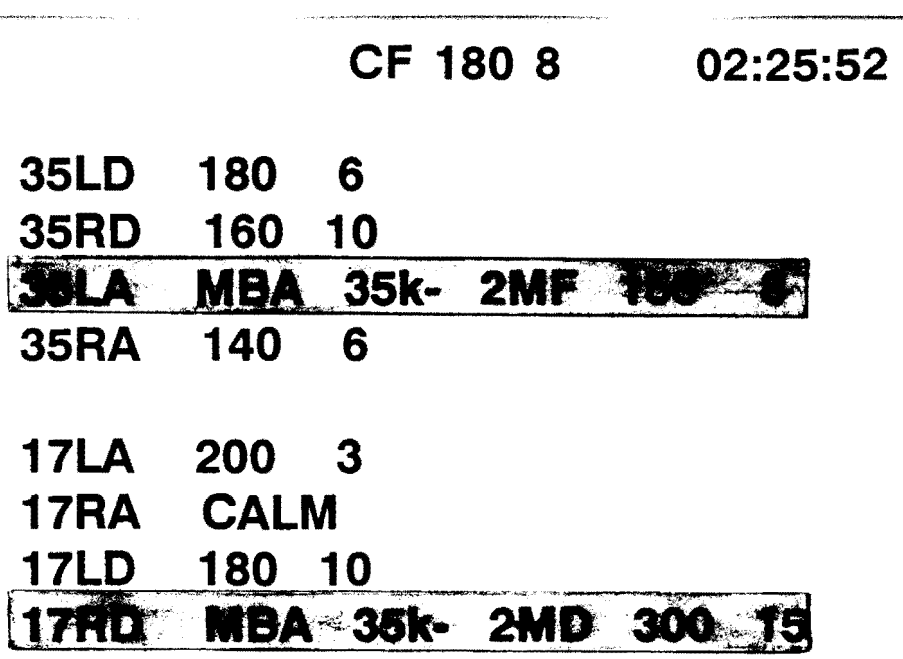
Figure 1. TDWR, TEST BED RADAR LOCATION

LOW-LEVEL WIND SHEAR ALERT SYSTEM (LLWAS). The LLWAS system with runway extensions is a commissioned system at Stapleton International Airport. It has operated with 12 sensors from its commissioning in early 1988 until June 1989, when the system was upgraded to 16 sensors and recommissioned. The LLWAS system is effective for the detection of wind shear and the identification of microbursts that occur within the network; however, false alarms have been noted on hot summer days with thermal activity and on days with strong and gusty winds. The LLWAS data processing and alarm generation remained unchanged after the new network stations geometry was incorporated; however, with the additional stations, the polling cycle was lengthened from approximately seven seconds to approximately 10 seconds.

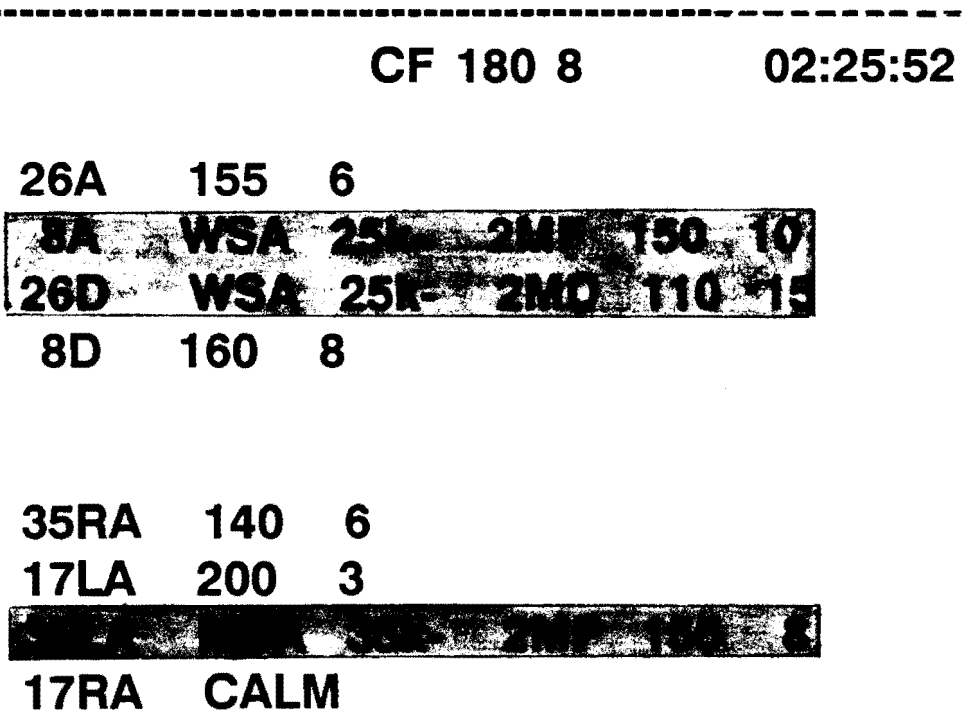
The output data was sent to the ATC Tower's, LLWAS Displays in a runway oriented, Wind Shear and Microburst Alert, format along with the Runway Thresholds and Center Field winds. The LLWAS, only, alphanumeric information for the Stapleton Airport Tower personnel was displayed in the same format, before and after the hours of the tests and demonstrations. The extended LLWAS network data was combined with the TDWR data to derive the integrated TDWR/LLWAS products. A description of the extended LLWAS performance parameters is provided in Appendix B.

THE DISPLAY SYSTEM. The alphanumeric products from the integrated TDWR/LLWAS were displayed on cathode ray tube type, Ribbon Display Terminals (RDT) located near the "Local Control" positions in the Tower and on the RDT at the TRACON Supervisor's position. Normally, the RDTs would display only the commissioned, LLWAS derived winds and hazardous weather products; however, during the periods designated for demonstrations and testing, Hazardous Alert Messages from the integrated TDWR/LLWAS were displayed along with the routine LLWAS data (center field and threshold winds, etc.), which would be present on the RDTs at all times.

The wind shear alert information on the RDTs, was presented to the ATC Tower's "Local" controllers in a format that could be read directly to pilots without interpretation. An alert message included the affected runway, the type of alert (wind shear or microburst), the expected intensity (gain or loss with the expected change in the combined head and tail winds), the location where the event will be encountered, and the LLWAS wind information oriented to the threshold or departure end of the runway. See Figure 2.



Example of Local Control 1 Display (Default Settings)



Example of Local Control 2 Display (Default Settings)

Figure 2. RDT DISPLAY IMAGES: THRESHOLD WINDS AND SAMPLE ALARMS

During tests and/or demonstrations, the color-graphic products from the integrated TDWR/LLWAS were presented on two (2) color-graphic, Geographical Situation Displays (GSD). One GSD was located at the Supervisory Position in the ATC Tower, the other was located near the Area Manager's position in the TRACON. The extended LLWAS winds (16 stations) were displayed on the GSDs. The GSDs presented the LLWAS winds in a vector format for each LLWAS location. See Figure 3. In addition, the GSDs displayed all of the available weather products, e.g., Microbursts, Gust Fronts, Wind Shear Alerts, Storm Motion and Nowcast. Examples are shown in Figure 4.

The GSDs' selectable features included; airport terminal display ranges, background maps, precipitation intensity levels and gust fronts' wind shift predictions for 10 to 20 minutes in the future and the active runways for display on the RDTs at the "Local" Control positions. Examples are shown in Figure 5.

A remote GSD terminal was available at the FAA, NM Region, ARTCC's CWSU. This terminal provided the CWSU meteorologists a comprehensive picture of the weather affecting the Stapleton International Airport's Terminal Area and provided an opportunity to determine the utility of the Storm Motion and Nowcast products for the ARTCC's air traffic planning.

THE NCAR OPERATIONS CENTER. A number of Meteorologists, radar observers and data analysts were stationed at the NCAR Operations Center, Boulder, CO to observe and record the weather conditions in the vicinity of the airport, as reported by various observing systems, to ensure that hazardous wind shear events were detected and appropriate warnings were provided to the ATC system.

At their disposal were displays of velocity and reflectivity from the TDWR (MHR) Doppler weather radar, displays of information from the airport's LLWAS, and displays that were available to the Controllers in the ATC Tower and TRACON.

Telephone communication with the ATC Tower personnel were provided. In the event that a hazardous wind shear event was not detected by the TDWR/LLWAS prototype, system or an equipment failure occurred, the ATC Tower personnel were notified immediately and the TDWR/LLWAS system was disconnected, which returned control of the LLWAS displays to the commissioned LLWAS. For reasons of safety, the actions taken, depended on what would yield the most appropriate windshear warnings.

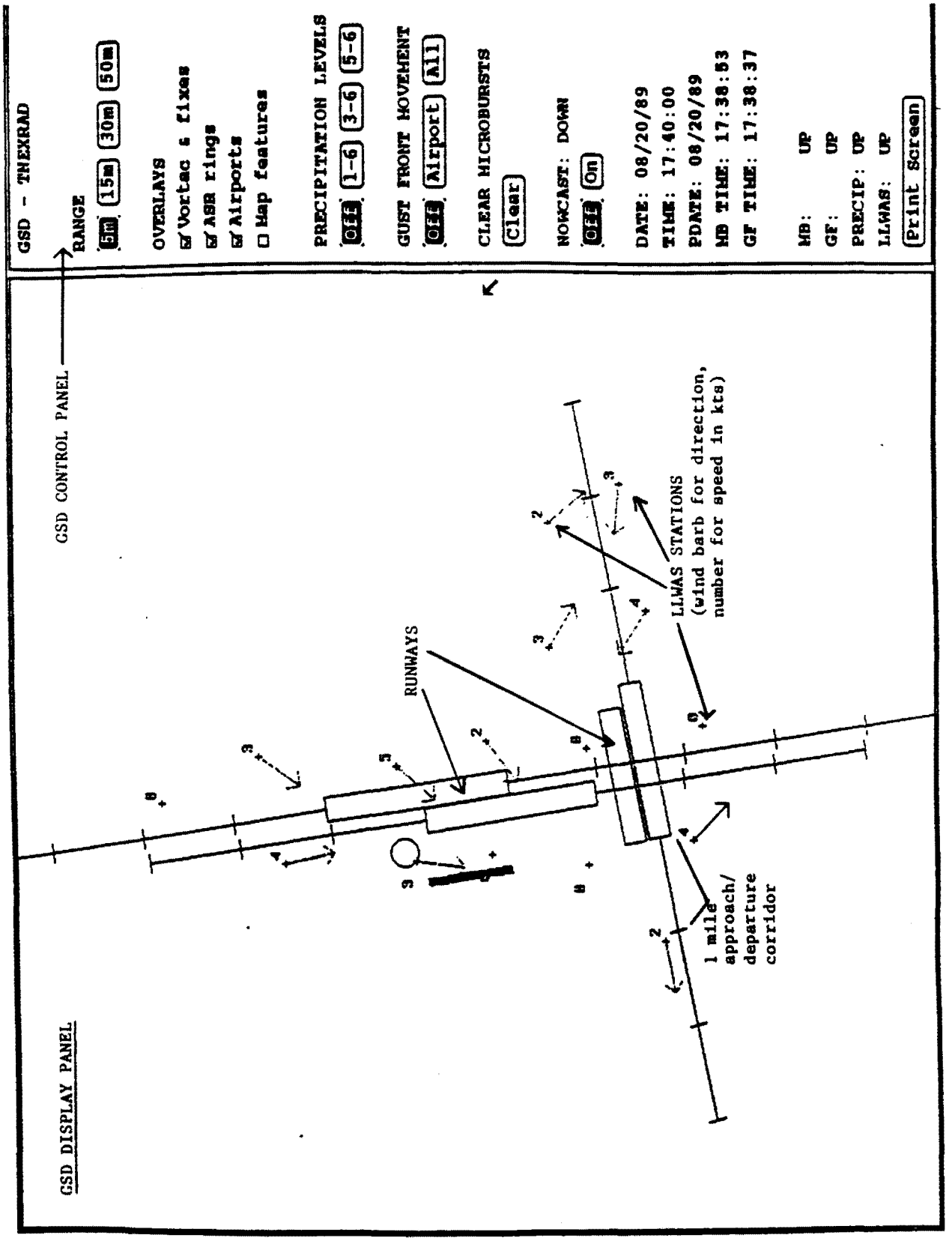


Figure 3. GSD DISPLAY PANEL - LLWAS WINDS IN VECTOR FORMAT

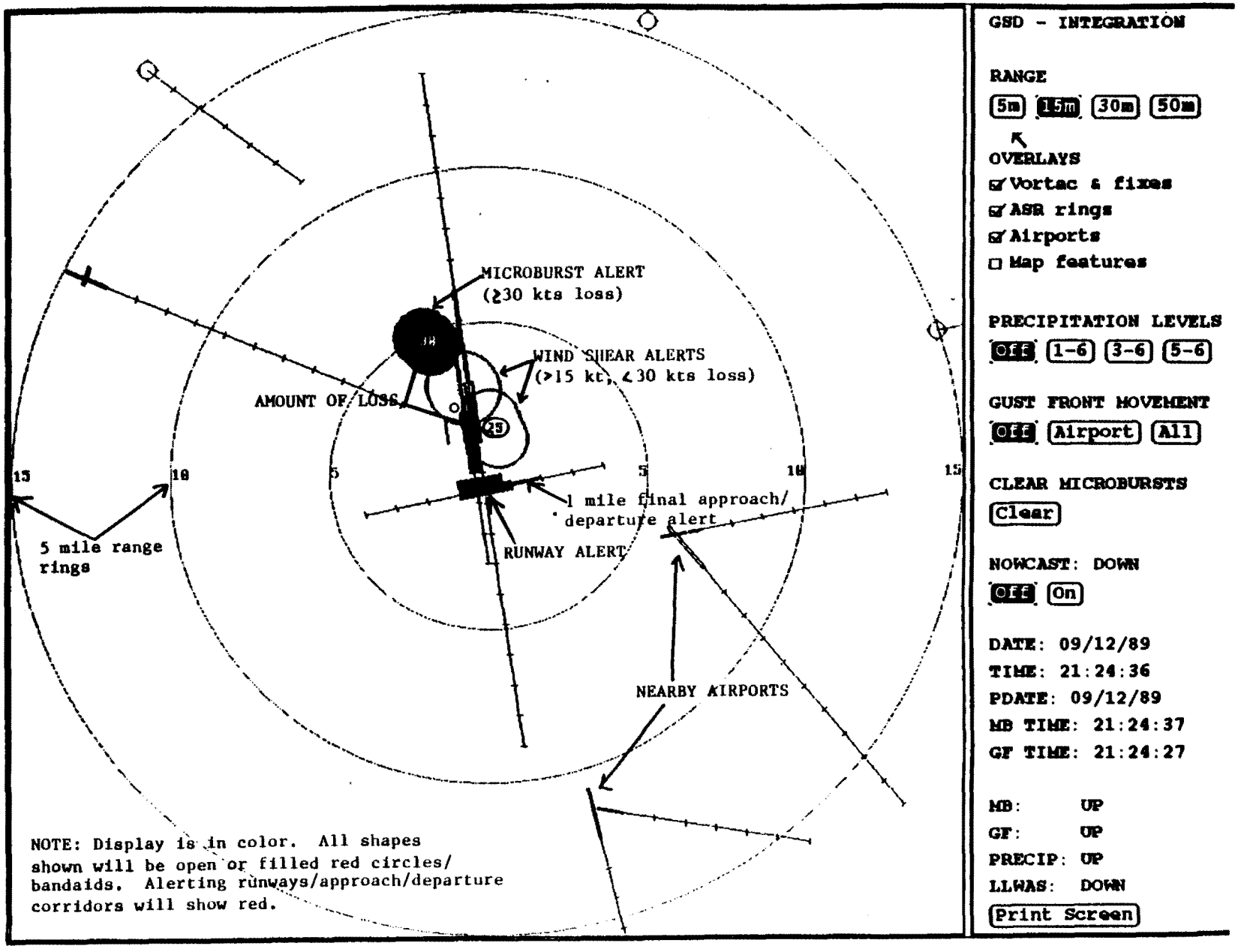


Figure 4. INTEGRATED TDWR/LLWAS PRODUCTS

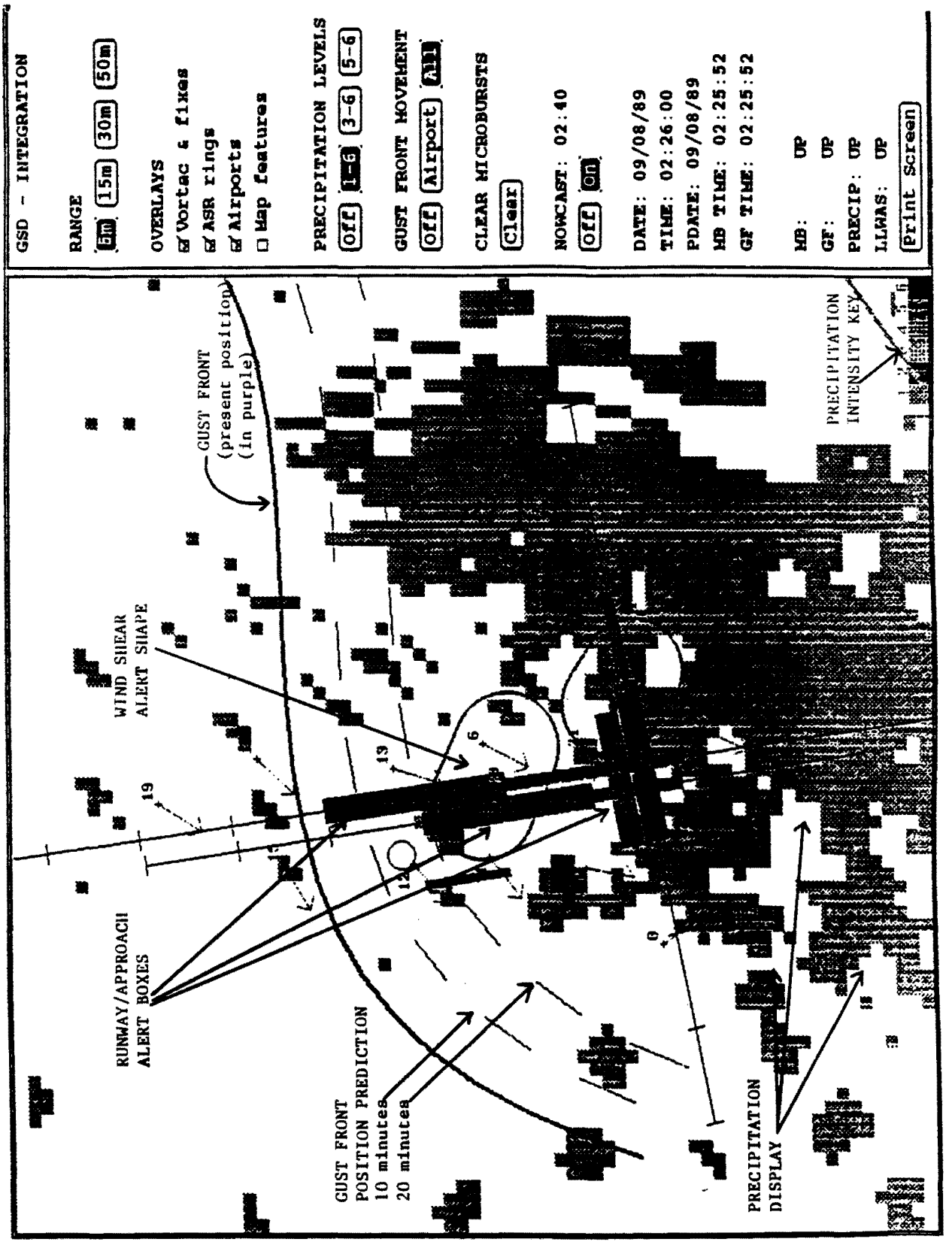


Figure 5. GSD DISPLAY - GUST FRONT WITH WIND SHIFT PREDICTIONS

An NCAR Meteorologist/Observer was stationed in the Stapleton International Airport, ATC Tower Cab, during the first three weeks of the tests and demonstrations to observe the use of the GSD and the RDTs (alphanumeric displays) and to answer any questions that the Air Traffic Controllers might have about the equipment. Thereafter, NCAR project personnel were reached by phone at the NCAR, Operations Center; however, NCAR observers, periodically, visited the ATC Tower, TRACON and the NW Mountain ARTCC, to observe the use of the GSD and to answer questions.

INTEGRATED TDWR/LLWAS WEATHER PRODUCTS.

There were several weather products, some of which have been improved, that were available for the 1990 tests and demonstrations. They included: (1) Divergent Outflow (Microburst) Algorithm; (2) Gust Front Detection Algorithm and Wind Shift Prediction; (3) Precipitation Intensity; (4) Network Expansion LLWAS; (5) TDWR/LLWAS Integration; and (6) Storm Motion. A brief description of these products and the additional Nowcast weather product follows:

THE DIVERGENT OUTFLOW (MICROBURST) ALGORITHM. The divergent outflow algorithm was developed to identify small regions of strong divergent flow near the earth's surface. This type of windshear is the primary signature of a microburst event.

Only the very lowest level, radar elevation scans were used for detection and identification. When radial divergent velocity signatures were recognized by the algorithm and, where the shear was significant, they were flagged as microburst or wind shear events. Only those events where the divergent outflow was equal or greater than 30 knots were flagged as microburst alerts. Those events in the region between 15 and 30 knots were flagged as wind shear alerts.

The outflow detection consisted of two processes: the identification of linear segments of increasing velocity along the radial and the association of these segments across radials to form two-dimensional clusters of segments. The results were passed through an editing process to minimize false alarms, coordinated with the features aloft algorithm and sent to the NCAR GSD display algorithm.

In addition to the above algorithm, a features aloft algorithm was developed to assist in the microburst detection process. There is evidence that meteorological features which occur at heights in excess of 1 kilometer above ground level can act as precursors to strong surface divergence. This algorithm searches the high level, radar elevation scans for reflectivity and shear signatures. These signatures imply the presence of features that can be associated with developing microbursts such as descending reflectivity cores, mid-level downdraft rotation and upper level divergence. When the algorithm identifies these precursors the information is combined with data from the microburst algorithm to issue the microburst alerts. The result of using the features aloft was that earlier, more timely alarms were available.

GUST FRONT DETECTION AND WIND SHIFT PREDICTION. The gust front detection algorithm utilized pattern recognition techniques to detect wind shear lines associated with gust fronts. The algorithm searched through the Doppler radar velocity data for large gradients (shears) along radial beams out to 60 km from the radar. Intense wind shift lines propagating away from or towards the radar produced very well-defined lines of convergent radial velocities. The Doppler radar interprets the convergence as a decrease in the velocities along the radials. The pattern recognition technique looks for runs of successive decreasing velocities along the given radials. Adjacent radial data are compared, passed through threshold tests and then grouped into convergence features to form a gust front line. Linear extrapolation estimates are made to the gust front movements for 10 and 20 minutes into the future to form the wind shift prediction products. The output from this algorithm is then sent to the NCAR display and alarm generation system for presentation on the GSD and alphanumeric displays.

This detection algorithm was ported to a Sun-4 work station by MIT, Lincoln Laboratories for use by NCAR in Denver, Colorado. The basic algorithm was developed by H. Uyeda and D. Zrnic of NSSL.

PRECIPITATION INTENSITY. Available for selection at the GSD stations was a display of precipitation intensity (radar reflectivity). Radar data from two elevation angles, was converted to Cartesian space and sent to the GSD displays. The low elevation angle (0.5 degree) data was displayed on the five (5) nautical miles range. The 4.0 degree elevation angle, precipitation data was provided on the 15, 30 and 50 nautical miles ranges. Precipitation intensities were displayed in six different colors representing the standard NWS six levels of reflectivity so that information about gradients and cores was available.

NETWORK EXPANSION LLWAS. The Stapleton International Airport's Expanded LLWAS System consisted of 16 stations. The latest configuration included extensions along the runway approach and departure zones with enhanced data processing and alarm generation. The Network Expansion LLWAS products included wind shear/microburst alerts, center field winds/gusts and the runways' arrival and departure threshold winds. Wind shear alerts from the LLWAS system were combined with the MHR TDWR radar derived warnings to produce the integrated TDWR/LLWAS products. The commissioned LLWAS System was operational in the ATC Tower and TRACON at all times, unless the integrated TDWR/LLWAS, tests and demonstrations were in progress.

TDWR/LLWAS INTEGRATION. The TDWR/LLWAS Integration product was developed as an advanced wind shear detection and display subsystem. Utilizing information from different sources, the integration algorithms produced a consensus set of RDT (alphanumeric) and GSD (graphical) alert and display products.

In 1989 the first operational tests and demonstration of the integrated TDWR/LLWAS windshear system were conducted. Based on the relative success of those tests, an upgraded version was developed and prepared for testing, during 1990. The most significant changes were implemented in the LLWAS portion of the windshear-with-loss algorithm; however, a major addition to the integration algorithms was the use of TDWR features-aloft data to validate the LLWAS windshear-with-loss computations.

The wind shear with loss alarms (microbursts and other wind shear loss situations) came from the microburst shapes generated, independently, by the TDWR and the runway oriented wind shear losses, generated by the Network Expansion LLWAS.
For those areas within the LLWAS network, the wind shear with gain alarms (gust fronts and other wind shear gain situations) came from the LLWAS runway oriented, windshear-with-gain algorithm; however, outside the LLWAS network, coverage area, the TDWR gust front algorithm was used to generate the alarms.

It should be noted, that the Network Expansion LLWAS algorithms for both the runway oriented gain and loss situations were updated to reflect the current FAA LLWAS system specifications.

Finally, an alarm generating, decision logic was applied to the windshear-with-loss and the windshear-with-gain data in order to generate wind shear warnings which would indicate a "worst case" magnitude and a "first expected encounter" location for each operational runway.

NOWCAST. The ultimate objective of the Nowcast product was to provide an automated prediction and display of impeding convection. During the 1990 tests and demonstrations, the NCAR meteorologists tested and refined the automation processes.

The preparation of a Nowcast product required the processing and display of Doppler weather radar data at several different work stations. This allowed the forecasters to examine the data in several ways and to generate an accurate 30-minute Nowcast. Certain work stations displayed three (3) radar variables: reflectivity, radial velocity and derived radial divergence. Two (2) computer generated, time lapse movies of these variables was available. The location of boundaries and storms was manually inserted at one of the work stations. A computer algorithm performed a linear extrapolation of the inserted features and displayed the predicted locations. Another work station provided three dimensional images of the radar data and real time, time height profiles to be used for element life-cycle forecasts, feature extraction and extrapolation.

Based on available data and other information, the forecast team provided a Nowcast product that was displayed on the GSD valid 30 minutes from the time of issuance. A box was displayed giving the location of an area where reflectivity at level 3 (40 dbZ) or greater was expected more than 60% of the time (POD = 0.6) within 30 minutes. See Figure 6., for an example of an outlined, Nowcast box, labelled "A". The forecast area was approximately 9000 sq km (2600˜sq˜n˜mi) encompassing Stapleton Airport and the Keene and Kiowa arrival gates to the east and was bounded by the foothills region to the west of Denver. This initial implementation of the 30-minute nowcast required several forecasters and computers. These are important first steps in the eventual automation of the Nowcast product.

STORM MOTION. The storm motion algorithm provided the current direction and speed of storm movements by locating and tracking storm cell cores. Based on an analysis of consecutive low level, radar elevation scans, vectors were displayed on the GSDs, which indicated the velocity and direction of the storm cells. An example of the Storm Motion product is shown in Figure 6. The tracking algorithm was updated with each new 4.0 degree elevation scan, which occurred every 6.2 minutes. This algorithm was developed by the MIT Lincoln Laboratory.

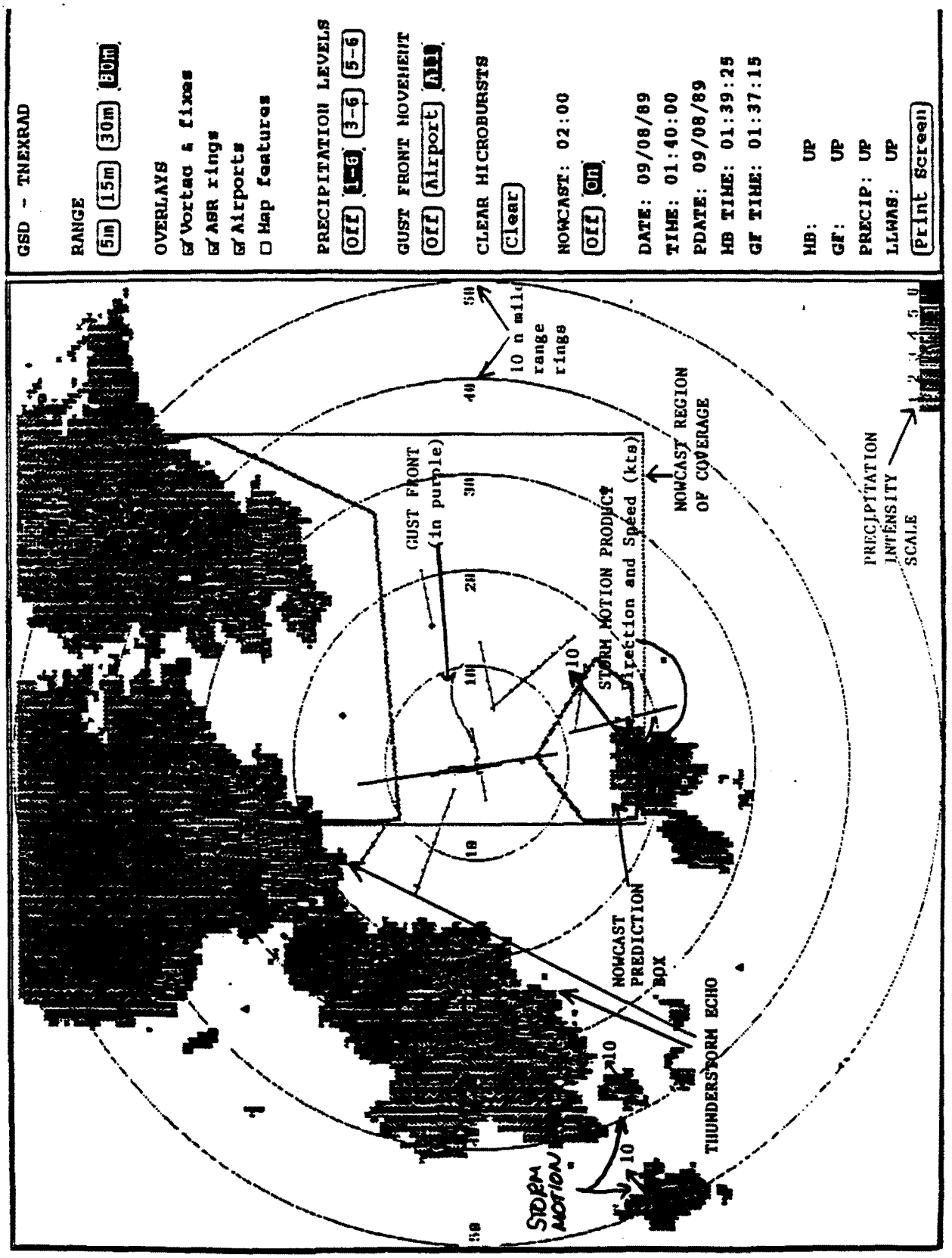


Figure 6. GSD DISPLAY - NOWCAST AND STORM MOTION WX PRODUCTS

TEST PLANNING AND CONDUCT.

The actions taken to plan and conduct the demonstrations and tests were as follows:

1. The overall technical tests and demonstration of the integrated TDWR/LLWAS System was planned and executed by the National Center for Atmospheric Research (NCAR) of Boulder, CO.

2. A limited, Human Factors evaluation was planned jointly by NCAR, the DOT Volpe National Transportation Systems Center (VNTSC) and the FAA Technical Center, ACN-240. NCAR personnel conducted interviews with all users at the various FAA facilities. The DOT VNTSC will provide an analysis of pertinent voice data tapes from the ATC Tower and the written pilot questionnaires. The FAATC, ACN-240, as part of the FAA oversight program, prepared and administered questionnaires to ATC Tower/TRACON ATCS personnel.

TECHNICAL/OPERATIONAL APPROACH.

The procedures and resources used to verify performance were as follows:

MICROBURST DETECTION. The effectiveness of the integrated TDWR/LLWAS, Microburst Detection Function in identifying a Wind Shear event as a Microburst and providing an acceptably Low False Alarm Rate was determined by correlating the Mile High Radar's (MHR) reflectivity and velocity profiles for (microburst and windshear events) with the corresponding wind sensor data from the LLWAS, if available, and comparing this data with the microburst and wind shear events declared by the integrated TDWR/LLWAS algorithms. Effectiveness is a quantitative rating and is based on the resultant of a high Probability Of Detection (POD), a low False Alarm Rate (FAR) and timely warnings of operational significance.

Data from the MHR, and the runway extended LLWAS, as well as, observations by the NCAR Operations Center, ATC Voice Tapes, Pilot Reports and Pilot Questionnaires were required to meet this objective.

GUST FRONT DETECTION AND WIND SHIFT PREDICTION. The assessment of the integrated TDWR/LLWAS, Gust Front Detection and Wind Shift Prediction Function in identifying a Wind Shear event as a Gust Front and providing an acceptably Low FAR will be assessed by correlating the MHR's reflectivity and velocity profiles for Wind Shear/Shift Detection with the corresponding wind sensor data from the extended LLWAS, if available, and comparing this data with the gust fronts and wind shift events declared by the integrated TDWR/LLWAS algorithms. Data from the MHR and the runway extended LLWAS, as well as, observations by the NCAR Operations Center personnel, ATC Voice Tapes, Pilot Reports (encounters with wind shift events) and Pilot Questionnaires are required to meet this objective. Assessment is a qualitative rating and is based on the resultant of a high POD, a low FAR combined with timely warnings of operational significance.

THE INTEGRATED TDWR/LLWAS WARNING FUNCTION. Evaluation of the integrated TDWR/LLWAS Hazardous Weather Messages by the Air Traffic Controllers and the timeliness and usefulness of the subsequent Controller's Message to the pilots was accomplished by means of ATC voice recordings, Pilot Reports (PIREPS) and aircraft pilot questionnaires. The Aircraft Pilot Questionnaires were available and were administered throughout the test period to commercial pilots in the Denver, CO airport's terminal area.

A questionnaire was administered to the Air Traffic Control Specialists, near the end of the test period. Numerical values were assigned to the responses to the questions and then analyzed with statistical methods. Narrative answers were entered into a computer data base and categorized. At the conclusion of the tests and demonstration, NCAR personnel conducted interviews with all users (FAA personnel) at the various facilities.

The evaluation also assessed the observations of the ATCS, Controllers and Supervisors, regarding acceptance of the physical characteristics and utility of the data displays.

THE INTEGRATED TDWR/LLWAS PLANNING FUNCTION. Evaluation by the ATC Supervisors of the usefulness of the integrated TDWR/LLWAS and the Geographical Situation Display (GSD) for Terminal Air Traffic planning and the assessment of the need for other or modified display equipment and techniques was accomplished by means of ATC questionnaires.

A questionnaire was administered to the Air Traffic Control Specialists, near the end of the test period. Numerical values were assigned to the responses to the questions and then analyzed with statistical methods. Narrative answers were entered into a computer data base and categorized. At the conclusion of the tests and demonstration, NCAR personnel conducted interviews with all users (FAA personnel) at the various facilities.

ADDITIONAL WEATHER PRODUCTS. The effectiveness of the Storm Motion and Nowcast products for the Terminal Area and ARTCC, ATC System were assessed based on ATC personnel use of the product and their appraisal of the timeliness and effectiveness of redirecting aircraft based on projected storm motion and/or the prediction and display of impending convection products.

A questionnaire was administered to the Air Traffic Control Specialists near the end of the test period. At the conclusion of the tests and demonstration, NCAR personnel conducted interviews with all users (FAA personnel) at the various facilities. Numerical values were assigned to the responses to the questions and then analyzed with statistical methods. Narrative answers were entered into a computer data base and categorized.

At the conclusion of the tests and demonstration, NCAR personnel conducted interviews with all users (FAA personnel) at the various facilities as another means of assessing the utility of the Storm Motion and the Nowcast products.

RESULTS

TEST CHRONOLOGY AND COLLECTED DATA.

Testing started June 1, 1990, from 1200 local, watch time (wt) time to 1900 wt and continued seven days a week through September 7, 1990. During this period, the integrated TDWR/LLWAS System generally functioned well and had no significant outages. During the tests, data was collected in the following two (2) categories; hazardous weather events and the Air Traffic Controller's (ATC) comments.

HAZARDOUS WEATHER DATA. During the tests and demonstrations, the integrated TDWR/LLWAS System detected and reported the presence of 95 Microbursts (Maximum Observed Divergence of 30 Knots or Greater), 58 Gust Fronts and 169 Wind Shear Alerts, within 5 nautical miles of Stapleton International Airport. At the present time, these events are undergoing quantitative analysis by the NCAR technical staff; however, the NCAR Project Director has furnished a preliminary, technical appraisal of the integrated TDWR/LLWAS System's microburst and windshear-with-loss detection capability. The NCAR data and analysis; as well as, background information on the post-season analyses of the data collected, during 1988 and 1989, are reported later in this Section under MICROBURST DETECTION.

ATC OPERATIONAL DATA. Before the operational tests the integrated TDWR/LLWAS System displays were installed in the Stapleton ATC Tower and TRACON and the users completed their training and equipment familiarization.

During the daily tests and demonstration periods, the ATCS Controllers and Supervisors were asked to use the displayed information in order to warn aircraft of hazardous wind shear events, near the airport, and to plan future runway traffic movement. Near the end of the tests and demonstrations, Questionnaires were administered to the ATCS personnel.

The Questionnaires, prepared by FAATC ACN-240, were given to the Air Traffic Controllers in the Tower and the ATCS Supervisors in the Tower and the TRACON. Appendix C. contains a complete summary of the Questionnaires' grouped responses and the written comments furnished by the ATC Controllers and Supervisors.

A review of the Questionnaires' revealed several inconsistencies in the written comments. In order to obtain clarification and resolution of the conflicting opinions, a number of interviews were arranged with selected Air Traffic Controllers. The following subjects were chosen for discussion:

1. Training in the interpretation and use of the Ribbon Display and Geographical Situation Display (GSD) Terminals.

2. Preceived Overwarnings and/or False Alarms by the System.

3. Pilot Notifications, when Microbursts downgrade to wind shear alerts or upgrade to higher intensities.

4. Ease of Runway Selection on the GSD for display on the Ribbon Display Terminals.

Tables 1. and 2. contain a summary of the Questionnaires' grouped responses to specific aspects of the integrated TDWR/LLWAS System. The scale of ratings available for selection, by the respondents, was; (+3) Very Good, (+2) Good, (+1) Fairly Good, (0) Fair, (-1) Fairly Poor, (-2) Poor, (-3) Very Poor and (?) Don't Know.

In addition to their grouped responses, the respondents contributed written comments. Some of their comments and a summary of the interviews with selected ATC Specialists are reproduced below.

Summary: ATC Interviews and Questionnaire Comments. The Controllers praised the concepts and the current implementation of the integrated TDWR/LLWAS System. Their comments were very similar to the those received, during the tests and demonstrations in the summer of 1988. The 1989 installation of the Mile High Radar (MHR), formerly the Raytheon Co.'s NEXRAD System, caused obvious setbacks in the performance of the System's Microburst and Gust Front products; however, the refinements incorporated in the System for 1990 improved the performance to near the levels of 1988. In addition, the integration of the Mile High, Doppler radar with the expansion, 16 sensor, network LLWAS was a definite improvement, as well as, the addition of the Storm Motion and Nowcast weather products. The users were very enthusiastic regarding the availability of the integrated TDWR/LLWAS System and the weather, forecast, products which were sorely missed when not available.

1. **Training:** In general the consensus was that the training was well prepared and well presented. Previous experience gained during the testing in 1987,88 and 89 was used by those not able to attend the scheduled sessions. There were several comments that the training could have been more extensive for the newer people who were not able to attend the hands-on training sessions. Note: Training in the phraseology used to warn pilots of weather alerts was not a problem. Before and after the tests and demonstration, the same Ribbon Display Terminals with the same "alert" message structure (format and phraseology) were used with the commissioned, stand-alone, network expansion LLWAS.

Table 1. Rating: Aspects of the Integrated TDWR/LLWAS System

	AVERAGE (MEAN) SCORE
1. Readability of displays.	
(1) GSD	VERY GOOD
(2) RDT	VERY GOOD
2. Adequacy of Display Size and Audibility of the alarm beeper.	
(1) GSD	GOOD
(2) RDT	GOOD
3. Completeness and accuracy of the displayed information. Freedom from misinterpretation.	
(1) GSD	VERY GOOD
(2) RDT	GOOD
4. Rate of false alarms (many=-3 ; few=+3)	
(1) GSD	VERY GOOD
(2) RDT	GOOD
5. Usefulness of the displayed info	
(1) GSD	VERY GOOD
(2) RDT	GOOD
6. Suitability for continued field use	
(1) GSD	VERY GOOD
(2) RDT	VERY GOOD
7. Rate usefulness of the TDWR/LLWAS System training received	GOOD

Table 2. Rating: Various Weather Products

Usefulness of the GSD features:	AVERAGE (MEAN) SCORE
Gust Front Presentation	GOOD
Storm Motion and Tract Presentation	VERY GOOD
Nowcast Presentation	FAIRLY GOOD
Ability to Select & Display Active Runways on Local Control's RDT	FAIRLY GOOD

2. Preceived Overwarnings and False Alarms: Among the Controllers' comments, there were various opinions and concerns but no consensus. Many of the comments were similar to those expressed, during the 1988 tests and demonstrations.

During the interviews with the Air Traffic Controllers, their usage of the terms, "Overwarnings" and "False Alarms" was discussed. The Controllers agreed that the term "False Alarms" was used when the System may have incorrectly identified windshear or microburst events. However, the situations, which were referred to as "Overwarnings", were easier to identify on the GSDs and seemed to occur when an event; e.g., a large microburst, touched or slightly overlapped a warning zone.** Even though they may consider the event's impact to be slight, aerodynamically, the Air Traffic Controllers must alert all aviation users of the runway within the warning zone.

Based on their experiences, the interviewed Controllers agreed with the following statement: "When either "False Alarms" or "Overwarnings" occur, during periods of heavy traffic, a significant number of pilots could receive repeated warnings or alerts and they would not experience either microbursts or substantial windshear effects." Furthermore, it must be assumed that unnecessary warnings contribute to the Controllers' and the pilots' workloads and increase the airport's missed approaches and traffic delays.

** Warning zones are rectangular boxes 0.5 nautical mile on either side of the runway's extended centerline. Each runway zone is centered on and parallel to the runways. The runway's approach zones extended outward, 3.0 nautical miles from the approach thresholds and the runway's departure zones extended outward, 2.0 nautical miles from the departure thresholds.

Several Controllers stated; "There was considerable "Overwarning" in 1990" and " The width of the warning zones is a definite factor". To alleviate the problem, it was suggested by the Controllers that the System be designed with a supplemental or alternate warning method. Their statements follow: "If more information were readily available, the Air Traffic Controllers could provide guidance regarding the intensity and distance to the runway from the center of the nearest microburst. A better method, would be to advise the pilots of the intensity of the microburst's wind component in the direction of the runway."

Other Controllers were emphatic that "Overwarnings" and "False Alarms" were no problem. Their statements follow: "There were not too many microbursts this year. Pilots are better trained and they understand that microbursts may be close enough to cause an alert but the windshear may not be felt. Low level microbursts (30 to 40 Knots) may be a challenge to the pilots, but if the microbursts are 45 to 60 Knots and higher, pilots tend to back off. Pilots don't question the microburst's location; i.e., the distance offset from the runway. Many pilots go around on mention of microbursts. In fact, it is getting harder to confirm the microburts' intensity through Pilot Reports (PIREP). In general, the microburst warning criteria is working. It is safe, don't fool with it."

3. Advising Pilots of Changes in the Intensity of Microbust/ Wind Shear Alerts: The interviewed, Air Traffic Controllers, were aware of those situations which occur when pilots, who were first notified of a Microburst/Wind Shear Alert (MB/WSA), while far out on the Final Approach Course and then the wind shear event dissipates and/or increases in intensity before their aircraft reaches the MB/WSA location. When this occurred all the Controllers indicated that they passed this information to the pilots on the Local Control frequencies. Their statements follow: "This has not been a problem, because alert messages are given to each new aircraft on the Final Approach Course. The "alert messages", back-lighted on the Ribbon Display Terminals are a plus, but it would be a great help if the display would also indicate when changes occur in the alert messages."

4. Ease of Runway Selection on the GSD. Based on the Questionnaires' written comments and the statements of those interviewed, few of the Air Traffic Controllers tried to reset the active runway configurations on the GSD, during their operating shifts. It was considered a time consuming process,when there were other more important tasks. The ATCS Supervisors choose to stay with the one default, runway configuration. It so happens that this runway configuration, during the tests and demonstrations, was the same configuration which was used year round for the stand-alone LLWAS. In general, the Supervisors could live with the one configuration; however, if a number of preselected default configurations were available, it would permit a fast change-over, during an airport wind shift and a rapid consolidation of the Local Control positions on the 11:00 PM to 7:00 AM (Midwatch).

MICROBURST DETECTION.

The FAA's System Requirement (FAA Order 1812.9) for the detection of microbursts in a stand-alone TDWR System can be summarized as follows:

"... The probability of detecting a reportable wind shear or turbulence event, when one exists within the coverage area, must be at least 0.90. The probability of reporting a reportable wind shear or turbulence event when one does not exist within the coverage area must be no greater than 0.10...."

The criteria for an integrated TDWR/LLWAS System has not been specified; however, the above criteria should also apply to the integrated System with the additional stipulations that the integration of the TDWR and the LLWAS must provide complementary alarms appropriate to each Subsystem's airport coverage and the integration must minimize the occurrence of false alarms. Further the integration must not degrade either Subsystem's performance and each Subsystem must be allowed to fail without aborting the other.

EARLIER SYSTEM TESTS AND DEMONSTRATIONS. The ability of the stand-alone TDWR system to detect microbursts was dramatically demonstrated, during the summer of 1988. The Probability of Detection (POD) was 97 percent and the False Alarm Ratio (FAR) was 5 percent.

During the 1988 stand-alone TDWR System tests, the detection of microbursts and gust fronts and their accompanying wind shifts were demonstrated to be operationally, useful and effective; however, the following year, the substitution of a different, TDWR at an alternate site combined with the System integration of a network expansion LLWAS, caused a resultant degradation in performance that was obvious to the System's users. Nothing was changed in the ATC Tower and TRACON display equipment but, despite the complimentary detection capabilities of the TDWR and the LLWAS, the differences in performance, especially the increase in false alarms was obvious on a day to day basis.

Analysis of the 1989 tests results, indicated that the expected performance of the integrated TDWR/LLWAS System would be a composite of the individual PODs and FARs for the LLWAS and the TDWR stand-alone Subsystems. For the prototype TDWR, the POD and FAR were 94 percent and 12 percent, respectively. For the LLWAS, the POD was 96 percent with an Overwarning of 14 percent. The NCAR test team conducted a post-season analysis with the following conclusions.

1. The sources for the false alarms in the TDWR Subsystem were traceable to the following:

a. Presence of moving targets (landing and departing aircraft).

b. Seasonal variation in the radar ground clutter returns and lack of adequate suppression and filtering.

c. Radar echoes (second trips) from storms far outside the airport vicinity.

d. The TDWR, Mile High Radar (MHR) operation. An evaluation of the microburst alarm system indicated that the algorithm's performance was not optimum when using the existing data filter. This problem coupled with crude ground-clutter removal produced more false alarms than should be expected. In the post-season analysis, when the data filter was removed, the FAR dropped by 50 percent.

2. The sources for the Overwarnings and False Alarms in the LLWAS Subsystem were traceable to the following:

a. False alarms were noted on hot summer days with high thermal activity and on days with strong gusty winds.

b. The network expansion LLWAS components of the integration algorithm. During the post-season analysis, the problems contributing to the overwarning were believed to be minor and could be fixed with changes in various parameter settings. The LLWAS component of the integration algorithm was believed to be too conservative on the side of safety. Windshear alarms were, sometimes, issued when little or no threat was present along the runway. As a result of these findings, the integration algorithm for 1990 was refined to reduce the Overwarnings and the FAR, while maintaining a high detection rate. Changes to the integration algorithm included; reducing the size of the LLWAS alarm shapes, changing filter parameters to decrease the "coasting" feature, checking the runway wind components before issuing weak alarms (15-20 Knots) and verifying the LLWAS data with information from the radar based, features-aloft algorithm. Using the same data, collected during the 1989 tests, the 1989 integration algorithm was compared with the 1990 version to determine the changes in performance. Based on this analysis, the expected results for the LLWAS component of the 1990 integration algorithm were a POD of 97% and a FAR of 4%.

3. In addition, certain inferences can be drawn from the 1989 post-season analysis.

a. Ideally, the false alarms on both Subsystems have been reduced to fairly low levels, which are approximately equal.

b. The TDWR/LLWAS integration process does add alarms that are missed by the TDWR radar acting alone. The combined Subsystems provide better overall detection capability; however, user confidence will remain high only as long as we do not exacerbate the overwarning problems.

c. In order to operationally implement a new integrated TDWR/LLWAS System, it is important to allow reasonable time to measure and collect the local site's TDWR and LLWAS data, to adjust and recheck the site adaptable parameters and to verify the actual System's operations.

1990 SYSTEM TESTS AND DEMONSTRATIONS. As mentioned earlier, the final, quantitative results of the 1990 tests and demonstrations were not available for this "Quick Look" report; however, the following is a preliminary, technical appraisal of the integrated TDWR/LLWAS System's microburst and windshear-with-loss detection capability. It was furnished by the NCAR Project Director with the stipulation that all the collected data has not been quantitatively evaluated.

***** 1990 TDWR/LLWAS Integration Quick Look Summary Statistics *****

For the preliminary scoring of the 1990 TDWR/LLWAS integration products, five microburst cases occurring within five nautical miles of the Stapleton International Airport were examined.

Table 3., provides information on all five cases for a total of 154 minutes of microburst activity. This table details the standard POD/FAR statistical measures for each day; as well as, the composite values for all five events. Human truthing was based on single Doppler radar data and LLWAS wind measurements. Included in these statistics are two "problematic" cases which were scored to illustrate the "value-added" to be gained by the use of the network expansion LLWAS in the integrated System.

Table 3. 1990 - Preliminary Scoring of the Integrated System

DATE (1990)	DURATION (Minutes)	MAX. VELOCITY CHANGE (knots)	TDWR POD	TDWR FAR	LLWAS POD	LLWAS FAR
25 June	40	40	92	1	94	0
9 July	40	50	98	1	97	0
29 July	17	30	70	0	99	0
1 August	16	25	0	0	95	0
19 August	41	60	96	8	93	7
COMPOSITE	154		89	3	95	2

The event on 29 July, was fairly weak and poorly detected by the Mile High Radar (MHR); the event on 1 August was a low reflectivity event, which was also poorly detected by MHR, due to second-trip contamination.

The statistics indicate that on 29 July. the TDWR system was only able to detect the event for approximately 12 of the 17 minutes. However, LLWAS was able to detect the event during all but 10 seconds of the event's lifecycle. A similar situation occurred on 1 August. The TDWR system was unable to detect the weak shear during its entire 16 minute lifecycle. However, the LLWAS properly added approximately 15 minutes of correct alarms.

The inclusion of the "problematic cases" in Table 3., reduces the composite POD for the TDWR for these five cases. For this reason, the composite TDWR statistics, shown here, are not indicative of the true performance of the TDWR system.

Table 4., indicates the compiled data from the three strongest events (25 June, 9 July, and 19 August) which were examined in Table 3. Table 4., reflects the summary statistics for only these three events, which would be representative of a larger sample set of days.

Table 4. 1990 Summary Statistics for the "Strong Events"

DATE (1990)	DURATION (Minutes)	TDWR POD	TDWR FAR	LLWAS POD	LLWAS FAR
COMPOSITE "Strong Events"	121	95	3	95	2

GUST FRONT DETECTION AND WIND SHIFT PREDICTION.

The gust front detection algorithm utilized pattern recognition techniques to detect the wind shear lines associated with gust fronts. The algorithm searched through Doppler radar velocity data for large gradients (shears) along the radial beams. Intense wind shift lines propagating away or toward the radar produced well defined line of convergent radial velocities at low levels. Radar data out to 60 kilometers at all azimuths were sampled in this algorithm. Linear extrapolation estimates were made of gust front movement for 10 and 20 minutes into the future to form the wind shift prediction product. In addition an estimate of the gust front's direction of motion and the magnitude of the wind, behind the boundary was provided. The output from the algorithm was sent to the NCAR display and alarm generation system for presentation on the GSD and RDT displays.

The ability, of the stand-alone TDWR, to detect gust fronts and provide wind shift predictions was demonstrated, during the summer of 1988. The POD was 78% with a very low false alarm rate of 2%. The gust front and wind shift prediction algorithms proved to be very useful to the Air Traffic Controllers. As was demonstrated, during the tests, and indicated in the 1988 "Quick Look" report, a high probability of correctly predicting the location of a gust front, both at ten and twenty minutes into the future can be very useful in the ATC Tower and TRACON, by warning of potentially hazardous airport operations and by providing improved traffic planning information.

During the 1989 test and demonstrations, the detection of gust front windshear was observed to be significantly poorer then, the previous year, when a similar prototype TDWR was located at an alternate site. During the 1988 tests, the prototype Doppler radar was located southeast of the airport so that gust fronts approaching from the northwest were at right angles to the radar's radials. The current gust front algorithm performed poorly in detecting gust fronts which lie along the radar radials. This is the case with the TDWR (Mile High Radar) at its present location. This emphasizes the importance of siting for system performance optimization. During the post-season analysis, it was suggested that since optimum sites may not be available for the TDWR at some airports, an effort should be made to develop an improved gust front algorithm whose performance will be less sensitive to the radar viewing angle.

Near the end of the 1990 tests and demonstrations, the ATC Controllers and their Supervisors rated the gust front product as good. Overall, the warning/alert messages on the RDT were usable and the presentation on the GSD was of some value in planning for future runway changes. Under the present operational circumstances, this is considered adequate. When the gust front algorithm worked properly, the output product was very good but, at other times, the gust front presentation would flicker or break up, unexpectedly. This erratic performance shook the users' confidence. The behavior of the algorithm can be attributed to the difficulty of detecting weak windshear events and the choice of a less then favorable radar site, which exacerbated the problem because the algorithm detected only the radial convergence. The NCAR personnel and other meteorologists have suggested that the next major improvements in the gust front algorithm will depend on modifications, which will cause the algorithm to detect reflectivity "thin lines" and/or azimuthal windshear. These changes/improvements to the algorithm are <u>essential</u> for those airports where the locations of the TDWR sites are unfavorable with respect to the local gust front climatology.

An analysis of the 1990 tests and demonstrations of gust front detection and wind shift prediction products will be discussed in the 1990 NCAR Summary Report. Given the staple TDWR (Mile High Radar) Subsystem and the improved integration detection system, during the 1990 season, it is believed that the analysis will be accurate and meaningful.

INTEGRATED TDWR/LLWAS WARNING FUNCTION.

The Ribbon Display Terminals (RDT), proved to be operationally effective, alphanumeric readout devices. These terminals incorporated the LLWAS wind data for the runways thresholds and the airport's center field and displayed in a timely manner the microbursts and both positive and negative windshear alarms.

The display characteristics of the RDTs were somewhat limited; thereby, indicating the need for improved display techniques. See the earlier discussion on "Advising Pilots of Changes in the Intensity of Microburst/Wind Shear Alerts", in the "RESULTS" Section; under "TEST CHRONOLOGY AND COLLECTED DATA". The present RDTs are cathode ray tube type, terminals and will be replaced in the production TDWR and integrated TDWR/LLWAS systems with electroluminescent display panels. However, the proposed changes in the RDT's display presentation should be implemented in the production equipment.

INTEGRATED TDWR/LLWAS PLANNING FUNCTION.

The integrated TDWR/LLWAS, planning function made extensive use of the high resolution graphics of the Geographic Situation Displays (GSD). The Air Traffic Controllers were generally enthusiastic about the features of the GSDs, which were located near the ATC Tower Supervisor's and the TRACON Area Manager's positions. The Supervisors indicated that the greatest utility of the GSDs was in providing warnings for the wind shifts and/or other hazardous weather which could impact the airport's traffic patterns. These advanced warning permitted the Supervisors to plan, in an orderly manner, for smooth transitions in the airport's traffic flow and runways utilization.

In the interest of improved service use, the ATCS Supervisors requested that improvements be made to ease the process for selecting active runways on the GSD. See the earlier discussion on "Ease of Runway Selection on the GSD", in the "RESULTS" Section; under "TEST CHRONOLOGY AND COLLECTED DATA".

ADDITIONAL WEATHER PRODUCTS.

The Graphic Situation Displays (GSD) also displayed Storm Motion and Nowcast weather products. The Storm Motion algorithm provided for locating and tracking storm cell cores. The product provided current direction and speed of the storm's movement. The objective of the Nowcast products was to provide an automated prediction and display of impeding convection products.

In the opinions of the ATC Tower and TRACON Supervisors, the utility of the Storm Motion product was rated very good and the Nowcast product was rated only fairly good. The expected ratings for these two products was expected to vary depending on the specific traffic management duties at the ATC Tower/TRACON (short term) versus the longer term perspective of the Traffic Management Unit at the Air Route Traffic Control Center; with both groups the display of these products was considered desirable for planning purposes. In general, the users were very enthusiastic regarding the availability of these products which were sorely missed when not available.

Following the 1990 post-season interviews with all FAA users, NCAR personnel compiled a listing of suggested improvements to the Storm Motion and Nowcast products, which will be reported in the NCAR Summary Final Report.

SUMMARY OF RESULTS

MICROBURST DETECTION.

The NCAR Project Director has stated that, " The preliminary analysis of five cases (microburst and/or windshear-with-loss events), during the 1990 tests and demonstrations, has shown that the integrated TDWR/LLWAS weather product performed extremely well, generating a probability of detection (POD) in excess of 90 percent and a false alarm ratio (FAR) of less than five (5) percent in the region within five nautical miles of the airport."

GUST FRONT DETECTION AND WIND SHIFT PREDICTION.

During the 1990 tests and demonstrations, the ATC Controllers and their Supervisors rated the gust front product as good. However, occasionally, the gust front product was erratic, which degraded user confidence. Changes/improvements in the gust front algorithm are essential for those airports where the locations of the TDWR sites are unfavorable with respect to the local gust front climatology.

INTEGRATED TDWR/LLWAS WARNING FUNCTION.

The Ribbon Display Terminals (RDT), proved to be operationally effective, alphanumeric readout devices, but the display characteristics of the RDTs were somewhat limited. Modifications to the present terminal's hardware/software are not advised, because future RDTs will utilize electroluminescent display panels. However, for the production, RDT display terminals, a methodology should be devised and implemented to alert the Local Controllers when changes occur in the status of the alarm/alert messages.

INTEGRATED TDWR/LLWAS PLANNING FUNCTION.

The integrated TDWR/LLWAS, planning function made extensive use of the high resolution graphics of the Geographic Situation Displays (GSD). The Air Traffic Controllers were generally enthusiastic with the depiction of weather events on the GSDs. In the interest of improved service use, the ATCS Supervisors requested that improvements be made to ease the process for selecting active runways on the GSD terminal for display on the RDTs.

ADDITIONAL WEATHER PRODUCTS.

The Graphic Situation Displays (GSD) also displayed Storm Motion and Nowcast weather products. The Storm Motion algorithm provided for locating and tracking storm cell cores. The objective of the Nowcast products was to provide an automated prediction and display of impeding convection.

In the opinions of the ATC Tower and TRACON Supervisors, the utility of the Storm Motion and Nowcast products were rated very good and fairly good, respectively. In general, the users were very enthusiastic regarding the availability of these products which were sorely missed when not available. Following the 1990 post-season interviews with all FAA users, NCAR personnel compiled a listing of suggested improvements to the Storm Motion and Nowcast products, which will be reported in the NCAR Summary Final Report.

CONCLUSIONS

The prototype, integrated TDWR/LLWAS System's concepts and algorithms, as tested and to the extent that the criteria has been studied, were operationally satisfactory. Changes in the Gust Front, Storm Motion, and Nowcast weather products; the GSDs' software and the production RDTs' hardware/software are desirable for improved service use.

RECOMMENDATIONS

Continue the testing and verification of the integrated TDWR/LLWAS in the "dry" microburst/windshear environment of the Denver, CO: Stapleton International Airport, especially in the case of microburst, gust fronts etc.. The limited data samples, collected in CY 1989 and 1990, do not provide statistically, desirable confidence levels.

Using the integrated TDWR/LLWAS test bed continue to improve the detection and tracking of wind related phenomena in weak signal, tangential target, azimuthal windshear and similar problem areas; so as, to improve hazardous weather warnings, which could expedite the orderly management of air traffic and increase safety within the air traffic control terminal area.

As suggested in this report, implement the changes which are desirable for improved service use. The specific areas addressed were: the Gust Front, Storm Motion, and Nowcast weather products; the GSDs' software and the production RDTs' hardware/software.

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APPENDIX A. (TDTPAPS2.MHR)

SYSTEM DESCRIPTION

OF

THE MILE HIGH RADAR (MHR)

DENVER, COLORADO

APPENDIX A. (TDTPAPS2.MHR)

SYSTEM DESCRIPTION

Figure A1 shows a block diagram of the Mile High Radar (MHR) testbed. Originally, the MHR system was a prototype NEXRAD system which was built by the Raytheon Company and modified by the National Center for Atmospheric Research (NCAR). Table A-1 shows the MHR specifications.

ANTENNA/SUBSYSTEM

The antenna consisted of a 27 ft (8.2 m) parabolic reflector focus fed by a horizontally polarized S-Band feed horn. The antenna produced a 0.9 degree beam width with the first sidelobe less than -25 dB below the main beam gain. The antenna scanning rates were 25 degree/sec peak, azimuth velocity, and 15 degree/sec peak, elevation velocity. Table A-2 indicates the scanning strategy used by the MHR.

TRANSMITTER/RECEIVER

The Mile High Radar's operating frequency was 2.725 Ghz, with a peak power of 850 KW. The receiver employed an "instantaneous" automatic gain control (AGC) which yielded a dynamic range of 100 dB. The MHR provided for selection of five different Pulse Repetition Frequencies (PRFs), which ranged from 250 to 1250 Hz. The transmitter's instability residue was less than -55 dB. The nominal radar range was 230 km. A longer range scan of 460 km was also available with a 1.0 degree beam width. A pulse pair Doppler processing scheme was used. Data resolution was 225 m in velocity and reflectivity. Spectrum width was also available. Improvements to the MHR, instituted for 1990, included provisions for clutter residue reduction.

DATA ACQUISITION AND PROCESSING SYSTEM

The Signal Processor consisted of the following:

1. An AGC compensation system, which yielded a 100 dB instantaneous linear dynamic range.

2. Infinite Impulse Response filter banks to produce the clutter suppression required in the TDWR specification.

3. A time series buffer for pulse-to-pulse I and Q recording.

4. Data interfaces.

DISPLAYS

At the NCAR Operations Center, the local radar displays included a three monitor processor for the base products and the microburst subsystem's work stations. These displays showed the basic weather information, algorithm outputs and various logistics data; such as, aircraft beacon position, geographical overlays, etc. These displays were used in real time to:

1. Verify that the antenna was scanning correctly and the base data generation system was functioning properly;

2. Determine whether TDWR wind shear detection algorithm computations were being correctly carried out;

3. Support the real time entry of "truth" data for gust fronts by expert human meteorologists; and

4. Identify significant weather events for later analysis, off-line.

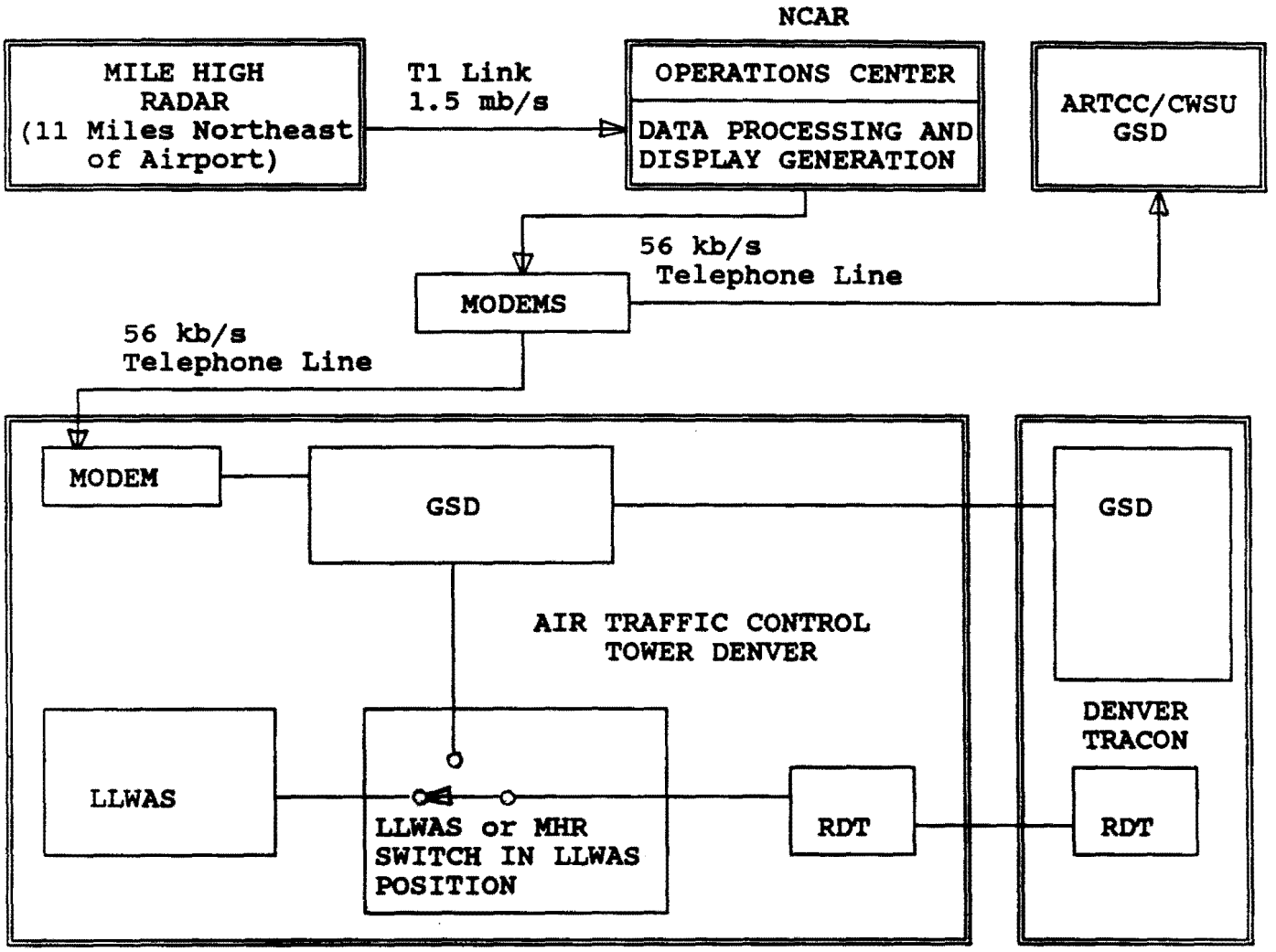


Figure A1. BLOCK DIAGRAM OF TDWR/LLWAS INTEGRATION TESTBED

Table A-1 MILE HIGH RADAR SPECIFICATIONS

Location:	
Latitude	39 52 42.5 N
Longitude	104 45 28.4 W
Height of Feedhorn (MSL)	1604.3 m (5262 ft)
Antenna:	
Gain	40.0 dB
Beamwidth	0.9 degree
First Sidelobe	-25.1 dB
Cross Polarization	-25.5 dB
Radome Loss	0.2 dB
Radome degradation	-52 dB
Waveguide Loss	1.0 dB
Transmitter:	
Peak Power (Narrow pulse Max. PRF)	840 kW
Variation between Wide and Narrow	.1 dB
Variation between PRF Changes	.12 dB
Stability	-55 dB
RF Spectrum	< 50 dB/decade
Receiver:	
Noise Figure	2.9 dB
Dynamic Range	101 dB
AGC Accuracy	+/- .25 dB
Image Rejection	65 dB
S-band Oscillator Noise	-69 dB
I and Q Phase Error	.09 degree
I and Q Amplifier Error	.14 dB
IF Filter at 3 dB Bandwidth	550 kHz
RF Frequency Tolerance	16 PPM
Test Signal Phase Shifter Accuracy	+/- 1 degree

Table A-2 MHR Scan Strategy

Scan Number	Elevation Angle (degree)	Scan Use	Time From Last Low-Level Tilt (sec)
1	0.5	Long Range	---
2	0.5	Airport/Gust Front (FAA)	49
3	1.2	Long Range	---
4	1.2	Gust Front (FAA)	---
5	0.5	Airport (FAA)	65
6	2.5	Metro (NWS)	---
7	2.5	Long Range	---
8	4.0	Precip.(FAA)	---
9	0.5	Airport (FAA)	65
10	5.5	Metro (NWS)	---
11	7.0	Metro (NWS)	---
12	8.5	Metro (NWS)	---
13	0.5	Airport (FAA)	65
14	1.2	Metro (NWS)	---
15	10.0	Metro (NWS)	---
16	0.5	Airport (FAA)	65
17	13.0	Metro (NWS)	---
18	17.0	Metro (NWS)	---
19	0.5	Airport (FAA)	49
20	22.0	Metro (NWS)	---

APPENDIX B. (TDTPAPS1.MHR)

SYSTEM DESCRIPTION

OF

THE STAPLETON INTERNATIONAL AIRPORT'S

NETWORK EXPANSION LLWAS

SYSTEM DESCRIPTION

The Network Expansion LLWAS is a real-time, computer controlled, electro-mechanical data acquisition, analysis and display system, designed for installation at major airports. Its primary function is to serve as a detection and warning device for alerting Air Traffic Controllers and pilots of the presence of thunderstorm induced wind shears in the vicinity of airport runways. The Network Expansion LLWAS system with runway extensions, is a commissioned system at Denver Stapleton, International Airport. It was operated with 12 sensors from its commissioning in early 1988 until June 1989.

The 12-station LLWAS has been expanded to a 16-station system by the addition of two stations off the east end of runways 26L/26R and two stations to the north end of runways 17L/17R. Two of the existing stations have been moved to improve overall geometry. All sensors that required elevation to conform to the LLWAS siting criteria have been raised on high mast towers. With the additional stations, the polling cycle was lengthened from seven seconds to approximately 10 seconds. The LLWAS data processing and alarm generation remain unchanged except that the new station geometry was incorporated.

The system products are microburst and wind shear alerts, centerfield winds/gusts and runways thresholds arrival/departure winds. This system is effective for the detection of wind shears and the identification of microbursts that occur within the network.

LLWAS REMOTE SENSOR STATIONS

At the remote sensor stations, each of the anemometers continuously generates three analog signals. Two of the analog signals represent the vector components needed by the LLWAS system to compute wind direction and speed. The third signal is a tachometer wind speed which is used only at the "centerfield" remote station, for wind gust. The remote stations convert the signals from analog to digital, arrange the data in a specific message format and, when interrogated by the Master Control Unit, transmit their messages.

The locations of the Network Expansion LLWAS sensors in Denver Stapleton Airport are shown in Figure B1., and their latitude and longitude locations are shown in Table B-1. The relationships between the sensors and the wind values assigned to the runway's threshold are shown in Table B-2.

MASTER CONTROL UNIT

The Master Control Unite is the nerve center of the Network Expansion LLWAS. It controls the timing of all transmissions. Approximately once every ten seconds, the PDP-11/73 computer of the Master Control Unit polls each remote station and stores the data in memory. Additionally, the PDP-11/73 carries out the final formatting of the wind data for the displays, performs system checks and stores data to the hard disk drive.

DISPLAYS

Each of the two Local Controller displays provide the Controllers with continuously updated data as to the "centerfield" wind direction, wind speed, wind gust and the occurrences of wind shear alarms. The maintenance terminal display enables status monitoring of the system program and diagnostics.

ALGORITHMS

The algorithm currently used with the Network Expansion LLWAS for detecting wind shear is known as Wind Shear Microburst Detection algorithm. This algorithm has the dual capability for detecting wind shear; as well as, confirming the event as a microburst. In addition, the runway oriented "loss" algorithm and a runway oriented "gain" algorithm compute wind speed loss along each affected runway, during wind shear events.

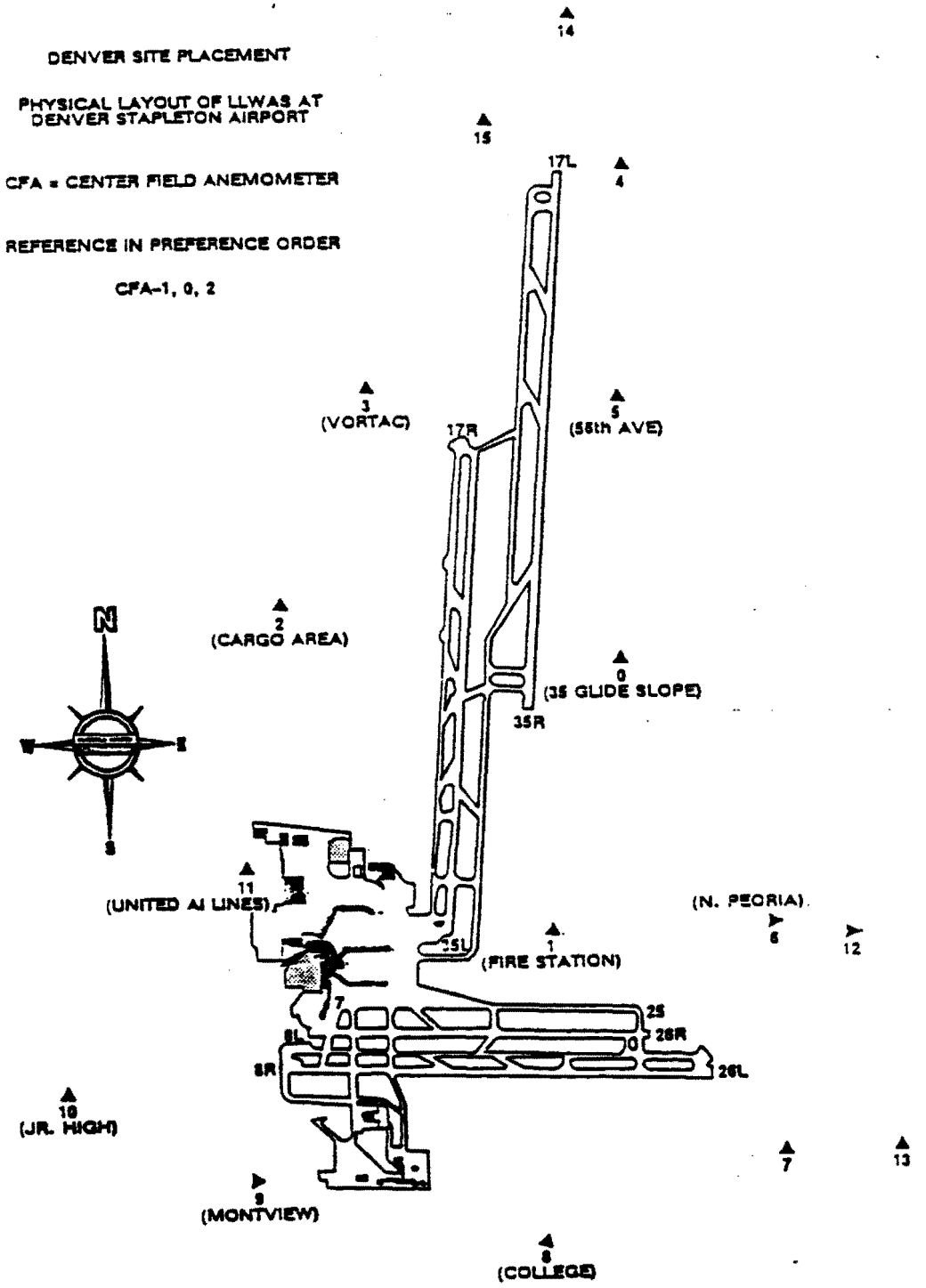


Figure B1. NETWORK EXPANSION LLWAS REMOTE STATION SITES AT STAPLETON INTERNATIONAL AIRPORT

TABLE B-1. PHYSICAL LOCATION OF NETWORK EXPANSION LLWAS (LATITUDE (N) AND LONGITUDE (W))

Sensor	Latitude	Longitude
0	39 46 55	104 51 58
1	39 45 51	104 52 21
2	39 47 06	104 53 29
3	39 47 56	104 53 21
4	39 49 21	104 51 32
5	39 47 56	104 52 02
6	39 46 03	104 50 54
7	39 44 55	104 50 41
8	39 44 33	104 52 22
9	39 44 53	104 53 52
10	39 45 25	104 55 08
11	39 46 05	104 53 54
12	39 45 47	104 49 14
13	39 44 55	104 48 57
14	39 50 32	104 51 52
15	39 49 18	104 53 01

TABLE B-2. RELATIONSHIP BETWEEN SENSORS AND RUNWAYS

LLWAS Sensors *	Runway Operations **
(0, 1, 2)	35RA
(5, 4, 15)	35RD
(5, 4, 15)	17LA
(0, 1, 2)	17LD
(1, 11, 0)	35LA
(3, 5, 2)	35LD
(3, 5, 2)	17RA
(1, 11, 0)	17RD
(9, 11, 10)	8A
(7, 6, 1)	8D
(7, 6, 1)	26A
(9, 11, 10)	26D
(9, 11, 10)	8A
(7, 6, 1)	8D
(7, 6, 1)	26A
(9, 11, 10)	26D

** R = Right
L = Left
A = Arrival
D = Departure

* The sensor locations are listed (left to right), in the same order of preference (priority), as was selected for the display of the indicated runway's threshold wind (intensity and direction).

APPENDIX C. (QDATAFNL.MHR)

ATC QUESTIONNAIRES

1990 FINAL TEST COMMENTS

ACN-240

HUMAN FACTORS EVALUATION

The ATCS personnel rated various aspects of the integrated TDWR/LLWAS system's displays (GSD and RTD) and also the training received on the system. Their numerical responses with data analysis (Mean and Stand. Deviation) are shown in Tables 1. and 2.

TABLE 1. RATINGS: ASPECTS OF THE INTEGRATED TDWR/LLWAS SYSTEM DISPLAYS (GSD & RDT (LLWAS) AND TRAINING

QDATADEN.FNL
1990 INTEGRATED TDWR/LLWAS (DENVER, CO) SCORE RATING
ATCS QUESTIONNAIRES DATA
RAW SCORES & ANALYSIS -3 -2 -1 0 1 2 3 ?

EXPLANATION:
-3 = VERY POOR | +3 = VERY GOOD
-2 = POOR | +2 = GOOD
-1 = FAIRLY POOR | +1 = FAIRLY GOOD
0 = FAIR | ? = DON'T KNOW

QUESTIONS: (Displays and Training)	RESPONDENTS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MEAN	STDEV
1. Readability of Display:																										
GSD	3	3	2	3	3	3	2	3	1	3	3	3	3	2	3	3		?	?	?	?	?	?	?	3	0.602
RDT (LLWAS)	3	3	1	2	3	1	?	3	2	3	3	3	3	3	3	2		?	?	?	?	?	?	?	3	0.743
2. Adequacy of Display Size:																										
GSD	3	2	1	2	3	3	2	3	1	3	3	3	3	1	2	3		?	?	?	?	?	?	?	2	0.806
RDT (LLWAS)	3	2	3	2	3	1	?	3	2	3	3	3	3	-2	3	3		?	?	?	?	?	?	?	2	1.345
3. Audibility of Alarm Beeper:																										
GSD	2	2	2	2	3	?	?	3	2	3	1	3	3	2	?	3		?	?	?	?	?	?	?	2	0.65
RDT (LLWAS)	2	2	2	2	3	0	?	3	2	3	1	3	3	?	0	3		?	?	?	?	?	?	?	2	1.072
4. Completeness of Displayed Info.:																										
GSD	3	3	2	3	3	3	3	3	2	3	1	2	3	1	2	3		?	?	?	?	?	?	?	3	0.73
RDT (LLWAS)	3	3	2	2	3	1	?	3	2	3	2	2	3	1	2	3		?	?	?	?	?	?	?	2	0.724
5. Accuracy of Displayed Info.:																										
GSD	3	3	2	3	3	3	3	3	2	3	2	2	3	2	3	3		?	?	?	?	?	?	?	3	0.479
RDT (LLWAS)	3	3	2	3	3	-1	?	3	2	3	2	1	3	-2	-1	3		?	?	?	?	?	?	?	2	1.74
6. Rate of False Alarms:																										
GSD	3	3	3	3	3	?	3	2	2	3	1	3	3	?	3	3		?	?	?	?	?	?	?	3	0.611
RDT (LLWAS)	3	1	3	2	3	?	?	2	2	3	2	1	3	-3	-1	3		?	?	?	?	?	?	?	2	1.773
7. Usefulness of Displayed Info.:																										
GSD	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	2		?	?	?	?	?	?	?	3	0.342
RDT (LLWAS)	3	3	3	3	3	1	?	3	3	3	3	3	3	-2	2	2		?	?	?	?	?	?	?	2	1.352
8. Freedom from Misinterpretation:																										
GSD	3	3	3	2	3	3	2	3	1	3	3	2	3	?	2	2		?	?	?	?	?	?	?	3	0.64
RDT (LLWAS)	3	3	3	2	3	2	?	3	1	3	3	3	3	-1	2	2		?	?	?	?	?	?	?	2	1.113
9. Suitability for Continued Field Use:																										
GSD	3	3	3	3	3	3	3	3	2	3	3	3	3	?	3	3		?	?	?	?	?	?	?	3	0.258
RDT (LLWAS)	3	3	3	3	3	1	?	3	2	3	3	3	3	0	3	3		?	?	?	?	?	?	?	3	0.91
10. Integrated TDWR/LLWAS Training:																										
GSD/RDT (LLWAS)	1	3	2	2	1	2	2	3	2	1	3	3	3	-3	3	2		?	?	?	?	?	?	?	2	1.5

TABLE 2. RATING : VARIOUS WEATHER PRODUCTS ON THE GSD TERMINALS

QDATADEN.FNL
1990 INTEGRATED TDWR/LLWAS (DENVER, CO)
ATCS QUESTIONNAIRES DATA
RAW SCORES & ANALYSIS

SCORE RATING: -3 -2 -1 0 1 2 3 ?

EXPLANATION:
-3 = VERY POOR ; +3 = VERY GOOD
-2 = POOR ; +2 = GOOD
-1 = FAIRLY POOR ; +1 = FAIRLY GOOD
0 = FAIR ; ? = DON'T KNOW

RATE USEFULNESS OF GSD FEATURES:	RESPONDENTS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	MEAN	STDEV
1. Gust Front Presentation:			
GSD	2 3 -1 2 3 2 2 3 2 3 2 3 3 ? 3 3 ? ? ? ? ? ? ? ?	2	1.047
2. Storm Motion Product:			
GSD	3 3 2 3 2 3 3 3 2 3 3 3 3 2 2 3 ? ? ? ? ? ? ? ?	3	0.479
3. Nowcast Presentation:			
GSD	2 3 2 1 1 0 2 3 2 ? ? ? 1 1 -2 3 ? ? ? ? ? ? ? ?	1	1.391
4. Ability to Select & Display Active Runways on RDTs:			
GSD	? ? ? ? -1 2 ? ? ? 3 3 ? 1 ? -1 3 ? ? ? ? ? ? ? ?	1	1.813

The ATCS personnel's written comments and responses to questions are listed below. Their remarks are grouped with the associated question or request for comment. Each remark contains a notation indicating the Air Traffic Controller's position and function in the ATC Tower or TRACON.

A. REQUEST: Please comment on the TDWR/LLWAS training received.

1. TOWER SUPERVISOR: No training was received this year. All knowledge was held over from the previous summer.

2. TRACON SUPERVISOR: I, among others, was thoroughly briefed by NCAR personnel on the TDWR/LLWAS operation. In addition, the questions I asked, during the test period, were answered promptly.

3. TRACON SUPERVISOR: Training is useful; however, training received was too brief and not thorough enough.

4. TOWER SUPERVISOR: Good! May need more training for Gust Front interpretation.

5. TOWER CONTROLLER: Phraseology for windshear and microburst situations need to be standardized, better.

6. TOWER SUPERVISOR: OK!

7. TRACON SUPERVISOR: Good training and previous experience made this relatively easy.

8. TOWER CONTROLLER: I thought the training could have been more extensive, especially for the newer people and the ones that have days off during the week who could not take advantage of the training that was available other than the 45 minute briefing.

9. TRACON SUPERVISOR: Well prepared and presented to anyone willing to receive same.

10. TOWER SUPERVISOR: Adequate for our use.

11. TOWER CONTROLLER: None to very little, not actually given any time to use, mainly a supervisors' function, not given any time to learn.

12. TOWER CONTROLLER: The training from NCAR was complete and thorough. The training from the FAA needed to stress how to read and interpret the wind display and needed to cover proper phraseology.

B. QUESTION 1.: Any comments on the role of the GSD in Air Traffic Planning and Management?

1. TOWER SUPERVISOR: Very helpful in determining runway changes in a timely manner

2. TRACON SUPERVISOR: As a TRACON Supervisor, I consider the GSD information as an invaluable tool for use in making real time traffic management decisions. I personally made extensive use of the information presented in planning runway changes, setting arrival rates, and in configuration decisions. The ability to see "red" weather enables us to assist pilots in avoiding these areas. In contrast, the weather information available on the ASR-8 is largely unusable, as all levels of precipitation show up the same on radar. The TDWR's GSD clearly gives us the advantage in this area.

3. TOWER SUPERVISOR: Gust Front did not appear as useful as in the past, Nowcast was the same, but Storm Track was useful.

4. TOWER CONTROLLER: Too many steps to select different runway configurations for RDT. Try to simplify it; otherwise, it is good.

5. TOWER SUPERVISOR: Need it all day - everyday !!

6. TRACON SUPERVISOR: Excellent tool, allows for traffic management for prevention of overload and selection.

7. TRACON SUPERVISOR: Most excellent - please drop a few more off. Thanks.

8. TOWER CONTROLLER: Did not know enough about the Nowcast feature.

9. TOWER SUPERVISOR: It will be very helpful to have ability to select active runways when installed permanently.

10. TRACON SUPERVISOR: As an area manager, I found the GSD to be very helpful, during the most difficult weather situations. We planned many runway changes based on the information presented on the GSD.

11. TOWER SUPERVISOR: Gust Front movement was help in runway changes. Storm Motion is a good feature - probably more so for the TRACON.

12. TOWER CONTROLLER: Not knowledgeable enough to rate.

C. QUESTION 2.: Do you see the TDWR/LLWAS as a help or hindrance to you in your job of controlling local traffic?

1. TOWER SUPERVISOR: A great help.

2. TRACON SUPERVISOR: A great help. I was on duty, July 8, 1989 when a record 95 knot microburst occurred. Without TDWR/LLWAS there was no way of knowing this.

3. TRACON SUPERVISOR: A great help.

4. TOWER SUPERVISOR: A help.

5. TOWER CONTROLLER: A great help and a slight hindrance.

6. TOWER SUPERVISOR: A great help.

7. TRACON SUPERVISOR: A great help. Have become spoiled and miss it when it is not available.

8. TRACON SUPERVISOR: A great help.

9. TOWER CONTROLLER: A help.

10. TOWER CONTROLLER: A great help.

11. Tower Supervisor: A great help.

12. TRACON SUPERVISOR: Neither help or hindrance. TDWR (GSD) info. not available to local controllers. (This is a bad question)

13. TOWER SUPERVISOR: A great help.

14. TOWER CONTROLLER: A great help.

D. QUESTION 3.: What's good about the TDWR/LLWAS ? What benefits do you see ?

1. TOWER SUPERVISOR: Predictability of when to expect gust fronts etc. More timely runway changes, better able to alert pilots as to changes.

2. TRACON SUPERVISOR: TDWR/LLWAS has clearly established the potential for aircraft to avoid microburst areas. I see the system as having great benefit.

3. TRACON SUPERVISOR: System overall is excellent.

4. TOWER SUPERVISOR: Tool to use for projection of weather and TFC management. Farther from our area we can see a WX trend better we are. Microburst accurate.

5. TOWER CONTROLLER: Can anticipate storm/wind situations better.

6. TOWER SUPERVISOR: Excellent picture of what is happening and what is going to happen.

7. TRACON SUPERVISOR: Planning traffic flow, runway selection, route selection, metering, all around excellent equipment for air traffic.

8. TRACON SUPERVISOR: Traffic management and, of course, safety.

9. TOWER CONTROLLER: Be able to see and predict the potential impact of thunderstorms.

10. TOWER SUPERVISOR: Traffic management in reference weather impact and movement, runway changes, gate hold, etc.

11. TRACON SUPERVISOR: Enhances safety due to reliable data on windshear and microburst activity. Provides valuable info for configuration planning.

12. TOWER SUPERVISOR: The TDWR/LLWAS has enabled us to advise pilots of phenomena (MB & WS) that otherwise were not detected - an obvious save of potential accidents. It has also been a tremendous help in planning the landing and departing configurations, especially in regard to a gust front movement that we would not ordinarily know about in advance.

13. TOWER CONTROLLER: From my limited knowledge, seems to help predict runway changes.

E. QUESTION 4.: What's poor about the TDWR/LLWAS ? What problems do you see ? Please list any changes you feel should be made to the TDWR/LLWAS System.

1. TRACON SUPERVISOR: Perhaps as we continue to use the system we will see the need for further refinements. At this point however, I have seen it work on many occasions, and pilots are beginning to accept the information derived from it. Let's don't kill it - let's just install it permanently. A second Doppler site would be a welcome addition to the system, especially in the area of detection of gust fronts.

2. TRACON SUPERVISOR: Gust front presentation is one of the most valuable features, but its presentation on the GSD is inadequate.

3. TOWER SUPERVISOR: Gust front hasn't been good since we had two radar sites. Nowcast is less useful than Storm Trac.

4. TOWER CONTROLLER: I wonder if pilots can consume all the information we give. It's too much at times, I think.

5. TOWER SUPERVISOR: None.

6. TRACON SUPERVISOR: Need more displays, would like to have TDWR available year round and 24 hrs a day.

7. TRACON SUPERVISOR: N/A

8. TOWER CONTROLLER: The System is excellent, but it can be a hindrance. When a controller is obligated to read, and sometimes repeat, all this information, there must be some other task that is being neglected. Perhaps the next logical step is to integrate these computers with the pilots and let them get the info first hand.

9. TOWER CONTROLLER: I thought having the NCAR personnel in the Tower like we had last year would have been more beneficial, so they would be on hand with questions.

10. TOWER SUPERVISOR: Any small problems that we've experienced can be corrected by a software change.

11. TRACON SUPERVISOR: We want it full time with latest (not 1988) software program. A dual antenna site would provide better data.

12. TOWER SUPERVISOR: What is poor about the TDWR is that it is not ours. We should have this equipment on a permanent basis.

13. TOWER CONTROLLER: Not accurate in what is actually happening a large percentage of the time.