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FAA Technical Center
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Evaluation of Enhancements to the Low Level Wind Shear Alert System (LLWAS) at Stapleton International Airport

John D. Barab
Richard D. Page
Bruce L. Rosenberg
Thomas E. Zurinskas
Glenn R. Smythe (Data Transformation Corp.)

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16. Abstract

An operational test and evaluation of enhancements to the 11-station Low Level Wind Shear Alert System (LLWAS) at Stapleton International Airport, Denver, Colorado, was conducted during the period August 3 to September 4, 1988. Enhancements included a 12th remote station for gathering wind data, a more sophisticated wind shear microburst detection (WSMD) algorithm, a Digital Equipment Corporation (DEC) PDP 11-73 computer, a DEC VT-240 Cathode Ray Tube (CRT) Display, and an LLWAS message display format, the latter two for local controller use in the air traffic control (ATC) tower cab.

Two sets of objectives were associated with this LLWAS evaluation: meterological objectives, which stressed determining the effectiveness of the WSMD algorithm in establishing the presence of hazardous wind shears on or near the airport and reducing the false alarm rate; and human factors objectives, which were concerned with evaluating the usefulness and effectiveness of the CRT display, the display message, and the local controller's message to pilots.

Weather data gathering equipment employed at the test bed at Stapleton International Airport included, in addition to the LLWAS itself, two Doppler weather radars and a network of automatic weather stations. During the operational evaluation, both Federal Aviation Administration (FAA) and contractor support meteorologists participated as ATC tower and radar site meteorologists. Questionnaire forms, developed by engineering research psychologists, were used to obtain responses from ATC tower local controller evaluation subjects relative to the human factors objectives.

This report discusses the methodology and dual scientific analyses carried out, and provides detailed results with conclusions and recommendations. Based on the conclusions, it was recommended that the WSMD algorithm remain as an operational constituent of the Denver LLWAS and that human factors considerations be further explored in improving the controller LLWAS interface.

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EXECUTIVE SUMMARY

The Low Level Wind Shear Alert System (LLWAS) Program was initiated by the Federal Aviation Administration (FAA) in 1976 for purpose of detecting hazardous changes in wind speed and direction (i.e., wind shears) occurring in the vicinity of an airport. The standard LLWAS is designed to detect the most common wind shears such as cold fronts, sea breeze fronts, and thunderstorm gust fronts. Wind shears are measured by a network of wind sensors at designated locations about the airport runways.

In the early 1980's, scientific studies confirmed the existence of small-scale meteorological phenomena called microbursts and the fact that they can pose a hazard to pilots. Moreover, indications were that some microbursts, very small in diameter, could go undetected by the typical 6-station (sensor) LLWAS configuration. These concerns prompted the FAA to undertake studies of denser LLWAS sensor configuration, initially at New Orleans in 1984 and, thereafter, at Denver.

As of June 1, 1987, 92 major airports in the United States operationally employed LLWAS for wind shear detection. Ninety of these systems were 6-station configurations while two were operating as 11-station configurations: one at Moisant Field, New Orleans, Louisiana, and the other at Stapleton International Airport, Denver, Colorado.

This final report concerns the operational test and evaluation of enhancements to the 11-station LLWAS at Stapleton International Airport, Denver, Colorado, conducted during the period of August 3 to September 4, 1987. Enhancements included the addition of a 12th remote station for gathering wind data, and a more complex wind shear microburst detection (WSMD) algorithm in place of the centerfield average (CFA) algorithm commonly in use. The WSMD algorithm affords the potential of having dual capability for detecting wind shear and identifying the event as a microburst (the CFA algorithm lacks this latter capability). Another enhancement relates to replacing the current master station employing a Digital Equipment Corporation (DEC) PDP 11-23 computer and using, instead, a new master station which contains a DEC PDP 11-73 computer. The new master station affords more memory for storage and operation of programs and has the capability to perform calculations of greater complexity. Two additional enhancements include a DEC VT-240 cathode ray tube (CRT) display and a message display format of LLWAS information, both for local controller use in the air traffic control (ATC) tower cab.

There were two sets of objectives associated with the evaluation: Meteorological and Human Factors. Specifically, these stressed the following issues:

1. Meteorological. Determine the effectiveness of a wind shear and microburst detection algorithm in (a) establishing the presence of hazardous wind shears on or near the airport; and (b) reducing the false alarm rate.

2. Human Factors. Evaluate the usefulness and effectiveness of (a) a CRT display for use by local air traffic controllers; (b) the display message format; and (c) the controller's message to pilots.

The test bed for the evaluation was established at Stapleton International Airport in 1985 as part of a continuing program to study low altitude wind shear events. This was expanded to include weather data gathering equipment of the Massachusetts Institute of Technology (MIT) Lincoln Laboratory and the National Center for Atmospheric Research (NCAR). Data for the field evaluation for the enhancement LLWAS were acquired from four source facilities. In addition to the LLWAS itself, source facilities included two Doppler weather radars and a network of automatic weather stations.

FAA and contractor support meteorologists participated in the capacity of ATC tower meteorologists and radar site meteorologists during the operational evaluation period. As ATC tower meteorologists, they were to monitor controller-pilot communications, observe weather conditions on the airport, and monitor LLWAS displays. Also, these meteorologists were to record information pertinent to LLWAS wind shear and microburst alarms on a worksheet. As radar site meteorologists, they were to observe and log all shear events within 5 miles of the Stapleton International Airport. For each wind shear or microburst event detected by the LLWAS, the radar, or both the LLWAS and radar, the meteorologists were to enter information pertinent to the event on a radar event log.

Determination of the effectiveness of the WSMD algorithm was accomplished through the verification of wind shear and microburst alarms. Alarms were verified through comparison with detections by the test bed Doppler radars and the automatic weather sensors as well as observations by the meteorologists. Evaluation of the usefulness and effectiveness of a CRT display, the display message format and the controller's message to pilots was accomplished through analysis of human factor questionnaire forms completed by Stapleton International Airport ATC tower local controller evaluation subjects.

An interim report concerning the Denver evaluation was submitted to the FAA Washington LLWAS Program Office on October 15, 1987. The intent was to furnish summary "quick look" type information that would afford interim conclusions and recommendations as a basis for inputs to the Deployment Readiness Review (DRR) process.

Based on the analysis of meteorological findings and results, it was concluded in the final report that the WSMD algorithm, as compared to the CFA algorithm, that: (1) was more effective in detecting hazardous wind shears and microbursts on the airport; and (2) had a lower false alarm rate. It was recommended, therefore, that the WSMD algorithm remain as an operational constituent of the Denver LLWAS. In addition, it was recommended that the FAA investigate the topics of: (1) ways to resolve certain sensor problems to improve the performance of the Denver LLWAS; and (2) increasing the number of Denver LLWAS sensors to provide better coverage of the runways.

Based on the analysis of human factors findings and results, it was concluded in the final report that the enhanced LLWAS provides accurate, flight-relevant information on low level wind shear and microbursts in a runway-oriented format that is readable by the local controller and understandable by the pilot. Some individual aspects of the system could be improved and these can be accomplished within current state-of-the-art engineering capabilities. It was recommended that the enhanced LLWAS at Stapleton International Airport be used while improving the human factors of the controller/LLWAS interface.

INTRODUCTION

PURPOSE.

The purpose of this report is to provide an in-depth account of the planning, operational conduct, and associated analyses relevant to the test and evaluation of enhancements to the Low Level Wind Shear Alert System (LLWAS) at Stapleton International Airport, Denver, Colorado. The report discusses the technical approach, explains the analytical methods employed, and furnishes summary type information as to related findings, test results, conclusions, and recommendations.

BACKGROUND.

The LLWAS is a real-time, computer controlled, electromechanical data acquisition, analysis, and display system installed at major airports. Its primary function is to serve as a detection and warning device for alerting controllers and pilots of the presence of thunderstorm induced wind shears in the vicinity of airport runways.

As of June 1, 1987, 92 major airports in the United States operationally employed LLWAS for wind shear detection. Ninety of these systems were 6-station configurations while two were operating as 11-station configurations, one located at Moisant Field, New Orleans, Louisiana, and the other at Stapleton International Airport, Denver, Colorado.

The 6-station and 11-station versions of the LLWAS gather wind speed and wind direction data from various geographic areas of the airport. Each LLWAS compares the wind speed and direction of each wind collecting boundary remote station to the 2-minute average of a centerfield remote station. The boundary remote stations are strategically placed in proximity to approach and takeoff areas of the various runways while the centerfield remote station is located in the middle of the airport. Additional details concerning the 11-station operational system at Denver Stapleton appear in appendix A.

A comprehensive test plan, concerning the test and evaluation of the enhanced Denver Stapleton LLWAS, was prepared by the LLWAS Program staff at the Federal Aviation Administration (FAA) Technical Center and approved by the FAA LLWAS Program Manager in July 1987. The data collection phase at Denver was approximately 5 weeks in duration, beginning August 3 and concluding September 4, 1987. An interim report containing preliminary findings, results, conclusions, and recommendations pertaining to the Stapleton LLWAS enhancements was submitted to the FAA Washington, D.C., LLWAS Program Office on October 15, 1987.

OBJECTIVES.

The eight basic objectives of the test and evaluation of enhancements to the Denver Stapleton LLWAS were as follows:

1. Determine the effectiveness of a wind shear detection algorithm in establishing the presence of hazardous wind shears near the airport.

2. Determine the effectiveness of a wind shear detection algorithm in reducing the false alarm rate.

3. Determine the effectiveness of a microburst detection algorithm in detecting the presence of hazardous microbursts near the airport.

4. Determine the false alarm rate associated with the microburst detection algorithm.

5. Determine the effectiveness of runway component algorithms in estimating the shear along the runway during hazardous shear events near the airport.

6. Evaluate the usefulness and effectiveness of the display message format and the air traffic controller's message to pilots.

7. Obtain reactions of local air traffic controllers to cathode ray tube (CRT) displays. Results will be used as inputs to human factors studies as well as follow-on display design.

8. Prepare and submit an interim report by October 15, 1987, containing conclusions and recommendations for consideration by the Deployment Readiness Review Committee.

The requirement for an interim report (i.e., objective 8) was satisfied through its submittal by the FAA Technical Center LLWAS Program Manager to the Washington, D.C., Program Office by the specified October 15th date. Additionally, analyses bearing on objective 5 were not addressed in the interim report due to the unavailability of sufficient data at that time.

For the interim report, the remaining six objectives were categorized in terms of those that addressed the meteorological and those that addressed the human factors aspects of the evaluation. A similar practice will be followed in this report to preserve coherency and consistency in the method of reporting. Objective 5 is included as a part of the meteorological objectives category in this final report.

OBJECTIVES RESTATED BY CATEGORY.

Meteorological. Determine the effectiveness of a wind shear and microburst detection algorithm in: (1) establishing the presence of hazardous wind shears on or near the airport; and (2) reducing the false alarm rate.

Also, determine the effectiveness of runway component algorithms in estimating the shear along the runway during hazardous shear events near the airport.

Human Factors. Evaluate the usefulness and effectiveness of: (1) a CRT display for use by local air traffic controllers; (2) the display message format; and (3) the controller's message to pilots.

SYSTEM ENHANCEMENTS.

System enhancements implemented for the Denver LLWAS test and evaluation were:

1. An additional (12th) LLWAS remote station for gathering wind data.

2. A master station consisting of a DEC PDP-11/73 computer with 1 megabyte (MB) of RAM, a Winchester RD53 71MB hard disk drive, a TK50 cartridge tape drive (95MB capacity per reel), and a real time clock. The new master station was needed because of the greater complexity in the calculations to be performed and the need for more memory to store and operate the program.

3. Two commercial quality, etched, unbonded office type CRT's were used as local controller displays. Temporary modifications to the displays allowed the operator to adjust contrast and brightness. Designated as VT-240's, these DEC displays were designed to interface with DEC equipment, and also were considered to be advantageous in that a change in the display format could be made through software if needed. (FAA standard practice is to require bonded safety panels on CRT's used by operational personnel, but for expediency, the essentially unmodified VT-240 displays were utilized.)

4. A more complex wind shear microburst detection (WSMD) algorithm as a replacement for the more recently used centerfield average (CFA) algorithm. The WSMD algorithm afforded dual capability for detecting wind shear and confirming the event as a microburst. (The CFA algorithm lacked the ability to distinguish between types of wind shear, e.g., it cannot identify a microburst.) The two other special purpose algorithms are a runway oriented loss (ROL) algorithm and a runway oriented gain/loss (ROG/L) algorithm. The purpose of the ROL algorithm is to furnish data as to wind speed loss along each affected runway during microburst events. The purpose of the ROG/L algorithm is to provide information relative to wind speed gain along a runway when there is a wind shear alarm but no microburst alarm associated with the runway.

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4. Rosenberg, B. and Zurinskas, T., "Rationale and Rules-of-Thumb for Questionnaire-Based System Evaluation Studies," published in the 31st Annual Air Traffic Control Association Fall Conference Proceedings, 1986.

5. Wilson, F. W. and Flueck, J. A., A Study of the Methodology of Low-Altitude Wind Shear Detection with Special Emphasis on the LLWAS Concept, Federal Aviation Administration, Final Report, DOT/FAA/PM-86/4, February 1986.

DISCUSSION

This section furnishes descriptive information concerning the characteristics and functional features of the WSMD algorithm. It also contains pertinent highlights concerning the systems and equipment comprising the Denver, Colorado, test bed that were employed for the acquisition and collection of field test data in evaluating the enhancements to the Stapleton Airport LLWAS.

WSMD ALGORITHM.

The WSMD algorithm consists of four procedures which are executed for each polling cycle: (1) temporal shear (TS), (2) network mean (NM), (3) divergence detection (DD), and (4) alarm association (AA). The TS procedure monitors temporal changes in wind measurement at each individual station and affects the issuance of an alarm as follows. If there is slight temporal shear, then the threshold is increased, making the issuance of an alarm more difficult. If there is moderate temporal shear, the threshold is not changed. If there is significant increase in temporal shear, then the threshold is decreased, facilitating the issuance of an alarm. The TS procedure is applied with the NM and DD procedures.

In the NM procedure, the vector differences (tempered by variance in the wind) between the spatial average of the sensor wind measurements and the measurements at each individual station are computed. These tempered vector differences are compared with a threshold using a chi-square test. The effective threshold for this test is at least 14.2 knots. If the threshold is exceeded at a station, then there is an "anomaly" at that station.

In the DD procedure, two methods of detection are employed: the triangle and line methods. The triangle method is designed to detect the flow of air out of an area bounded by a triangle, whereas, the line method detects divergence along a straight line between two measurement points. The Denver LLWAS triangles are of different sizes and shapes, overlap, and share edges. Divergence is computed for each triangle and each edge (line) of the triangle. A threshold is different for each triangle due to its physical shape and size and for each edge because of its length.

Sixty-nine triangles and 51 edges were chosen for implementation of the divergence detection procedure for the Denver LLWAS configuration. Seventeen of the 69 triangles having vertices at the 12 Denver LLWAS stations are illustrated in figure 1. Each triangle, edge, and station is associated with a runway, or with a distance of 1, 2, or 3 miles from the departure or arrival ends of the runway. These positions are used in locating detected hazardous wind shears.

The logic of the AA procedure which is executed once for each runway is shown in figure 2. Initially, a check is made of the results of the DD procedure to determine if any of the runway elements have triangle or edge divergence threshold crossings. If so, then the runway oriented losses are computed for each element using the microburst model for computing loss. If one or more of the runway elements have associated losses equal to or in excess of 25 knots, a microburst loss alarm is issued for the element with the greatest loss. If

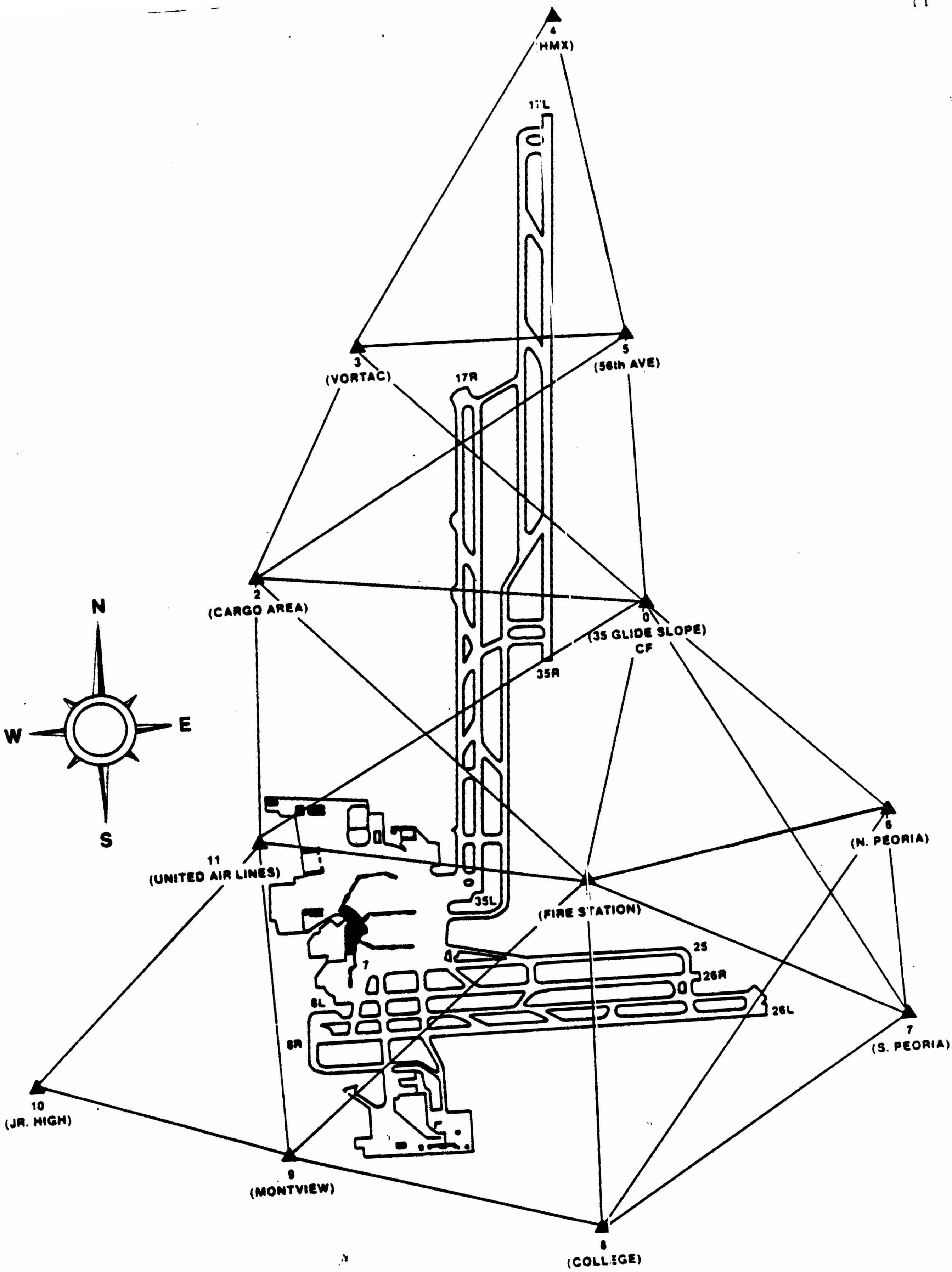

FIGURE 1. DENVER STAPLETON DIVERGENCE DETECTION TRIANGLES

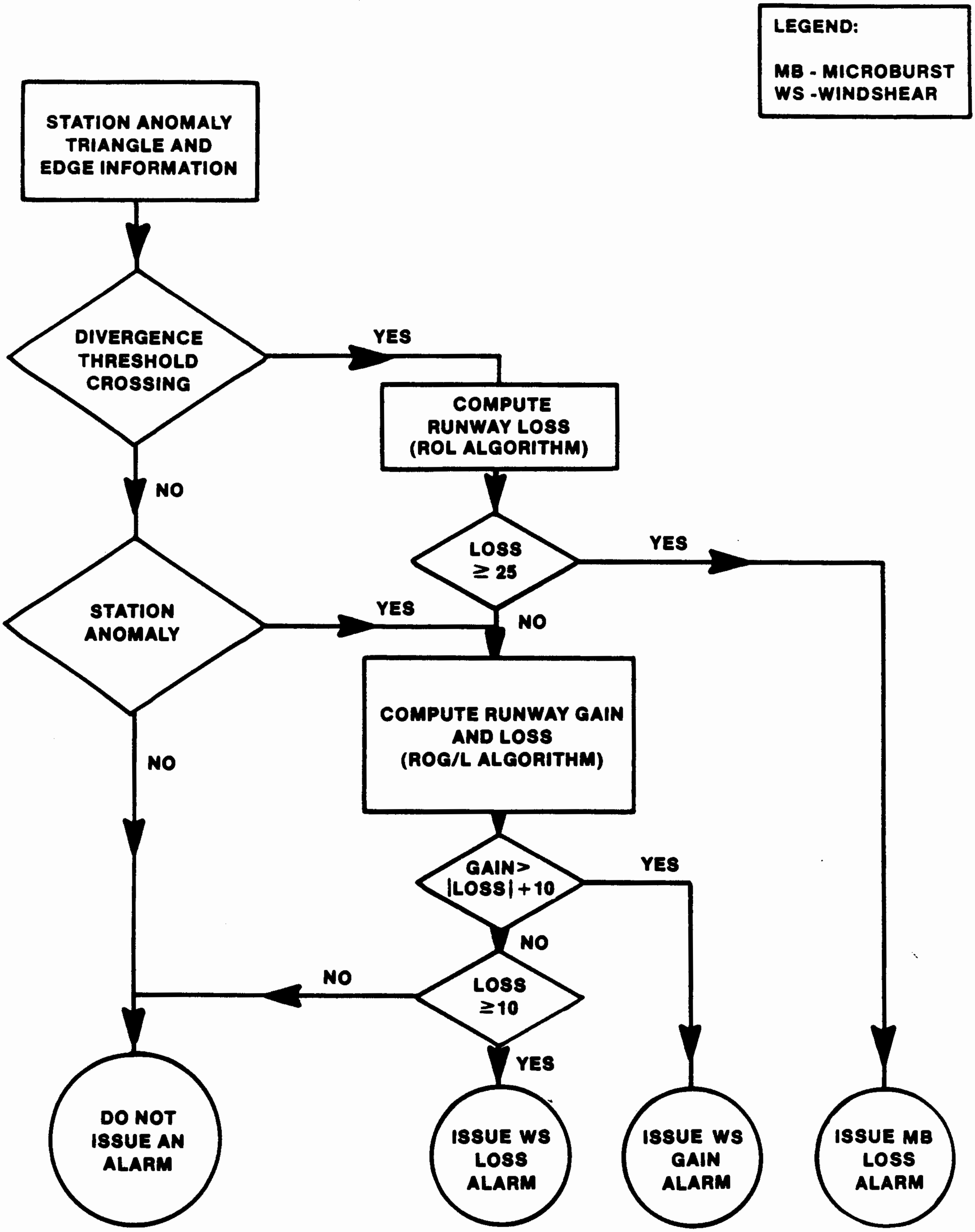

FIGURE 2. ALARM LOGIC FOR A SPECIFIC RUNWAY (EACH 7-SEC SCAN)

losses for several elements are the same (losses are rounded to the nearest 5 knots) then the element closest to the aircraft is placed in alarm status. This is the only path to microburst alarm status.

On the other hand, if there are no divergence threshold crossings, then there is a check for station anomalies. If there are no station anomalies, then no alarm is issued, otherwise, point-to-point gains and losses are computed for all stations associated with each runway that has an associated station anomaly. If the gain is greater than the loss + 10 knots, then a wind shear gain alarm is issued along with the computed gain. If the gain is less than or equal to the loss + 10 knots and the loss is equal to or in excess of 10 knots, then a wind shear loss alarm is issued; otherwise, no alarm is issued. Before an alarm message appears on the local controller's display, there must be a persistence of four consecutive alarms for a runway. Also, after the alarm actually ends, the alarm message continues for 30 seconds. This allows intermittent alarms to be continuous alarms.

DENVER, COLORADO, TEST BED.

The test bed at the Denver, Colorado, Stapleton Airport was established in 1985 as part of a continuing program to study low altitude wind shear events. More recently, the test bed was expanded through the addition of weather data gathering facilities by the Massachusetts Institute of Technology (MIT) Lincoln Laboratory and the National Center for Atmospheric Research (NCAR). Lincoln Laboratory and NCAR, in support of the FAA program, have conducted experimental measurements using Doppler weather radars, a system of automatic weather stations and instrumented aircraft to obtain detailed information from storms occurring in the Stapleton Airport area. The test bed for the evaluation had the capability of providing data from five types of source facilities including LLWAS. The others were three Doppler radars and a network of FAA/Lincoln Laboratory Operational Weather Studies (FLOWS) automatic weather stations.

Figure 3 shows the 12 LLWAS remote station (sensor) sites and their respective locations in relation to the primary runways at the Stapleton Airport: two north/south runways and two east/west runways. The LLWAS anemometer sensor at station 0 is referred to as the centerfield (CF) sensor; all others as boundary remote sensors. Pertinent data from LLWAS consist of remote station windspeed and direction applied as input to the PDP 11/73, and the output information displayed to controllers in runway oriented wind shear and microburst alert formats.

Figure 4 shows the locations of the various systems and equipment items used at the Denver test bed. FL-2 shown in the figure is a state-of-the-art Doppler weather radar built and operated by Lincoln Laboratory and which used a 28-foot (ft) diameter antenna in acquiring data. FL-2 is located at the Buckley Air National Guard Base and is approximately 15 kilometers (km) from the mid-point of the airport's north/south runways.

A second Doppler weather radar, identified as UND in the figure, was operated by the University of North Dakota. This system was somewhat smaller, having a 12-ft diameter antenna. The FL-2 and UND radar beams are at right angles to

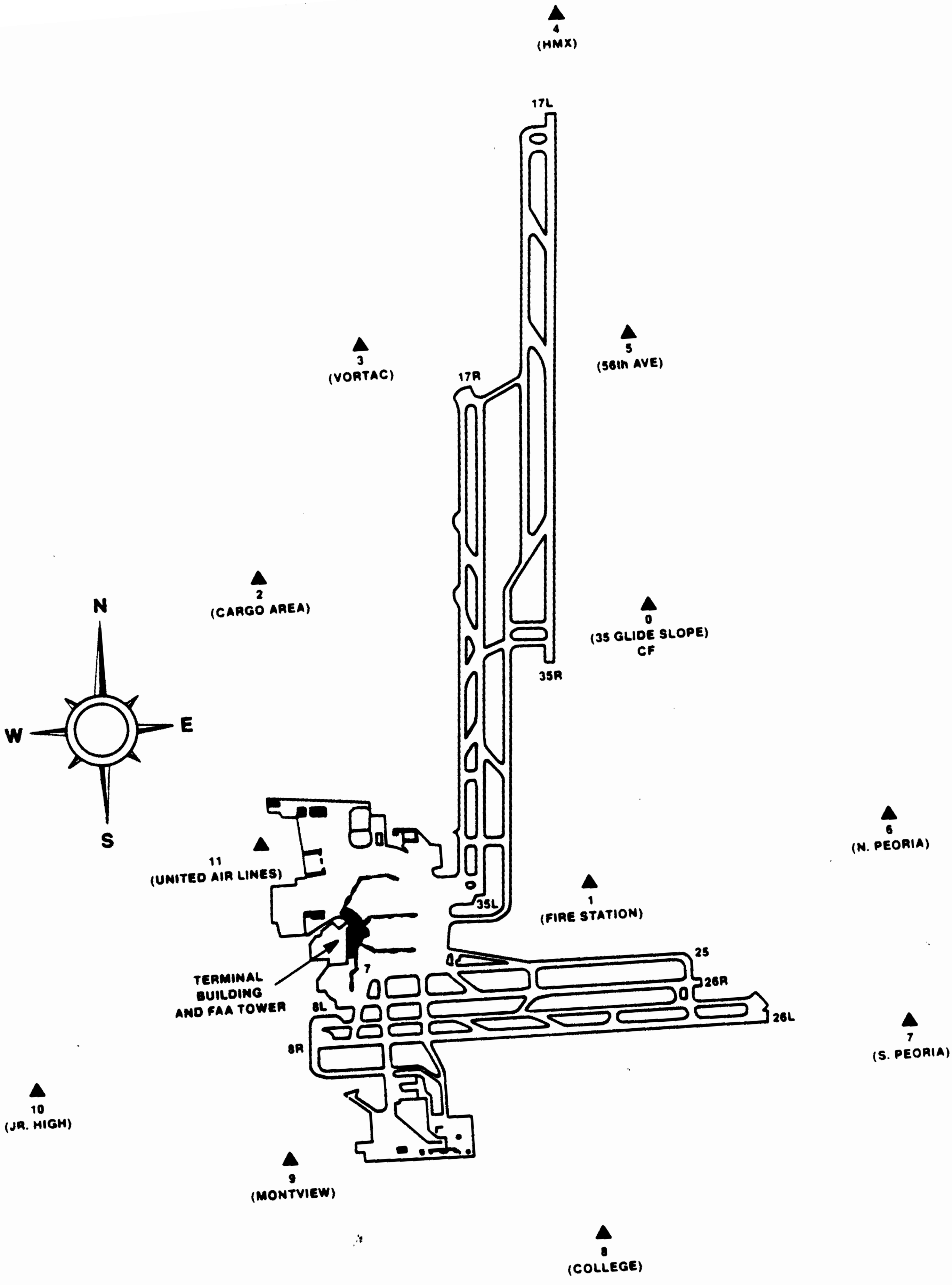

FIGURE 3. LLWAS REMOTE STATION SITES AT DENVER, COLORADO, TEST BED

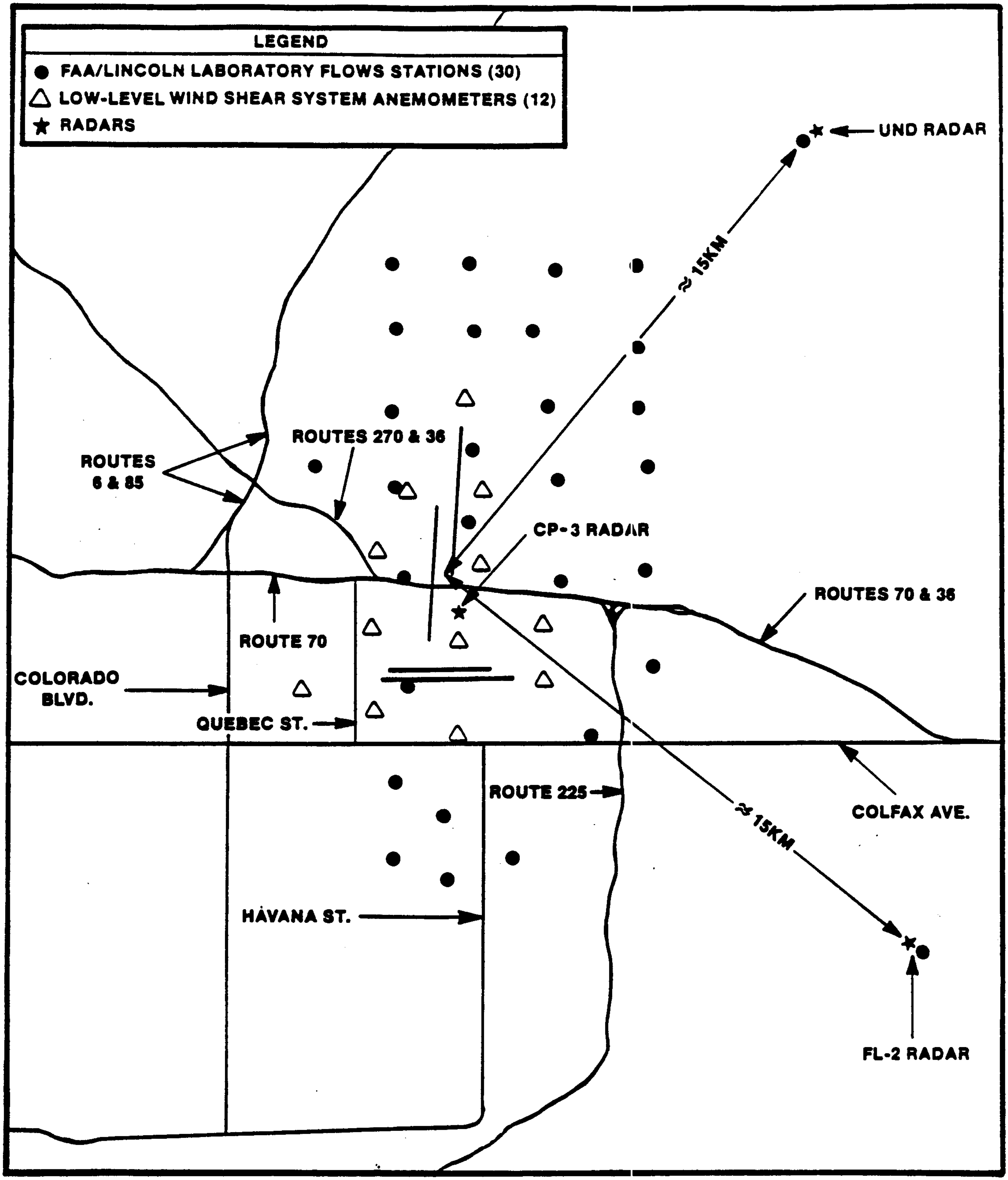

FIGURE 4. DENVER STAPLETON AIRPORT TEST BED

one another. The right angle beam configuration was intended to provide very good dual Doppler case studies of microburst events occurring in the airport environment.

A third Doppler weather radar, identified as CP-3 in the figure, was operated by NCAR. Its characteristics were comparable to the UND radar. The CP-3 radar was to provide good case studies of velocity data for the Stapleton north/south runways.

A network of 30 FLOWS automatic weather stations was to collect data on wind speed, wind direction, rainfall, temperature, humidity, and pressure. The wind data from these stations were to be used to validate the wind shear detection performance of the Doppler radars. The other types of FLOWS data were to be used for meteorological analysis of wind shear events.

TECHNICAL APPROACH

GENERAL METHODOLOGY.

The various strategies and resources used by the FAA Technical Center in meeting the meteorological and human factors test and evaluation objectives are indicated below:

METEOROLOGICAL. The effectiveness of the wind shear and microburst detection algorithm in detecting and identifying wind shear events and providing an acceptably low false alarm rate was determined by correlating algorithm results with wind shear detections by the three Doppler radars, the FLOWS stations in the immediate airport area, and the LLWAS, as well as by observations by tower and radar site meteorologists, and pilot reports (PIREPS) extracted from ATC tower voice tapes.

The effectiveness of the runway component algorithms in providing a suitable estimation of (1) gain or loss in headwind during a wind shear event, or (2) loss in headwind during a microburst event, was intended to be determined by comparison of computed estimates with headwind gain or loss reported by pilots (PIREPS) and runway shear estimates from single- and dual-Doppler radar data. Dual-Doppler radar data from FL-2 and UND, as well as single-Doppler radar data from CP-3, were required to meet this objective. However, problems in data collection and reduction were encountered. See Meteorological Analysis, Limitations and Constraints section for further discussion.

HUMAN FACTORS. The usefulness and effectiveness of the local air traffic controllers' CRT display, the display message format, and the controller's message to pilots were determined through analyses of the controllers' responses to comprehensive questionnaires. Other human factors aspects such as benefits versus problems, helpfulness, field-use suitability, etc., were also determined. Details of the display and message format are provided in appendix B.

Two very similar questionnaire versions, Forms A and B, were used to evaluate the pre- and post-enhancement LLWAS, respectively. Prior to installation of the enhanced LLWAS at the Denver Tower, a briefing on the human factors data collection was given to each of the seven shifts of tower controllers. At that time, a copy of the questionnaire Form A was handed to each controller to evaluate the present LLWAS. Questionnaire Form B was administered after 2-weeks experience with the enhanced LLWAS. The fact that many of the questions in Forms A and B were the same allowed a pre- and post-enhancement comparison on an item by item basis.

Fully qualified local controllers working in the Denver Tower served as subjects for the human factors evaluation. The controller subjects were asked to complete the questionnaire forms and return them to an onsite representative for forwarding to the FAA Technical Center. The subjects were instructed to give their own opinions, not what they perceived as the consensus of the group. Completion of both forms was voluntary and on a time available basis.

Numerical values were assigned to the answers on questions asking for ratings. These rating scale values were then analyzed using standard parametric statistical tests. Means, standard errors of the mean, ranges, and t scores were computed. The Student's t test was used to determine whether there was a statistically significant agreement among the respondents as to their rating of various human factors aspects of the pre- and post-enhanced LLWAS.

PROJECT ORGANIZATIONAL PARTICIPANTS.

The principal organizations participating in the test and evaluation of the Denver Stapleton Enhanced LLWAS included: (1) the FAA Washington Headquarters Weather Sensors Program Office; (2) the FAA Technical Center; (3) the FAA Northwest Mountain Regional Office; (4) the systems engineering and integration contractor (SEIC) to the FAA - The Martin Marietta Corporation; (5) the Data Transformation Corp. (DTC); (6) the MIT Lincoln Laboratory; and (7) the National Center for Atmospheric Research (NCAR). Support type functions were provided by two local FAA organizational units: DEN-30 and AFSFO-1. The FAA Technical Center had overall responsibility for the coordination and conduct of the test and evaluation. A representative of the Martin Marietta Corporation acted as co-test director with the LLWAS Technical Program Manager from the FAA Technical Center.

METEOROLOGIST EVALUATION PARTICIPANTS.

FAA contractor support meteorologists from DTC, Martin Marietta Corporation, and NCAR served in important roles at the Denver test bed during the conduct of the test and evaluation; some in the capacity of ATC tower meteorologists, others as radar site meteorologists.

1. ATC Tower Meteorologists. Two contractor support meteorologists were stationed at the Stapleton Airport ATC tower on a daily basis. Their functions essentially involved monitoring LLWAS displays and controller-pilot communications, observing airport weather conditions, and recording pertinent weather event data.

At any one time, two FAA local controllers were on duty in the Stapleton ATC tower. One handled arriving aircraft; the other departing aircraft. One of the two meteorologists monitored the LLWAS display and radio frequency for arrivals; the other monitored the LLWAS display and frequency for departures. They were instructed not to communicate with the controllers during the test and evaluation.

The meteorologists were to record information pertinent to LLWAS wind shear and microburst alarms on a worksheet similar to the one shown in figure 5. On the upper part of the form, the meteorologists were to indicate whether LLWAS, a PIREP, or a visual observation prompted them to fill out the form. They were also to note the runways for which LLWAS was alarming, and whether the controller relayed the alarm message to the pilot. In addition, they were to describe the visually observed meteorological event, and note the PIREPS heard on the radio.

Illustrated in the lower part of the form in figure 5 is a sketch showing the Stapleton International Airport runways and LLWAS sensor locations relative to these runways. Several landmarks are indicated in the sketch to aid the meteorologist in reporting the location of observed phenomena. The pear shape configuration outlines the extent of dual-Doppler radar coverage while the circle outlines the extent of the LLWAS test area.

2. <u>The Radar Site Meteorologist</u>. A contractor support meteorologist was stationed at the Lincoln Laboratory weather radar site. His functions were to observe and log all shear events detected within 5 miles of the Stapleton Airport. At his disposal were displays of real-time velocity and reflectivity data from the FL-2 Doppler radar as well as displays of real-time LLWAS information identical to that provided to controllers at the ATC tower.

For each wind shear or microburst event detected by the LLWAS, the radar, or both the LLWAS and radar, the meteorologist was to enter information pertinent to the event on a radar event log form. An exhibit of this form is shown in figure 6. On the radar event log form, he was to record information regarding event location (range and azimuth) and affected runways. Also, if the event were a microburst, then he would log the velocity differential (V) between the highest approaching and receding radial velocities, and the distance between these centers for each tilt in which the event was detected.

PERFORMANCE EFFECTIVENESS SCORING PROCEDURES.

A meeting was held on July 9, 1987, at the Buckley Air National Guard Terminal Doppler Weather Radar (TDWR) Site in Denver for purposes of establishing a set of ground rules and procedures for scoring of the performance effectiveness of the LLWAS wind shear microburst detection algorithm. Attendees consisted of the FAA LLWAS Program Manager, the FAA Technical Center LLWAS Program Manager, and representatives from MIT Lincoln Laboratory, NCAR, and the Martin Marietta Corp.

As a basis for determining the accuracy of the wind shear microburst detection algorithm, data were to be collected from a number of sources and then analyzed and compared. These sources of data consisted of:

1. Observations made by meteorologists in the Denver Tower.

2. Logs from the TDWR site: LL/FAA Technical Center.

OBSERVER ______________________________ TIME __________ DATE ________

DATA PROMPT: LLWAS ______ PIREP ______ OBSERVATION ______________

LOCAL ______

	A		D	
RUNWAYS	___/___	___/___	___/___	___/___
ADVISORIES ISSUED Y/N	___/___	___/___	___/___	___/___
NUMBER OF ADVISORIES	___/___	___/___	___/___	___/___

OBSERVATION ____

____

____

____

PIREPS ____

____

____

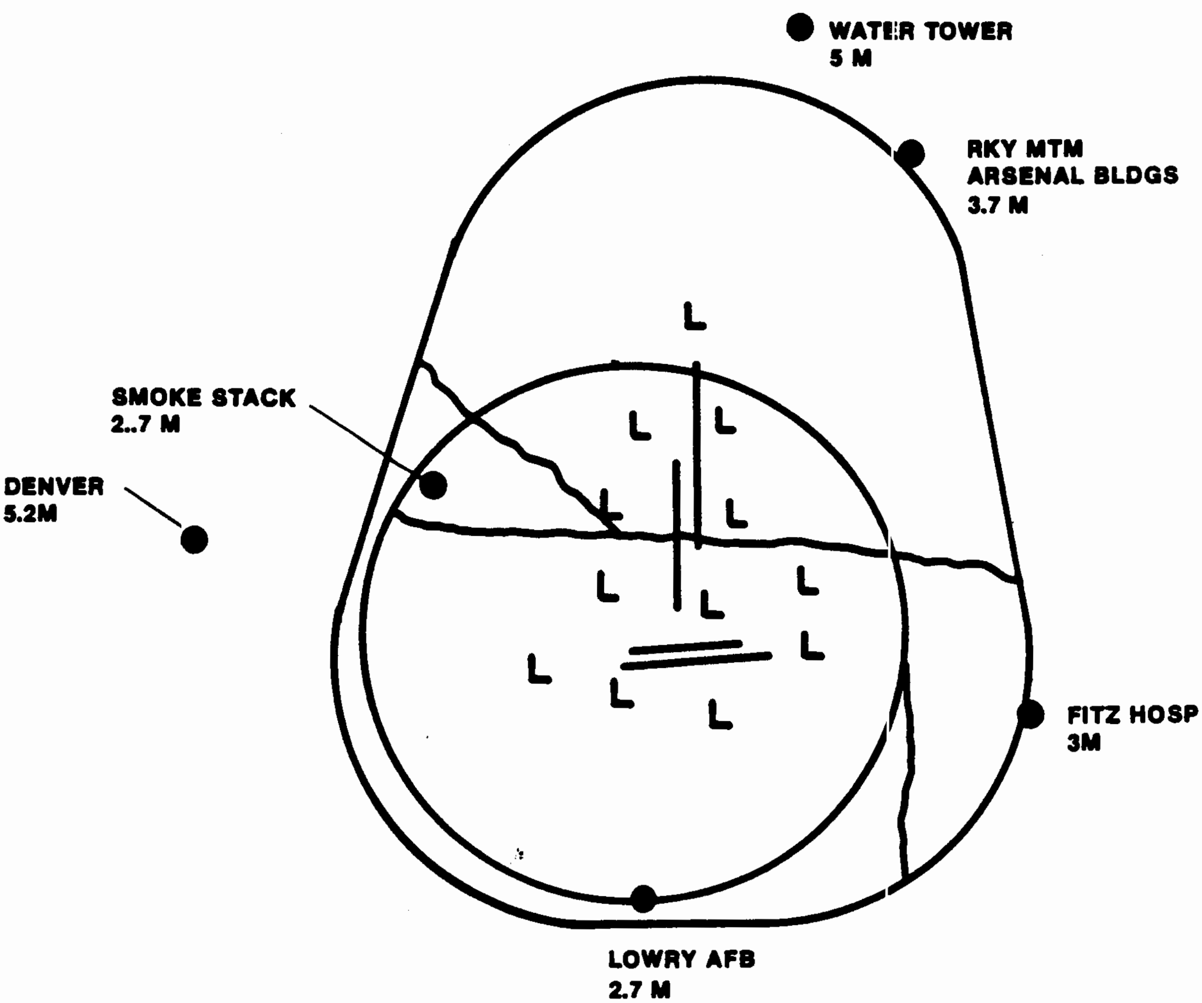

FIGURE 5. ATC TOWER METEOROLOGIST LLWAS ADVISORY WORKSHEET

OBSERVER________________DATA PROMPT: LLWAS ________ RADAR________ DATE______

LLWAS EVENT START______ END______

TIME (MDT)	ELEV. (deg)	RANGE (km)	AZIM. (deg)	Z (dBz)	ΔV (ms^{-1})	DISTANCE (km)	AFFECTED RUNWAYS	COMMENTS

FIGURE 6. RADAR EVENT LOG-DENVER TEST AND EVALUATION

3. PIREPS.

4. Single-Doppler ground truth analysis from FL-2 radar.

5. Single-Doppler ground truth analysis from CP-3 radar.

6. Dual-Doppler analysis from FL-2 and UND radars.

7. FLOWS automatic weather station data.

In the comparison of data from the various data sources, there was the likelihood of contradictory and inconsistent results because no absolute reference existed. Each of the three radars was developmental and the FLOWS stations had no prior history in the Denver test bed. The evidence, consequently, had to be weighed and conclusions reached as to the best determination. Contradictory and inconsistent results were to be assessed collectively by the principal organizations participating in the test and evaluation.

The following characteristics of each wind shear event were to be determined:

1. Nature of the event (microburst, wind shear line, other).

2. Location, size, and movement (if applicable) of the event.

3. Duration of the event (start and stop times limited by measurement device tolerances approximating 30 seconds).

4. Intensity of the event.

5. Magnitude of runway component.

The statistical measures for scoring included the following:

1. Probability of detection.

2. Probability of false alarm.

Difficulties expected with the scoring procedures included instances of sheltering, equipment problems, and communication errors.

METEOROLOGICAL ANALYSIS

This report section addresses analysis of the performance of the meteorological aspects of the enhanced LLWAS at Denver. Four principal topics are covered: (1) limitations and constraints, (2) data, (3) procedures, and (4) results.

LIMITATIONS AND CONSTRAINTS.

1. During the finalization stage of software development by the contractor, an important parameter was inadvertently changed: the difference threshold used in the network mean (NM) procedure. The intended value for the difference threshold was to be approximately 14.2 knots, but the actual value used during the data collection period was found to be 10.0 knots. As a direct consequence, this report contains analyses and evaluations based on results from using the 10.0-knot threshold. (It is to be noted that the contractor changed the operational threshold parameter in January 1988 to 14.2 knots.)

2. Evaluation of the performance of the runway loss and gain algorithms,through comparisons with PIREPS and Doppler radar data, was not possible because:

a. Few PIREPS, either solicited or volunteered, were obtained during the data collection period. Several PIREPS contained only comments (e.g., "little tiny bit on takeoff roll") without a numerical estimate of headwind loss or gain. Even for those PIREPS that did contain a numerical estimate, it was frequently not possible to determine when and where the pilot encountered the event.

b. CP-3 single-Doppler radar data, although available, were not usable due to limited coverage ($\pm 7°$ from 2° azimuth) and contamination from ground clutter in the area of interest.

c. Dual-Doppler radar analyses were generally unreliable for this effort due to very weak signal return.

DATA.

During the data collection period of the Denver test and evaluation, a considerable amount of data was collected by the data sources of the test bed. Due to time constraints, it was not possible to examine all of the data forthis report. Therefore, four time periods, each approximately 1 hour in duration, were chosen for detailed analysis. Each period contained either wind shear or microburst events. Chronologically, these periods were:

Date	Time (UTC)
1. August 20, 1987	2100-2140
2. August 21, 1987	2130-2230
3. August 26, 1987	0000-0055
4. September 2, 1987	2230-2330

The primary data sources used for this analysis were: (1) LLWAS messages recorded from data lines to the ATC tower cab displays, (2) raw LLWAS wind data, (3) FL-2 and UND synthesized dual-Doppler radar winds, (4) tower observer forms, (5) radar observer forms, (6) PIREPS, and (7) FLOWS automatic weather station data. Dual-Doppler radar winds were not available for the August 20, 1987, case.

PROCEDURE.

The WSMD algorithm was to be evaluated in terms of its performance relative to the centerfield average algorithm. Performance was to be measured in terms of the ability of these algorithms to detect wind shear and microburst events while generating few false alarms.

The three measures of performance used in this endeavor were the probability of detection, the false alarm ratio, and the true skill score (these measures are defined in appendix C). A detection was confirmed if one or more of the test bed data sources also detected the same wind shear or microburst event.

The detection in this case was called a predicted event (pe). If there were sufficient data, but a lack of support for the LLWAS detection, then the detection was false and was called a predicted non-event (pn). An unpredicted event (ue) was an event that was detected by one or more of the other test bed sources, but not by the LLWAS.

The results of the WSMD algorithm were known from the recorded tower messages. However, because results of the CFA algorithm were not produced by the Denver system, it was necessary for the CFA algorithm to be applied to the raw LLWAS data in the laboratory. The CFA algorithm was applied: (1) to the original 6-sensor Denver configuration with the original centerfield sensor (see station 1 in figure 1); and (2) to the present 12-sensor configuration with the present centerfield sensor. The CFA algorithm was applied to both configurations using 10.0-knot as well as 14.2-knot thresholds on the magnitude of the vector difference of the wind. It was appropriate that the algorithms be compared with an equivalent threshold, as well as with the intended threshold.

As a first step in determining the presence of wind shears, the data from each of the four time periods were examined using computer graphic depictions of raw LLWAS winds, dual-Doppler winds, and winds from the Lincoln Laboratory network of automated weather stations. Other aids were the tower and radar observer forms, as well as the pilot reports. From this information, periods of time for which alarms should or should not have occurred were determined. Periods during which microbursts occurred were labeled as microburst events. Likewise, periods during which wind shears were evident were labeled wind shear events. Early analysis indicated the need to introduce two definitions by which wind shears and microbursts were classified. These were the Meteorological definition and the System definition.

To be classified as a microburst under the Meteorological definition, an event (one LLWAS polling cycle) must have been divergent, with an apparent shear of at least 10 ms^{-1}. Since these shear estimates were made by visual observation of data, it was possible that shears of intensity slightly less than 10 ms^{-1} were included, and those slightly greater than 10 ms^{-1} were excluded. Events classified as wind shear by LLWAS could be either divergent or convergent. Estimated shears associated with divergent wind shear events were typically 5-10 ms^{-1}, and those associated with convergent wind shear events were in excess of 5 ms^{-1}. These shears were estimated from either the LLWAS winds, dual-Doppler winds, or Lincoln Laboratory weather station winds.

For an event to be classified as a microburst under the System definition, the WSMD algorithm requires that a loss of 25 knots along a runway or along a line parallel to the runway at 1-, 2-, or 3-mile arrival or 1-, 2-, or 3-mile departure intervals be computed before a microburst alarm is issued. Also, a minimum of 10 knots loss or gain on a runway or in an arrival or departure corridor is required for a wind shear alarm under the System definition. So, even though a microburst or a wind shear is present over the airport, if it does not affect the runways in this manner, it is not reported by the WSMD algorithm.

WSMD alarms were compared with both the meteorological and the system truth using a matrix which we have called "time window matrix." This matrix is described in full in appendix D. Briefly, a time window (for example, 2100-2140 on August 20, 1987) was divided into time slices. Each time slice corresponded to a period when there was either no alarm, a continuous wind shear alarm, a continuous microburst alarm, or a period during which an event other than the one corresponding to the issued alarm type occurred. For each time slice, questions such as "do LLWAS raw winds support the alarm?," "do pilots/observers support the alarm?," "was LLWAS correct?," etc., were answered.

The time window matrix used for comparing CFA algorithm alarms with the truths differed from that used for the WSMD algorithm. For this type matrix the only question asked was "was the CFA algorithm correct?." Examples of these matrices are in appendix E.

Performance statistics were computed for the WSMD algorithm as well as the CFA algorithm for the four combinations of configurations and thresholds from the time window matrices. Additional categories were considered for the WSMD algorithm. These were (1) microburst events only, (2) all events, (3), with equipment malfunctions and sheltering, and (4) without equipment malfunctions and sheltering. Separate sets of statistics were computed for the meteorological and system definitions.

Also examined were the percentages of alarm occurrence for all events for the WSMD algorithm and each of the CFA algorithm combinations. In addition, the delay in detecting each microburst for the system as well as the meteorological definition is presented and discussed. Examples of LLWAS only and composite LLWAS and dual-Doppler radar wind fields are presented in order to substantiate findings in this report.

RESULTS.

Performance statistics for the WSMD algorithm appear in table 1. As expected, the WSMD algorithm performed best when the System definition was used as truth. Also, as expected, equipment malfunction and sensor shielding contributed considerably to degraded detection performance. In fact, the exclusion of malfunctions and shielding with the System definition used as truth produced probabilities of detection of 1.00 for microburst events only as well as for all events (microburst and wind shear) combined. False alarm ratios for the System definition without equipment problems were 0 for all events and 0.075 for microbursts only. High true skill scores indicate overall good performance of the WSMD algorithm.

TABLE 1. WSMD ALGORITHM PERFORMANCE STATISTICS

Meteorological

	Probability of Detection (POD)	False Alarm Ratio (FAR)	True Skill Score (TSS)
Microburst Events[1]	0.362	0.108	0.351
Microburst Events[2]	0.450	0.108	0.439
All Events[1,3]	0.675	0.026	0.661
All Events[2,3]	0.702	0	0.702
All Events[1,4]	0.437	0.040	0.423
All Events[2,4]	0.481	0	0.481

System

	Probability of Detection (POD)	False Alarm Ratio (FAR)	True Skill Score (TSS)
Microburst Events[1]	0.649	0.108	0.639
Microburst Events[2]	1.00	0.075	0.994
All Events[1,3]	0.946	0.026	0.934
All Events[2,3]	1.00	0	1.00
All Events[1,4]	0.872	0.029	0.860
All Events[2,4]	1.00	0	1.00

[1]Equipment problems included.

[2]Equipment problems not included.

[3]MB occurrences accompanied by LLWAS WS advisories and WS occurrences accompanied by LLWAS MB advisories count as predicted events.

[4]MB occurrences accompanied by LLWAS WS advisories count as unpredicted events; WS occurrences accompanied by LLWAS MB advisories count as predicted events.

With the exclusion of equipment problems, the probability of detection for microbursts only using the meteorological definition was 0.450 and 1.000 using the System definition. The false alarm ratio for microbursts only using the Meteorological definition was 0.108 and 0.075 using the System definition. The implications of these numbers are that microburst alarms do not begin early enough and do not continue long enough, even though the presence of a microburst is clearly evident. This is most likely due to the system requirement that a loss of 25 knots or more be computed for a runway segment before a microburst alarm is issued. Detailed WSMD algorithm alarm summaries and analysis (time window matrices), along with the System and Meteorological definition truth, are tabularized in appendix D.

CFA algorithm performance statistics appear in table 2. Equipment problems were included in the calculations. Examination of the POD column reveals that although POD's are considerably different for each configuration and threshold combination, the POD's for each combination are nearly the same regardless of whether the meteorological or system truth was used. FAR's are particularly high and much higher than the FAR's for the WSMD algorithm. One interesting item to note is that the 12-station configuration detected events better than the 6-station configuration and had a lower FAR. The higher threshold had a lower probability of detection for system as well as meteorological truth. The true skill scores indicate overall poor performance for the CFA algorithm. Detailed summaries of alarms and analysis (time window matrices) for the CFA algorithm are provided in tables in appendix E along with Meteorological and System definition truth.

Table 3 contains the percentage of alarm occurrence for each of the CFA algorithm configurations and threshold combinations, as well as the WSMD algorithm. Microburst and wind shear events are considered. The WSMD algorithm alarmed for 31.5 percent of the time. This is much lower than the CFA algorithm with the exception of the CFA algorithm 6-station configuration with the 14.2 knot threshold (31.7 percent of time). However, the POD for this configuration and threshold is very low for both of the definitions. Also, FAR's are high for the other configurations and thresholds. Therefore, the WSMD algorithm alarms less frequently than the CFA algorithm.

Tables 4 and 5 contain information relating to the timely identification of microbursts by the WSMD algorithm. According to the System definition there was a total of 18 microbursts. These microbursts had an average lifetime of 86.5 seconds. Of these 18 microbursts, one was not identified for 322 seconds of its 355 second lifetime, and two others were not identified at all. The other 16 microbursts were detected without delay. In contrast, there were 11 microbursts according to the Meteorological definition. The average lifetime was 262.2 seconds. Of these 11, only one was identified without delay. Four others were not detected. (Note: The statistics discussed above in regard to timely identification of microbursts do not take into account possible earlier detection that was labeled wind shear alert). There are several reasons for microbursts not being detected. The remainder of this section deals with examples of microbursts that were either detected or not detected.

TABLE 2. CFA ALGORITHM PERFORMANCE STATISTICS

Meteorological

# Stations	Threshold (knots)	POD	FAR	TSS
6	10.0	0.867	0.454	0.291
6	14.2	0.575	0.193	0.464
12	10.0	0.967	0.415	0.417
12	14.2	0.763	0.296	0.505

System

# Stations	Threshold (knots)	POD	FAR	TSS
6	10.0	0.857	0.617	0.220
6	14.2	0.553	0.450	0.344
12	10.0	0.992	0.575	0.373
12	14.2	0.808	0.473	0.474

TABLE 3. PERCENTAGE OF ALARM OCCURRENCE

(All Events)

Algorithm	# Stations	Threshold (knots)	% Alarms
CFA	6	10.0	70.6
CFA	6	14.2	31.7
CFA	12	10.0	53.7
CFA	12	14.2	48.3
WSMD			31.5

TABLE 4. DELAY IN MICROBURST IDENTIFICATION BY LLWAS (SYSTEM)

Microburst No.	Date	Microburst Start Time (UTC)	Microburst End Time (UTC)	LLWAS Microburst Identification Time (UTC)	Delay (Seconds)	Duration of Microburst (Seconds)
1	8/20	2121:59	2123:56	2121:59	0	124
2	8/20	2124:57	2127:21	2124:57	0	151
3	8/21	2144:15	2145:57	*	109	109
4	8/26	0027:18	0028:05	0027:18	0	54
5	8/26	0028:59	0029:20	0028:59	0	28
6	8/26	0031:22	0032:31	0031:22	0	76
7	8/26	0033:05	0033:59	0033:05	0	61
8	8/26	0034:13	0036:56	0034:13	0	170
9	8/26	0037:23	0037:43	0037:23	0	27
10	9/2	2239:05	2244:53	2244:27	322	355
11	9/2	2249:06	2249:12	2249:06	0	13
12	9/2	2249:26	2250:13	2249:26	0	54
13	9/2	2251:01	2251:48	2251:01	0	54
14	9/2	2251:27	2253:17	*	117	117
15	9/2	2252:30	2252:57	2252:30	0	34
16	9/2	2253:44	2254:52	2253:44	0	75
17	9/2	2304:39	2305:06	2304:39	0	34
18	9/2	2307:50	2308:04	2307:50	0	21

* Did not identify as a microburst

TABLE 5. DELAY IN MICROBURST IDENTIFICATION BY LLWAS (METEOROLOGICAL)

Microburst No.	Date	Microburst Start Time (UTC)	Microburst End Time (UTC)	LLWAS Microburst Identification Time (UTC)	Delay (Seconds)	Duration of Microburst (Seconds)
1	8/20	2115:24	2115:58	*	41	41
2	8/20	2117:00	2129:04	2121:59	299	731
3	8/21	2144:15	2145:57	*	109	109
4	8/26	0026:51	0037:43	0027:18	27	659
5	9/2	2239:05	2246:49	2244:27	322	471
6	9/2	2248:52	2255:13	2249:06	14	388
7	9/2	2251:27	2253:17	*	117	117
8	9/2	2256:21	2258:16	*	122	122
9	9/2	2253:44	2255:13	2253:44	0	89
10	9/2	2304:05	2305:47	2304:39	34	109
11	9/2	2307:50	2308:31	2307:50	0	48

* Did not identify as a microburst

Depicted in figure 7 is an LLWAS wind field recorded on August 20, 1987, at 212503. This wind field is indicative of a microburst that was detected by the operational system. (Unfortunately, no dual-Doppler radar winds were available for this time due to lack of coordination between the two radars.)

Figure 8 is a composite of LLWAS raw winds and dual-Doppler winds in the 0-100 meter layer. These data were collected on August 21, 1987, at 214428 UTC. Strong divergence is apparent between LLWAS stations 7 and 8. Radar winds, although products of weak signal, also indicate strong divergence. The operational LLWAS with the WSMD algorithm called this a wind shear event. However, it is evident that a microburst entered the LLWAS network from the southeast. We considered this to be a microburst event for both the Meteorological and the System definition and one that was missed by the LLWAS.

Figure 9 presents a most interesting situation which occurred on September 2, 1987, at 224016. The Dual-Doppler radar winds show a microburst at the north end of the airport. There may also be another divergence feature (perhaps another microburst) about 1.5 km southwest of the microburst. The wind direction at station 3 appears to be inconsistent with that of the radar winds. In fact, station 3 never turned northwesterly during the lifetime of the microburst.

At this time the LLWAS was issuing the messages that appear in figure 10 (see appendix B for an interpretation of the enhanced LLWAS display). A wind shear alert with loss of 15 knots on the runway (RWY) was displayed for runway 17 right arrival (RA). It would seem more appropriate for this case that the loss alert be given at 1 or 2 miles final (MF), where divergent wind flow is evident in both LLWAS and radar data. Additional sensors at the north end of the airport would have probably aided the LLWAS in providing more appropriate information to the controller.

Another interesting case is depicted in figure 11. It occurred on September 2, 1987, at 225224. A microburst accompanied by moderately weak radar reflectivity was located just to the east of runways 8 and 26, and centered between LLWAS stations 6 and 7. The wind sensors at these stations indicate weak winds, with station 6 westerly. The radar winds are twice as strong and from the south in the vicinity of station 6. The effect of this microburst was not detected by the LLWAS until the center passed over station 6 and the wind became easterly (figure 12). It was the convergence between stations 1 and 6 that finally triggered a wind shear alarm.

Winds at stations 6 and 7 were very light. Windroses for these and the centerfield station are contained in appendix F. The centerfield sensor has the best exposure of all the sensors. The windroses show that stations 6 and 7 performed very poorly when compared with the centerfield station during the operational test. They are either severely shielded in all directions, require maintenance, or both. The lack of detection of this microburst was due to these problems with stations 6 and 7. Another sensor located east of these stations would have improved the detection capability of the LLWAS in this case.

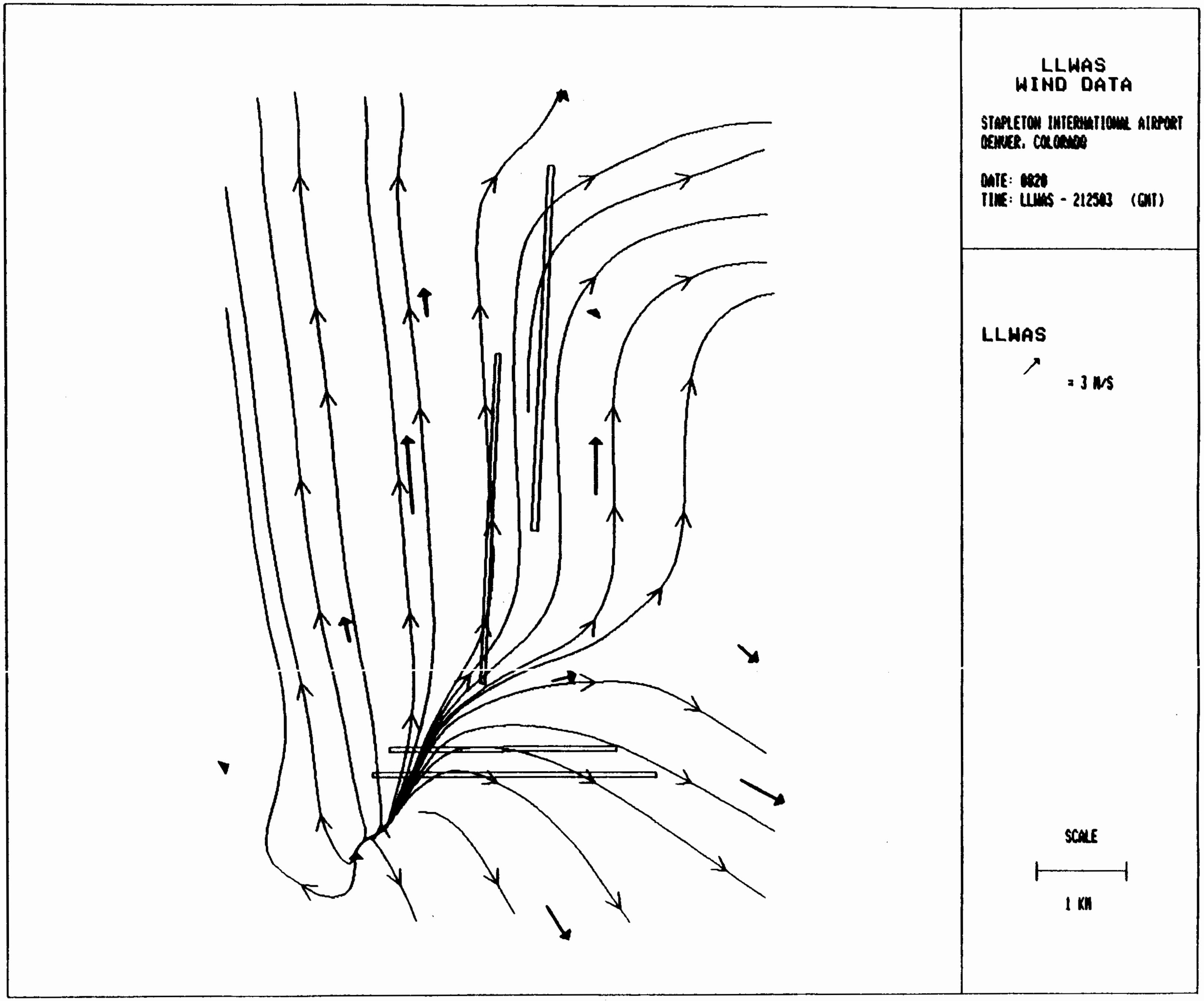

FIGURE 7. LLWAS WINDS, AUGUST 20, 1987, 212503 UTC

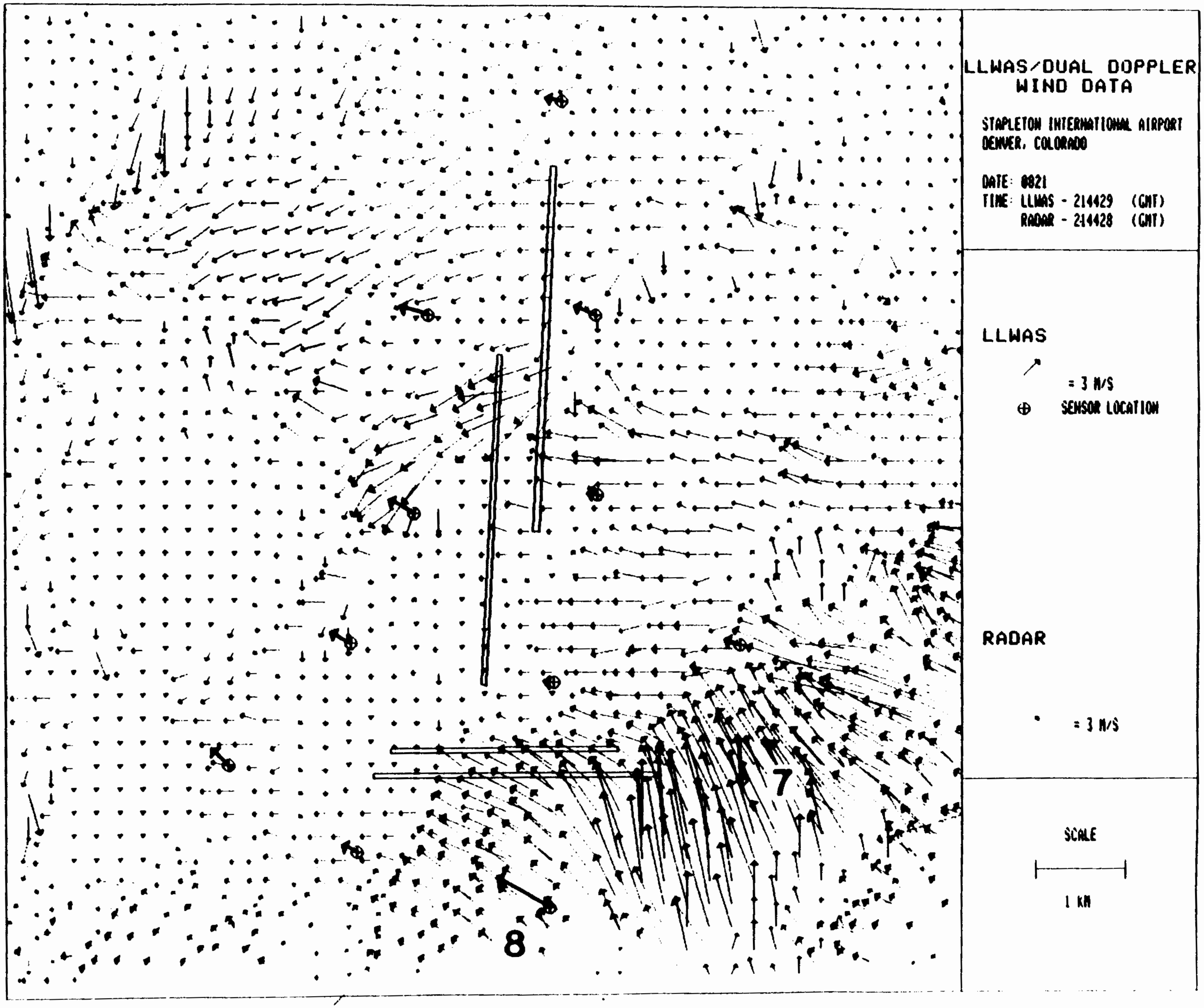

FIGURE 8. LLWAS/DUAL-DOPPLER COMPOSITE WINDS, AUGUST 21, 1987, 214428 UTC

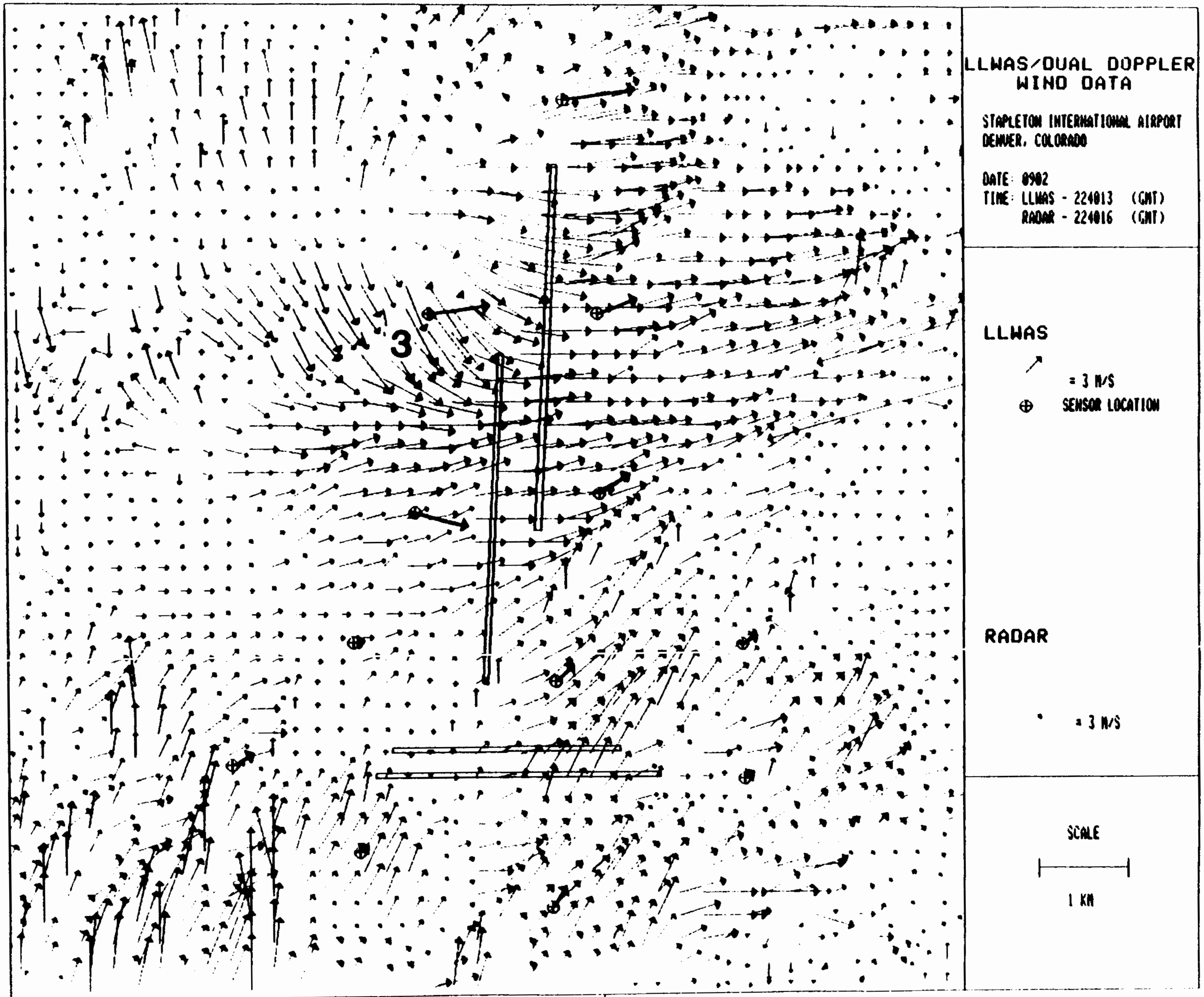

FIGURE 9. LLWAS/DUAL-DOPPLER COMPOSITE WINDS, SEPTEMBER 2, 1987, 224016 UTC

	CF	220	12			22:40:13
WSA	35LA	210	7	-15k	1MF	
WSA	35RA	230	12	-15k	2MF	
WSA	35LD	220	12	-15k	RWY	Psbl WS OTSD
WSA	35RD	220	12	-15k	RWY	Psbl WS OTSD
WSA	17LA	250	23	-15k	RWY	Psbl WS OTSD
WSA	17RA	250	20	-15k	RWY	Psbl WS OTSD
WSA	17LD	220	12	-15k	RWY	
WSA	17RD	220	12	-15k	RWY	
WSA at 22:40						

FIGURE 10. LOCAL CONTROLLER 1 DISPLAY, SEPTEMBER 2, 1987, 224013 UTC

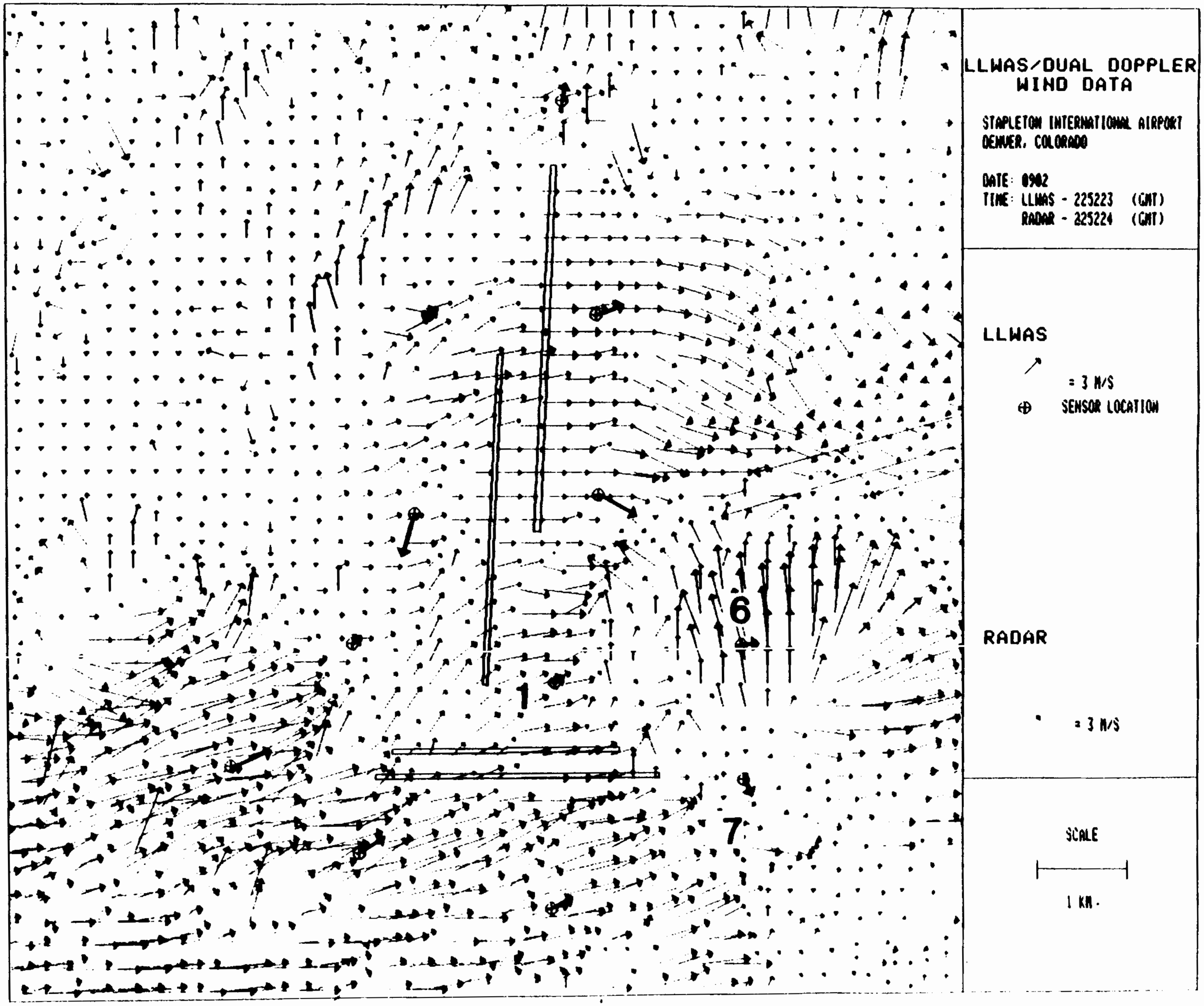

FIGURE 11. LLWAS/DUAL-DOPPLER COMPOSITE WINDS, SEPTEMBER 2, 1987, 225223 UTC

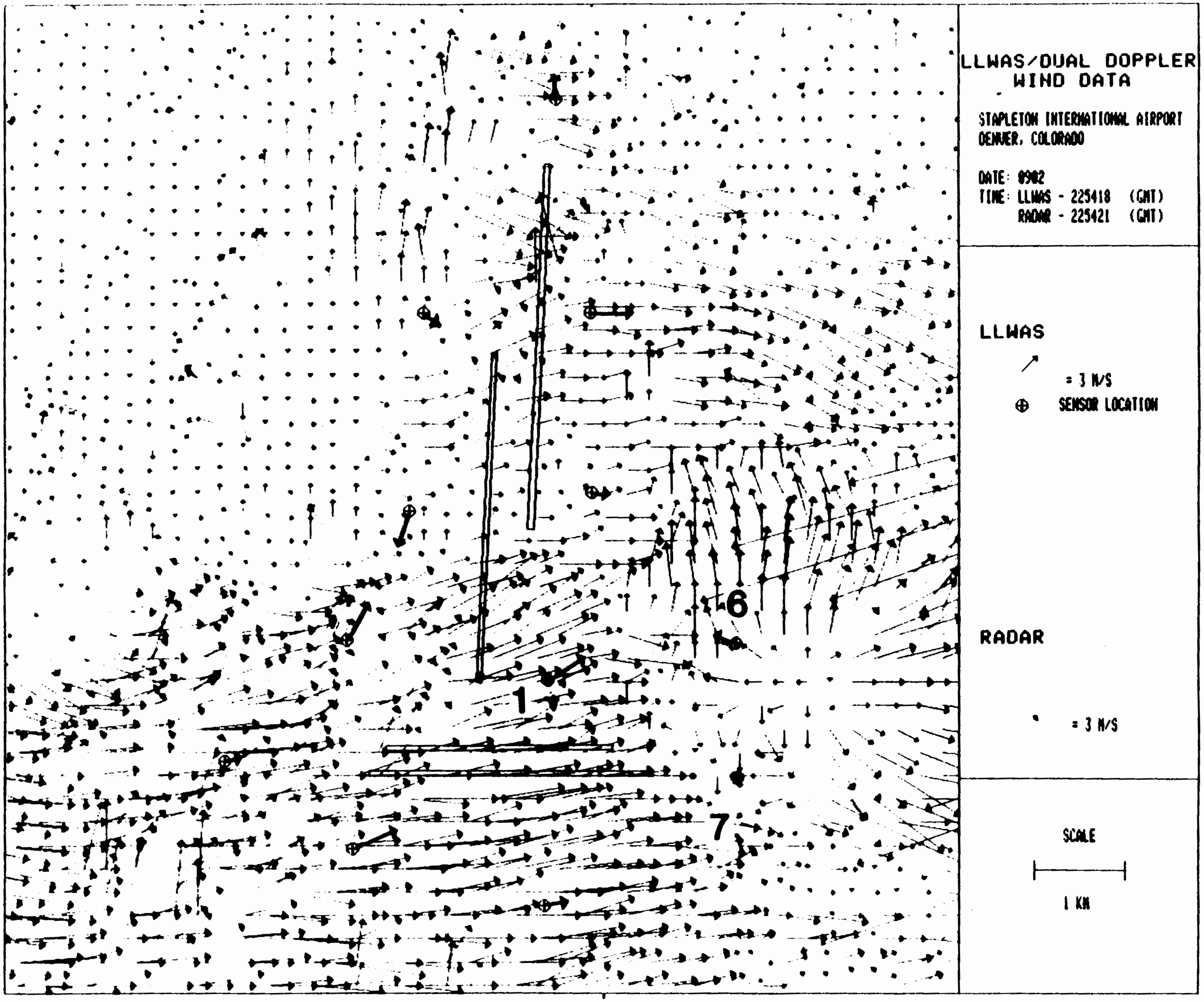

FIGURE 12. LLWAS/DUAL-DOPPLER COMPOSITE WINDS, SEPTEMBER 2, 1987, 225418 UTC

At the same time, a microburst was evident in the LLWAS data over the northern half of the sensor network. Radar winds in figure 11 do not indicate this microburst. The LLWAS winds corresponding to this time are shown in figure 13. The WSMD algorithm did detect this microburst. However, the detection was intermittent because the runway component loss dropped below 25 knots several times. Apparently the signal returned to the radar was very weak, and the detection of this microburst by the radar was impeded.

In summary, the WSMD algorithm performed better than the CFA algorithm in both detection and in the reduction of false alarms, based on analysis of over 3.5 hours of data. Equipment problems prevented the detection of some wind shear and microburst events. The absence of LLWAS sensors at certain locations on the periphery of the network resulted in missed or incomplete detections of events. If maintenance and shielding problems were corrected, and coverage of the north and east ends of the airport were increased, then the performance of the Denver LLWAS would be greatly improved.

HUMAN FACTORS ANALYSIS

LIMITATIONS AND CONSTRAINTS.

Human factors questionnaire forms were intended to be administered to local controller evaluation subjects at four different time intervals. The overall goal was to rate the old LLWAS and to monitor, over a period of time, changes in local controller judgments as they gained experience with the new system.

The following was the questionnaire event sequence scheduled:

Order	Form	When Administered
1st	A	Prior to installation of the new LLWAS
2nd	B	About 1 week after installation of new LLWAS
3rd	B	About halfway through the test period
4th	B	At the end of the test period

Due to time constraints, only the first and second scheduled questionnaire events were accomplished. The Human Factors Questionnaire Form B was administered only once to Denver Stapleton local ATC tower controllers. This occurred two weeks after implementation of the enhancements to the LLWAS at that facility.

PROCEDURE.

BRIEFING OF LOCAL CONTROLLER EVALUATION SUBJECTS. An FAA Technical Center representative briefed each of seven shifts of Stapleton Airport ATC tower local controllers the week of July 19, 1987. The purpose of the briefings was

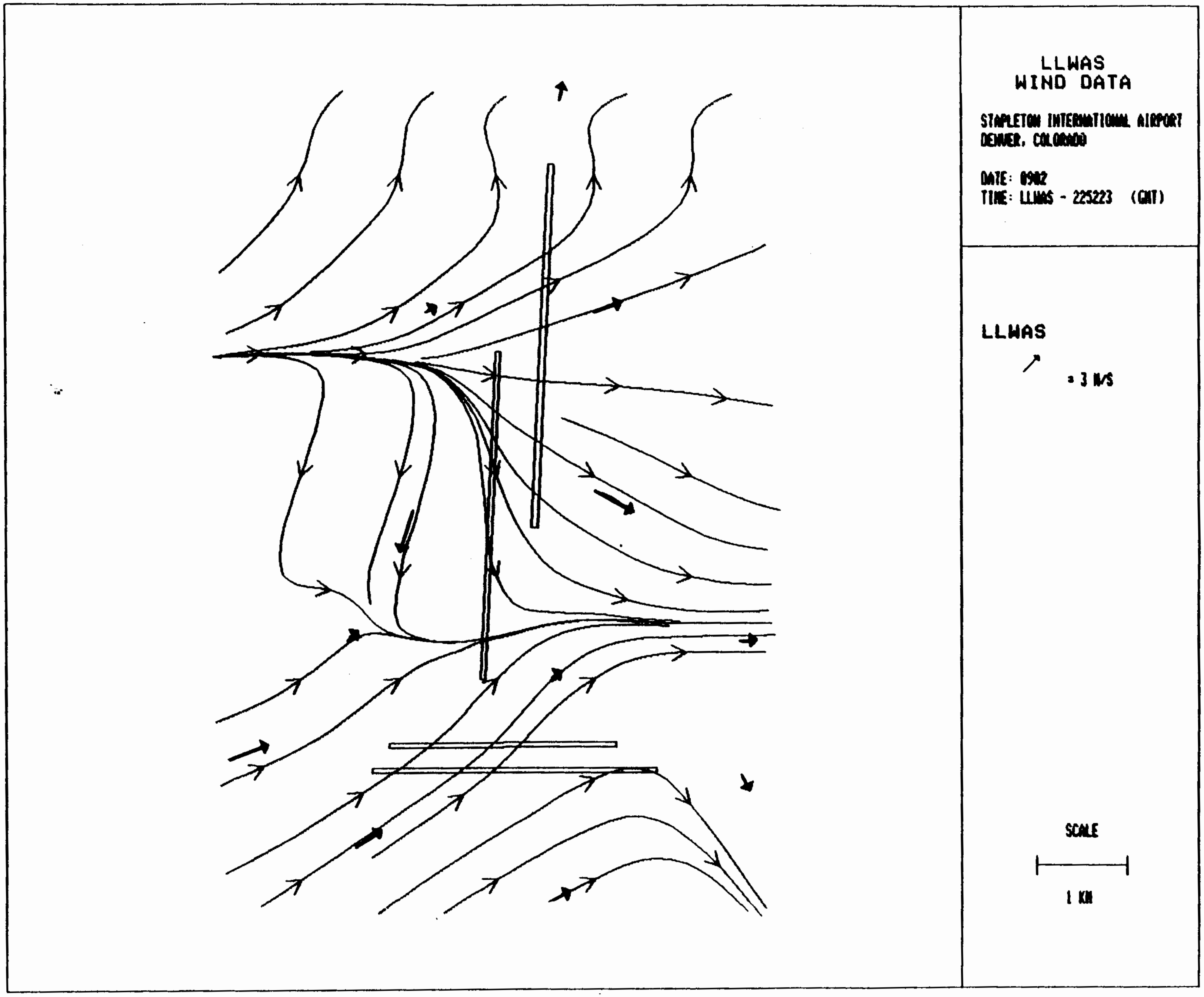

FIGURE 13. LLWAS WINDS, SEPTEMBER 2, 1987, 225223 UTC

to cover details of the Denver LLWAS study and to indicate the need for collecting data from them through use of a Human Factors questionnaire. (A copy of the handout given to the controllers appears on page G-1 of appendix G.) The controllers were thoroughly familiarized with the two Human Factors questionnaire Forms A and B (see appendix G) to insure understanding of the questions. They were asked when completing the forms, to provide their own individual perceptions and evaluations of the LLWAS and to not be swayed by others.

DATA COLLECTION METHODS. Questionnaire Form A was utilized to evaluate the performance of the 11-station pre-enhanced Denver LLWAS in which standard seven-segment incandescent indicator displays were used. Form B was used to evaluate the LLWAS after modification to a 12-station configuration having CRT displays (DEC VT-240's) and new algorithms for improving wind shear detection and the detection and reporting of microbursts.

Forms A and B each consist of three pages and are very similar. Form A differs from Form B in that it does not contain questions 8 and 9 and has the choice for question 1.p. blanked out. Form A questionnaires were distributed at the briefings. All Form A questionnaires were completed prior to the operation of the enhanced LLWAS. Form B questionnaires were distributed about 2 weeks after the startup. Most of the Form B's were returned within 2 weeks of the distribution.

QUESTIONNAIRE DESIGN. The questionnaire design was based on human factors questionnaire design and administration guidelines published in document 4, Reference Documents.

Two types of items were used in the questionnaire: numerical ratings and written narratives. The numerical ratings were made either by checking one of seven columns or circling one of seven multiple-choice responses. There were totals of 23 numerical rating type questions on Form A, 26 on Form B, and 23 in which the differences could be computed. Written narrative items were of two types. The first type were written responses to the solicitation, "Any Comments?" part of the numerical rating-type questions. The second were responses to questions which ask solely for a written, narrative answer; three questions of this type were asked in both Forms A and B.

THE SUBJECTS. Fully qualified, local controllers working in the Stapleton tower were used as subjects for this questionnaire-based evaluation study. Eighteen controllers completed Form A, and 20 completed Form B. Some who completed Form A did not complete Form B and vice versa, so that differences between the two forms could be computed for only 16 of the subjects.

Subjects put their operating initials on each page of the questionnaire. To insure anonymity, a number was assigned on a random basis to each subject. The assigned numbers associated with their forms thereby allowed direct comparison by subject of Form A data with Form B data.

Since not every subject answered every numerical rating question, there were a total of 188 rating responses for Form A, 268 for Form B, and 162 for the differences between the two forms. If every subject had answered every question, there would have been 23 questions x 18 subjects = 414 responses for Form A, 26 x 20 = 520 for Form B, and 23 x 16 = 368 for the differences. The 18 subjects wrote a total of 75 narrative comments on Form A and the 20 subjects wrote a total of 109 comments on Form B.

STATISTICAL ANALYSIS METHODS. The rating responses on the questionnaire forms were assigned numbers which were transcribed onto a computer for analysis. A seven-point scale was used as a means for assigning ratings as follows:

Verbal Anchor	Value	Interval
VERY GOOD	7	6.50 - 7.49...
GOOD	6	5.50 - 6.49...
FAIRLY GOOD	5	4.50 - 5.49...
FAIR (midscale)	4	3.50 - 4.49...
FAIRLY POOR	3	2.50 - 3.49...
POOR	2	1.50 - 2.49...
VERY POOR	1	0.50 - 1.49...

Descriptive and inferential statistics were performed on the ratings for each of the questionnaire items using a spreadsheet program.

Although a multivariate analysis of variance is the theoretically preferred approach to analyzing these data, in the interest of simplicity, speed, and ease of interpretation, independent Student's t tests were performed on each of the items in the questionnaire (document 2, Reference Documents).

T scores (appendix H) were computed for two comparisons (Scs and Sgm):

Scs. Deviation of each question's average rating from the center scale value of 4. This tests whether the rating is significantly to the "good" or to the "poor" side of "fair," using the center or midpoint of the scale (4) as an absolute reference.

Sgm. Deviation of each question's average rating from the Grand Mean for the particular form. The Grand Mean differs for different forms. This test is comparable to "grading on a curve" and shows which aspects were rated significantly above or below the center of the group. It shows which aspects stand out from the others. There should be approximately the same number of aspects falling significantly above and below the Grand Mean, since it should approximate the normal curve.

The Grand Mean per form was computed by summing all the rating responses for all controllers for all questions and dividing by the total number of rating responses. This was possible because all of the questions were phrased so that numerical ratings above 4 always meant favorable, and below 4, unfavorable. Thus, a Grand Mean above or below 4 would show a favorable or unfavorable overall judgment. An alpha level of 0.05 was used to test the statistical significance of all the t tests.

STATISTICAL ANALYSIS RESULTS.

Detailed statistical results for the numerical rating items of the questionnaire appear in six tables of appendix H. Table 6 presents a bottom-line summary of the statistical results shown in appendix H. It shows both Scs and Sgm for the numerical rating data from questionnaire Forms A and B, and the difference between A and B. This format makes it easier to compare the final outcomes for the different tests.

The column labeled Scs for Forms A and B show which questions or aspects had average ratings deviating significantly from the midscale value of 4.0, whereas, midscale for the difference is 0.0. The Sgm columns under Forms A and B show which average ratings deviated significantly from their grand means. The Sgm column under Form B-A shows which differences deviated significantly from the grand mean of the differences. Totals at the bottom of the Scs columns for Forms A and B show many more significantly favorable aspects for Form B (enhanced WSMD LLWAS) than for Form A (prior CFA LLWAS). Twenty aspects were favorable for Form B, whereas, there were only nine for Form A. Form B had no significant unfavorable aspects, whereas, Form A had 3.

An important result in the Form B-A comparison is for questions 22 and 23. It shows that controllers judged that the best aspect of the enhanced WSMD LLWAS was that it provided a greater level of help for both local controllers <u>and</u> pilots than did prior LLWAS.

CONTENT ANALYSIS RESULTS.

Appendix I provides the complete text of all written narrative comments made by the local controllers. The first portion of the appendix shows the results for Form A, while the second section shows the results for Form B. These categories are listed in rank order, the highest number of responses given initially for the first category and, thereafter, in decreasing order.

The content analysis was performed by carefully reading controller comments and creating categories into which similar comments could be placed. The category titles were chosen so that they summarized the gist of the comments which fell under them. It was found that categorizing the comments under the questionnaire items to which they were made was unproductive, since several comments falling in different categories were often made under a given question. Separate sets of categories were used for Forms A and B. Comments for Form A were assigned to 14 categories and those for Form B were assigned to 20 categories.

Table 7 affords a summary of the results of the content analysis of the narrative comments from the questionnaires. The 18 local controllers completing Form A made a total of 75 comments. The 20 local controllers who completed Form B on the enhanced LLWAS wrote 109 comments. The categories are ordered by decreasing frequency of comments in each case. Categories which matched for Forms A and B, show two entries in the number of comments column for Form A. The number of the matching Form B category is shown to the right of its comments count.

TABLE 6. STATISTICAL RESULTS SUMMARY FOR HUMAN FACTORS QUESTIONNAIRE

#	Abbreviated Text of Question	Form A Scs	Form A Sgm	Form B Scs	Form B Sgm	Form B-A Scs	Form B-A Sgm
1	Daytime readability	+	+	+	+	+	
2	Nighttime readability	+	+	+	+		-
3	Readability in glare			+			
4	Noticeability of blinking	+	+	+	+		
5	Audibility of the alarm	+	+	+			
6	Placement of display	+		+			
7	Completeness of info				-		
8	Accuracy of info			+			
9	Absence of false alarms	-	-	+			
10	Timeliness of info	+		+			
11	Usefulness of info			+			
12	Freedom from misinterp.						
13	Ease of accessing info				-	-	-
14	Speed of response			+			
15	Info grouping and order	+			-	-	-
16	Aptness of abbreviations	X	X	+		X	X
17	Naturalness of phraseology	-	-		-	+	
18	Ease of changing runways				-		-
19	Speed of recovery					-	-
20	Effectiveness under outages	-	-	+			
21	Suitability for field use			+		+	
22	ATCS help/hindrance			+	+	+	+
23	Pilot help/hindrance	+		+	+	+	+
24	Relative benefits/problems	+		+	+		
25	Mod. LLWAS better/worse prior	X	X	+	+	X	X
26	Mod. LLWAS suitable opn'l use	X	X	+	-	X	X
27	Grand Mean	+	X	+	X		X
	Total Number Significant +	9	4	20	7	5	2
	-	3	3	0	6	3	5

Form A = Evaluation of prior, 11-station LLWAS with 7-segment incandescent displays (7-31-87).

Form B = Evaluation of enhanced 12-station LLWAS with CRT displays (8-21-87).

Form B-A = Comparison of enhanced amd prior LLWAS: + means enhanced is better.

Scs = t tests showing mean ratings significantly above (+) or below (-) Center Scale, e.g., aspects rated better or worse than FAIR for Forms A and B; enhanced rated better or worse than prior for Form B-A.

Sgm = t tests showing mean differences in ratings significantly above (+) or below (-) the form's Grand Mean, i.e., Overall Average.

X = Not tested or not applicable.

TABLE 7. CONTENT ANALYSIS OF HUMAN FACTORS QUESTIONNAIRE COMMENTS

	Gist of the Comments (Category)	Number of Controllers Commenting Form A	Number of Controllers Commenting Form B
	Form A (Total of 18 Controllers Responded)		
1A	LLWAS is better than previous equipment	9	
2A	Phraseology needs changes	9	7 (5B)
3A	False alarms should be reduced	7	
4A	Pilot gets too much information	7	
5A	Boundary wind information is useful	6	2 (17B)
6A	Make LLWAS easier to use	6	
7A	Question 11 was accuracy and reliability	6	
8A	More specific runway-oriented winds needed	5	11 (2B)
9A	Relocate display	4	3 (12B)
10A	Controller has difficulty interpreting info	2	
11A	System alarms too late for action	2	
12A	Information seems good	2	13 (1B)
13A	Display is easily readable	2	
14A	Miscellaneous (8 comments)		
	Form B (Total of 20 Controllers Responded)		
1B	LLWAS as modified gives good information		13
2B	Adapt display for discrete runway information		11
3B	Replace flashing alarm		9
4B	Display has some readability problems		7
5B	Phraseology needs changes		7
6B	Wind information near runway is preferred		6
7B	Pilot interpretation is easier		4
8B	Centerfield wind is not optimal		4
9B	System shows promise		4
10B	Move headwind "+" and "-" symbols		3
11B	There are some system accuracy problems		3
12B	Move display location		3
13B	Use same displayed message sequence as spoken		3
14B	False alarms are less prevalent		2
15B	Phraseology has decreased		2
16B	Move centerfield wind placement on display		2
17B	Need boundary wind reported		2
18B	Make display tilt and swivel		2
19B	There are some abbreviation problems		2
20B	Miscellaneous (20 comments)		

Note: For the complete text of the comments within each category, refer to appendix I.

DISCUSSION OF RESULTS.

Questionnaire Form B (enhanced LLWAS) results are discussed in this section. Questionnaire Form A (prior LLWAS) results will be addressed only insofar as they provide a baseline for questionnaire Form B results. Table 8 provides combined results of the statistical analysis of the numerical ratings and the content analysis of the written narrative comments as related to four topical categories: I. The Display Equipment; II. Format and Content of the LLWAS Information; III. System Usability and Accuracy; and IV. Overall Evaluation. Ratings are discussed with respect to the Human Factors Aspects of Form B, as appropriate, as related to each of the respective topical categories.

There are four ratings: (1) aspects rated better than the grand mean; (2) aspects rated better than prior LLWAS; (3) aspects rated worse than the grand mean; and (4) aspects rated worse than prior LLWAS.

I. THE DISPLAY EQUIPMENT.

Aspects Rated Better than the Grand Mean.

Aspect 2. "Nighttime readability" of the CRT display was rated VERY GOOD. Our expectations were that the display would be readable under low lighting but suffer readability problems under bright ambient lighting. Thus, the rating of GOOD to VERY GOOD for aspect 1, "Daytime readability" came as a surprise. The readability problems under category 4B of appendix I refer to excessive amounts of information on the display making it crowded and difficult to find needed information.

Aspect 4. "Noticeability of blinking" was rated FAIRLY GOOD to VERY GOOD. In fact, comments indicated that the reverse contrast blinking of alarms was too noticeable and made the message difficult to read. Specific comments are found under category 3B of appendix I.

Aspects Rated Better than Prior LLWAS.

Aspect 1. "Daytime readability" was the only aspect in this group rated significantly better for enhanced LLWAS. Once again, this finding of better daytime readability of the CRT display over the incandescent display was unexpected and contrary to the physical brightness capabilities of the two display types. One explanation for these results might be that the brightness control of the incandescent display was normally kept too low. Placement of the enhanced LLWAS displays (comment category 12B) might also have been a factor in this rating. Another explanation could be that controllers interpreted "readability" as meaning "easiness to read at position" rather than "easiness to see from any position in the cab".

Aspects Rated Worse than the Grand Mean. None.

Aspects Rated Worse than Prior LLWAS. None.

II. FORMAT AND CONTENT OF THE LLWAS INFORMATION.

Aspects Rated Better than the Grand Mean. None.

TABLE 8. NUMERICAL AND NARRATIVE EVALUATION OF THE ENHANCED LLWAS

I. THE DISPLAY EQUIPMENT

Rated Aspects	Statement of the Numerical Results
1 Daytime readability 2+*	Better than FAIR, better than PRIOR
2 Nighttime readability 1+	Better than FAIR, not diff. from PRIOR
3 Readability in glare	Better than FAIR, not diff. from PRIOR
4 Noticeability of blinking 5+	Better than FAIR, not diff. from PRIOR
5 Audibility of the alarm	Better than FAIR, not diff. from PRIOR
6 Placement of display	Better than FAIR, not diff. from PRIOR

Comment Categories	% Controllers Making Comment
3B Replace flashing alarm	45%
4B Display has some readability problems	35%
12B Move display location	15%
18B Make display tilt and swivel	10%

II. FORMAT AND CONTENT OF THE LLWAS INFORMATION

Rated Aspects	Statement of the Numerical Results
7 Completeness of info 6-	Not better than FAIR, not diff. from PRIOR
12 Freedom from misinterp	Not better than FAIR, not diff. from PRIOR
15 Info grouping and order 4-	Not better than FAIR, worse than PRIOR
16 Aptness of abbreviations	Better than FAIR, not asked of PRIOR
17 Naturalness of phraseology 1-	Not better than FAIR, but better than PRIOR

Comment Categories	% Controllers Making Comment
5B Phraseology needs changes	35%
7B Pilot interpretation is easier	20%
10B Move headwind "+" and "-" symbols	15%
13B Use same displayed message sequence as spoken	15%
15B Phraseology has decreased	10%
16B Move centerfield wind placement on display	10%
19B There are some abbreviation problems	10%

Note:
*Aspects followed by a number and a plus or minus sign differ significantly from the grand mean. The number is the rank of the size of the difference (1 = greatest) and the sign its direction (- = worse than, + = better than). Thus, 1+ indicates the highest rated aspect and 1- the lowest.

TABLE 8. NUMERICAL AND NARRATIVE EVALUATION OF THE ENHANCED LLWAS (CONT'D)

III. SYSTEM USABILITY AND ACCURACY

Rated Aspects	Statement of the Numerical Results
9 Absence of false alarms	Better than FAIR, not diff. from PRIOR
10 Timeliness of info	Better than FAIR, not diff. from PRIOR
11 Usefulness of info	Better than FAIR, not diff. from PRIOR
13 Ease of accessing info 3-*	Not better than FAIR, worse than PRIOR
14 Speed of response	Better than FAIR, not diff. from PRIOR
18 Ease of changing runways 5-	Not better than FAIR, not diff. from PRIOR
19 Speed of recovery	Not better than FAIR, worse than PRIOR
20 Effectiveness under outages	Better than FAIR, not diff. from PRIOR

Comment Categories	% Controllers Making Comment
2B Adapt display for discrete runway information	55%
6B Wind information near runway is preferred	30%
8B Centerfield wind is not optimal	20%
11B There are some system accuracy problems	15%
14B False alarms are less prevalent	10%
17B Need boundary wind reported	10%

IV. OVERALL EVALUATION

Rated Aspects	Statement of the Numerical Results
21 Suitability for field use	Better than FAIR, better than PRIOR
22 ATCS help/hindrance 4+	A HELP to A GREAT HELP, better than PRIOR
23 Pilot help/hindrance 3+	A HELP to A GREAT HELP, better than PRIOR
24 Relative benefits/problems 6+	BENEFITS GREATER THAN PROBLEMS, not diff. from PRIOR
25 Mod. LLWAS rel. to prior 7+	Enhanced LLWAS better than PRIOR
26 Mod. LLWAS suited opn'l use 2-	SUITABLE, INSTALL & USE, BUT SOME CHANGES BENEFICIAL, not asked of PRIOR
27 Grand Mean	Better than FAIR, not different from PRIOR

Comment Categories	% Controllers Making Comment
1B LLWAS as modified gives good information	65%
9B System shows promise	20%

Note:
*Aspects followed by a number and a plus or minus sign differ significantly from the grand mean. The number is the rank of the size of the difference (1 = greatest) and the sign its direction (- = worse than, + = better than). Thus, 1+ indicates the highest rated aspect and 1- the lowest.

Aspects Rated Better than Prior LLWAS.

Aspect 17. "Naturalness of phraseology" was not rated better than FAIR but was significantly better than PRIOR. This result relates primarily to comments in categories 7B and 15B.

Aspects Rated Worse than the Grand Mean.

Aspect 17. "Naturalness of phraseology" was rated FAIRLY POOR to FAIR. It was the lowest rated aspect of enhanced LLWAS. This result relates to comments under category 5B, "Phraseology needs changes."

Aspect 15. "Info grouping and order" was rated FAIR to FAIRLY GOOD. The fact that it was worse than the grand mean may be accounted for by the comments under category 13B, "Use same message sequence as spoken" and also comments under category 10B. "Move headwind "+" and "-" symbols."

Aspect 7. "Completeness of information" was rated FAIR to FAIRLY GOOD. This was below the Grand Mean probably because of the comments included under category 2B, "Adapt display for discrete runway information" and category 17B, "Need boundary wind reported." These indicate that the controllers want to be able to access more information on screen, such as boundary winds and gusts.

Aspects Rated Worse than Prior LLWAS.

Aspect 15. "Info grouping and order" was rated not better than FAIR and worse than PRIOR. This relates to comment categories 5B, 10B, and 13B.

III. SYSTEM USABILITY AND ACCURACY.

Aspects Rated Better than the Grand Mean. None.

Aspect Rated Better than Prior LLWAS. None.

Aspect Rated Worse than the Grand Mean.

Aspect 13. "Ease of accessing information" was rated FAIRLY POOR to FAIRLY GOOD. Controllers reported problems with display crowding and reading difficulty in group I, The Display Equipment, comment category 4B, "Display has some readability problems." Also, in group III, categories 2B and 17B, the controllers report items they want now and cannot get.

Aspect 18. "Ease of changing runways" was rated FAIR to FAIRLY GOOD. This result reflects the comments in category 2B.

Aspects Rated Worse than Prior LLWAS.

Aspect 13. "Ease of accessing information" was rated FAIRLY POOR to FAIRLY GOOD, and was also rated worse than the prior LLWAS. This result relates to comments in categories 2B, 6B, and 17B.

Aspect 19. "Speed of recovery" was rated significantly worse than prior LLWAS. This may relate to general lack of confidence in a new system. However, only 9 of the 16 respondents to both questionnaire forms responded here.

IV. OVERALL EVALUATION.

Aspects Rated Better than the Grand Mean.

Aspect 23. "Pilot help/hindrance" for the enhanced LLWAS was rated as a HELP to a GREAT HELP. This appears to relate primarily to comment category 7B, "Pilot interpretation is easier."

Aspect 22. "ATCS help/hindrance" for the enhanced LLWAS was also rated as A HELP to a GREAT HELP. This finding relates to comment category 15B, "Phraseology has decreased."

Aspect 24. "Relative benefits/problems" was rated as BENEFITS SLIGHTLY GREATER THAN to BENEFITS GREATER THAN PROBLEMS. This result relates to the evaluation comments in 1B, 9B, and 14B.

Aspect 25. "Modified LLWAS relative to prior LLWAS" was rated as SLIGHTLY BETTER THAN to BETTER THAN. This result relates to comparative comments made in comment categories 1B, 7B, 14B, 15B, and 17B. Comments in 17B are interesting in that the controllers want to be able to see boundary winds and gusts, which were supplied with the old system, but not with the new one.

Aspects Rated Better than Prior LLWAS.

Aspect 23 Pilot help/hindrance" and Aspect 22 "ATCS help/hindrance." Relate to comparison of modified LLWAS to prior LLWAS. Both aspects were rated significantly better for modified LLWAS than prior LLWAS. The same comments as in Aspects 23 and 22 above.

Aspect 20. "Suitability for field use." The modified LLWAS was rated significantly better than prior LLWAS. Comments in categories 1B, 7B, 14B, 15B, and 20B support this rating.

Aspect 25. "Modified LLWAS relative to prior LLWAS." The modified LLWAS was rated higher than prior. The same comments as above apply.

Aspects Rated Worse than the Grand Mean.

The mean rating response for Aspect 26 "Modified LLWAS's suitability for widespread operational use" was SUITABLE, INSTALL AND USE, BUT SOME CHANGES BENEFICIAL. Positive comments in categories 1B, 7B, 14B, 15B, and 20B are reflected in this final judgment. This result is somewhat less favorable than the grand mean probably because it is an overall summary question and 13 of the 20 comment categories (appendix I) represent changes that the controllers report would improve the system.

Aspect Rated Worse than Prior LLWAS. None.

SUMMARY OF COMMENTS.

A review was performed of the Form B narrative comment categories (appendix I) for purpose of summarizing and identifying the more frequent comment categories (four or more controller responses). The objective was to identify those categories that contained positive comments and those where changes were requested. A listing of those two categories appear below.

POSITIVE COMMENTS.

Category 1B. LLWAS as modified gives good information (13 controllers commented).

Comments indicate that enhanced LLWAS is much improved, giving accurate winds more precisely relative to the runways, in a fashion more usable by the pilot. Four controllers indicated that the accuracy was verified by the pilots (PIREPS).

Category 7B. Pilot interpretation is easier (four controllers commented).

The LLWAS message transmitted from controller to pilot is much easier for pilots to interpret so that there are fewer questions from them.

Category 9B. System shows promise (four controllers commented)

Capability to detect microbursts and their location with respect to the runway serves as an early warning and improves safety by helping the pilot anticipate problems.

COMMENTS REQUESTING CHANGES.

Category 2B. Adapt display for discrete runway information (11 controllers commented).

Controllers want more ability to select what information is displayed on the position CRT display. The most common request was to be able to select any runway wind at either local position.

Category 3B. Replace flashing alarm (nine controllers commented).

The manner in which the alarm line is flashed makes it difficult to read. Replace the flashing with a more readable method.

Category 4B. Display has some readability problems (seven controllers commented).

Because of the LLWAS display's high information density and complexity,the needed data can be hard to find. The display should be enlarged and spread out for easier reading.

Category 5B. Phraseology needs changes (seven controllers commented).

Added phraseology makes local positions difficult to work during busy periods. This may improve as experience with the new phraseology increases.

Category 6B. Wind information near runway is preferred (six controllers commented).

Although runway-oriented wind information is good, controllers would like to be able to see winds at the approach ends of runways when they want to, not just when wind shear or microburst alerts are occurring.

Category 8B. Centerfield wind is not optimal (four controllers commented).

Centerfield wind is not appropriate for runway complexes 26, 8, and 17. Replace centerfield wind by an average of sensors 0, 1, 2, with 11 as a backup.

CONCLUSIONS

METEOROLOGICAL.

Based on the results of the meteorological analysis, it is concluded that:

1. The wind shear microburst detection (WSMD) algorithm was more effective in detecting hazardous wind shears and microbursts on the airport than the centerfield average (CFA) algorithm.

2. The WSMD algorithm had a higher probability of detection and true skill score than the CFA algorithm.

3. The WSMD algorithm had a lower false alarm rate than the CFA algorithm.

4. The effectiveness of runway component algorithms in estimating runway oriented losses and gains could not be addressed due to the unavailability of adequate comparative data.

5. The increase in the number of sensors for the Denver Low Level Wind Shear Alert System (LLWAS) increased the capability to detect wind shear.

6. Maintenance or shielding problems at two of the LLWAS stations prevented the detection of microbursts.

7. More sensors are needed in the north and east ends of the airport to provide adequate coverage in those areas.

8. If maintenance and shielding problems were resolved, and coverage over the airport were increased, then the performance of the Denver LLWAS would be improved.

HUMAN FACTORS.

Based on the results of the analysis of the Denver Controller LLWAS questionnaire, conclusions are provided for four main topical areas, as follows:

I. THE DISPLAY EQUIPMENT. The DEC Model VT-240 CRT was found to be suitable for operational use under various daytime/nightime conditions and under glare situations. However, problems exist with the high information density of the display which causes crowding and, therefore, difficulty in locating needed data. In addition, blinking of the alarm message was distracting and caused difficulty in reading the alert information displayed.

II. FORMAT AND CONTENT OF THE LLWAS INFORMATION. Phraseology of the LLWAS information requires improvement. Format and content of LLWAS information needs further refinement. Improvements need to be investigated in the reporting of runway-oriented winds.

III. SYSTEM USABILITY AND ACCURACY. The CRT display layout should be tailored to show the most pertinent information to the active position. Methods for improvement to consider are organizing the information in a way which the message is spoken, deleting extraneous information, increasing cathode ray tube (CRT) screen size, and/or improving the method of displaying information; e.g., interactive display methods, such as use of paging, scrolling, or global data search.

Centerfield wind as reported is not appropriate for runway complexes 26, 8, and 17.

IV. OVERALL EVALUATION. The consensus of local controller evaluation subjects indicates that the enhanced LLWAS provides accurate, flight-relevant information on low level wind shears and microbursts in a runway-oriented format that is readable by the controller and understandable by the pilot. Some individual aspects of the system could be improved, and these can be accomplished with current state-of-the-art engineering capabilities.

RECOMMENDATIONS

METEOROLOGICAL.

Based on the meteorological conclusions, it is recommended that:

1. The Federal Aviation Administration (FAA) enhance the Low Level Wind Shear Alert System (LLWAS) from a 6-sensor system to an "n"-sensor system.

2. The FAA install an enhanced wind shear microburst detection (WSMD) algorithm such as the one evaluated in this document.

3. The FAA upgrade the master station computer to enable handling of increased processing requirements due to additional sensors and enhanced algorithms.

4. The FAA repair or move problem sensors to improve the performance of the Denver LLWAS.

5. The FAA increase the number of sensors at Denver to provide better coverage of the runways.

HUMAN FACTORS.

Based on the human factors conclusions, it is recommended that the following be accomplished:

I. THE DISPLAY EQUIPMENT. Investigate alternative locations in the air traffic control (ATC) tower cab to determine an optimal location for placement of the cathode ray tube (CRT).

Consider changes to the display to make it easier to access information such as: enlarging the CRT, rearranging, and spreading-out information.

Modify or eliminate the reverse-video or flashing (blinking) to make the alarm information more readable.

II. FORMAT AND CONTENT OF THE LLWAS INFORMATION. Investigate ways to make new phraseology more consistent with currently used phraseology to gain its acceptability by controllers and pilots.

Look for ways to display the LLWAS line message exactly as spoken and with proper abbreviations.

Find better methods for reporting runway-oriented winds; i.e., optimize the format and content of the LLWAS line message.

III. SYSTEM USABILITY AND ACCURACY. Facilitate access to LLWAS data by improving the method of displaying information or by tailoring the layout of LLWAS information on the CRT display.

Investigate ways to give controllers at the active position more control over what information is displayed on their CRT display.

Find an appropriate replacement for the currently used centerfield wind.

Monitor the timeliness and accuracy of the enhanced LLWAS by having controllers solicit pilot reports (PIREPS) and by comparing these with LLWAS alarms.

IV. OVERALL EVALUATION. Continue using the enhanced LLWAS at the Stapleton International Airport while improving the human factors of the controller/LLWAS interface.

Conduct follow-on administrations of the human factors questionnaire (using Form B with minor additions) to obtain information on how the controllers are reacting to continued use of the enhanced LLWAS at Stapleton International

Airport. Such monitoring would be valuable for detecting the presence of positive (Halo or Hawthorne effect) or negative (resistance to change) biases on the part of the controller as refinement of the system continues.

If the results of further human factors questionnaire evaluations warrant, make necessary changes to the LLWAS system. Assure that FAA-ER-500-007/2 engineering requirements, such as safety-bonded CRT faceplates, are in the system specifications.

APPENDIX A

SYSTEM DESCRIPTION OF THE 11-STATION DENVER STAPLETON LLWAS

The 11-station Denver Low Level Wind Shear Alert System (LLWAS) was procured from Fairchild Weston Systems Incorporated (FWSI), Sarasota, Florida. Equipment items comprising this FWSI LLWAS include:

1. Eleven remote stations for gathering wind data. Each remote station consists of an anemometer, status/controller, analog/digital converter, a transceiver with modem, an antenna, and a power supply with an uninterruptible power system.

2. A master station consisting of a Digital Equipment Corporation (DEC) PDP-11/23 computer with 512 kilobytes of random access memory (RAM), two DEC RL02 hard disk drives with 10.4 megabytes (MB), a Cipher model 100 tape drive, a transceiver with modem, an antenna, and a power supply.

3. Seven displays, including two local controller displays (LCD's), four centerfield wind displays (CWD's), and one maintenance terminal display.

The following paragraphs provide a functional description of the LLWAS.

1. Remote Stations. At the remote stations, each of the anemometers continuously generates three analog signals. Two of the analog signals represent the vector components needed by LLWAS to compute wind direction and wind speed. The third signal is tachometer wind speed which is only used at the centerfield remote station for wind gust. The remote station converts these analog signals to digital, arranges the data in a specific message format and, when interrogated by the master control unit, transmits the message.

2. Master Control Unit. The master control unit is the nerve center of the LLWAS. It controls the timing of all transmissions. Approximately once every 7 seconds the PDP-11/23 computer of the master control unit polls each remote station and stores the data in memory. Additionally, the PDP-11/23 carries out final formatting of wind data for the displays, performs system checks and stores data to the hard disk drive. The tape drive is used to back-up data off the hard disk drive so that data can be later processed at the Federal Aviation Administration (FAA) Technical Center.

3. Displays. Each of the two local controller displays provides the controllers with continuously updated data as to centerfield wind direction, wind speed, wind gust (when gusts occur), and the occurrences of wind shear alarms. The CWD provides data as to centerfield wind speed, direction, and gust. The maintenance terminal display enables status monitoring of system performance as well as a means for controlling the loading of the system program and diagnostics.

The functional relationship of the individual LLWAS units and ancillary equipment items is illustrated in figure A-1. A gecgraphical depiction of a typical six station LLWAS, as exists at most of the 92 LLWAS airports in the United States, is shown in figure A-2.

4. Algorithms. The algorithm that has been in general use with the Denver Stapleton 11-station LLWAS for detecting wind shear is known as the

centerfield average (CFA) algorithm. Approximately once every 7 second(s) polling cycle, a 30 second average of measurements from each remote is obtained and compared with a 2 minute (min) running average of measurements at centerfield. If the magnitude of the vector difference between the average at centerfield and the average at a remote is in excess of 15 knots (kt), a wind shear exists and the LLWAS alarms.

Laboratory evaluations of the CFA algorithm at the FAA Technical Center have shown that the CFA does not perform as well as other algorithms (e.g., the airport area average algorithm) for detecting wind shear. Moreover, the CFA algorithm lacked the ability to distinguish between types of wind shear, e.g., it cannot identify a microburst. As a consequence, the CFA algorithm was replaced for the field evaluation with a more complex wind shear microburst detection (WSMD) algorithm.

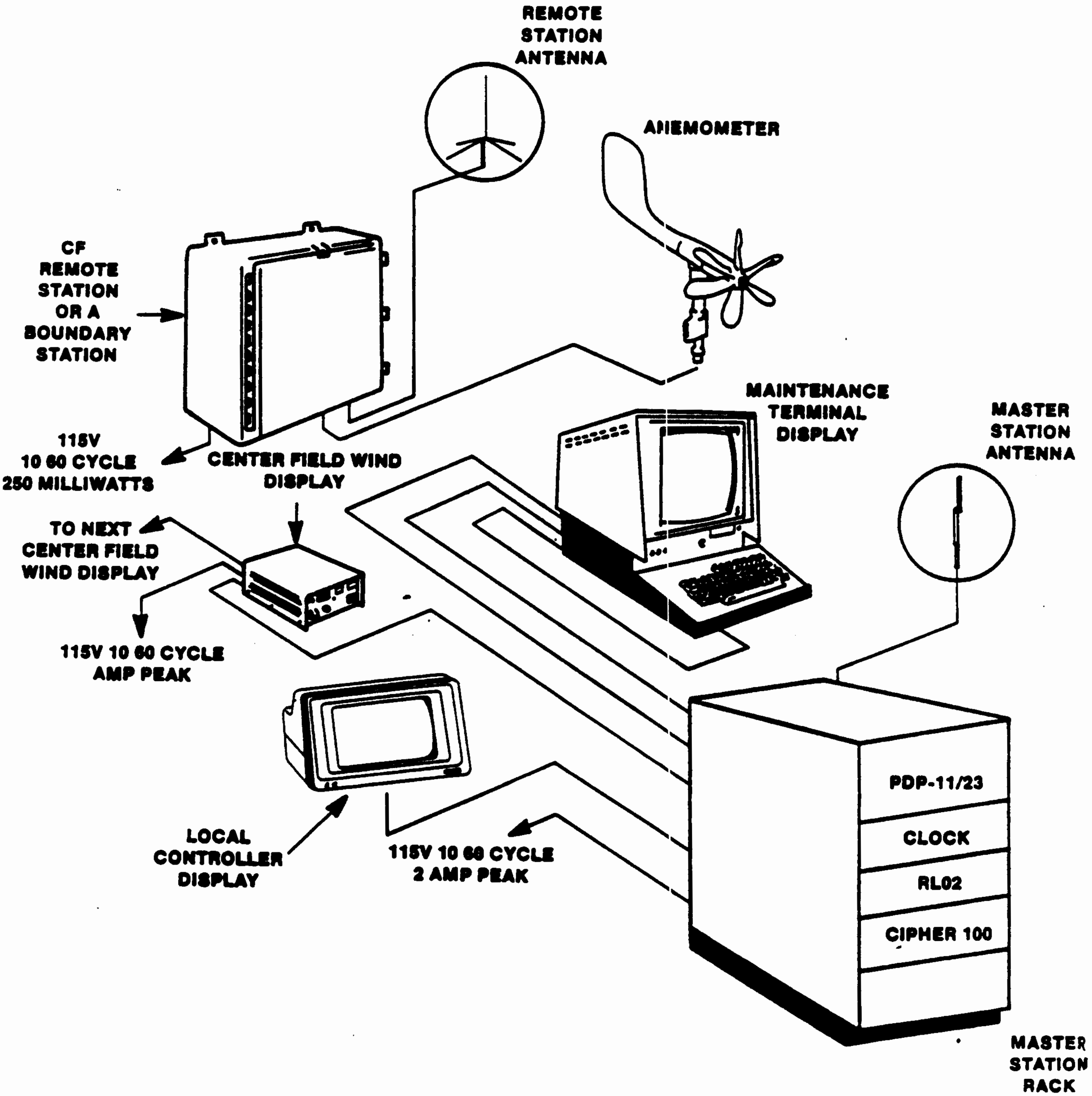

FIGURE A-1. LLWAS FUNCTIONAL RELATIONSHIP OF UNITS

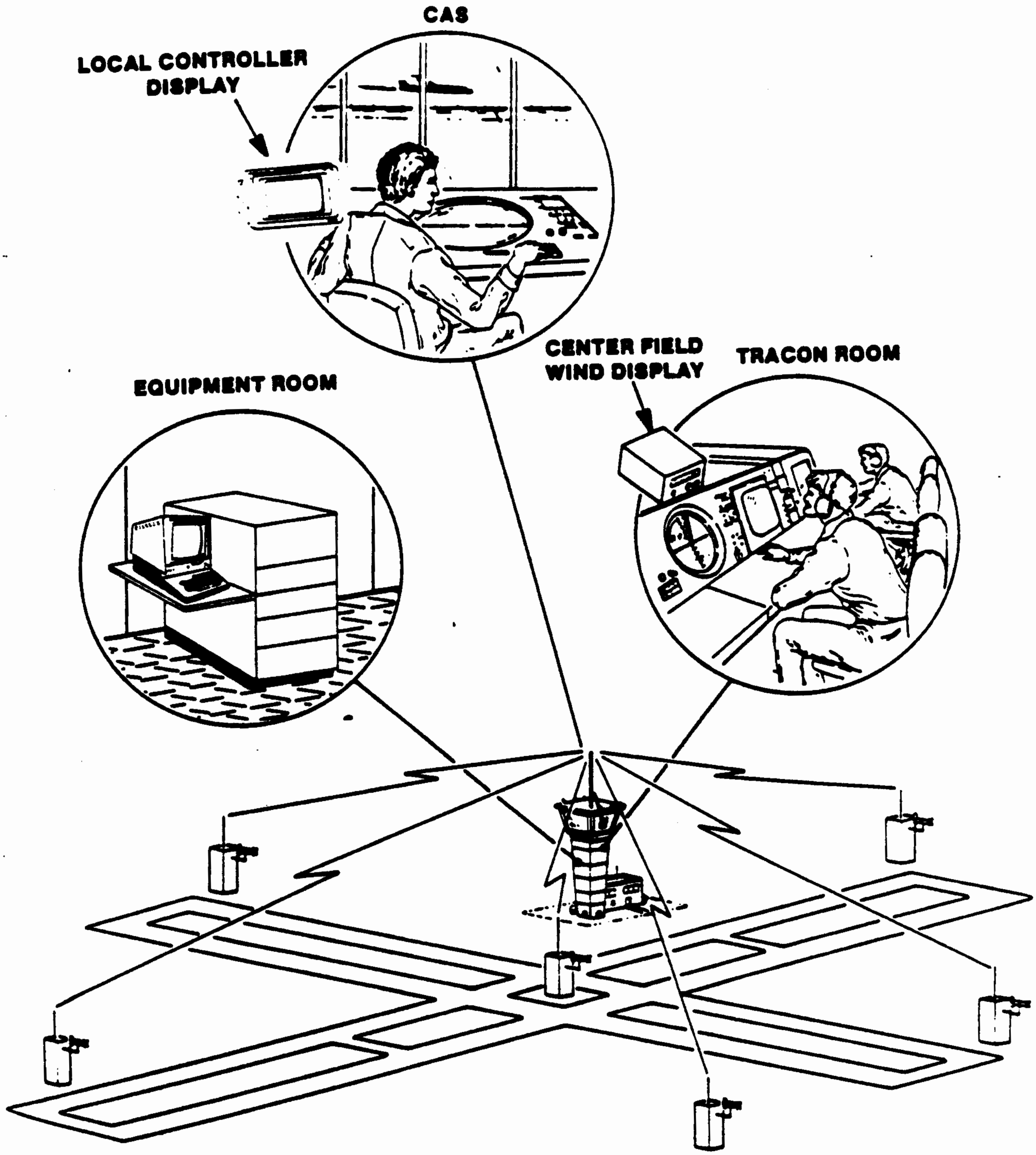

FIGURE A-2. TYPICAL LLWAS

APPENDIX B

OVERVIEW OF DISPLAY TYPES AND FORMATS

The intent of this appendix is to describe the two types of Low Level Wind Shear Alert System (LLWAS) displays that have been used in the Denver Stapleton tower cab to provide wind shear information to the air traffic controller. The Basic LLWAS used an incandescent display while the current Enhanced LLWAS employs a cathode ray tube (CRT) type display. The CRT display was also used during the test and evaluation in August and September 1987. It should be noted that changes were made to the Denver test bed during January 1988 as a result of controller comments to the test and evaluation. The following discussion does not address those changes and the resultant configuration.

In the Basic LLWAS, the local controller display (LCD) (figure B-1) was an incandescent lamp type display and was mounted in the tower control position console. This display was removed when the system was enhanced with the new CRT display. The top line of the LCD continuously displayed the centerfield average wind direction/speed. If a center field reading is not available, 9's are displayed in the field. Gust information was displayed only if a gust was active; otherwise, the gust display was blank. When present, gust information was displayed to the right of the wind direction/speed on the same line. The next five lines displayed each assigned sector's wind direction and speed.

The controller could elect to blank each of the bottom five lines on the LCD corresponding to data from the remote wind units via front panel blanking switches. If a wind shear occurred, the wind data for the reporting wind unit would override the blanking functions and cause the corresponding lines to blink. Each line was identified by a sector designator. Status indicators were located to the left of the wind speed/direction segments. Brightness and alarm volume levels were controlled manually by means of adjusting controls mounted on the display panel in addition to a power on/off control.

The incandescent displays conformed to the Federal Aviation Administration (FAA) engineering requirement FAA-ER-500-007/2, "Consolidated Cab Display/Remote Maintenance Monitor System: Part 2 Display Subsystem," dated May 17, 1979.

The displays used presently in the Denver tower cab and also used during the test and evaluation are DEC VT-240's (figure B-2). They are located at the LC1 and LC2 positions, but are not mounted in the consoles. They are mounted on the window ledge behind the console, just above the upper console edge where viewing angle is optimized. The units were modified to provide access to the brightness and contrast controls at the front of the unit. The VT-240 does not have a safety-bonded faceplate, antireflectivity, or self-test features. It was adopted on a temporary basis for test and evaluation purposes.

The VT-240 display uses a raster scan with larger than standard characters produced by program software. The characters are not as large nor (potentially) as bright as those on the incandescent segment display, but judged acceptable by tower personnel prior to installation for the test and evaluation. The raster scan display shows considerably more information with up to 9 rows of 32 alphanumeric characters on each row. The information format for LC1 position is not the same as that of LC2. LC1 displays a departure configuration while LC2 displays an arrival configuration. Both screens had reverse video and flash when the system displayed an alert message.

An example of the screen format of the LC1 position is shown in figure B-3. Line one displays the centerfield average wind direction and speed in addition to the current system time (UTC). During non-alert times the next eight lines display the runway designator, and wind direction/speed for the arrival runway configurations and only the runway designator for the departure runways of the LC1 position. During an alert, the line changes by displaying the type of event before the runway designator (WSA or MBA) and the loss or gain plus location after the wind direction/speed (see figure B-3). Also, during an alert, the wind direction/speed for the centerfield average appears following the runway designator for the departure runways. The last line of the display indicates the last time a microburst or wind shear event occurred during the last 2 hours (20 minutes for wind shear) in addition to the status of the system. The LC2 position is similar except that a different format is used primarily for the east-west arrival runways (figure B-4). A third indication of a microburst or wind shear occurring is the message "Psbl WS OTSD," which means that a microburst or wind shear may be in progress just outside the network. The message is located just to the right of the event location indicator.

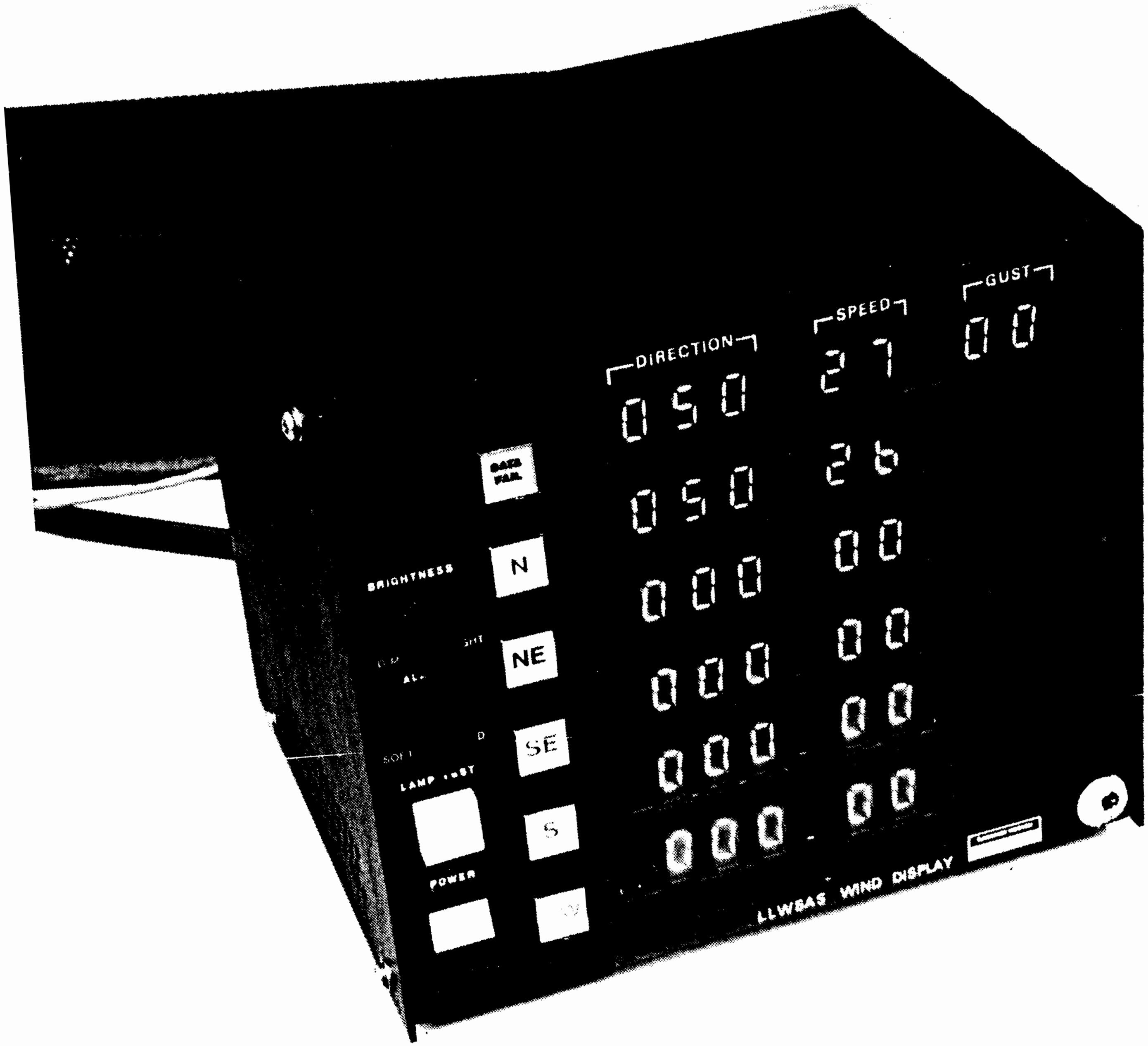

FIGURE B-1. BASIC LLWAS INCANDESCENT LOCAL CONTROLLER DISPLAY

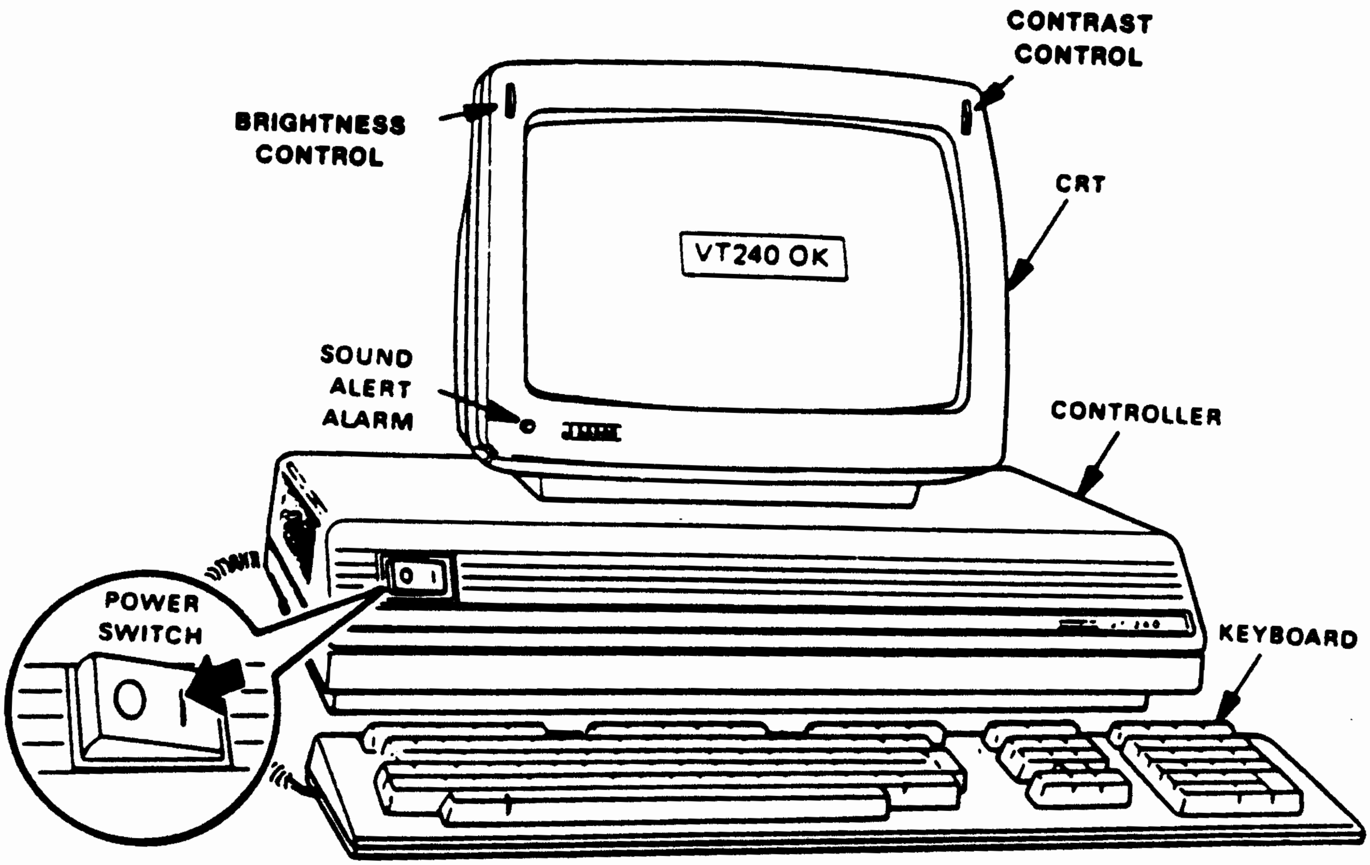

FIGURE B-2. VT240 - FRONT VIEW

```
      CF 280 12                              22:53:44
WSA 35LA 230 10 -15k RWY    Psbl WS OTSD
WSA 35RA 250  6 -15k 1MF    Psbl WS OTSD
WSA 35LD 280 12 -15k RWY
WSA 35RD 280 12 -15k RWY

WSA 17LA 360  0 -15k RWY
WSA 17RA 300  6 -15k 1MF
WSA 17LD 280 12 -15k RWY    Psbl WS OTSD
WSA 17RD 280 12 -15k RWY    Psbl WS OTSD

MBA at 22:52  WSA at 22:53
```

FIGURE B-3. ENHANCED LLWAS DISPLAY FORMAT FOR LC1 POSITION

```
     CF 280 11                              22:53:58
WSA 26A 360   0 +30k 2MF    Psbl WS OTSD
WSA 26D 280  11 +30k RWY

WSA  8A 240  18 +30k 1MF
WSA  8D 280  11 +30k RWY    Psbl WS OTSD


MBA 35LA 230  9 -25k RWY
MBA 35RA 240  6 -25k 1MF
MBA 17LA 360  0 -25k RWY
MBA 17RA 310  6 -25k 1MF

MBA at 22:53 WSA at 22:53
```

FIGURE B-4. ENHANCED LLWAS DISPLAY FORMAT FOR LC2 POSITION

APPENDIX C

PERFORMANCE STATISTICS

This appendix addresses the topic of defining the three measures of algorithm performance used in the meteorological analysis.

1. The probability of detection (POD) is defined by

$$POD = \frac{N_{pe}}{N_{pe} + N_{ue}}$$

It is the number of predicted events (N_{pe}) divided by the sum of N_{pe} and the number of unpredicted events (N_{ue}). This quantity is a measure of how successful the algorithm was at detecting events. Its value ranges from 0 to 1.

2. The false alarm rate (FAR) is defined by

$$FAR = \frac{N_{pn}}{N_{pn} + N_{pe}}$$

It is the number of predicted non-events (N_{pn}) divided by the sum of N_{pn} and the number of predicted events (N_{pe}). The FAR is a measure of algorithm failure and can have values between 0 and 1.

3. The true skill score (TSS) is defined by

$$TSS = \frac{N_{pe}}{N_{pe} + N_{ue}} - \frac{N_{pn}}{N_{total} - (N_{pe} + N_{ue})} .$$

It is the difference between the probability of detection and the probability of false detection, where N_{total} is the total number of polls. The TSS is a relationship between the observed skill of the algorithm and the skill expected if the algorithm performance were perfect. Its value ranges from -1 to +1.

APPENDIX D

TIME WINDOW MATRICES, WSMD ALGORITHM

TABLE D-1. TIME WINDOW MATRIX WSMD ALGORITHM, 8/20/87

All Runways
Date: 8/20/87 Window: 2100-2140

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Sys	Comments
1	2100:00 2115:17 (133)	No Alarm	Y	No Data Available	--	--	None	None	Y	Y	
2	2115:24 2115:31 (2)	WS	N		--	--	MB	WS	N	Y	
3	2115:37 2115:58 (4)	No Alarm	N		--	--	MB	None	N	Y	Symmetric MB was over SW part of field
4	2116:05 2116:53 (8)	No Alarm	Y		--	--	None	None	Y	Y	
5	2117:00 2117:34 (6)	No Alarm	N		--	--	MB	None	N	Y	
6	2117:41 2121:52 (38)	WS	N		N	--	MB	WS	N	Y	
7	2121:59 2123:56 (18)	MB	Y		Y	Y	MB	MB	Y	Y	
8	2124:03 2124:50 (8)	WS	N		Y	--	MB	WS	N	Y	

TABLE D-1. TIME WINDOW MATRIX WSMD ALGORITHM, 8/20/87 (CONT'D)

All Runways
Date: 8/20/87 Window: 2100-2140

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Was LLWAS Correct? Sys	Comments
9	2124:57 2127:21 (22)	MB	Y	No Data Available	Y	--	MB	MB	Y	Y	
10	2127:28 2127:35 (2)	WS	N		--	--	MB	WS	N	Y	
11	2127:41 2128:23 (7)	No Alarm	N		--	--	MB	None	N	Y	MB was observed using FLOWS automated wind sensing stations
12	2128:30 2129:04 (6)	WS	N		--	--	MB	WS	N	Y	
13	2129:10 2130:19 (11)	WS	Y		Y	--	WS	WS	Y	Y	
14	2130:25 2132:56 (23)	No Alarm	N		Y	--	WS	None	N	Y	
15	2133:02 2136:35 (32)	WS	Y		N	--	WS	WS	Y	Y	
16	2136:42 2140:00 (30)	No Alarm	Y		--	--	None	None	Y	Y	

TABLE D-2. TIME WINDOW MATRIX WSMD ALGORITHM, 8/21/87

All Runways
Date: 8/21/87 Window: 2130-2230

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Sys	Comments
1	2130:00 2142:53 (112)	No Alarm	Y	Y	--	--	None	None	Y	Y	
2	2143:00 2144:08 (11)	No Alarm	N	N	--	--	WS	None	N	Y	
3	2144:15 2144:56 (7)	WS	N	N	--	--	MB	MB	N	N	Sheltering and/ or malfunction at stations 6 & 7 caused MB over SE part of field to go undetected
4	2145:03 2145:57 (9)	No Alarm	N	N	--	--	MB	MB	N	N	
5	2146:04 2148:44 (24)	No Alarm	N	N	--	--	WS	None	N	Y	
6	2148:51 2149:32 (7)	WS	Y	Y	--	--	WS	WS	Y	Y	
7	2149:38 2157:33 (70)	No Alarm	N	N	--	--	WS	None	N	Y	
8	2157:40 2207:39 (88)	No Alarm	Y	Y	--	--	None	None	Y	Y	

TABLE D-2. TIME WINDOW MATRIX WSMD ALGORITHM, 8/21/87 (CONT'D)

All Runways
Date: 8/21/87 Window: 2130-2230

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Sys	Comments
9	2207:46 2208:28 (7)	No Alarm	N	N	--	--	WS	None	N	Y	
10	2208:35 2218:42 (90)	WS	Y	Y	N,Y	Y	WS	WS	Y	Y	Gust Front crossed from NW
11	2218:49 2230:00 (98)	No Alarm	Y	Y	--	--	None	None	Y	Y	

TABLE D-3. TIME WINDOW MATRIX WSMD ALGORITHM, 8/26/87

All Runways
Date: 8/26/87 Window: 0000-0100 UTC

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Sys	Comments
1	0000:00 0014:27 (127)	No Alarm	Y	Y	--	--	None	None	Y	Y	
2	0014:33 0015:13 (7)	WS	Y	Y	--	--	WS	WS	Y	Y	
3	0015:20 0023:21 (72)	No Alarm	N	N	N	--	WS	None	N	Y	
4	0023:28 0024:02 (6)	WS	N	N	--	--	None	None	N	N	Sheltering/ alignment prob. at station 11
5	0024:08 0026:44 (24)	No Alarm	Y	Y	--	--	None	None	Y	Y	
6	0026:51 0027:11 (4)	WS	N	N	--	--	MB	WS	N	Y	
7	0027:18 0028:05 (8)	MB	Y	Y	--	--	MB	MB	Y	Y	
8	0028:12 0028:53 (7)	WS	N	N	--	--	MB	WS	N	Y	

TABLE D-3. TIME WINDOW MATRIX WSMD ALGORITHM, 8/26/87 (CONT'D)

All Runways
Date: 8/26/87 Window: 0000-0100 UTC

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Sys	Comments
9	0028:59 0029:20 (4)	MB	Y	Y	--	--	MB	MB	Y	Y	
10	0029:27 0031:15 (17)	WS	N	N	--	--	MB	WS	N	Y	
11	0031:22 0032:31 (11)	MB	Y	Y	--	--	MB	MB	Y	Y	
12	0032:38 0032:58 (4)	WS	N	N	Y	--	MB	WS	N	Y	
13	0033:05 0033:59 (9)	MB	Y	Y	--	--	MB	MB	Y	Y	
14	0034:06 (1)	WS	N	N	--	--	MB	WS	N	Y	
15	0034:13 0036:56 (25)	MB	Y	Y	Y	--	MB	MB	Y	Y	
16	0037:03 0037:16 (3)	WS	N	N	Y	--	MB	WS	N	Y	

TABLE D-3. TIME WINDOW MATRIX WSMD ALGORITHM, 8/26/87 (CONT'D)

All Runways
Date: 8/26/87 Window: 0000-0100 UTC

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Was LLWAS Correct? Sys	Comments
17	0037:23 0037:43 (4)	MB	Y	Y	--	--	MB	MB	Y	Y	
18	0037:50 0038:58 (11)	No Alarm	N	N	Y	--	WS	None	N	Y	
19	0039:04 0039:18 (3)	WS	Y	Y	--	--	WS	WS	Y	Y	
20	0039:25 0100:00 (181)	No Alarm	Y	Y	--	--	None	None	Y	Y	

TABLE D-4. TIME WINDOW MATRIX WSMD ALGORITHM, 9/2/87

All Runways
Date: 9/2/87 Window: 2230-2330

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Sys	Comments
1	2230:00 2238:58 (77)	No Alarm	Y	Y	--	--	None	None	Y	Y	
2	2239:05 2239:52 (8)	No Alarm	Y	N	--	--	MB	MB	N	N	Problem at station 3 prevented detection of MB over NW part of field
3	2239:59 2244:20 (39)	WS	Y	N	Y	--	MB	MB	N	N	" " "
4	2244:27 2244:53 (5)	MB	Y	Y	--	Y	MB	MB	Y	Y	
5	2245:00 2246:49 (17)	WS	N	N	--	N	MB	WS	N	Y	
6	2246:56 2248:45 (17)	WS	Y	Y	--	N	WS	WS	Y	Y	
7	2248:52 2248:59 (2)	WS	N	*	--	N	MB	WS	N	Y	*Not enough signal
8	2249:06 2249:12 (2)	MB	Y	*	--	Y	MB	MB	Y	Y	

TABLE D-4. TIME WINDOW MATRIX WSMD ALGORITHM, 9/2/87 (CONT'D)

All Runways
Date: 9/2/87 Window: 0000-0100 UTC

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Was LLWAS Correct? Sys	Comments
9	2249:19 (1)	WS	N	*	--	N	MB	WS	N	Y	*Not enough signal
10	2249:26 2250:13 (8)	MB	Y	*	Y[1]	Y	MB	MB	Y	Y	1 PIREP + 10 kts leading edge of MB
11	2250:20 2250:54 (6)	WS	N	*	--	N	MB	WS	N	Y	
12	2251:01 2251:48 (8)	MB	Y	*	--	Y	MB	MB	Y	Y	
13	2251:55 2252:23 (5)	WS	N	*	--	N	MB	WS	N	Y	
14	2252:30 2252:57 (5)	MB	Y	*	--	Y	MB	MB	Y	Y	Microburst over N part of field affected N-S runways
15	2251:27 2253:17 (17)	No Alarm	N	N	--	--	MB	MB	N	N	Microburst over E part of field affected E-W runways; was not detected by stations 6 or 7 because of sheltering or malfunction
16	2253:04 2253:37 (6)	WS	N	*	--	N	MB	WS	N	Y	

TABLE D-4. TIME WINDOW MATRIX WSMD ALGORITHM, 9/2/87 (CONT'D)

All Runways
Date: 9/2/87 Window: 2230-2330

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct ? Met	Sys	Comments
17	2253:44 2254:52 (11)	MB	Y	*	--	Y	MB	MB	Y	Y	*Not enough signal
18	2254:59 2255:13 (3)	WS	N	*	--	N	MB	WS	N	Y	
19	2255:19 2256:14 (9)	WS	Y	Y	--	N*	WS	WS	Y	Y	*Observer indicated MB until 2257:00 east of sensors
20	2256:21 2258:16 (17)	WS	N	N	--	--	MB	WS	N	Y	Divergence behind gust front over SW part of field
21	2258:23 2258:43 (4)	WS	Y	Y	--	--	WS	WS	Y	Y	Divergence was disappearing
22	2258:50 2300:47 (17)	No Alarm	Y	Y	--	--	None	None	Y	Y	
23	2300:54 2301:08 (3)	WS	Y	Y	--	--	WS	WS	Y	Y	
24	2301:14 2303:38 (21)	No Alarm	Y	Y	--	--	None	None	Y	Y	

TABLE D-4. TIME WINDOW MATRIX WSMD ALGORITHM, 9/2/87 (CONT'D)

All Runways
Date: 9/2/87 Window: 2230-2330

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Sys	Comments
25	2303:45 2303:58 (3)	WS	Y	Y	Y*	N	WS	WS	Y	Y	*On 35RD -10 kts
26	2304:05 2304:32 (5)	WS	N	N	--	--	MB	WS	N	Y	
27	2304:39 2305:06 (5)	MB	Y	Y	--	Y	MB	MB	Y	Y	
28	2305:13 2305:47 (6)	WS	N	N	--	N	MB	WS	N	Y	
29	2305:54 2307:43 (17)	WS	Y	Y	--	N	WS	WS	Y	Y	
30	2307:50 2308:04 (3)	MB	Y	Y	--	Y	MB	MB	Y	Y	
31	2308:11 2308:17 (2)	WS	N	N	--	--	MB	WS	N	Y	
32	2308:24 2308:31 (2)	No Alarm	N	Y	--	--	MB	None	N	Y	

TABLE D-4. TIME WINDOW MATRIX WSMD ALGORITHM, 9/2/87 (CONT'D)

ALL RUNWAYS
DATE: 9/2/87 WINDOW: 2230-2330

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Sys	Comments
33	2308:37 2309:33 (9)	No Alarm	Y	Y	--	N	None	None	Y	Y	
34	2309:40 2310:28 (8)	WS	Y	Y	--	--	WS	WS	Y	Y	
35	2310:35 2311:49 (12)	MB	N	N	--	Y	WS	WS	N	N	
36	2311:56 2312:30 (6)	WS	Y	Y	--	N	WS	WS	Y	Y	
37	2312:37 2313:04 (5)	No Alarm	N	N	Y	N	WS	None	N	Y	
38	2313:10 2313:17 (2)	WS	Y	Y	--	--	WS	WS	Y	Y	
39	2313:24 2313:58 (6)	No Alarm	N	N	--	--	WS	None	N	Y	
40	2314:05 2314:39 (6)	No Alarm	Y	Y	--	--	None	None	Y	Y	

TABLE D-4. TIME WINDOW MATRIX WSMD ALGORITHM, 9/2/87 (CONT'D)

All Runways
Date: 9/2/87 Window: 2230-2330

No.	Time Slice	LLWAS Message	LLWAS Raw Winds	FL2/UND Dual Doppler	Pilot Reports	Tower Obs	Meteorological Definition	System Definition	Was LLWAS Correct? Met	Was LLWAS Correct? Sys	Comments
41	2314:46 2314:53 (2)	WS	Y	N	--	N	None	None	N	N	Problem at station 3 caused WS alarm
42	2314:59 2318:00 (26)	No Alarm	Y	Y	--	--	None	None	Y	Y	
43	2318:06 2318:20 (3)	WS	Y	Y	--	--	WS	WS	Y	Y	
44	2318:27 2218:34 (2)	No Alarm	N	N	--	--	WS	None	N	Y	
45	2318:40 2319:21 (7)	No Alarm	Y	Y	--	--	None	None	Y	Y	
46	2319:28 2320:01 (6)	MB	N	N	--	--	None	None	N	N	Problem at station 3 caused MB alarm
47	2320:08 2320:15 (2)	WS	N	N	--	--	None	None	N	N	Problem at station 3 caused WS alarm
48	2320:22 2330:00 (144)	No Alarm	Y	Y	--	--	None	None	Y	Y	

APPENDIX E

TIME WINDOW MATRICES, CFA ALGORITHM

TABLE E-1. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 8/20/87

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2100:03 2102:36 (23)	No Alarm	None	None	Y	Y
2	2102:42 2104:48 (19)	Alarm	None	None	N	N
3	2104:55 2107:54 (27)	No Alarm	None	None	Y	Y
4	2108:01 2109:44 (16)	Alarm	None	None	N	N
5	2109:51 2115:03 (46)	No Alarm	None	None	Y	Y
6	2115:10 2115:17 (2)	Alarm	None	None	N	N
7	2115:24 2115:31 (2)	Alarm	Event	Event	Y	Y
8	2115:37 2115:58 (4)	Alarm	Event	None	Y	N

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TABLE E-1. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 8/20/87 (CONT'D)

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2116:05 2116:53 (8)	Alarm	None	None	N	N
10	2117:00 2117:34 (6)	Alarm	Event	None	Y	N
11	2117:41 2117:55 (3)	Alarm	Event	Event	Y	Y
12	2118:02 2118:08 (2)	No Alarm	Event	Event	N	N
13	2118:15 2119:10 (9)	Alarm	Event	Event	Y	Y
14	2119:17 2119:44 (5)	No Alarm	Event	Event	N	N
15	2119:51 2120:38 (8)	Alarm	Event	Event	Y	Y
16	2120:45 2122:40 (18)	No Alarm	Event	Event	N	N

TABLE E-1. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 8/20/87 (CONT'D)

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
17	2122:47 2127:35 (43)	Alarm	Event	Event	Y	Y
18	2127:41 2128:23 (7)	Alarm	Event	None	Y	N
19	2128:30 2130:19 (17)	Alarm	Event	Event	Y	Y
20	2130:25 2132:56 (23)	Alarm	Event	None	Y	N
21	2133:02 2134:32 (14)	Alarm	Event	Event	Y	Y
22	2134:39 2135:13 (6)	No Alarm	Event	Event	N	N
23	2135:20 2136:35 (12)	Alarm	Event	Event	Y	Y
24	2136:42 2140:00 (29)	Alarm	None	None	N	N

TABLE E-2. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 8/20/87

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2100:03 2115:17 (133)	No Alarm	None	None	Y	Y
2	2115:24 2115:31 (2)	No Alarm	Event	Event	N	N
3	2115:37 2115:58 (4)	No Alarm	Event	None	N	Y
4	2116:05 2116:53 (8)	Alarm	None	None	N	N
5	2117:00 2117:07 (2)	Alarm	Event	None	Y	N
6	2117:14 2117:34 (4)	No Alarm	Event	None	N	Y
7	2117:41 2123:08 (49)	No Alarm	Event	Event	N	N
8	2123:14 2127:35 (39)	Alarm	Event	Event	Y	Y
9	2127:41 2128:23 (7)	Alarm	Event	None	Y	N

TABLE E-2. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 8/20/87 (CONT'D)

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
10	2128:30 2129:38 (11)	Alarm	Event	Event	Y	Y
11	2129:45 2129:52 (2)	No Alarm	Event	Event	N	N
12	2129:58 2130:19 (4)	Alarm	Event	Event	Y	Y
13	2130:25 2130:59 (6)	Alarm	Event	None	Y	N
14	2131:06 2132:56 (17)	No Alarm	Event	None	N	Y
15	2133:02 2136:01 (27)	No Alarm	Event	Event	N	N
16	2136:08 2136:35 (5)	Alarm	Event	Event	Y	Y
17	2136:42 2137:29 (8)	Alarm	None	None	N	N
18	2137:36 2140:00 (21)	No Alarm	None	None	Y	Y

TABLE E-3. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 8/20/87

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2100:03 2105:30 (48)	No Alarm	None	None	Y	Y
2	2105:36 2107:13 (15)	Alarm	None	None	N	N
3	2107:20 2110:32 (29)	No Alarm	None	None	Y	Y
4	2110:39 2111:21 (7)	Alarm	None	None	N	N
5	2111:28 2114:22 (26)	No Alarm	None	None	Y	Y
6	2114:29 2115:17 (8)	Alarm	None	None	N	N
7	2115:24 2115:31 (2)	Alarm	Event	Event	Y	Y
8	2115:37 2115:58 (4)	Alarm	Event	None	Y	N
9	2116:05 2116:53 (8)	Alarm	None	None	N	N

TABLE E-3. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 8/20/87 (CONT'D)

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct?	
					Met	Sys
10	2117:00 2117:34 (6)	Alarm	Event	None	Y	N
11	2117:41 (1)	Alarm	Event	Event	Y	Y
12	2117:48 2118:09 (4)	No Alarm	Event	Event	N	N
13	2118:15 2127:35 (83)	Alarm	Event	Event	Y	Y
14	2127:41 2128:23 (7)	Alarm	Event	None	Y	N
15	2128:30 2130:19 (17)	Alarm	Event	Event	Y	Y
16	2130:25 2132:56 (23)	Alarm	Event	None	Y	N
17	2133:02 2136:35 (32)	Alarm	Event	Event	Y	Y
18	2136:42 2140:00 (29)	Alarm	None	None	N	N

TABLE E-4. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 8/20/87

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2100:03 2115:03 (131)	No Alarm	None	None	Y	Y
2	2115:10 2115:17 (2)	Alarm	None	None	N	N
3	2115:24 2115:31 (2)	Alarm	Event	Event	Y	Y
4	2115:37 2115:58 (4)	Alarm	Event	None	Y	N
5	2116:05 2116:19 (3)	Alarm	None	None	N	N
6	2116:26 2116:53 (5)	No Alarm	None	None	Y	Y
7	2117:00 2117:34 (6)	No Alarm	Event	None	N	Y
8	2117:41 2122:54 (47)	No Alarm	Event	Event	N	N

TABLE E-4. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 8/20/87 (CONT'D)

Date: 8/20/87 Window: 2100-2140

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2123:01 2127:35 (41)	Alarm	Event	Event	Y	Y
10	2127:41 2128:23 (7)	Alarm	Event	None	N	Y
11	2128:30 2130:19 (17)	Alarm	Event	Event	Y	Y
12	2130:25 2132:01 (15)	Alarm	Event	None	Y	N
13	2132:08 2132:42 (6)	No Alarm	Event	None	N	Y
14	2132:49 2132:56 (2)	Alarm	Event	None	Y	N
15	2133:02 2133:16 (3)	Alarm	Event	Event	Y	Y
16	2133:23 2136:35 (29)	No Alarm	Event	Event	N	N
17	2136:42 2140:00 (29)	No Alarm	None	None	Y	Y

TABLE E-5. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 8/21/87

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2130:00 2142:53 (112)	No Alarm	None	None	Y	Y
2	2143:00 2144:08 (11)	No Alarm	Event	None	N	Y
3	2144:15 2145:57 (16)	No Alarm	Event	Event	N	N
4	2146:04 2147:35 (14)	No Alarm	Event	None	N	Y
5	2147:42 2148:44 (10)	Alarm	Event	None	Y	N
6	2148:51 2149:32 (7)	Alarm	Event	Event	Y	Y
7	2149:38 2157:33 (70)	Alarm	Event	None	Y	N
8	2157:40 2207:39 (88)	Alarm	None	None	N	N

TABLE E-5. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 8/21/87 (CONT'D)

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2207:46 2208:28 (7)	Alarm	Event	None	Y	N
10	2208:35 2218:42 (90)	Alarm	Event	Event	Y	Y
11	2218:49 2221:20 (23)	Alarm	None	None	N	N
12	2221:27 2223:31 (19)	No Alarm	None	None	Y	Y
13	2223:38 2227:25 (34)	Alarm	None	None	N	N
14	2227:32 2228:07 (6)	No Alarm	None	None	Y	Y
15	2228:13 2229:15 (10)	Alarm	None	None	N	N
16	2229:22 2230:00 (6)	No Alarm	None	None	Y	Y

TABLE E-6. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 8/21/87

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2130:00 2142:53 (112)	No Alarm	None	None	Y	Y
2	2143:00 2144:08 (11)	No Alarm	Event	None	N	Y
3	2144:15 2145:57 (16)	No Alarm	Event	Event	N	N
4	2146:04 2148:37 (23)	No Alarm	Event	None	N	Y
5	2148:44 (1)	Alarm	Event	None	Y	N
6	2148:51 2149:32 (7)	Alarm	Event	Event	Y	Y
7	2149:38 2157:19 (68)	Alarm	Event	None	Y	N
8	2157:26 2157:33 (2)	Alarm	Event	None	Y	N

TABLE E-6. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 8/21/87 (CONT'D)

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2157:40 2158:01 (29)	Alarm	None	None	N	N
10	2158:08 2158:56 (8)	No Alarm	None	None	Y	Y
11	2159:03 2202:44 (33)	Alarm	None	None	N	N
12	2202:50 2207:19 (40)	No Alarm	None	None	Y	Y
13	2207:26 2207:39 (3)	Alarm	None	None	N	N
14	2207:46 2208:28 (7)	Alarm	Event	None	Y	N
15	2208:35 2216:18 (69)	Alarm	Event	Event	Y	Y
16	2216:25 2216:52 (5)	No Alarm	Event	Event	N	N

TABLE E-6. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 8/21/87 (CONT'D)

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
17	2216:59 2218:15 (12)	Alarm	Event	Event	Y	Y
18	2218:21 2218:42 (4)	No Alarm	Event	Event	N	N
19	2218:49 2220:31 (16)	No Alarm	None	None	Y	Y
20	2220:38 2221:06 (5)	No Alarm	None	None	Y	Y
21	2221:13 2225:49 (41)	No Alarm	None	None	Y	Y
22	2225:56 2226:23 (5)	Alarm	None	None	N	N
23	2226:30 2230:00 (33)	No Alarm	None	None	Y	Y

TABLE E-7. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 8/21/87

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2130:00 2142:53 (112)	No Alarm	None	None	Y	Y
2	2143:00 2143:41 (7)	No Alarm	Event	None	N	Y
3	2143:48 2244:08 (4)	Alarm	Event	None	Y	N
4	2144:15 2145:57 (16)	Alarm	Event	Event	Y	Y
5	2146:04 2146:25 (4)	Alarm	Event	None	Y	N
6	2146:32 2147:56 (13)	No Alarm	Event	None	N	Y
7	2148:03 2148:44 (7)	Alarm	Event	None	Y	N
8	2148:51 2149:32 (7)	Alarm	Event	Event	Y	Y

TABLE E-7. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 8/21/87 (CONT'D)

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2149:38 2150:39 (10)	Alarm	Event	None	Y	N
10	2150:46 (1)	No Alarm	Event	None	N	Y
11	2150:53 2157:33 (59)	Alarm	Event	None	Y	N
12	2157:40 2206:17 (76)	Alarm	None	None	N	N
13	2206:24 2206:45 (4)	No Alarm	None	None	Y	Y
14	2206:51 2207:39 (8)	Alarm	None	None	N	N
15	2207:46 2208:28 (7)	Alarm	Event	None	Y	N
16	2208:35 2218:42 (90)	Alarm	Event	Event	Y	Y

TABLE E-7. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 8/21/87 (CONT'D)

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
17	2218:49 2222:08 (30)	Alarm	None	None	N	N
18	2222:15 2222:49 (6)	No Alarm	None	None	Y	Y
19	2222:56 2230:00 (62)	Alarm	None	None	N	N

TABLE E-8. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 8/21/87

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2130:00 2142:53 (112)	No Alarm	None	None	Y	Y
2	2143:00 2144:02 (10)	No Alarm	Event	None	N	Y
3	2144:08 (1)	Alarm	Event	None	Y	N
4	2144:15 2144:49 (6)	Alarm	Event	Event	Y	Y
5	2144:56 2145:58 (10)	No Alarm	Event	Event	N	N
6	2146:04 2148:44 (24)	No Alarm	Event	None	N	Y
7	2148:51 2149:32 (7)	No Alarm	Event	Event	N	N
8	2149:38 2151:21 (16)	No Alarm	Event	None	N	Y
9	2151:28 2154:26 (27)	Alarm	Event	None	Y	N

TABLE E-8. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 8/21/87 (CONT'D)

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
10	2154:34 2155:29 (9)	No Alarm	Event	None	N	Y
11	2155:36 2156:52 (12)	Alarm	Event	None	Y	N
12	2156:58 2157:33 (6)	No Alarm	Event	None	N	Y
13	2157:40 2159:51 (20)	No Alarm	None	None	Y	Y
14	2159:58 2200:25 (5)	Alarm	None	None	N	N
15	2200:32 2201:55 (13)	No Alarm	None	None	Y	Y
16	2202:02 2202:30 (5)	Alarm	None	None	N	N
17	2202:37 2207:33 (44)	No Alarm	None	None	Y	Y

TABLE E-8. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 8/21/87 (CONT'D)

Date: 8/21/87 Window: 2130-2230

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
18	2207:40 (1)	Alarm	None	None	N	N
19	2207:46 2208:28 (7)	Alarm	Event	None	Y	N
20	2208:35 2218:42 (90)	Alarm	Event	Event	Y	Y
21	2218:48 2219:50 (10)	Alarm	None	None	N	N
22	2219:57 2220:17 (4)	No Alarm	None	None	N	N
23	2220:24 2221:06 (7)	Alarm	None	None	N	N
24	2221:13 2225:01 (34)	No Alarm	None	None	Y	Y
25	2225:08 2228:48 (33)	Alarm	None	None	N	N
26	2228:55 2230:00 (10)	No Alarm	None	None	Y	Y

TABLE E-9. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 8/26/87

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	0000:05 0002:42 (24)	No Alarm	None	None	Y	Y
2	0002:49 0005:21 (23)	Alarm	None	None	N	N
3	0005:28 0009:40 (38)	No Alarm	None	None	Y	Y
4	0009:47 0010:55 (11)	Alarm	None	None	N	N
5	0011:02 0013:19 (21)	No Alarm	None	None	Y	Y
6	0013:26 0014:27 (10)	Alarm	None	None	N	N
7	0014:33 0015:13 (7)	Alarm	Event	Event	Y	Y
8	0015:20 0022:34 (65)	Alarm	Event	None	Y	N

TABLE E-9. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 8/26/87 (CONT'D)

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	0022:41 0022:47 (2)	No Alarm	Event	None	N	Y
10	0022:54 0023:21 (5)	Alarm	Event	None	Y	N
11	0023:28 0023:41 (3)	Alarm	None	None	N	N
12	0023:48 0024:56 (11)	No Alarm	None	None	Y	Y
13	0025:02 0026:04 (10)	Alarm	None	None	N	N
14	0026:10 0026:44 (6)	No Alarm	None	None	Y	Y
15	0026:51 0029:06 (21)	No Alarm	Event	Event	N	N
16	0029:13 0037:43 (76)	Alarm	Event	Event	Y	Y

TABLE E-9. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 8/26/87 (CONT'D)

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
17	0037:50 0038:58 (11)	Alarm	Event	None	Y	N
18	0039:04 0039:18 (3)	Alarm	Event	Event	Y	Y
19	0039:25 0053:05 (121)	Alarm	None	None	N	N
20	0053:12 0053:53 (7)	Alarm	None	None	N	N
21	0054:00 0059:55 (51)	Alarm	None	None	N	N

TABLE E-10. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 8/26/87

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	0000:05 0014:27 (127)	No Alarm	None	None	Y	Y
2	0014:33 0014:53 (4)	No Alarm	Event	Event	N	N
3	0015:00 0015:13 (3)	Alarm	Event	Event	Y	Y
4	0015:20 0019:17 (36)	Alarm	Event	None	Y	N
5	0019:24 0020:05 (7)	No Alarm	Event	None	N	Y
6	0020:11 0020:52 (7)	Alarm	Event	None	Y	N
7	0020:59 0023:21 (22)	No Alarm	Event	None	N	Y
8	0023:28 0026:44 (30)	No Alarm	None	None	Y	Y
9	0026:51 0030:35 (34)	No Alarm	Event	Event	N	N

TABLE E-10. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 8/26/87 (CONT'D)

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
10	0030:41 0035:01 (39)	Alarm	Event	Event	Y	Y
11	0035:08 0037:30 (22)	No Alarm	Event	Event	N	N
12	0037:36 0037:43 (2)	Alarm	Event	Event	Y	Y
13	0037:50 0038:44 (9)	Alarm	Event	None	N	Y
14	0038:51 0038:58 (2)	No Alarm	Event	None	N	Y
15	0039:04 0039:18 (3)	No Alarm	Event	Event	N	N
16	0039:25 0042:15 (26)	No Alarm	None	None	Y	Y
17	0042:22 0043:17 (9)	Alarm	None	None	N	N
18	0043:24 0059:55 (146)	No Alarm	None	None	Y	Y

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TABLE E-11. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 8/26/87

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	0000:05 0011:02 (97)	No Alarm	None	None	Y	Y
2	0011:09 0014:27 (30)	Alarm	None	None	N	N
3	0014:33 0015:13 (7)	Alarm	Event	Event	Y	Y
4	0015:20 0023:21 (72)	Alarm	Event	None	Y	N
5	0023:28 0025:09 (16)	Alarm	None	None	N	N
6	0025:16 0025:50 (6)	No Alarm	None	None	Y	Y
7	0025:57 0026:44 (8)	Alarm	None	None	N	N
8	0026:51 0037:43 (97)	Alarm	Event	Event	Y	Y
9	0037:50 0038:58 (11)	Alarm	Event	None	Y	N

TABLE E-11. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 8/26/87 (CONT'D)

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
10	0039:04 0039:18 (3)	Alarm	Event	Event	Y	Y
11	0039:25 0043:51 (40)	Alarm	None	None	N	N
12	0043:58 0050:02 (54)	No Alarm	None	None	Y	Y
13	0050:09 0052:58 (26)	Alarm	None	None	N	N
14	0053:05 0053:53 (8)	No Alarm	None	None	Y	Y
15	0054:00 0055:29 (14)	Alarm	None	None	N	N
16	0055:36 0055:50 (3)	No Alarm	None	None	Y	Y
17	0055:56 0057:19 (13)	Alarm	None	None	N	N
18	0057:25 0059:55 (23)	No Alarm	None	None	Y	Y

TABLE E-12. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 8/26/87

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	0000:05 0011:37 (102)	No Alarm	None	None	Y	Y
2	0011:44 0014:27 (25)	Alarm	None	None	N	N
3	0014:33 0015:13 (67)	Alarm	Event	Event	Y	Y
4	0015:20 0022:20 (63)	Alarm	Event	None	Y	N
5	0022:27 0023:08 (7)	No Alarm	Event	None	N	Y
6	0023:14 0023:21 (2)	Alarm	Event	None	Y	N
7	0023:28 0024:29 (10)	Alarm	None	None	N	N
8	0024:35 0025:57 (13)	No Alarm	None	None	Y	Y

TABLE E-12. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 8/26/87 (CONT'D)

Date: 8/26/87 Window: 0000-0055

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	0026:04 0026:44 (7)	Alarm	None	None	N	N
10	0026:51 0037:43 (97)	Alarm	Event	Event	Y	Y
11	0037:50 0038:58 (11)	Alarm	Event	None	Y	N
12	0039:04 0039:18 (3)	Alarm	Event	Event	Y	Y
13	0039:25 0041:34 (20)	Alarm	None	None	N	N
14	0041:41 0059:55 (161)	No Alarm	None	None	Y	Y

TABLE E-13. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 9/2/87

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2230:00 2238:58 (79)	No Alarm	None	None	Y	Y
2	2239:05 (1)	No Alarm	Event	Event	N	N
3	2239:12 2247:23 (73)	Alarm	Event	Event	Y	Y
4	2247:30 2247:50 (4)	No Alarm	Event	Event	N	N
5	2247:57 2248:31 (6)	Alarm	Event	Event	Y	Y
6	2248:38 2248:45 (2)	No Alarm	Event	Event	N	N
7	2248:52 2248:59 (2)	No Alarm	Event	Event	N	N
8	2249:06 2249:12 (2)	No Alarm	Event	Event	N	N

TABLE E-13. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2249:19 2254:18 (79)	Alarm	Event	Event	Y	Y
10	2254:25 2255:13 (8)	No Alarm	Event	Event	N	N
11	2255:19 2258:43 (31)	Alarm	Event	Event	Y	Y
12	2258:50 2300:47 (18)	Alarm	None	None	N	N
13	2300:54 2301:08 (3)	Alarm	Event	Event	Y	Y
14	2301:14 2303:38 (22)	Alarm	None	None	N	N
15	2303:45 2308:17 (41)	Alarm	Event	Event	Y	Y
16	2308:24 2308:31 (2)	Alarm	Event	None	Y	N

TABLE E-13. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
17	2308:38 2309:33 (9)	Alarm	None	None	N	N
18	2309:40 2312:30 (26)	Alarm	Event	Event	N	N
19	2312:37 2313:04 (5)	Alarm	Event	None	Y	N
20	2313:10 2313:17 (2)	Alarm	Event	Event	Y	Y
21	2313:24 2313:58 (6)	Alarm	Event	None	Y	N
22	2314:05 2318:00 (35)	Alarm	None	None	N	N
23	2318:06 2318:20 (3)	Alarm	Event	Event	Y	Y
24	2318:27 2318:34 (2)	Alarm	Event	None	Y	N

TABLE E-13. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 10 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
25	2318:40 2321:09 (23)	Alarm	None	None	N	N
26	2321:16 2324:22 (28)	No Alarm	None	None	Y	Y
27	2324:29 2327:56 (37)	Alarm	None	None	N	N
28	2328:03 2328:10 (2)	No Alarm	None	None	Y	Y
29	2328:17 2329:19 (10)	Alarm	None	None	N	N
30	2329:26 2329:47 (4)	No Alarm	None	None	Y	Y
31	2329:53 2330:00 (2)	Alarm	None	None	N	N

TABLE E-14. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 9/2/87

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2230:00 2238:58 (79)	No Alarm	None	None	Y	Y
2	2239:05 2240:20 (12)	No Alarm	Event	Event	N	N
3	2240:27 2243:18 (26)	Alarm	Event	Event	Y	Y
4	2243:25 2249:32 (55)	No Alarm	Event	Event	N	N
5	2249:39 2250:40 (10)	Alarm	Event	Event	Y	Y
6	2250:47 2251:01 (3)	No Alarm	Event	Event	N	N
7	2251:07 2252:23 (12)	Alarm	Event	Event	Y	Y
8	2252:30 2252:43 (3)	No Alarm	Event	Event	N	N

TABLE E-14. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2252:50 2253:17 (5)	Alarm	Event	Event	Y	Y
10	2253:24 2256:21 (27)	No Alarm	Event	Event	N	N
11	2256:27 2258:43 (21)	Alarm	Event	Event	Y	Y
12	2258:50 2300:05 (12)	Alarm	None	None	N	N
13	2300:12 2300:19 (2)	No Alarm	None	None	Y	Y
14	2300:26 2300:47 (4)	Alarm	None	None	N	N
15	2300:54 (1)	Alarm	Event	Event	Y	Y
16	2301:01 2301:08 (2)	No Alarm	Event	Event	N	N

TABLE E-14. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
17	2301:14 2303:24 (20)	No Alarm	None	None	Y	Y
18	2303:31 2301:38 (2)	Alarm	None	None	N	N
19	2303:45 2308:17 (41)	Alarm	Event	Event	Y	Y
20	2308:24 2308:31 (2)	Alarm	Event	None	Y	N
21	2308:37 2309:33 (9)	Alarm	None	None	N	N
22	2309:40 2310:28 (8)	Alarm	Event	Event	Y	Y
23	2310:35 2311:49 (12)	Alarm	Event	Event	Y	Y
24	2311:56 2312:30 (6)	Alarm	Event	Event	Y	Y

TABLE E-14. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
25	2312:37 2313:04 (5)	Alarm	Event	None	Y	N
26	2313:10 2313:17 (2)	Alarm	Event	Event	Y	Y
27	2313:24 2313:58 (6)	Alarm	Event	None	Y	N
28	2314:05 2314:39 (6)	Alarm	None	None	N	N
29	2314:46 2314:53 (2)	Alarm	None	None	N	N
30	2314:59 2316:22 (13)	Alarm	None	None	N	N
31	2316:29 2318:20 (17)	No Alarm	Event	Event	N	N
32	2318:27 2318:34 (2)	No Alarm	Event	None	N	Y

TABLE E-14. TIME WINDOW MATRIX CFA ALGORITHM
6-STN, 14 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
33	2318:40 2319:21 (7))	No Alarm	None	None	Y	Y
34	2319:28 2320:01 (6)	No Alarm	None	None	Y	Y
35	2320:08 2320:15 (2)	No Alarm	None	None	Y	Y
36	2320:22 2330:00 (84)	No Alarm	None	None	Y	Y

TABLE E-15. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 9/2/87

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2230:00 2232:53 (26)	No Alarm	None	None	Y	Y
2	2233:00 2233:55 (9)	Alarm	None	None	N	N
3	2234:02 2238:58 (44)	No Alarm	None	None	Y	Y
4	2239:05 (1)	No Alarm	Event	Event	N	N
5	2239:12 2258:43 (173)	Alarm	Event	Event	Y	Y
6	2255:19 2258:50 (18)	Alarm	None	None	N	N
7	2300:54 2301:08 (3)	Alarm	Event	Event	Y	Y
8	2301:14 2303:38 (22)	Alarm	None	None	N	N

TABLE E-15. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2303:45 2308:17 (41)	Alarm	Event	Event	Y	Y
10	2308:24 2308:31 (2)	Alarm	Event	None	Y	N
11	2308:37 2309:33 (9)	Alarm	None	None	N	N
12	2309:40 2312:30 (26)	Alarm	Event	Event	Y	Y
13	2312:37 2313:04 (5)	Alarm	Event	None	Y	N
14	2313:10 2313:17 (2)	Alarm	Event	Event	Y	Y
15	2313:24 2313:58 (6)	Alarm	Event	None	Y	N
16	2314:05 2317:59 (35)	Alarm	None	None	N	N

TABLE E-15. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 10 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
17	2318:06 2318:20 (3)	Alarm	Event	Event	Y	Y
18	2318:27 2318:34 (2)	Alarm	Event	None	Y	N
19	2318:40 2330:00 (100)	Alarm	None	None	N	N

TABLE E-16. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 9/2/87

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
1	2230:00 2238:58 (79)	No Alarm	None	None	Y	Y
2	2239:05 2239:52 (8)	No Alarm	Event	Event	N	N
3	2239:59 2243:05 (28)	Alarm	Event	Event	Y	Y
4	2243:12 2243:59 (8)	No Alarm	Event	Event	N	N
5	2244:06 2246:15 (20)	Alarm	Event	Event	Y	Y
6	2246:22 2246:42 (4)	No Alarm	Event	Event	N	N
7	2246:49 2247:43 (9)	Alarm	Event	Event	Y	Y
8	2247:50 2247:57 (2)	No Alarm	Event	Event	N	N

TABLE E-16. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
9	2248:04 2254:52 (61)	Alarm	Event	Event	Y	Y
10	2254:59 2255:12 (3)	No Alarm	Event	Event	N	N
11	2255:19 2258:50 (32)	Alarm	Event	Event	Y	Y
12	2258:56 2300:40 (16)	No Alarm	None	None	Y	Y
13	2300:47 (1)	Alarm	None	None	N	N
14	2300:54 2301:08 (3)	Alarm	Event	Event	Y	Y
15	2301:14 2303:38 (22)	Alarm	None	None	N	N
16	2303:45 2308:17 (41)	Alarm	Event	Event	Y	Y

TABLE E-16. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 9/2/87 (CONT'D)

Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
17	2308:24 2308:31 (2)	Alarm	Event	None	Y	N
18	2308:38 2309:33 (9)	Alarm	None	None	N	N
19	2309:40 2312:30 (26)	Alarm	Event	Event	Y	Y
20	2312:37 2313:04 (5)	Alarm	Event	None	Y	N
21	2313:10 2313:17 (2)	Alarm	Event	Event	Y	Y
22	2313:24 2313:58 (6)	Alarm	Event	None	Y	N
23	2314:05 2318:00 (35)	Alarm	None	None	N	N
24	2318:06 2318:20 (3)	Alarm	Event	Event	Y	Y

TABLE E-16. TIME WINDOW MATRIX CFA ALGORITHM
12-STN, 14 KNOTS, 9/2/87 (CONT'D)

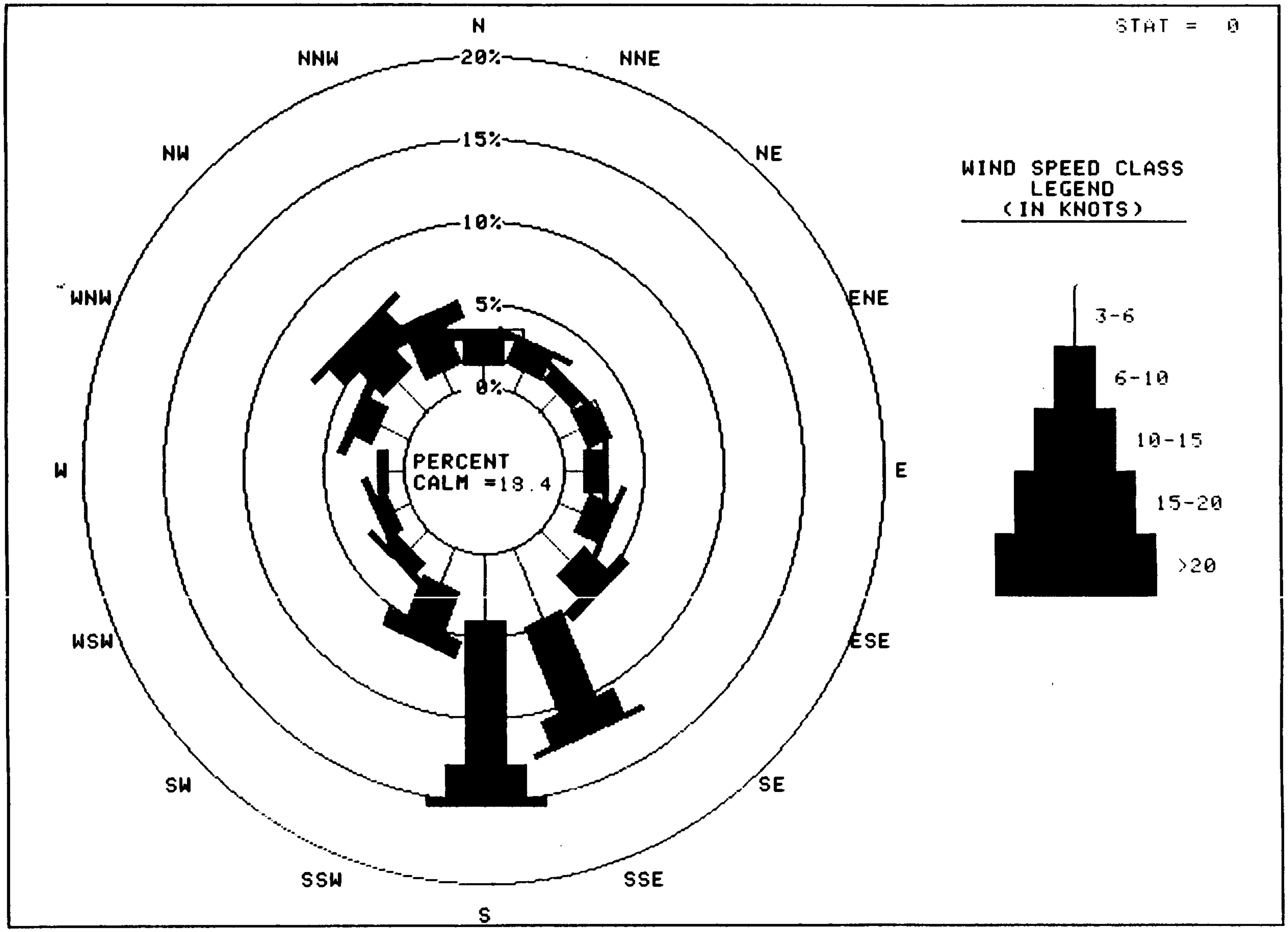
Date: 9/2/87 Window: 2230-2330

No.	Time Slice	Message	Meteorological Definition	System Definition	Was CFA Correct? Met	Sys
25	2318:27 2318:34 (2)	Alarm	Event	None	Y	N
26	2318:40 2326:06 (66)	Alarm	None	None	N	N
27	2326:13 2327:15 (10)	No Alarm	None	None	Y	Y
28	2327:21 2328:44 (13)	Alarm	None	None	N	N
29	2328:51 2329:53 (10)	No Alarm	None	None	Y	Y

APPENDIX F

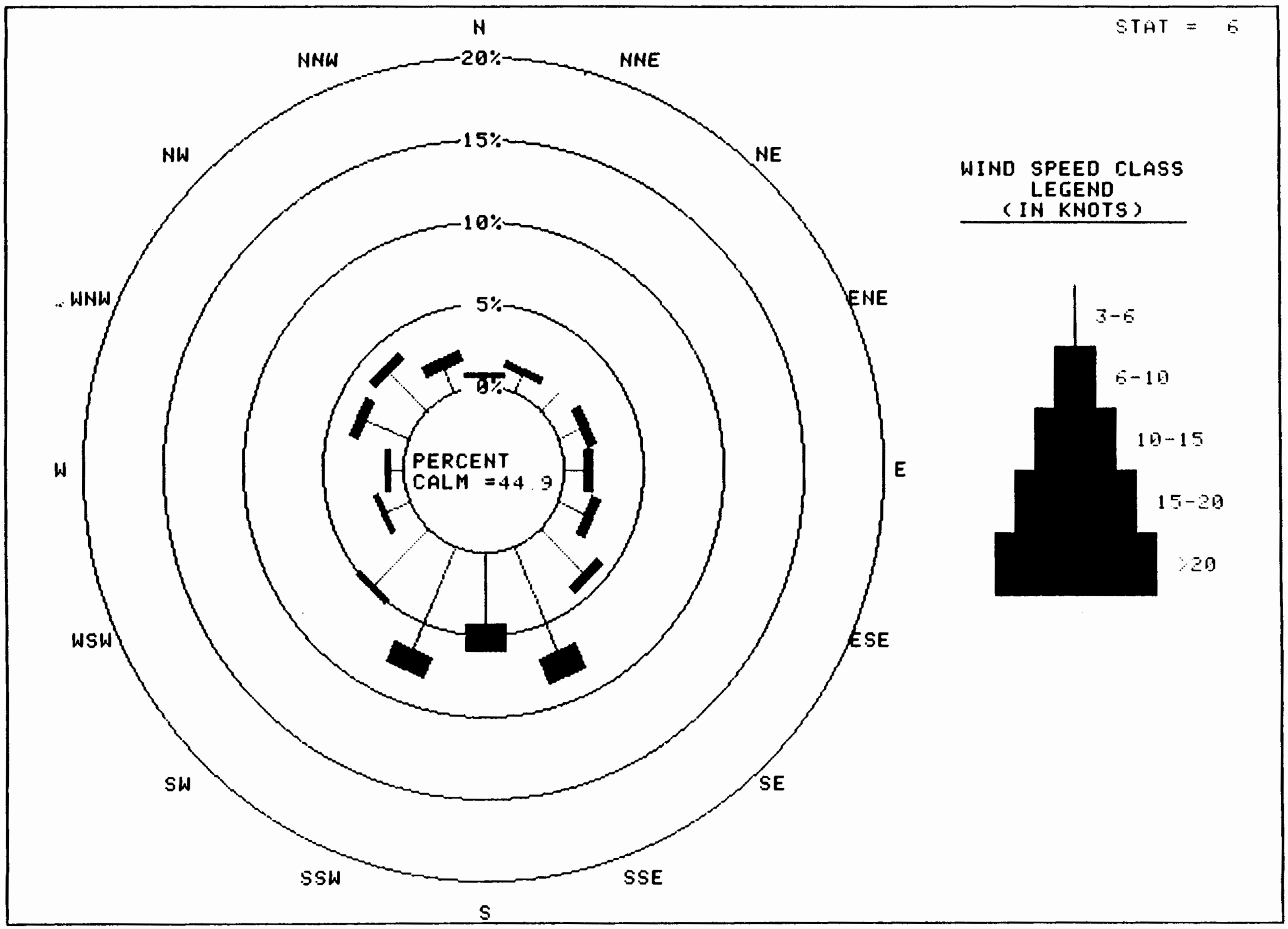
STATION WINDROSES, AUGUST 3 - SEPTEMBER 5, 1987

STATION WINDROSE FOR 8/ 3 TO 9/ 5

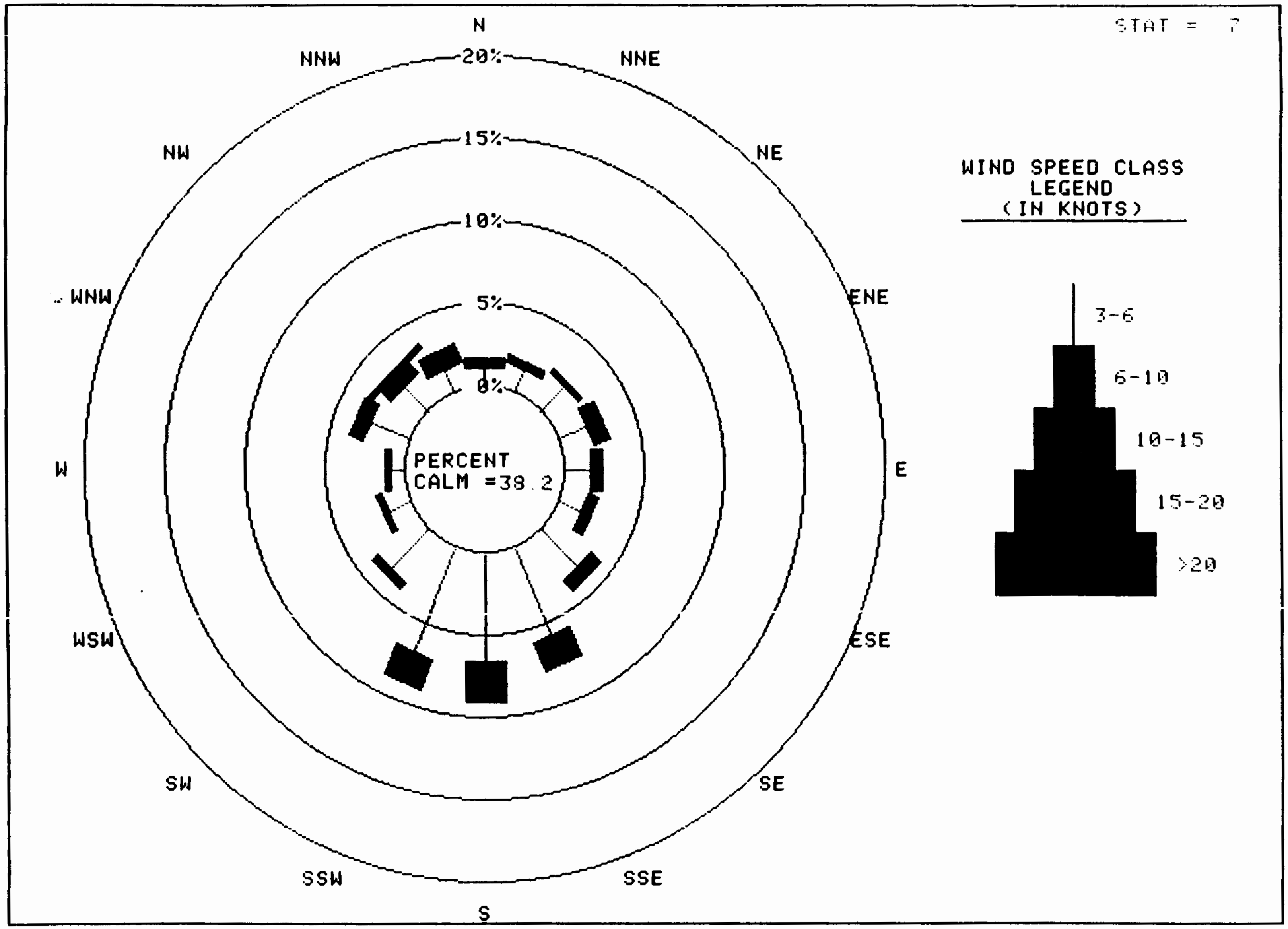


F-1

STATION WINDROSE FOR 8/ 3 TO 9/ 5



STATION WINDROSE FOR 8/ 3 TO 9/ 5



F-3

APPENDIX G

DENVER TOWER HUMAN FACTORS LLWAS EVALUATION: BRIEFING AND EXHIBITS OF THE LOCAL CONTROLLER QUESTIONNAIRE FORMS

BRIEFING ON THE HUMAN FACTORS EVALUATION OF LLWAS AT THE DENVER TOWER
FOR TOWER SUPERVISORS AND CONTROLLER PARTICIPANTS

The FAA Technical Center is supporting the test of the experimental LLWAS at Denver. One of our support roles is the collection and analysis of user evaluations from you, the Denver controller/users of the system. We are collecting data by means of questionnaires. There are two questionnaire forms: A and B. We want to get your evaluation of the LLWAS now in use ("current" in Form A) prior to the installation of the new LLWAS ("modified" in Form B) and then your evaluation of the new LLWAS after it is installed.

Forms A and B are both 3 pages long and are very similar. Form A differs from Form B in that it does not contain questions 7 and 8 and has had the choices for question 1.p. blanked out. You will be asked to complete Form A once prior to the installation of the modified LLWAS and Form B three times following the installation according to the following schedule:

ORDER	FORM	WHEN ADMINISTERED
1st	A	Prior to installation of the new LLWAS
2nd	B	About 1 week after installation of the new LLWAS
3rd	B	About halfway through the test period
4th	B	At the end of the test period.

Why should you have to fill out the questionnaire four times? Typically most of us get used to a given system and, when changes are made, we tend to resist them and have problems just because the new setup is different. The above timing in the administration of the questionnaires will allow us to see how you rate the present system and then to see how your rating of the new system changes over time as you become familiar with it.

We realize that you are busy and have designed the questionnaires to minimize the time and effort needed to complete them. Your considered inputs as users of LLWAS and its display/control interface are very important in this effort to improve airport weather hazard detection and the display interface.

Please read over the questions carefully. If any of them are unclear, ask the FAA Technical Center representative for clarification. The reason for briefing you on this data collection effort is to establish an analytical mental set, to alert you to things to look for and to think about when you use the LLWAS. This should be helpful to you when you come to completing the questionnaires.

It is important that you answer based on your own perception of the LLWAS. Please do not share your answers with your coworkers. It is essential for the evaluation to have as many independent viewpoints as possible. Thank you for your cooperation in this effort.

Paul J. O'Brien

Paul J. O'Brien, Technical Program Manager, ACT-110

Form A Current LLWAS Evaluation Project Number T1203B
ATCS Operating Initials ______ Form Completion Date __________

U.S. Department of Transportation
Federal Aviation Administration

QUESTIONNAIRE FOR LOCAL CONTROLLERS AT DENVER TOWER

HUMAN FACTORS EVALUATION OF CURRENT LLWAS

Please complete this form and return to the representative of the FAA Technical Center. Place your operating initials and the date of completing the form at the top of each page. Your answers will be held in confidence.

1. Please rate different aspects of the current LLWAS using the following scale: (Place check marks in appropriate columns.)

+3 = Very Good
+2 = Good
+1 = Fairly Good
0 = Fair
-1 = Fairly Poor
-2 = Poor
-3 = Very Poor
? = Don't Know

ASPECT OF CURRENT LLWAS	RATING SCALE							
	+3	+2	+1	0	-1	-2	-3	?
a. Daytime readability of the display								
b. Nighttime readability of the display								
c. Readability of display in glare								
d. Noticeability of blinking messages								
e. Audibility of the alarm beeper								
f. Placement of the display								
g. Completeness of the displayed info								
h. Accuracy of the displayed info								
i. Absence of false alarms								
j. Timeliness of the displayed info								
k. Usefulness of the displayed info								
l. Freedom from misinterpretation								
m. Ease of accessing needed wind info								
n. Speed of system response								
o. Info grouping and order within rows								
p. Aptness of message abbreviations	ZZZZ	ZZZZ	ZZZZ	ZZZZ	ZZZZ	ZZZZ	ZZZZ	ZZZ
q. Naturalness of spoken phraseology								
r. Ease of changing runway configuration								
s. Speed of recovery from power failure								
t. Effectiveness under sensor outages								
u. Suitability for continued field use								

Any comments on the above? ____

____

____

Form A Current LLWAS Evaluation Project Number T1203B
ATCS Operating Initials ______ Form Completion Date __________

2. Do you see current LLWAS as a help or a hindrance to you in your job of controlling local traffic? (Please circle one letter below.)

a. A great help
b. A help
c. A slight help
d. Neither help nor hindrance
e. A slight hindrance
f. A hindrance
g. A great hindrance
h. Don't know

Any comments? ____________________________

3. Do you see current LLWAS as a help or a hindrance to the pilot? (Please circle one letter below.)

a. A great help
b. A help
c. A slight help
d. Neither help nor hindrance
e. A slight hindrance
f. A hindrance
g. A great hindrance
h. Don't know

Any comments? ____________________________

4. What's good about the current LLWAS? What benefits do you see?

5. What's poor about the current LLWAS? What problems do you see?

Form A Current LLWAS Evaluation Project Number T1203B
ATCS Operating Initials ______ Form Completion Date __________

6. Please rate the relative magnitude of benefits and problems of the current LLWAS by circling the appropriate letter below.

a. Benefits greatly exceed problems. Any comments? ______________________
b. Benefits exceed problems.
c. Benefits slightly exceed problems. ______________________
d. Benefits equal problems.
e. Problems slightly exceed benefits. ______________________
f. Problems exceed benefits.
g. Problems greatly exceed benefits. ______________________
h. Don't know.

Please list here any changes you feel should be made to the current LLWAS.

As an experienced ATCS and user of this equipment, your input is valuable to us in our efforts to improve it and to increase the efficiency and safety of the National Airspace System. Thank You.

Form B Modified LLWAS Evaluation Project Number T1203B
ATCS Operating Initials ______ Form Completion Date __________

U.S. Department of Transportation
Federal Aviation Administration

QUESTIONNAIRE FOR LOCAL CONTROLLERS AT DENVER TOWER

HUMAN FACTORS EVALUATION OF MODIFIED LLWAS

Please complete this form and return to the representative of the FAA Technical Center. Place your operating initials and the date of completing the form at the top of each page. Your answers will be held in confidence.

1. Please rate different aspects of the modified LLWAS using the following scale: (Place check marks in appropriate columns.)

+3 = Very Good
+2 = Good
+1 = Fairly Good
0 = Fair
-1 = Fairly Poor
-2 = Poor
-3 = Very Poor
? = Don't Know

ASPECT OF MODIFIED LLWAS	RATING SCALE							
	+3	+2	+1	0	-1	-2	-3	?
a. Daytime readability of the display								
b. Nighttime readability of the display								
c. Readability of display in glare								
d. Noticeability of blinking messages								
e. Audibility of the alarm beeper								
f. Placement of the display								
g. Completeness of the displayed info								
h. Accuracy of the displayed info								
i. Absence of false alarms								
j. Timeliness of the displayed info								
k. Usefulness of the displayed info								
l. Freedom from misinterpretation								
m. Ease of accessing needed wind info								
n. Speed of system response								
o. Info grouping and order within rows								
p. Aptness of message abbreviations								
q. Naturalness of spoken phraseology								
r. Ease of changing runway configuration								
s. Speed of recovery from power failure								
t. Effectiveness under sensor outages								
u. Suitability for continued field use								

Any comments on the above? ______________________________________

____

____

Form B | Modified LLWAS Evaluation | Project Number T1203B

ATCS Operating Initials ______ Form Completion Date __________

2. Do you see modified LLWAS as a help or a hindrance to you in your job of controlling local traffic? (Please circle one letter below.)

a. A great help — Any comments? ______________________
b. A help
c. A slight help
d. Neither help nor hindrance
e. A slight hindrance
f. A hindrance
g. A great hindrance
h. Don't know

3. Do you see modified LLWAS as a help or a hindrance to the pilot? (Please circle one letter below.)

a. A great help — Any comments? ______________________
b. A help
c. A slight help
d. Neither help nor hindrance
e. A slight hindrance
f. A hindrance
g. A great hindrance
h. Don't know

4. What's good about the modified LLWAS? What benefits do you see?

5. What's poor about the modified LLWAS? What problems do you see?

Form B Modified LLWAS Evaluation Project Number T1203B
ATCS Operating Initials ______ Form Completion Date __________

6. Please rate the relative magnitude of benefits and problems of the modified LLWAS by circling the appropriate letter below.

a. Benefits greatly exceed problems. Any comments? ____________________
b. Benefits exceed problems.
c. Benefits slightly exceed problems. ______________________________
d. Benefits equal problems.
e. Problems slightly exceed benefits. ______________________________
f. Problems exceed benefits.
g. Problems greatly exceed benefits. ______________________________
h. Don't know.

7. Compare the overall effectiveness of the modified LLWAS (runway-oriented winds) to the prior LLWAS (boundary winds). Choose a phrase below to fill the blank, "The modified LLWAS is ____________________. the prior LLWAS.

a. Much better than Any comments? ____________________
b. Better than
c. Slightly better than ______________________________
d. About the same as
e. Slightly worse than ______________________________
f. Worse than
g. Much worse than ______________________________
h. Don't know

8. Based on your present knowledge, please rate the modified LLWAS's suitability for widespread operational use in the field. Please circle one of the letters a. through h.

a. Suitable, install and use, fine as is, don't make any changes.
b. Suitable, install and use, minor adjustments optional.
c. Suitable, install and use, but some changes beneficial.
d. Marginally suitable, proceed with installation but make changes before use.
e. Unsuitable, don't install, changes definitely needed prior to installation.
f. Unsuitable, don't install, concept OK, but extensive rework mandatory.
g. Unsuitable, don't install, entire concept inappropriate.
h. Don't know.

Please list here any changes you feel should be made to the modified LLWAS.

____

____

____

____

As an experienced ATCS and user of this equipment, your input is valuable to us in our efforts to improve it and to increase the efficiency and safety of the National Airspace System. Thank You.

APPENDIX H

HUMAN FACTORS NUMERICAL RESULTS

Detailed statistical results are presented in tables H-1 through H-6 for the numerical rating items. Tables H-1 through H-3 present results for Form A, Form B, and their difference, respectively, in the order in which they occurred in the questionnaire. In the second set, tables H-4 to H-6, the items are ordered according to their t score relative to the Grand Mean, with the most positive (highest t score) item at the top. Because of the differences between Forms A and B, the numbering of the questionnaire items differs following item 15.

NUMERICAL RATING RESULTS FOR QUESTIONNAIRE FORM A, PRIOR LLWAS.

1. Contrasts with Respect to Center Scale. N was found to be 188 in the analysis of Form A for all controllers and questions, as shown in table H-1. The Form A Grand Mean was 4.60 with a 95 percent confidence interval of 4.34 to 4.86. This is significantly higher than FAIR (center scale); but significantly lower than FAIRLY GOOD. This positive offset is a common finding in questionnaire data. Nine of the human factors aspects of Form A were rated significantly higher than center scale, three rated significantly lower than center scale, and eleven did not differ significantly from center scale.

2. Contrasts with Respect to the Grand Mean. Four human factors aspects were rated significantly higher than the Grand Mean. They are in order of significance (high to low):

Aspect

2. Nightime readability, VERY GOOD;

5. Audibility of the alarm, GOOD;

4. Noticeability of blinking, FAIRLY GOOD to GOOD; and

1. Daytime readability, FAIRLY GOOD to GOOD.

The three human factor aspects which were rated significantly lower than the Grand Mean are:

Aspect

9. Absence of false alarms, FAIRLY POOR;

19. Effectiveness under outages, FAIRLY POOR to POOR; and

16. Naturalness of phraseology, FAIRLY POOR to POOR.

Ratings for the remaining 16 of the 23 items did not deviate significantly from the Grand Mean of 4.60 at an alpha level of 5 percent.

NUMERICAL RATING RESULTS FOR QUESTIONNAIRE FORM B, ENHANCED LLWAS.

1. Contrast with Respect to Center Scale. The Grand Mean was computed across all controllers and questions for an N of 268 (table H-2). The value of the Grand Mean was 5.24 with a 95 percent confidence interval of 5.06 to 5.42.

This is significantly higher than FAIRLY GOOD, but significantly lower than GOOD. It is to be noted that this is 1.24 above the center scale value of FAIR and a more favorable offset than that for Form A.

Twenty of the human factors aspects were rated significantly higher than center scale, none were rated significantly lower than center scale, and seven did not differ significantly from center scale. These results are considerably more positive than those for Form A.

2. Contrasts with Respect to the Grand Mean. The following seven human factor aspects were rated significantly higher than the Grand Mean for all controllers and questions:

Aspect

2. Nighttime readability, VERY GOOD;

1. Daytime readability, GOOD to VERY GOOD;

23. Pilot help/hindrance, A HELP to A GREAT HELP;

22. ATCS help/hindrance, A HELP to A GREAT HELP;

4. Noticeability of blinking, FAIRLY GOOD TO VERY GOOD;

24. Relative benefits/problems, BENEFITS SLIGHTLY GREATER THAN to BENEFITS GREATER THAN PROBLEMS; and

25. Modified LLWAS is better/worse prior LLWAS, SLIGHTLY BETTER THAN to BETTER THAN.

The following six lowest-rated human factors aspects were found to be significantly lower than the Grand Mean for all controllers and questions, but were not significantly worse than center scale (FAIR = 4):

Aspect

7. Completeness of information, FAIR to FAIRLY GOOD;

18. Ease of changing runways, FAIR to FAIRLY GOOD;

15. Info grouping and order, FAIR to FAIRLY GOOD;

13. Ease of accessing info, FAIRLY POOR to FAIRLY GOOD;

26. Modified LLWAS's suitability for widespread operational use, SUITABLE, INSTALL AND USE, BUT SOME CHANGES BENEFICIAL; and

17. Naturalness of phraseology, FAIRLY POOR to FAIR.

The ratings for the remaining 14 of the 27 items did not deviate significantly from the Grand Mean of 5.24 at an alpha level of 5 percent.

NUMERICAL RATING RESULTS FOR THE DIFFERENCES BETWEEN FORM A AND FORM B.

In the 16 cases where both Forms A and B were completed by the local controllers, the ratings for Form A were subtracted from those for Form B and the data submitted to the same type of analyses as described previously. A positive value indicates that the LLWAS human factors aspect in Form B was rated more highly than that aspect in Form A. Although contrasts with respect to the Grand Mean were computed, their meaning is unclear; therefore, they are not discussed below.

Contrasts with Respect to Center Scale. The Grand Mean of the differences was computed across all controllers and questions for an N of 162 (table H-3). The value of the grand mean was 0.36 with a 95 percent confidence interval of 0.08 to 0.79. This result is in the direction of B being better, but is not significant since the confidence interval overlaps zero. Also, the t score for the difference does not differ significantly from zero which is the center scale value for the differences between Forms A and B.

Five of the human factors aspects were rated significantly higher than center scale, three were rated significantly lower than center scale, and sixteen did not differ significantly from center scale.

The local controllers rated the following five human factors aspects significantly better for the new LLWAS:

Aspect

22. Pilot help/hindrance, AFTER BETTER THAN BEFORE;

21. ATCS help/hindrance, AFTER BETTER THAN BEFORE;

20. Suitability for field use, AFTER BETTER THAN BEFORE:

1. Daytime readability, AFTER BETTER THAN BEFORE; and

16. Naturalness of phraseology, AFTER BETTER THAN BEFORE.

The following three human factor aspects were rated significantly worse for the new LLWAS:

Aspect

13. Ease of accessing info, AFTER WORSE THAN BEFORE;

15. Info grouping and order, AFTER WORSE THAN BEFORE;

18. Speed of recovery, AFTER WORSE THAN BEFORE.

The ratings for the other 15 questionnaire form aspects showed no significant differences.

Table H-1. PRE-ENHANCEMENT LLWAS NUMERICAL RATING RESULTS: QUESTIONNAIRE ITEMS ORDERED AS THEY OCCUR IN FORM A

Human Factors Aspects as Addressed in Questionnaire	Descriptive Statistics			Inferential Statistics					
				5% Confid. Interval		Student's t Score		Signif. p<0.05	
# Abbreviated Text of Item	N	Mean	SE	Low	High	tcs	tgm	Scs	Sgm
1 Daytime readability	18	5.44	0.32	4.78	6.11	4.58	2.68	+	+
2 Nighttime readability	18	6.94	0.06	6.83	7.06	53.00	42.21	+	+
3 Readability in glare	18	4.17	0.44	3.23	5.10	0.37	-0.97	NS	NS
4 Noticeability of blinking	16	5.44	0.29	4.82	6.05	4.99	2.91	+	+
5 Audibility of the alarm	18	5.67	0.16	5.33	6.01	10.31	6.60	+	+
6 Placement of display	18	4.83	0.33	4.15	5.52	2.56	0.72	+	NS
7 Completeness of info	18	4.17	0.41	3.31	5.02	0.41	-1.07	NS	NS
8 Accuracy of info	15	3.73	0.43	2.81	4.66	-0.62	-2.01	NS	NS
9 Absence of false alarms	15	3.00	0.46	2.02	3.98	-2.18	-3.49	-	-
10 Timeliness of info	16	4.75	0.27	4.18	5.32	2.82	0.57	+	NS
11 Usefulness of info	18	4.67	0.36	3.90	5.43	1.84	0.19	NS	NS
12 Freedom from misinterp.	18	4.28	0.45	3.33	5.22	0.62	-0.72	NS	NS
13 Ease of accessing info	17	4.29	0.44	3.37	5.22	0.68	-0.70	NS	NS
14 Speed of response	14	4.36	0.31	3.69	5.02	1.16	-0.79	NS	NS
15 Info grouping and order	18	5.11	0.25	4.57	5.65	4.37	2.01	+	NS
16 Naturalness of phraseology	18	2.72	0.38	1.93	3.52	-3.38	-4.97	-	-
17 Ease of changing runways	18	4.83	0.48	3.82	5.85	1.74	0.49	NS	NS
18 Speed of recovery	9	4.22	0.40	3.30	5.15	0.55	-0.94	NS	NS
19 Effectiveness under outages	10	2.60	0.43	1.63	3.57	-3.28	-4.68	-	-
20 Suitability for field use	18	4.06	0.47	3.05	5.06	0.12	-1.15	NS	NS
21 ATCS help/hindrance	17	4.88	0.52	3.77	5.99	1.69	0.54	NS	NS
22 Pilot help/hindrance	16	5.06	0.47	4.06	6.06	2.26	0.99	+	NS
23 Relative benefits/problems	16	5.25	0.47	4.25	6.25	2.66	1.38	+	NS
24 Grand Mean	188	4.60	0.13	4.34	4.86	4.57	0.00	+	NS

Note:

A list of notes explaining the column headings appears on page H-13.

Table H-2. POST-ENHANCEMENT LLWAS NUMERICAL RATING RESULTS: QUESTIONNAIRE ITEMS ORDERED AS THEY OCCUR IN FORM B

Human Factors Aspects as Addressed in Questionnaire		Descriptive Statistics			Inferential Statistics					
					5% Confid. Interval		Student's t Score		Signif. p<0.05	
#	Abbreviated Text of Item	N	Mean	SE	Low	High	tcs	tgm	Scs	Sgm
1	Daytime readability	20	6.35	0.13	6.07	6.63	17.90	8.46	+	+
2	Nighttime readability	20	6.80	0.09	6.61	6.99	30.51	17.00	+	+
3	Readability in glare	19	5.42	0.21	4.98	5.86	6.87	0.88	+	NS
4	Noticeability of blinking	15	6.20	0.34	5.47	6.93	6.45	2.82	+	+
5	Audibility of the alarm	17	5.71	0.29	5.08	6.33	5.80	1.59	+	NS
6	Placement of display	19	4.89	0.35	4.16	5.63	2.56	-0.99	+	NS
7	Completeness of info	19	4.53	0.31	3.87	5.18	1.70	-2.31	NS	-
8	Accuracy of info	17	4.82	0.31	4.16	5.48	2.64	-1.33	+	NS
9	Absence of false alarms	17	5.00	0.36	4.23	5.77	2.75	-0.66	+	NS
10	Timeliness of info	18	5.72	0.34	5.00	6.44	5.05	1.41	+	NS
11	Usefulness of info	19	5.42	0.34	4.69	6.15	4.12	0.53	+	NS
12	Freedom from misinterp.	19	4.58	0.35	3.83	5.32	1.64	-1.87	NS	NS
13	Ease of accessing info	17	3.76	0.44	2.83	4.70	-0.53	-3.34	NS	-
14	Speed of response	17	5.53	0.30	4.90	6.16	5.12	0.97	+	NS
15	Info grouping and order	20	3.95	0.44	3.01	4.89	-0.11	-2.90	NS	-
16	Aptness of abbreviations	19	4.89	0.38	4.09	5.70	2.34	-0.90	+	NS
17	Naturalness of phraseology	20	3.50	0.33	2.81	4.19	-1.52	-5.30	NS	-
18	Ease of changing runways	16	4.38	0.36	3.60	5.15	1.03	-2.38	NS	-
19	Speed of recovery	3	4.00	0.58	1.52	6.48	0.00	-2.15	NS	NS
20	Effectiveness under outages	6	5.17	0.40	4.13	6.20	2.91	-0.18	+	NS
21	Suitability for field use	19	5.47	0.26	4.93	6.02	5.72	0.91	+	NS
22	ATCS help/hindrance	20	6.10	0.24	5.59	6.61	8.77	3.59	+	+
23	Pilot help/hindrance	20	6.35	0.15	6.03	6.67	15.67	7.40	+	+
24	Relative benefits/problems	20	5.80	0.20	5.38	6.22	9.00	2.80	+	+
25	New LLWAS better/worse old	20	5.85	0.23	5.36	6.34	7.96	2.62	+	+
26	New LLWAS suitable opnl use	19	4.74	0.10	4.52	4.96	7.10	-4.84	+	-
27	Grand Mean	268	5.24	0.09	5.05	5.42	13.45	0.00	+	NS

Note:

A list of notes explaining the column headings appears on page H-13.

Table H-3. PRE AND POST-ENHANCEMENT COMPARISON NUMERICAL RESULTS (POST - PRE): QUESTIONNAIRE ITEMS ORDERED AS THEY OCCUR IN FORMS A AND B

Human Factors Aspects as Addressed in Questionnaire		Descriptive Statistics			Inferential Statistics					
					5% Confid. Interval		Student's t Score		Signif. p<0.05	
#	Abbreviated Text of Item	N	Mean	SE	Low	High	tcs	tgm	Scs	Sgm
1	Daytime readability	16	1.06	0.38	0.25	1.88	2.78	1.85	+	NS
2	Nighttime readability	16	-0.13	0.13	-0.39	0.14	-1.00	-3.86	NS	-
3	Readability in glare	16	1.06	0.67	-0.37	2.50	1.58	1.05	NS	NS
4	Noticeability of blinking	15	-0.47	0.86	-2.30	1.37	-0.55	-0.96	NS	NS
5	Audibility of the alarm	16	-1.06	0.67	-2.50	0.37	-1.58	-2.11	NS	NS
6	Placement of display	16	-0.31	0.53	-1.44	0.82	-0.59	-1.26	NS	NS
7	Completeness of info	16	0.19	0.53	-0.93	1.31	0.36	-0.32	NS	NS
8	Accuracy of info	15	1.27	0.78	-0.40	2.93	1.63	1.17	NS	NS
9	Absence of false alarms	15	1.67	0.98	-0.43	3.77	1.70	1.34	NS	NS
10	Timeliness of info	16	0.88	0.85	-0.93	2.68	1.03	0.61	NS	NS
11	Usefulness of info	16	0.69	0.55	-0.48	1.85	1.26	0.60	NS	NS
12	Freedom from misinterp.	16	0.06	0.74	-1.52	1.65	0.08	-0.40	NS	NS
13	Ease of accessing info	16	-1.25	0.54	-2.39	-0.11	-2.33	-3.00	-	-
14	Speed of response	16	1.00	0.86	-0.82	2.82	1.17	0.75	NS	NS
15	Info grouping and order	16	-1.56	0.50	-2.63	-0.50	-3.13	-3.84	-	-
16	Naturalness of phraseology	16	1.00	0.44	0.07	1.93	2.28	1.47	+	NS
17	Ease of changing runways	16	-1.44	0.79	-3.12	0.25	-1.82	-2.27	NS	-
18	Speed of recovery	9	-3.44	0.77	-5.21	-1.68	-4.50	-4.97	-	-
19	Effectiveness under outages	10	0.90	1.06	-1.50	3.30	0.85	0.51	NS	NS
20	Suitability for field use	16	1.63	0.64	0.25	3.00	2.52	1.97	+	NS
21	ATCS help/hindrance	16	1.63	0.54	0.48	2.77	3.01	2.35	+	+
22	Pilot help/hindrance	16	2.13	0.58	0.90	3.35	3.69	3.07	+	+
23	Relative benefits/problems	16	1.38	0.70	-0.12	2.87	1.96	1.45	NS	NS
24	Grand Mean	162	0.36	0.22	-0.08	0.79	1.62	0.00	NS	NS

Note:

A list of notes explaining the column headings appears on page H-13.

Table H-4. PRE-ENHANCEMENT LLWAS NUMERICAL RATING RESULTS (FORM A): ITEMS SORTED ACCORDING TO t SCORE RELATIVE TO THE GRAND MEAN (tgm)

Human Factors Aspects as Addressed in Questionnaire		Descriptive Statistics			Inferential Statistics					
					5% Confid. Interval		Student's t Score		Signif. p<0.05	
#	Abbreviated Text of Item	N	Mean	SE	Low	High	tcs	tgm	Scs	Sgm
2	Nighttime readability	18	6.94	0.06	6.83	7.06	53.00	42.21	+	+
5	Audibility of the alarm	18	5.67	0.16	5.33	6.01	10.31	6.60	+	+
4	Noticeability of blinking	16	5.44	0.29	4.82	6.05	4.99	2.91	+	+
1	Daytime readability	18	5.44	0.32	4.78	6.11	4.58	2.68	+	+
15	Info grouping and order	18	5.11	0.25	4.57	5.65	4.37	2.01	+	NS
23	Relative benefits/problems	16	5.25	0.47	4.25	6.25	2.66	1.38	+	NS
22	Pilot help/hindrance	16	5.06	0.47	4.06	6.06	2.26	0.99	+	NS
6	Placement of display	18	4.83	0.33	4.15	5.52	2.56	0.72	+	NS
10	Timeliness of info	16	4.75	0.27	4.18	5.32	2.82	0.57	+	NS
21	ATCS help/hindrance	17	4.88	0.52	3.77	5.99	1.69	0.54	NS	NS
17	Ease of changing runways	18	4.83	0.48	3.82	5.85	1.74	0.49	NS	NS
11	Usefulness of info	18	4.67	0.36	3.90	5.43	1.84	0.19	NS	NS
24	Grand Mean	188	4.60	0.13	4.34	4.86	4.57	0.00	+	NS
13	Ease of accessing info	17	4.29	0.44	3.37	5.22	0.68	-0.70	NS	NS
12	Freedom from misinterp.	18	4.28	0.45	3.33	5.22	0.62	-0.72	NS	NS
14	Speed of response	14	4.36	0.31	3.69	5.02	1.16	-0.79	NS	NS
18	Speed of recovery	9	4.22	0.40	3.30	5.15	0.55	-0.94	NS	NS
3	Readability in glare	18	4.17	0.44	3.23	5.10	0.37	-0.97	NS	NS
7	Completeness of info	18	4.17	0.41	3.31	5.02	0.41	-1.07	NS	NS
20	Suitability for field use	18	4.06	0.47	3.05	5.06	0.12	-1.15	NS	NS
8	Accuracy of info	15	3.73	0.43	2.81	4.66	-0.62	-2.01	NS	NS
9	Absence of false alarms	15	3.00	0.46	2.02	3.98	-2.18	-3.49	-	-
19	Effectiveness under outages	10	2.60	0.43	1.63	3.57	-3.28	-4.68	-	-
16	Naturalness of phraseology	18	2.72	0.38	1.93	3.52	-3.38	-4.97	-	-

Note:

A list of notes explaining the column headings appears on page H-13.

Table H-5. POST-ENHANCEMENT LLWAS NUMERICAL RATING RESULTS (FORM B): ITEMS SORTED ACCORDING TO t SCORE RELATIVE TO THE GRAND MEAN (t_{gm})

Human Factors Aspects as Addressed in Questionnaire		Descriptive Statistics			Inferential Statistics					
					5% Confid. Interval		Student's t Score		Signif. $p<0.05$	
#	Abbreviated Text of Item	N	Mean	SE	Low	High	tcs	tgm	Scs	Sgm
2	Nighttime readability	20	6.80	0.09	6.61	6.99	30.51	17.00	+	+
1	Daytime readability	20	6.35	0.13	6.07	6.63	17.90	8.46	+	+
23	Pilot help/hindrance	20	6.35	0.15	6.03	6.67	15.67	7.40	+	+
22	ATCS help/hindrance	20	6.10	0.24	5.59	6.61	8.77	3.59	+	+
4	Noticeability of blinking	15	6.20	0.34	5.47	6.93	6.45	2.82	+	+
24	Relative benefits/problems	20	5.80	0.20	5.38	6.22	9.00	2.80	+	+
25	New LLWAS better/worse old	20	5.85	0.23	5.36	6.34	7.96	2.62	+	+
5	Audibility of the alarm	17	5.71	0.29	5.08	6.33	5.80	1.59	+	NS
10	Timeliness of info	18	5.72	0.34	5.00	6.44	5.05	1.41	+	NS
14	Speed of response	17	5.53	0.30	4.90	6.16	5.12	0.97	+	NS
21	Suitability for field use	19	5.47	0.26	4.93	6.02	5.72	0.91	+	NS
3	Readability in glare	19	5.42	0.21	4.98	5.86	6.87	0.88	+	NS
11	Usefulness of info	19	5.42	0.34	4.69	6.15	4.12	0.53	+	NS
27	Grand Mean	268	5.24	0.09	5.06	5.42	13.45	0.00	+	NS
20	Effectiveness under outages	6	5.17	0.40	4.13	6.20	2.91	-0.18	+	NS
9	Absence of false alarms	17	5.00	0.36	4.23	5.77	2.75	-0.66	+	NS
16	Aptness of abbreviations	19	4.89	0.38	4.09	5.70	2.34	-0.90	+	NS
6	Placement of display	19	4.89	0.35	4.16	5.63	2.56	-0.99	+	NS
8	Accuracy of info	17	4.82	0.31	4.16	5.48	2.64	-1.33	+	NS
12	Freedom from misinterp.	19	4.58	0.35	3.83	5.32	1.64	-1.87	NS	NS
19	Speed of recovery	3	4.00	0.58	1.52	6.48	0.00	-2.15	NS	NS
7	Completeness of info	19	4.53	0.31	3.87	5.18	1.70	-2.31	NS	-
18	Ease of changing runways	16	4.38	0.36	3.60	5.15	1.03	-2.38	NS	-
15	Info grouping and order	20	3.95	0.44	3.01	4.89	-0.11	-2.90	NS	-
13	Ease of accessing info	17	3.76	0.44	2.83	4.70	-0.53	-3.34	NS	-
26	New LLWAS suitable opnl use	19	4.74	0.10	4.52	4.96	7.10	-4.84	+	-
17	Naturalness of phraseology	20	3.50	0.33	2.81	4.19	-1.52	-5.30	NS	-

Note:

A list of notes explaining the column headings appears on page H-13.

Table H-6. PRE AND POST-ENHANCEMENT COMPARISON NUMERICAL RESULTS (POST - PRE): ITEMS SORTED ACCORDING TO t SCORE RELATIVE TO THE GRAND MEAN (tgm)

Human Factors Aspects as Addressed in Questionnaire		Descriptive Statistics			Inferential Statistics					
					5% Confid. Interval		Student's t Score		Signif. p<0.05	
#	Abbreviated Text of Item	N	Mean	SE	Low	High	tcs	tgm	Scs	Sgm
22	Pilot help/hindrance	16	2.13	0.58	0.90	3.35	3.69	3.07	+	+
21	ATCS help/hindrance	16	1.63	0.54	0.48	2.77	3.01	2.35	+	+
20	Suitability for field use	16	1.63	0.64	0.25	3.00	2.52	1.97	+	NS
1	Daytime readability	16	1.06	0.38	0.25	1.88	2.78	1.85	+	NS
16	Naturalness of phraseology	16	1.00	0.44	0.07	1.93	2.28	1.47	+	NS
23	Relative benefits/problems	16	1.38	0.70	-0.12	2.87	1.96	1.45	NS	NS
9	Absence of false alarms	15	1.67	0.98	-0.43	3.77	1.70	1.34	NS	NS
8	Accuracy of info	15	1.27	0.78	-0.40	2.93	1.63	1.17	NS	NS
3	Readability in glare	16	1.06	0.67	-0.37	2.50	1.58	1.05	NS	NS
14	Speed of response	16	1.00	0.86	-0.82	2.82	1.17	0.75	NS	NS
10	Timeliness of info	16	0.88	0.85	-0.93	2.68	1.03	0.61	NS	NS
11	Usefulness of info	16	0.69	0.55	-0.48	1.85	1.26	0.60	NS	NS
19	Effectiveness under outages	10	0.90	1.06	-1.50	3.30	0.85	0.51	NS	NS
24	Grand Mean	162	0.36	0.22	-0.08	0.79	1.62	0.00	NS	NS
7	Completeness of info	16	0.19	0.53	-0.93	1.31	0.36	-0.32	NS	NS
12	Freedom from misinterp.	16	0.06	0.74	-1.52	1.65	0.08	-0.40	NS	NS
4	Noticeability of blinking	15	-0.47	0.86	-2.30	1.37	-0.55	-0.96	NS	NS
6	Placement of display	16	-0.31	0.53	-1.44	0.82	-0.59	-1.26	NS	NS
5	Audibility of the alarm	16	-1.06	0.67	-2.50	0.37	-1.58	-2.11	NS	NS
17	Ease of changing runways	16	-1.44	0.79	-3.12	0.25	-1.82	-2.27	NS	-
13	Ease of accessing info	16	-1.25	0.54	-2.39	-0.11	-2.33	-3.00	-	-
15	Info grouping and order	16	-1.56	0.50	-2.63	-0.50	-3.13	-3.84	-	-
2	Nighttime readability	16	-0.13	0.13	-0.39	0.14	-1.00	-3.86	NS	-
18	Speed of recovery	9	-3.44	0.77	-5.21	-1.68	-4.50	-4.97	-	-

Note:

A list of notes explaining the column headings appears on page H-13.

Notes explaining the column headings of the previous six tables are shown below:

= The order in which the item appears in the form (1 = first).

N = Number of local controllers responding to the questionnaire item.

Mean = The average item rating across all the responding controllers. General meanings of scale values are: 1 = WORST, 4 = MIDSCALE, 7 = BEST.

SE = Standard Error of the Mean; a measure of rating variability across subjects.

5% Confid.
Interval = The range centered about the Mean within which, if the study were repeated several times, the new means should fall 95% of the time.

Low = Low limit of the range. Any lower value is significantly below the Mean.

High = High limit of the range. Any higher value is significantly above the Mean.

t Score = In this case a two-tailed statistical test to determine whether the Mean deviates significantly from (falls above or below) a criterion value.

tcs = t test in which the criterion value is Center Scale (4.0 for Form A and Form B and 0.0 for the difference between the two forms).

tgm = t test in which the criterion value is the Grand Mean for the entire form.

Scs, Sgm = Significance levels ($p < 0.05$) for the items' t scores; + = "better than" the criterion value, - = "worse than" the criterion value, and NS = Not Significantly different from the criterion value.

APPENDIX I

HUMAN FACTORS NARRATIVE RESULTS

CONTENT ANALYSIS OF LOCAL CONTROLLER COMMENTS WITH FULL TEXT OF COMMENTS

FORM A - CATEGORIZATION OF ALL COMMENTS (18 CONTROLLERS)

1A. LLWAS IS BETTER THAN PREVIOUS EQUIPMENT	(9 Controllers)
2A. PHRASEOLOGY NEEDS CHANGES	(9 Controllers)
3A. FALSE ALARMS SHOULD BE REDUCED	(7 Controllers)
4A. PILOT GETS TOO MUCH INFORMATION	(7 Controllers)
5A. BOUNDARY WIND INFORMATION IS USEFUL	(6 Controllers)
6A. MAKE LLWAS EASIER TO USE	(6 Controllers)
7A. QUESTION LLWAS ACCURACY AND RELIABILITY	(6 Controllers)
8A. MORE SPECIFIC RUNWAY-ORIENTED WINDS NEEDED	(5 Controllers)
9A. RELOCATE DISPLAY	(4 Controllers)
10A. CONTROLLER HAS DIFFICULTY INTERPRETING INFORMATION	(2 Controllers)
11A. SYSTEM ALARMS TOO LATE FOR ACTION	(2 Controllers)
12A. ACCURACY SEEMS GOOD	(2 Controllers)
13A. DISPLAY IS EASILY READABLE	(2 Controllers)
14A. MISCELLANEOUS RESPONSES (Mentioned Once)	(8 Comments)

INDIVIDUAL CONTROLLER COMMENTS PER CATEGORY - FORM A

1A. LLWAS IS BETTER THAN PREVIOUS EQUIPMENT (9 Controllers)

Controller No.

2. Good start on getting wind information not available before.
3. Better than dials, but technology is outmoded.
4. Improvement over dials.
5. Numerical display is simpler.
6. At least it gives more information than wind indicator.
11. Better than nothing.
12. Better than nothing.
15. Excellent aid for pilot in determining the possibility of wind shear.
22. Draws your attention to possible wind shear in area.

2A. PHRASEOLOGY NEEDS CHANGES (9 Controllers)

Controller No.

1. Long phraseology compounds difficult changing wind situation.
4. Required phraseology is time consuming and cumbersome.
5. Phraseology is cumbersome when all quadrants alarming.
6. Too much phraseology to repeat for each aircraft.
9. Required phraseology has too much verbiage, cumbersome. Does not give pilot what he needs.
12. Keep phraseology simple to issue and understand.
13. Phraseology is too lengthy for all shears and quadrants. Current requirement is cumbersome.
17. Phraseology is (1) too long, (2) cumbersome, (3) unnecessary.
22. Phraseology is too extensive during busy traffic periods.

3A FALSE ALARMS SHOULD BE REDUCED (7 Controllers)

Controller No.

3. Make LLWAS always accurate, without false alarms.
4. Centerfield wind alarm and shear information are poor.
5. Alert can be caused by helicopters on calm day.
6. Too many false alarms.
7. Less false alarms.
11. Too many false alarms - based solely on wind direction divergence.
12. Many alarms occur.

4A. PILOT GETS TOO MUCH INFORMATION (7 Controllers)

Controller No.

1. Difficult for pilot to interpret shear information.
3. Too many readings.
5. Pilots can't comprehend all those numbers at once, especially on short final.
6. Too much interpretation for the pilot to actually know how it will affect him.
9. Pilots cannot comprehend all the information nor have time to assimilate.
12. Sometimes so much information cannot be assimilated by the pilot.
13. Too much information based on current requirement.

5A. BOUNDARY WIND INFORMATION IS USEFUL (6 Controllers)

Controller No.

1. Useful to know winds at different points on the airport.
2. Several aircraft ask for boundary winds. There is value there.
6. Boundary winds give warning of runway change.
8. Winds from different areas show patterns.
9. Showing quadrant winds gives the possibility of wind shear.
13. Capability to issue quadrant wind is less limiting than single centerfield wind.

6A. MAKE LLWAS EASIER TO USE (6 Controllers)

Controller No.

1. Present information better - less diverted attention and time to interpret for user.
2. Tends to give too much information on some quadrant winds. You can get overly involved.
3. Too many readings.
6. Too much interpretation, and when real busy.
12. Giving information is time consuming when I'm already very busy.
13. Too much information is required to be issued.
15. LLWAS adds to controller workload.

7A. QUESTION LLWAS ACCURACY AND RELIABILITY (6 Controllers)

Controller No.

4. Usually PIREP's and LLWAS don't coincide. Is it useful to the operators of the ATC system?
5. Too many erroneous readings or flashing 9999's.
12. Many times the system is inoperative.
13. I question the reliability and validity of the data received. Reading of CALM with gusts 15 - 20 knots leaves room for misinterpretation.
14. Sometimes unreliable to use for trying to plan runway changes.
16. Sometimes it doesn't appear to be as accurate as it could be.

8A. MORE SPECIFIC RUNWAY-ORIENTED WINDS NEEDED (5 Controllers)

Controller No.

7. Not enough specific data in relation to runway.
9. Not an accurate indication of wind shear because not runway sensitive.
12. Not very specific, but gives pilot idea to expect some kind of wind change. Should be specific to an area, not blanket.
13. If we have the technology, give pilot what he needs - specific runway winds.
22. Place sensors more closely to lift off and touchdown points.

9A. RELOCATE DISPLAY (4 Controllers)

Controller No.

2. Place the display in front of the controller, not to the side. Possibly at bottom of BRITE.
8. Put in area with less glare and more line of sight.
9. Display is unreadable in sunshine. A glare exists.
11. Hard to read in sun glare.

10A. CONTROLLER HAS DIFFICULTY INTERPRETING INFORMATION (2 Controllers)

Controller No.

2. Which wind is relevant, centerfield or boundary?
6. Too much interpretation.

11A. SYSTEM ALARMS TOO LATE FOR ACTION (2 Controllers)

Controller No.

1. By the time the system alarms, it's usually too late to change a situation.
11. LLWAS is not effective in interpreting changes in a speedy manner.

12A. INFORMATION SEEMS GOOD (2 Controllers)

Controller No.

2. Information seems quite accurate.
16. Displays good information and it's versatile.

13A. DISPLAY IS EASILY READABLE (2 Controllers)

Controller No.

3. You can read it easily.
11. Easy to see at night.

14A. MISCELLANEOUS COMMENTS (8 Comments Mentioned Once)

Controller No.

2. Gust factor stays on too long.
2. Audio is sometimes missed due to other noises.
2. On several occasions PIREP's verify LLWAS, so it's quite accurate.
2. Show wind below 3 knots as CALM.
4. The best wind shear information comes from correctly transmitted PIREP's.
6. I'd like to see microburst data displayed. I'm aware that microbursts do occur that aren't picked up.
16. We haven't had sufficient power outages to judge recovery time.
16. The pilots have become knowledgeable, and know how it works and what to ask for.

FORM B - CATEGORIZATION OF ALL COMMENTS (20 CONTROLLERS)

1B. LLWAS AS MODIFIED GIVES GOOD INFORMATION	(13 Controllers)
2B. ADAPT DISPLAY FOR DISCRETE RUNWAY INFORMATION	(11 Controllers)
3B. REPLACE FLASHING ALARM	(9 Controllers)
4B. DISPLAY HAS SOME READABILITY PROBLEMS	(7 Controllers)
5B. PHRASEOLOGY NEEDS CHANGES	(7 Controllers)
6B. WIND INFORMATION NEAR RUNWAY IS PREFERRED	(6 Controllers)
7B. PILOT INTERPRETATION IS EASIER	(4 Controllers)
8B. CENTERFIELD WIND IS NOT OPTIMAL	(4 Controllers)
9B. SYSTEM SHOWS PROMISE	(4 Controllers)
10B. MOVE HEADWIND "+" AND "-" SYMBOLS	(3 Controllers)
11B. THERE ARE SOME SYSTEM ACCURACY PROBLEMS	(3 Controllers)
12B. MOVE DISPLAY LOCATION	(3 Controllers)
13B. USE SAME DISPLAYED MESSAGE SEQUENCE AS SPOKEN	(3 Controllers)
14B. FALSE ALARMS ARE LESS PREVALENT	(2 Controllers)
15B. PHRASEOLOGY HAS DECREASED	(2 Controllers)
16B. MOVE CENTERFIELD WIND PLACEMENT ON DISPLAY	(2 Controllers)
17B. NEED BOUNDARY WIND REPORTED	(2 Controllers)
18B. MAKE DISPLAY TILT AND SWIVEL	(2 Controllers)
19B. THERE ARE SOME ABBREVIATION PROBLEMS	(2 Controllers)
20B. MISCELLANEOUS COMMENTS (Mentioned Once)	(20 Comments)

INDIVIDUAL CONTROLLER COMMENTS PER CATEGORY - FORM B

1B. LLWAS AS MODIFIED GIVES GOOD INFORMATION (13 Controllers)

Controller No.

2. Valuable, most appropriate information is relayed to aircraft.
3. More accurate picture.
5. There is good information. System does notify controllers of wind shear in strong wind activities.
6. Much improved over previous system. Several pilots have concurred with accuracy of the system.
8. It gives the wind on the runway, which is more important to the pilot.
9. It gives correct information, verified almost every time by the pilot.
11. More accurate than before.
12. The information displayed is much more usable for the pilot; thus, it is more effective and sensible to issue.
13. Gives more precise location of the WSA.
14. Able to give the wind in a more defined and/or specific location to the pilot.
15. More usable information for the pilot.
19. A more accurate depiction of field conditions is given. Greater accuracy in the information needed for runway changes. PIREPS confirm accuracy.
21. It has proven to be reasonably accurate as verified by pilot reports and feedback.

2B. MAKE DISPLAY ADAPTABLE FOR DISCRETE RUNWAY INFORMATION (11 Controllers)

Controller No.

2. Give pilot real-time wind 3/4's down runway. Make display adaptable for controller operation.
5. Should be able to select pertinent information to runway configuration.
6. I'd like to select any runway wind at either position.
8. Give only lines needed by local at any time. Make these selectable. Need winds at arrival end and departure end for each runway.
11. Include the ability to program other runways on Local Controller one (LC1) display and vice versa.
12. Want the ability to select which sensors to display on individual CRT displays.
13. LC1 should have 26 threshold winds when locals are combined.
14. Wind shear information is not available for 08/26 at LC1.
17. I would like to be able to select runways I want to watch.
20. Let us use the whole system as we deem necessary, and use the sensors at the runways we are working.
21. Display only data pertinent to the position.

3B. REPLACE FLASHING ALARM (9 Controllers)

Controller No.

2. Do not alternate flashing when an "event" takes place. (Use bright background with dark characters.)
4. Too much flashing.
5. Too much information is flashing on one display.
12. Display hard to read during alarm.
13. Rolling is distracting. WSA should be indicated by brightened line.
17. Blinking display is distracting.
18. When it flashes it's hard to read the CRT.
19. Biggest problem is flashing. Instead, lines could be separated and highlighted.
20. Blinking has to go. Let it blink once then maintain steady white background.

4B. DISPLAY HAS SOME READABILITY PROBLEMS (7 Controllers)

Controller No.

1. Needed data are sometimes hard to find, e.g., boundary winds, separate runways when responsible for more than one.
5. Too much information on display must be read to determine what you have to transmit.
8. Low marks because of readability and excessive complexity of display.
11. Display is too crowded. Enlarge and spread information for easier reading.
16. No full display in TRACON, or make it optional.
17. Information was in the wrong place or sequence. Readability of the display - poor.
21. I would like easier readability.

5B. PHRASEOLOGY NEEDS CHANGES (7 Controllers)

Controller No.

3. Phraseology needs changes.
4. The phraseology is a little cumbersome, but should come in time.
5. Phraseology very cumbersome.
12. The phraseology seems awkward, but may improve with familiarity.
20. Change format and phraseology to ATC as presently read.
21. Phraseology added to required phraseology makes local virtually impossible to work during busy wind situations.
22. Phraseology not clear at this point.

6B. WIND INFORMATION NEAR RUNWAY IS PREFERRED (6 Controllers)

Controller No.

2. Real-time information near aircraft movement should give the aircraft the most accurate information for its flightpath.
4. If the information is accurate, the wind information as related to the runway is very beneficial.
5. Should be able to use wind at approach end of applicable runway when there is no windshear or microburst event occurring.
9. Use sensor at appropriate landing threshold or departure runway.
16. Information providing threshold winds - location of event - is good.
20. Let us use all the indicators at runways.

7B. PILOT INTERPRETATION IS EASIER (4 Controllers)

Controller No.

1. Much easier for pilots to interpret. Less chance of questions from pilots.
6. There is less the pilots have to interpret.
11. Pilots seem to understand the information better than before.
18. Amount of information conveyed to pilot is simplified.

8B. CENTERFIELD WIND IS NOT OPTIMAL (4 Controllers)

Controller No.

2. Possibly eliminate centerfield wind (unless needed for backup in power outage).
5. Centerfield wind is not appropriate for runway 26, 8, and 17 complexes.
16. The centerfield wind is not representative. I think it should be a triangulated wind value from sensors 0, 1, 2, and 11 as backup.
20. Use centerfield wind as a backup. It's useless for north-south runways.

9B. SYSTEM SHOWS PROMISE (4 Controllers)

Controller No.

2. Benefits could be excellent. Pilots can anticipate problems.
6. Capability to warn of microbursts is a definite plus.
9. Runway sensitivity is a plus for safety and early warning for pilots.
20. If information is accurate, it could be exactly what is needed.

10B. MOVE HEADWIND "+" AND "-" SYMBOLS (3 Controllers)

Controller No.

2. Move "gain" and "loss" symbols behind speed.
4. "+" and "-" need to be moved to other side.
17. The "+" and "-" should be behind knots.

11B. THERE ARE SOME ACCURACY PROBLEMS (3 Controllers)

Controller No.

5. System reported +10 to -15 knots but aircraft did not experience event at all. Centerfield showed 00 wind gusts 12 knots. Equipment showed -10 knots runway, but aircraft experienced +10 knots runway. Readings are not always validated by aircraft. On a calm day heavy DC-8 passing over sensors causes erroneous alarms.
13. How can 17L Departure and 35R Departure show 10 knot loss on the runway at the same time?
17. Ten departure aircraft receiving -20 WSA on runway did not report shear.

12B. MOVE DISPLAY LOCATION (3 Controllers)

Controller No.

3. Location should be changed.
14. Suggest LC1 be located at right side of position.
22. I would like better placement of the display.

13B. USE SAME DISPLAYED MESSAGE SEQUENCE AS SPOKEN (3 Controllers)

Controller No.

2. MBA/WSA should be displayed exactly as read.
5. Phraseology should be written on screen as spoken.
17. You should be able to say it as you read it.

14B. FALSE ALARMS ARE LESS PREVALENT (2 Controllers)

Controller No.

6. Less false alarms.
11. Less false alarms.

15B. PHRASEOLOGY HAS DECREASED (2 Controllers)

Controller No.

4. Less verbiage is needed to get the existing conditions across to the pilots.
6. Phraseology actually slightly less than used to be.

16B. MOVE CENTERFIELD WIND PLACEMENT ON DISPLAY (2 Controllers)

Controller No.

2. Move centerfield wind to middle top line of display.
17. Move centerfield wind to center of display.

17B. NEED BOUNDARY WIND REPORTED (2 Controllers)

Controller No.

12. Display gust factors at indicators other than centerfield.
21. We have lost the capacity to issue boundary winds when requested by the pilot. Expand to include boundary winds.

18B. MAKE DISPLAY TILT AND SWIVEL (2 Controllers)

Controller No.

3. Display should swivel and tilt.
14. Put LC1 on small stand for rotating.

19B. THERE ARE SOME ABBREVIATION PROBLEMS (2 Controllers)

Controller No.

1. Hard to find data, possibly due to the abbreviations (17LA, 17LD, 35RA, 35LD, 17RA, etc.).
5. Use FAA ATC abbreviations and phraseology. Abbreviations are not in ATC or NWS language.

20B. MISCELLANEOUS COMMENTS (20 Comments Mentioned Once)

Controller No.

1. Pilot education is needed - especially for "MBA." I have had pilots refuse to take off because of issued alert.
2. Benefits could be excellent if we can keep false alarms to a minimum.
2. Two hours is too long to carry MBA on ATIS. (One hour should be sufficient.)
3. The runways should be listed.
6. Certainly has reduced the number of alarms the controller has to issue. The north-south controller seems to have more alarms than the east-west controller.
6. I'd like to see a color display with microburst shown in red, windshear in yellow, and normal wind information in white.
8. Uncertain about how information is derived.
9. When a shear is detected at + or -20 kts, the system immediately indicates a microburst. This has happened on several occasions. Is this normal?
11. Aural alarm could be louder.
17. Runways are in the wrong order.
17. More sensors - reporting data from off the airport - alerting pilots to the possibility of WSA's or MBA's in the area.
17. Information was not timely.
18. Hopefully, LLWAS will eliminate controller reporting PIREPS.
18. I think the word "expect" should precede the loss or gain information.
18. I think we need more than 2 weeks use before drawing a conclusion as to usefulness.
20. We get windshear and microburst information on final we didn't have before. But we need more wind information available at times without events.
21. Available data decreased.
21. Alarms take extra time away from prime function.
21. What we gain from LLWAS is about equal to what we lose.
22. A short class of use of system would be beneficial.

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