

ORDER

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

1812.9

5/28/87

SUBJ: SYSTEM REQUIREMENTS STATEMENT FOR THE TERMINAL DOPPLER WEATHER RADAR SYSTEM

1. PURPOSE. This order establishes the requirements for Terminal Doppler Weather Radar (TDWR) and is consistent with the National Airspace System (NAS) Plan Project 7-08.

2. DISTRIBUTION. This order is distributed to the director level in the Offices of Airport Planning and Programming, Airport Standards, Aviation Policy and Plans, Budget, and Personnel and Technical Training; to the branch level in the Advanced Automation Program Office, Office of Flight Standards, Air Traffic Operations Service, Air Traffic Plans and Requirements Service, Program Engineering and Maintenance Service, Systems Engineering Service, and Acquisition and Materiel Service; to the branch level at the FAA Technical Center and the FAA Depot at the Aeronautical Center; and to the branch level in the regional Airway Facilities, Logistics, Air Traffic, and Flight Standards Divisions.

3. BACKGROUND. Although the current NAS weather sensing programs address most of the FAA's weather requirements, there are hazardous weather conditions that will continue to go undetected in the terminal environment. The most significant of these are low altitude wind shears due to gust fronts and microbursts.

a. Low Level Wind Shear Alert System (LLWAS). Currently, the only operational ground-based wind shear hazard detection system in use by the FAA is the LLWAS. This system was originally designed to detect thunderstorm gust fronts and frontal types of wind shear. In more recent years, analysis of aircraft accidents has shown microbursts to be an additional threat to aviation safety. Although LLWAS will be improved by adding additional sensors, optimizing the array of sensors for the detection of microbursts, and improving the detection algorithm, it will not be capable of detecting all the weather phenomena available using Doppler techniques and will not be predictive in nature.

b. Doppler Radar Technology. Recent advances in Doppler radar technology and algorithms for identifying and characterizing wind shear have demonstrated the potential usefulness of Doppler radar as the basis for a wind shear detection system. The availability of Doppler radar in the terminal area can also provide more advanced warning information on wind shifts affecting airport operation.

4. DEFINITIONS. The definitions for terms used in this order are shown in appendix 1.

5. MISSION NEED.

a. Requirements Statement. The primary purpose of the TDWR is to meet requirements for timely and accurate detection of hazardous wind shear in and near terminal approach and departure corridors and report this information to pilots

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and local controllers. A secondary requirement to be addressed by the TDWR is to provide warning of sustained wind shifts and hazardous weather, including turbulence, to air traffic control (ATC) supervisory personnel to allow for improved planning of airport operation.

b. This document defines operational requirements for the TDWR equipment during its life cycle. The currently defined TDWR Program will have an operational capability that will include the primary safety and delay benefits products; i.e., microburst and gust-front detection and wind-shift forecast. The initial operational capability will not include turbulence products. The TDWR will provide for growth and flexibility to support the full operational requirements as technology and funding permit.

c. Functional Capabilities. The TDWR system must have the following capabilities and characteristics:

(1) Operation. TDWR will be an automated system consisting of sensor, communication, processing, and display components. The TDWR sensor component will have the functional capabilities described in subparagraphs (2) thru (6). Research may show that better wind shear products will result if LLWAS data is merged into TDWR data. To allow for this possibility, the TDWR will accept LLWAS data for processing and display.

(a) TDWR (not including LLWAS) reliability, availability, and maintenance requirements are as follows:

1. Reliability. System Mean Time Between Failure (MTBF) must not be less than 2,160 hours (90 days).

2. Availability. TDWR must have an operational availability of at least 0.999.

3. Maintenance. TDWR must provide for both local and remote maintenance and monitoring as follows:

(aa) Capability to perform online diagnostics, line replaceable unit (LRU) replacement, and LRU testing without impairing online radar operations.

(bb) Full compatibility with the NAS Remote Maintenance Monitoring System (RMMS) as specified in NAS-MD-790, NAS-MD-792, and NAS-MD-793.

(cc) Maximum annual maintenance man-hours must not exceed 120 hours (combined corrective and preventive maintenance).

(dd) Online performance monitoring diagnostics and off-line fault isolation diagnostics controlled through the RMMS. Offline fault isolation must be provided down to the LRU with a confidence of 0.95.

(2) Event Characterization. The TDWR sensor component must automatically detect wind shear, turbulence, tornadoes, and sustained wind shifts. In this context, wind shear shall be defined as any change in the windspeed and/or direction between two points in the atmosphere.

(a) Thresholds. The following thresholds for detection of wind shear and turbulence shall apply:

1. Wind Shear. The threshold for reporting of wind shear shall be a horizontal windspeed change oriented in the direction of the runway centerline that exceeds the rate of change of speed of 20 knots per nautical mile (nmi), extending over 1/2 to 4 nmi.

2. Turbulence. The threshold for reporting of turbulence shall be the "moderate" intensity level as defined in the National Weather Service Operations Manual, Chapter D-22.

(b) Intensity. TDWR must provide a quantitative estimate of expected change in the component of the wind vector oriented along the runway centerline, as well as the distance over which this change will occur. In addition, TDWR must provide an estimate of expected turbulence intensity in three categories: moderate, severe, and extreme, as defined in the National Weather Service Operations Manual, Chapter D-22.

(c) Location. The location of hazardous wind shear or turbulence within the terminal area must be given in terms of position along the runway or distance from the runway and its extension along the flightpath.

(d) Trend. TDWR must indicate whether the wind shear or turbulence phenomenon is stable, increasing, or decreasing in intensity.

(3) Coverage. The TDWR sensor component must provide hazardous wind shear, microburst, and turbulence detection coverage for approaching and departing aircraft up to an altitude of 1,500 feet above ground level (AGL) and to a distance of 6 nmi from the airport reference point. Wind-shift detection and tornado detection must cover all areas within 40 nmi of the airport reference point.

(4) Accuracy. The probability of detecting a reportable wind shear or turbulence event, when one exists within the coverage area, must be at least 0.90. The probability of reporting a reportable wind shear or turbulence event when one does not exist within the coverage area must be no greater than 0.10. TDWR must report the location and extent of reportable wind shear and turbulence events to an accuracy of 0.5 nmi. The intensity of reportable wind shear events must be reported at least 95 percent of the time to an accuracy of plus or minus (+) 5 knots or 20 percent, whichever is higher. The intensity of reportable turbulence events must be reported with an accuracy equivalent to a derived gust velocity of 5 feet-per-second. (Derived gust velocity is defined in accordance with FAR Part 23, paragraph 23.341, Gust Load Factors, or FAR Part 25, paragraph 25.341 Gust Factors.) Sustained wind-shift direction must be measured to an accuracy of $\pm$ 10 degrees.

(5) Timeliness. Radar scanning, product generation, and product dissemination for wind shear events relayed to pilots must be performed within sufficient time to allow pilots to receive at least a 1-minute warning prior to the existence of any hazardous wind shear or turbulence condition. Radar scanning, product generation, and product dissemination for gust-front and wind-shift events

relayed to ATC supervisory personnel must provide at least 20 minutes advanced warning of potential approaching events and must be updated at intervals of no more than 5 minutes.

(6) Radar Characteristics. The radar components of TDWR must have the following characteristics:

- (a) Operation over a frequency range of 5.6 to 5.65 GHz.
- (b) Local and remote operational control.
- (c) Interference reduction capabilities including rejection and avoidance. Avoidance capabilities include sector radiation control.
- (d) The radar must meet the stated detection and false alarm probability requirements for wind shear and turbulence events of reflectivity as low as -8 dBz at a range of 6 nmi from the airport reference point.
- (e) The radar must meet the stated detection and false alarm probability requirements for wind shear or turbulence events within the coverage area in an urban ground clutter environment.
- (f) The velocity processor must automatically unfold ambiguous velocities.
- (g) The radar must automatically minimize obscuration from multiple trip echoes. If obscuration cannot be completely eliminated, priority shall be given to the area over the airport and on the approach paths.

(7) System Outputs. The system must produce several types of outputs, including a simple text message for appropriate controllers and supervisors and for potential direct uplink to pilots, indicating the existence, location, and characteristics of reportable wind shear or turbulence events; a graphical situation display product showing approaching wind-shift and gust-front information to ATC supervisory personnel; and a graphical depiction of shear, microbursts, turbulence, and tornadoes to area control computer complex (ACCC) and tower control computer complex (TCCC) for distribution to appropriate controllers and supervisors.

(a) Textual display characteristics must include:

- 1. Automatic and unambiguous indication of the existence of reportable wind shear or turbulence with no interpretation required.
- 2. Audible and/or visual alert to signal a transition from a nonreportable to a reportable condition.
- 3. Location of the wind shear or turbulence event with respect to the appropriate runway and approach.
- 4. Extent of the event and indication of the trend in the wind shear or turbulence event (increasing or decreasing in intensity).

5. Expected decrease in true airspeed and distance over which speed loss will occur (speeds and distances to be given in runway oriented coordinates).

6. Output to be in the form of a text message that can be quickly and easily read to pilots.

7. Output also amenable to automated direct transmission to aircraft via digital and/or computer-generated voice uplink.

(b) The graphical situation display information for ATC supervisory personnel must include:

1. Graphic display showing the location, intensity, and speed of movement of sustained wind shifts and gust fronts that will impact on airport operations.

2. Text and numeric information showing estimated arrival time of wind shift at airport location.

(c) The graphical situation display information (via ACCC and TCCC) for reportable wind shear, turbulence, heavy precipitation, and tornado events must include:

1. The location, intensity, and trend of reportable wind shear and microburst events.

2. The location of tornadoes.

(8) Interfaces. TDWR will be installed before many of the terminal area components of the NAS are in place. For this reason, it must provide a means of displaying alphanumeric data to controllers. In addition, however, TDWR must be capable of transitioning into the next generation of terminal area systems; therefore, TDWR must provide controlled digital data ports to interface with the ACCC, TCCC, RMMS, weather communications processors, and LLWAS at those terminals where it is available. The TDWR should also allow for possible future interfacing to additional systems such as the Central Weather Processor (CWP).

6. EXISTING AND PLANNED CAPABILITIES.

a. Existing Capabilities.

(1) LLWAS. The LLWAS is presently a six-station array of windspeed and direction sensors with one station located at center field on the airport and the other five sensors nominally located about 2 miles from the center site. Locations for the peripheral sensors are selected to provide best coverage of runway corridors with minimal interference from surrounding wind obstructions. The center field site is considered a reference site for which a 2-minute running average of wind velocity is maintained. The remote sites are polled at 10-second intervals by a central processor which compares the wind velocity at each of the five peripheral sites with the 2-minute average wind velocity at center field. Whenever the magnitude of the vector difference between the center field average wind and one or more of the peripheral sensors exceeds 15 knots, visual and

audible alarms are signaled to the tower controller. The wind velocities at center field and at the alarming sensor(s) are presented on the tower controller's display. It is the responsibility of the controller to relay an appropriate warning to affected pilots. Controllers are required to report windspeed and direction for the averaged center field reading and the remote station(s) that caused the alarm.

(2) Pilot Reports (PIREP). PIREP's include information on meteorological phenomena encountered by aircraft in flight. They are an important source of information for both controllers and pilots on immediate weather conditions along the approach and departure corridors.

b. Planned Capabilities.

(1) Enhancements to LLWAS.

(a) Programs are underway which will:

1. Improve siting and reduce sheltering problems.
2. Develop and apply an improved detection algorithm.
3. Enhance maintenance support.
4. Provide lightning protection.
5. Provide recording/archiving capability.
6. Expand processing capabilities.

(b) All of these improvements are directed toward reducing the false alarm rate of LLWAS and restoring user confidence in the system. In addition, a program is underway to expand LLWAS sites to include 11 wind sensors. Potential benefits of an 11-station expansion include algorithm enhancements to provide runway-oriented estimates of airspeed loss and crosswind, as well as differentiation between microburst and gust-front wind shears.

(2) Next Generation Doppler Weather Radar (NEXRAD). The NEXRAD will consist of a long-range weather-detection radar and its associated processing hardware and software. It is a joint United States Air Force, National Weather Service (NWS), and FAA program that is designed to meet the three agencies' weather radar requirements, primarily for upper altitude coverage. The NEXRAD 5- or 6-minute update rate is considered to be too slow for timely detection of microbursts, which can reach a reportable threshold in less time than the NEXRAD update rate.

(3) Airport Surveillance Radar Ninth Generation (ASR-9). The ASR-9 will consist of a surveillance radar primarily tasked to detect aircraft in an airport area. There will be a weather channel that will detect six levels of reflectivity. The ASR-9 as presently designed will not provide wind-related data.

(4) Terminal NEXRAD. In order to provide some wind shear detection capability at major airports at the earliest possible date, plans have been made to

install 16 operational NEXRAD systems, modified for use in terminal areas, as interim TDWR Systems. Modifications from NEXRAD include changes to the internal software, as well as modified scanning strategies.

7. ASSESSMENT.

a. Shortfalls in Existing Capability. Present methods for the detection of hazardous wind shear and turbulence events are limited principally to PIREP's and LLWAS. Limitations of the current PIREP System are well known and need not be repeated here. In addition, pilots are generally interested in avoiding these events rather than encountering and reporting them. This biases the PIREP. The LLWAS System was designed primarily to detect larger scale wind shear events, such as gust fronts, frontal passages, and mesoscale wind shifts (e.g., sea breeze). Many smaller scale wind shear events, such as microbursts, cannot be adequately detected by LLWAS due to the spacing of LLWAS sensors. No adequate system for detecting AGL wind shear events exists. Enhancements to the LLWAS are planned to expand coverage and improve detection of smaller scale events. However, the system will still be limited to ground-level detection.

b. Prediction Capability. Doppler radar, such as TDWR, will have better capabilities than the LLWAS in both spatial coverage and resolution of small scale events. This will provide detection of events farther from the airport and events of smaller size. Detection will also be available AGL in the critical approach and departure corridors. Current research results indicate that algorithms may be developed to allow Doppler radar to detect precursors of hazardous wind shear. The TDWR system architecture must not preclude the possibility of expansion to include the detection of wind shear and turbulence precursors, if methods for their detection become operationally feasible.

c. Relationship to NEXRAD. The NEXRAD is a joint FAA, Department of Defense, and NWS program. NEXRAD is currently being developed to use Doppler radar technologies to detect radial velocity of weather phenomena. While NEXRAD has Doppler radar technology similar to that necessary for implementing a wind shear/microburst weather-detection system, NEXRAD does not meet all requirements considered important for a terminal weather coverage system.

(1) The following shortfalls keep the NEXRAD system from fully meeting the terminal area requirements:

(a) The NEXRAD system has a slower update rate than that needed to detect microbursts and windshear in a timely fashion.

(b) The NEXRAD network cannot simultaneously meet the long-range full-volume weather-detection requirements of the three sponsoring agencies while meeting FAA needs for rapid update coverage of low-altitude phenomena at major airports. Frequency congestion at S-band will not permit the permanent installation of additional NEXRAD units for airport coverage in many areas of the United States. However, the terminal NEXRAD units that the FAA plans to install can be accommodated on a temporary basis.

d. Technological Opportunity. The opportunity exists for meeting the mission need through the application of existing Doppler radar technologies. In addition, extensive work has been done on developing and improving computer algorithms for real-time detection and characterization of wind shear via Doppler radar.

e. Obsolescence of Existing Approach. The LLWAS system was designed originally at a time when gust fronts were considered to be the primary low altitude wind hazard to aircraft; as a result LLWAS is optimized for the detection of gust fronts. In recent years, it has become apparent that microbursts are the more hazardous type of wind shear. Improvements to LLWAS performance are possible through software enhancements and an increased number of sensors.

f. Opportunity for Cost Savings. The primary cost savings attributable to TDWR are expected to be from safety improvements. Safer handling of hazardous weather conditions in the terminal area could result in a reduction in the number of aircraft accidents, with an associated reduction in loss of life and property. In addition, the preplanning for orderly runway changes will allow for reduced delays and therefore less fuel consumption and more efficient airport utilization.

g. Potential Impact on Human Resources. The TDWR Project is a part of the continuing FAA effort to improve the weather information at airports by using sensing devices with greater system reliability and reduced operating costs. The potential impact on human resources is as follows:

(1) Air Traffic Controllers. The impact to the operating air traffic controllers will be minimal, since the TDWR will be completely automatic. Training requirements for controllers will be minimal since the TDWR System outputs will not require interpretation, and the format for any messages displayed by the system will be the same as that for messages voiced by controllers to pilots.

(2) Airway Facilities Maintenance Staff. There will not be a significant impact to the Airway Facilities maintenance staff, since the TDWR will be a highly reliable system with built-in test at an unmanned facility. A small increase in Airway Facilities maintenance staffs will be required for periodic and corrective maintenance. Since RMMS will report on any TDWR System failures, on-call maintenance staff is only needed to replace the reported LRU.

(3) Training. Training will be accomplished for the maintenance technician in accordance with current practices and will be detailed as part of the project implementation plan. Training will be planned to minimize impact on operations.

h. Budgetary Impact. The budget impact will be an estimated \$550 million (inflated 1986 dollars) for 100 operational and two support systems. Funding will be secured through normal budgetary procedures. The estimated life-cycle costs are \$1,325 million (inflated 1986 dollars). The source of these cost data is the "Life-Cycle Cost-Benefit Analysis for Terminal Doppler Weather Radar (TDWR) Project," Appendix E, dated April 1987.

i. Human Factors Engineering. The project office will ensure that human factors considerations, such as ease of maintenance, occupational safety and health, ergonomic design, user friendly software, etc., are part of the procurement package and specification and are given high visibility and attention throughout the

development and implementation phases of the project. In addition, the Advanced Automation System contractor will be responsible for the "ergonomic design" for the output data to be displayed to the tower and area control facility personnel.

8. ESTIMATED COSTS AND BENEFITS.

a. General Cost and Benefit. Based on the cost/benefit study, the current estimated acquisition cost per system is approximately \$5.5 million.

b. Cost/Benefit Analysis Alternatives. The following alternatives to meeting the mission need were used in performing the cost/benefit analysis for the TDWR:

(1) NEXRAD Derivative. Requirements for the NEXRAD were modified to meet the requirements of a terminal radar. This option was deleted because of the requirement for competitive procurement.

(2) Newly Developed System. Requirements would be developed for a radar system which could detect rapidly evolving hazardous weather phenomena within a terminal area.

(3) Modified Commercial Off-the-Shelf System. Although Commercial Off-the-Shelf Systems (COTS) for Doppler weather radar are available, they do not meet the TDWR requirements.

c. Cost Benefit Analysis Results Summary. The following table is a summary of the TDWR cost/benefit figures developed by the System Engineering and Integration (SEI) contractor. (Values are in discounted 1986 millions of dollars and are based on 102 units installed, 100 operational and 2 support systems).

TABLE 1. Cost Benefit Analysis Results Summary for 102 Systems

Estimated Discounted Life-Cycle Cost	\$339.0
Estimated Minimum Discounted Life-Cycle Benefit	339.0

d. Potential Benefits. The primary benefit that the TDWR Project will provide to users is improved detection of short-lived hazardous-weather phenomena. Additional benefits will be reduced user delays and associated reductions in aircraft fuel consumption due to the availability of improved wind shift and hazardous-weather information for airport operations planning.

9. APPROACH ALTERNATIVES.

a. Continuation of Present Approach. If no action is taken to develop TDWR, the only existing wind shear detection systems for the terminal area will be LLWAS and NEXRAD. Both of these systems have limitations that keep them from fully meeting the requirements for terminal area detection. The inability of the LLWAS to provide winds aloft data intrinsically limits detection to near-ground wind shear phenomena. The siting criteria and update rates for NEXRAD lead to poor terminal area coverage of wind shear.

b. Enhance Current Systems. Algorithm enhancements at existing 6-station LLWAS sites and planned 11-station enhancements are designed to provide improvements in LLWAS performance. These enhancements will not meet the long-term

requirements, as outlined in this SRS, for terminal area wind shear, wind-shift, and hazardous-weather coverage.

c. Nontechnical/Noncapital Approaches. A wind shear training guideline development has been sponsored by the FAA to train pilots on how to recognize conditions conducive to hazardous wind shear and the proper actions to take when exposed to unexpected wind shear phenomena. This training does not eliminate the need for timely and accurate information on wind shear in the terminal area.

d. Proposed TDWR Approach. The new procurement will be completed for a contractor-developed system. The algorithms will be Government furnished.

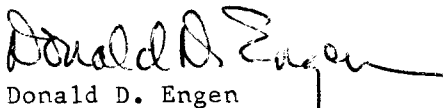
(1) Anticipated areas of risk in this development include:

(a) Development of a C-Band klystron tube may be a schedule risk.

(b) Automated detection of microbursts with a probability of detection of 0.90 or greater and false alarm probability of 0.10 or less may be difficult to achieve.

(2) Continued development efforts are required to determine the optimum threshold values for declaration of hazardous conditions and to define the operational methods for dissemination and use.

(3) Establishment criteria is required for determining locations qualifying for installation of TDWR.


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APPENDIX 1. METEOROLOGICAL DEFINITIONS

1. THUNDERSTORM. An atmospheric phenomenon whose existence is determined solely by the presence of lightning or the sound of thunder. In addition to lightning, thunderstorms may produce the following hazards to aviation: strong updrafts and downdrafts, hail, turbulence, restrictions to visibility, microbursts (wet and dry), macrobursts, outflows, downbursts (rain and wind types), gust fronts, wind shifts, wind shear, tornadoes (and their parent mesocyclone), and heavy rain. Thunderstorms can be classified singly or collectively as airmass, high plains (high thunderstorm base), supercell (a large solitary cell, often tornado bearing), squall line, or mesoscale convective complex (MCC).
2. MICROBURST. A small scale (0.5 to 1.5 nmi) downburst wind event associated with thunderstorms, characterized by a narrow downdraft creating (when it nears the ground) an outflow spreading horizontally in all directions or in a preferred direction depending upon the horizontal translation of the downward-directed shaft of air. The leading edge of a microburst outflow is a wind-shift zone (gust front) having a small horizontal radius of curvature in which the boundary is closed. WET OR DRY MICROBURSTS are distinguished by whether rainfall is observed at the ground level.
3. MACROBURST. Same as microburst except the horizontal diameter of the major downdraft is greater than 2.5 nmi.
4. OUTFLOW (GROUND LEVEL). The primarily horizontal rush of air near the ground originating as a thunderstorm downdraft but turning into the horizontal direction as the downdraft approaches the ground. Outflows from a microburst are confined to a small area and have a closed gust front (circle or ellipse), in contrast to outflows from a squall line that covers a relatively large area in which the gust front is an open surface described by either a nearly straight line or a curve with a large horizontal radius of curvature. Outflows are typically 500 to 3,000 feet in depth. (There is also an overflow at the top of a mature thunderstorm caused by updrafts and manifest by the cirrus anvil.)
5. WIND SHIFT (AVIATION CONTEXT). A boundary, straight or curved, representing a transition zone of a sustained change in the horizontal windspeed and/or direction, but primarily the wind direction. When moving, the usual case, it often results in the need to change active runways. The boundary usually separates airmasses of different temperatures. Wind shifts are associated with thunderstorm gust fronts (macroburst and straight wind), cold fronts, warm fronts, and sea breeze fronts. The transition zone widths vary from 0.5 mi (gust fronts and some cold fronts) to tens of miles (warm fronts and some cold fronts). All wind shifts are characterized by wind shear.
6. GUST FRONT. A moving wind-shift zone separating ambient air from a thunderstorm outflow. Associated with gust fronts are strong updrafts ahead of the front, wind shear in the frontal (wind shift) zone, and strong turbulence in the frontal zone and above the outflow directly behind the frontal zone. The wind-shift zone associated with a gust front is typically 0.5 mi in width.

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7. WIND SHEAR. Any change in the windspeed and/or direction between two points in the atmosphere.
8. TURBULENCE (AVIATION CONTEXT). Very small scale undulations in the horizontal and vertical windflow that result in rapid oscillations in aircraft pitch, yaw, and/or altitude. SEVERE TURBULENCE occurs when the wind undulations have large amplitudes.
9. DOWNBURST (RAIN). A narrow shaft of very heavy rain.
10. DOWNBURST (WIND). A strong downdraft that induces an outburst of damaging winds on or near the ground.