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Report to the Chairman, Committee on Science, Space and Technology, House of Representatives

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AVIATION WEATHER

Status of FAA's New Hazardous Weather Detection and Dissemination Systems

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Resources, Community, and
Economic Development Division

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The Honorable Robert A. Roe
Chairman, Committee on Science,
Space, and Technology
House of Representatives

Dear Mr. Chairman:

This report summarizes our review of the Federal Aviation Administration's (FAA's) efforts to develop better ground-based hazardous weather detection systems and disseminate the information to pilots in a more timely manner.

We are sending copies of this report to the Secretary of Transportation; the Administrator, FAA; the Director, Office of Management and Budget; and other interested parties.

This review was performed under the direction of Herbert R. McLure, Associate Director. Major contributors are listed in appendix III.

Sincerely yours,

J. Dexter Peach

J. Dexter Peach
Assistant Comptroller General

Executive Summary

Purpose

More than 50 percent of all fatal air carrier accidents are in some way attributable to weather. Wind shear—a rapid change in wind speed or direction—has been identified as a cause or factor in 18 accidents since 1970, including the loss of 575 lives. Both the National Transportation Safety Board and the Federal Aviation Administration (FAA) have concluded that more accurate wind-shear detection and more timely weather warnings to pilots are needed, particularly during the critical takeoff and landing phases of flight. Thus, FAA's $16 billion National Airspace System (NAS) plan includes $1.5 billion for new weather detection and dissemination systems.

The Chairman, House Committee on Science, Space, and Technology, asked GAO to review FAA's plan for new hazardous weather systems and determine, among other things,

- how FAA plans to address the problem of detecting wind shear and other hazardous weather around airports and what unresolved issues remain,
- whether hazardous weather information will be transmitted to pilots in a more timely manner, and
- when these new systems will be available and what their cost is estimated to be.

Background

The existing aviation weather system has two major problems: inadequate weather detection and an inadequate method for communicating timely weather information to pilots.

To improve the existing system, FAA plans, among other things, to install five new, ground-based hazardous weather detection systems. FAA plans to have all of these systems installed by 1995.

Three of the new systems—the enhanced low-level wind-shear alert system (enhanced LLWAS), the terminal next-generation weather radar (terminal NEXRAD), and the terminal Doppler weather radar—are for detecting wind shear. Another—a new airport surveillance radar (ASR-9)—is for detecting phenomena associated with thunderstorms around airports, and the fifth—the NEXRAD—is to detect weather conditions between airports on FAA's enroute system. The objective of these new systems is to improve weather detection.

FAA also plans to install an automated ground-to-air communication system to relay some weather information directly to pilots. Its objective is to make weather information more timely by transmitting it automatically to pilots rather than transmitting it to pilots through controllers.

Results in Brief

FAA's planned wind-shear detection systems will provide progressively better wind-shear protection than is presently available. However, FAA's optimal ground-based wind-shear detection system—the terminal Doppler weather radar—has several unresolved technical issues that could reduce its anticipated effectiveness and/or increase its cost.

Similarly, FAA's ASR-9 radar provides improved weather detection over that of existing airport surveillance radars. The usefulness of the ASR-9 data is clouded, however, because FAA is uncertain of how the radar is to be monitored by air traffic controllers and what information they are to disseminate to pilots.

Finally, while FAA intends to improve the timeliness of weather information dissemination, its current NAS plan states that hazardous weather information from the new detection systems will not be sent directly to pilots for at least a decade. Until its communication system is implemented, busy controllers will continue to disseminate this information, and FAA is not likely to be able to meet its objective of providing timely hazardous weather information to pilots.

Principal Findings

Unresolved Technical Issues Remain for FAA's Optimal Wind-Shear Detection System

Although more effective than the existing wind-shear detection system, the enhanced LLWAS cannot detect wind shears that occur above or beyond its ground-based sensors. Such a situation occurred in August 1985 when Delta Flight 191 crashed at Dallas/Ft. Worth International Airport after encountering a wind shear.

The terminal NEXRAD radar system will have a much greater range and will be able to more accurately determine the location of wind shears than the enhanced LLWAS. The terminal NEXRAD is, however, only an interim system to protect aircraft at 19 airports. It is to be replaced when FAA's optimal ground-based wind-shear detection system—the terminal Doppler weather radar—becomes available.

FAA plans to award a procurement contract for 100 terminal Doppler weather radars in 1988. Some of the radar's performance objectives have not been realized, and, according to FAA, several of the objectives will be difficult to achieve by that time. For example, FAA is not sure that the radar can forecast a wind shear early enough to give controllers and pilots adequate warning. Research on these unresolved technical issues is to continue in 1987 and 1988.

FAA's research contractors also have said that some of the objectives create competing siting and scanning demands that may require trade offs. For example, an on-airport siting may provide more accurate measurements of a wind shear's strength while an off-airport siting may provide for earlier detection and warnings to pilots.

How Best to Use the Improved Precipitation Data Is Still Uncertain

The ASR-9 radar will provide improved weather detection by distinguishing between six levels of precipitation. The higher the rate of precipitation, the more likely that it contains phenomena associated with thunderstorms, such as lightning, hail, or turbulence, which are hazardous to aviation.

While FAA officials told us that they plan to provide some of the ASR-9 weather information to pilots, the agency has not developed guidance for controllers on how the levels of weather are to be monitored and what information is to be disseminated to pilots.

Automatic Dissemination of Hazardous Weather to Pilots Will Not Occur for at Least a Decade

FAA is beginning to research the feasibility of automatically transmitting hazardous weather data directly to pilots from its new detection systems, but such a communication system is at least a decade away, according to current NAS plan projections. Meanwhile, busy air traffic controllers will continue as the primary source of weather information to pilots.

Automatic transmission of weather data is an important challenge facing FAA. On the basis of past GAO reviews of controller activities, there will be times when controllers will be too busy performing their primary duty of separating aircraft during peak traffic periods to provide pilots with weather information.

Recommendations

GAO recommends that the Secretary of Transportation direct the Administrator, FAA, to

- inform the Department and the Congress of any performance objectives that the terminal Doppler weather radar cannot meet and their impact on safety and cost before committing funds for a procurement contract; and
- develop guidance on how air traffic controllers are to monitor the ASR-9 weather display and what hazardous weather information they are to disseminate to pilots.

Agency Comments

GAO discussed the results of its review with agency officials who generally agreed with the findings, conclusions, and recommendations. As requested, GAO did not obtain official agency comments on this report.

Contents

Abbreviations

ASR	airport surveillance radar
FAA	Federal Aviation Administration
GAO	General Accounting Office
LLWAS	low-level wind-shear alert system
NAS	National Airspace System
NEXRAD	next-generation weather radar
NWS	National Weather Service
TDWR	terminal Doppler weather radar
WCP	weather communications processor

Introduction

Hazardous weather has been a longstanding problem of aviation safety. The National Transportation Safety Board has identified weather as a contributing factor in more than 50 percent of all fatal air carrier accidents since 1975. In 1985 alone, hazardous weather was responsible for 185 deaths in commercial aviation accidents in the United States.

According to the National Transportation Safety Board, wind shear—a rapid change in wind speed or direction over a very short distance—has been a cause or factor in 18 accidents and 575 deaths since 1970. Included were 134 fatalities resulting from a wind-shear encounter at Dallas/Ft. Worth International Airport on August 2, 1985.

As depicted in figure 1.1, the most dangerous type of wind shear—the microburst—can have a disastrous impact on aircraft that are landing or taking off. A microbust creates highly divergent wind outflows over a very short distance (1/4 to 2-1/2 miles). These wind outflows cause aircraft to encounter a sudden increase in headwind, followed by a sudden increase in tailwind. To compensate for the increase in headwind, pilots may reduce aircraft speed in an attempt to maintain an appropriate angle for landing. The sudden increase in tailwind reduces aircraft lift, which combined with reduced aircraft speed, can result in accidents when planes are landing or taking off.

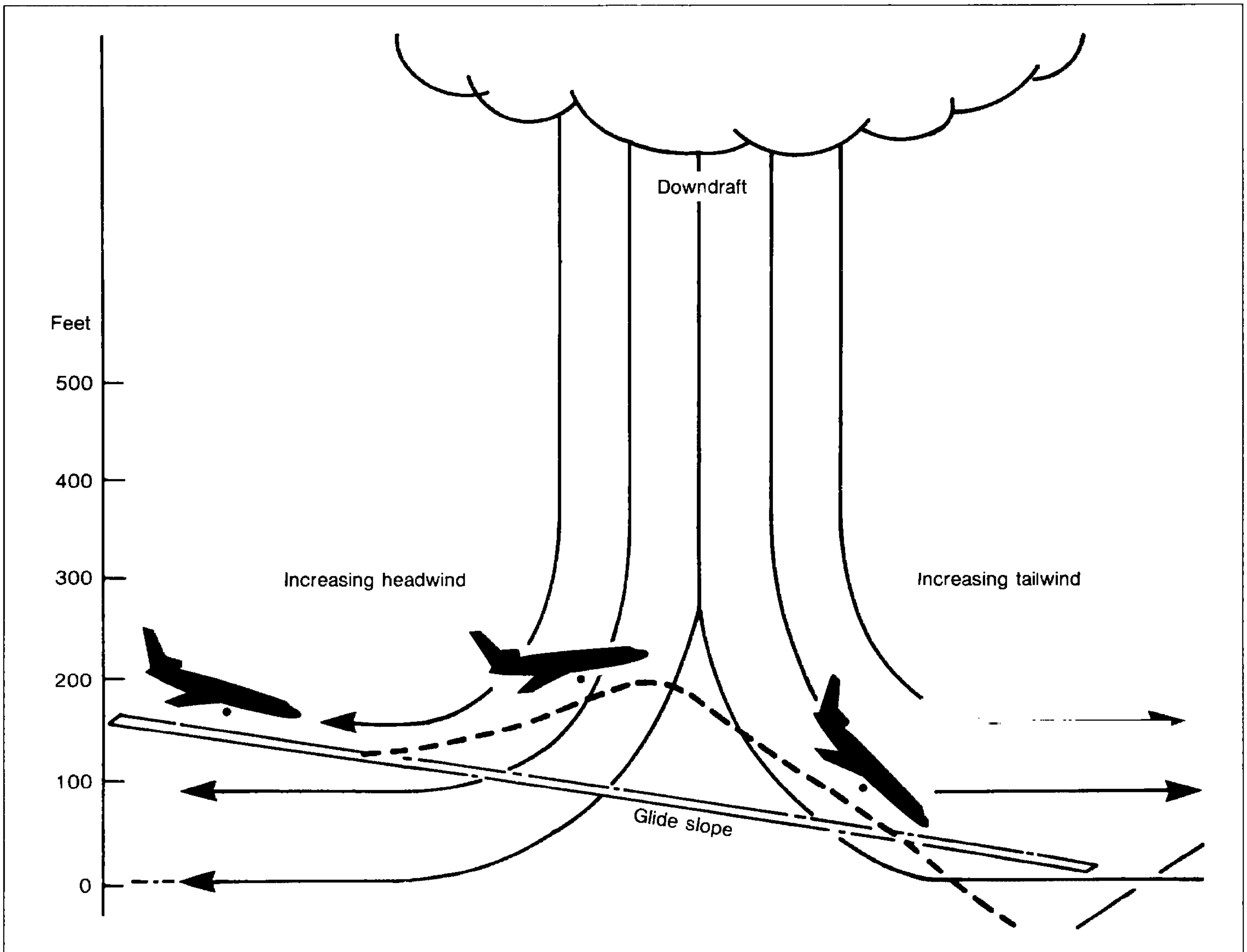
This report examines the Federal Aviation Administration's (FAA's) efforts to improve hazardous weather detection at major airports[1] and its efforts to make this information more timely.

FAA's Existing Airport Weather System

Other federal agencies, including the National Transportation Safety Board, perform certain aviation safety-related functions, but primary responsibility rests with FAA. This includes providing weather information to pilots. FAA obtains weather information from its own weather detection systems as well as weather warnings from the National Weather Service (NWS). FAA distributes this weather information to its

[1] Major airports, as used in this report, are defined as those airports scheduled to receive FAA's optimal ground-based wind-shear detection system and or its new airport surveillance radar that is capable of distinguishing between levels of precipitation. All of these airports have an FAA control tower staffed by air traffic controllers who provide services to airborne aircraft operating in the vicinity of the airport and to aircraft operating on the airport surface. In general, these airports primarily service air carrier pilots, including air taxis, commuters, and air travel clubs, as opposed to private aircraft pilots (general aviation)

Figure 1.1: Effects of Wind Shear on Landing Aircraft



Source: Weatherwise Magazine

air traffic controllers and flight service station specialists,[2] who disseminate the information to pilots.

[2]Flight service station specialists provide a broad range of preflight and in-flight services specially aimed at general aviation pilots, including preflight weather briefings and disseminating weather information.

Today's airports have two weather detection systems: the low-level wind-shear alert system (LLWAS) and the airport surveillance radar (ASR). Both of these systems have weather detection limitations.

Although capable of detecting some wind shears, FAA has found LLWAS to be unreliable for detecting microbursts and plagued by false alarms. LLWAS is unreliable because microbursts may be missed by hitting between or occurring outside the boundary of system's ground-based sensors. False alarms occur when the system gives warnings that do not represent a true hazard to aircraft safety. Hence, the system has low credibility with pilots, who sometimes ignore its warnings and continue taking off and landing. Both, the National Transportation Safety Board and FAA have concluded that a more effective wind-shear detection system is needed.

While the ASR can detect precipitation, it cannot distinguish between precipitation intensities or indicate the likelihood that the precipitation contains phenomena hazardous to aviation, such as hail, lightning, or turbulence. As a result, the radar is ineffective for identifying areas of hazardous weather.

At major airports, FAA depends upon controllers to give weather information to pilots. This includes reading NWS weather warnings, which are hand passed from controller to controller and read to pilots as time permits. On the basis of past GAO reviews of controller activities, we have found that controllers are sometimes too busy to disseminate weather information to pilots.[3]

FAA's Weather Improvement Program

To improve safety, FAA is implementing a $1.5 billion weather information improvement program. This program is designed to (1) provide more accurate weather detection by installing new weather detection systems and (2) improve the timeliness of weather information dissemination.

To provide more accurate weather detection, FAA plans to install six new weather detection systems—five to detect hazardous conditions such as wind shear, hail, and lightning, and one to measure routine weather conditions such as temperature, dew point, and wind direction. To provide

[3]See Aviation Weather Hazards: FAA System for Disseminating Severe Weather Warnings to Pilots (GAO/RCED-86-152BR, Apr. 22, 1986), and Serious Problems Concerning the Air Traffic Control Work Force (GAO/RCED-86-121, Mar. 6, 1986).

more timely weather dissemination to pilots, FAA plans to develop a communication system whereby pilots with the necessary on-board equipment can automatically access a ground data-base system and obtain certain weather information without the assistance of controllers.

FAA's Planned Weather Detection Systems

The five hazardous weather detection systems FAA plans to install are

- the enhanced low-level wind-shear alert system (enhanced LLWAS),
- the next-generation weather radar (NEXRAD),
- the terminal NEXRAD,
- the terminal Doppler weather radar, and
- a new airport surveillance radar (ASR-9).

Three of these systems—enhanced LLWAS, terminal NEXRAD, and terminal Doppler weather radar—are designed to improve detection of wind shear at airports. The ASR-9 is designed to improve airport detection of hazards associated with precipitation, such as lightning, hail, and turbulence. The NEXRAD will provide hazardous weather detection between airports on FAA's enroute system.

In addition to the five hazardous weather detection systems, FAA is procuring an automated weather-observing system. Its objective is to measure and automatically report airport weather conditions such as wind speed and direction, visibility, and temperature. It is being installed at general aviation airports,[4] many of which do not have controllers. Pilots flying to these airports, therefore, presently lack information on current weather conditions.

Enhanced LLWAS

The existing LLWAS is located at 87 airports across the United States. Each LLWAS consists of six ground-based wind sensors and a computer processor. When more than a 15-knot difference in wind speed arises or a change in direction is measured by the sensors, an alarm sounds and controllers pass the warnings to pilots preparing for takeoffs or landings.

The enhanced LLWAS is to be installed at 110 airports by August 1992. The number of wind sensors will be increased from 6 to 11, and an improved computer processor will be added. In addition, some sensors at airports already having an LLWAS will be relocated to reduce false

[4]General aviation airports serve private aircraft pilots

alarms. The objective of enhanced LLWAS is to increase the number and density of sensors, thereby reducing the likelihood that microbursts will hit between the sensors without being detected.

Although an improvement, the enhanced LLWAS is not viewed by FAA as the optimal solution to the wind-shear detection problem because, for the most part, the sensors are located on the airport and cannot detect wind shears that occur above ground or beyond the airport's boundaries. For example, Delta Air Lines flight 191, which crashed at Dallas/Ft. Worth International Airport on August 2, 1985, encountered a microburst beyond the airport's LLWAS sensors. This microburst was not detected by LLWAS until some 10-12 minutes after the crash, when the microburst came closer to the airport and within range of the LLWAS sensors. Enhanced LLWAS, however, will remain a part of the total FAA wind-shear program to supplement the new Doppler radar systems.

NEXRAD and Terminal NEXRAD

The NEXRADS are part of an interagency NWS, FAA, and Air Force procurement. This procurement includes 113 NEXRADS that are to replace the existing NWS conventional radar network by 1994. These radars will be located away from airports and will be used primarily to detect enroute rather than airport weather.

In addition to participating in the interagency NEXRAD network, FAA is procuring 16 NEXRADS to provide weather information to enroute air traffic in Alaska, Hawaii, and the Caribbean. However, before going to their enroute locations, FAA plans to install these radars—known as terminal NEXRADS—near 19 of the nation's busiest airports between 1990 and 1992, at a cost of $103 million. This cost includes $10 million for installing these 16 NEXRADS in terminal areas and their subsequent redeployment to enroute locations when FAA's optimal terminal system is available.

The terminal NEXRADS will be sited away from the airports and will improve wind-shear detection by extending coverage beyond the area covered by the enhanced LLWAS system. They will provide interim wind-shear coverage while the terminal Doppler weather radar is being developed.

Terminal Doppler Weather Radar

The terminal Doppler weather radar is FAA's optimal ground-based wind-shear detection system. FAA plans to award a procurement contract in late fiscal year 1988, and the terminal Doppler weather radar is to be installed at 100 airports between 1992 and 1995, at a cost of $562 million.

The terminal NEXRAD and terminal Doppler weather radars will change the method of detecting wind shear from LLWAS' ground-based sensors to radars. These radars will use state-of-the-art Doppler technology to measure the intensity of winds. Existing FAA and NWS radars do not have this capability.

ASR-9

In addition to its wind-shear detection systems, FAA has developed a new airport surveillance radar, the ASR-9. This radar is to be installed at 101 airports between 1988 and 1991, at an estimated cost of $575 million, which includes about $89 million for relocating existing airport surveillance radars to less busy airports.

The ASR-9 will provide improved weather detection by distinguishing between six levels of precipitation. The higher the rate of precipitation, the more likely that it is associated with hazardous phenomena such as lightning, hail, or turbulence.

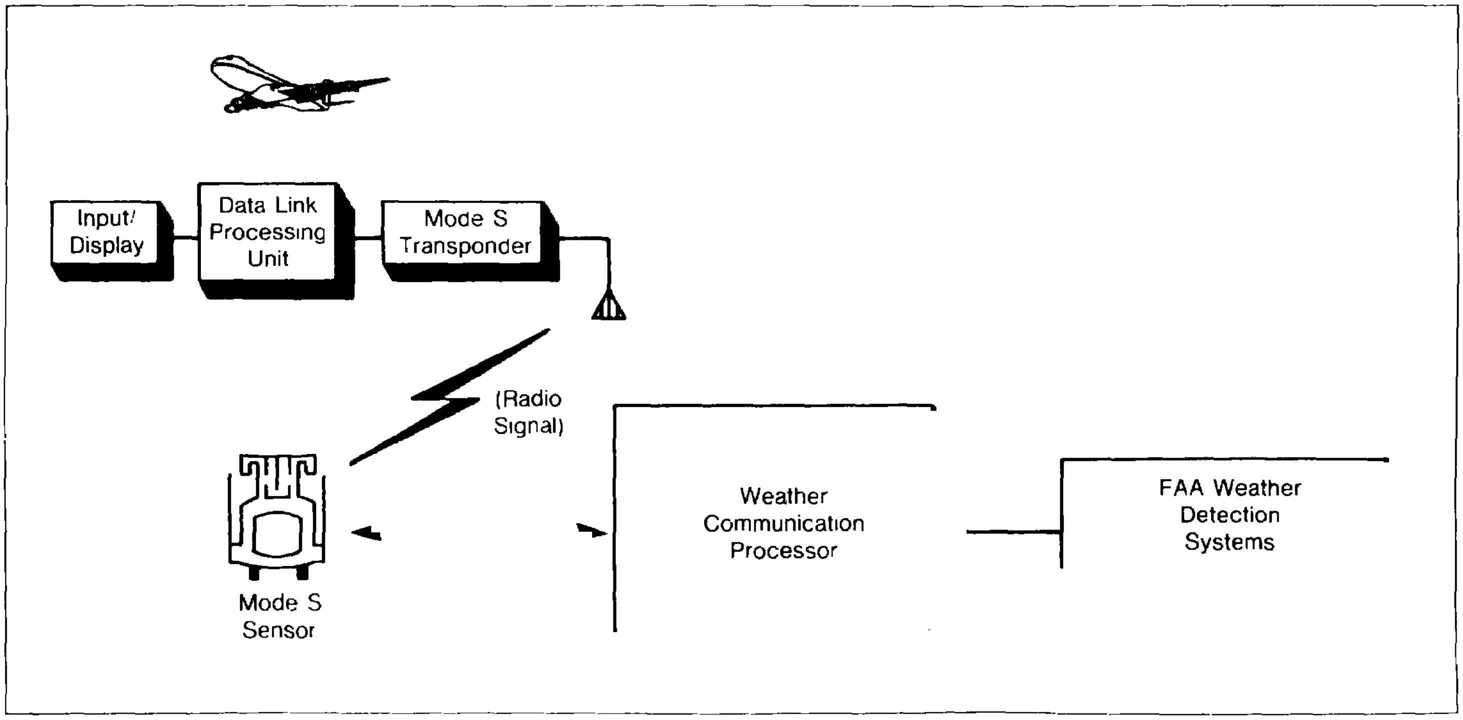
FAA's Planned Weather Dissemination System

According to the Air Lines Pilots Association, its highest weather priority is for real-time[5] information on wind shear, thunderstorms, and runway conditions at airports. To provide more timely weather information to pilots and reduce the work load of controllers, FAA is developing a ground-to-air communication system—called the Mode S data link—that will give pilots direct access to some weather data. To receive information via the data link, aircraft must be equipped with a Mode S transponder (a piece of avionics equipment that can receive and transmit information by radio signals), an on-board computer, and a computer printer or display.

FAA is also developing a ground-based weather communications processor (WCP) which will act as the interface between Mode S data-link-equipped aircraft and pilot-desired weather information. It will receive pilot requests for weather data, decode the requests, format the replies, and return them to the pilot. (See fig. 1.2.)

[5]Real-time is the period in which the occurrence and reporting of an event are almost simultaneous.

Figure 1.2: The Mode S Data Link Weather System



Source FAA

Objectives, Scope, and Methodology

The objectives of this review were to examine FAA's plan for improving hazardous weather detection and dissemination at major airports, particularly during the critical takeoff and landing phases of flight. As requested by the Chairman, House Committee on Science, Space, and Technology, we determined

- how FAA plans to address the problem of detecting wind shear and other hazardous weather around airports and what unresolved technical issues remain,
- whether hazardous weather information will be communicated to pilots in a more timely manner and
- when FAA's new systems will be available and what their cost is estimated to be. (See app. I for systems cost and app. II for implementation schedule.)

We determined how FAA plans to address the wind-shear detection problem by examining the wind-shear projects in FAA's National Airspace

System (NAS) plan. A goal of FAA's $16 billion NAS plan is to improve aviation safety.

We were unable to compare actual equipment specifications between the terminal NEXRAD and terminal Doppler weather radars because the latter radar's specifications have not been finalized and tests and evaluations of the former have not been completed because of schedule delays. Unresolved technical issues of the terminal Doppler weather radar were ascertained from the technical literature, reported test results, and interviews with researchers at Lincoln Laboratory and the National Center for Atmospheric Research, as well as FAA program officials.

To determine how FAA plans to improve the detection of other hazardous weather around airports, we reviewed the airport surveillance radar program. To identify system capabilities and limitations involved with the radar and its expected performance in detecting hazardous weather phenomena, we interviewed FAA program officials as well as the program manager of the ASR-9 contractor.

To determine whether hazardous weather information will be conveyed to pilots more quickly, we reviewed FAA's NAS plan and determined whether information from FAA's new hazardous weather detection systems will be disseminated directly to pilots via the Mode S data link. To identify the type of equipment needed on-board an aircraft to obtain information via the Mode S data link, we reviewed documents and interviewed officials in several FAA program offices and the Radio Technical Commission for Aeronautics. The commission is comprised of industry and FAA representatives responsible for establishing on-board avionics standards.

Our review focused on FAA's five new hazardous weather detection systems and the Mode S data link. Availability dates for the new technologies were determined from FAA's March 1987 National Airspace System Program Master Schedule. Costs of the new systems were obtained from FAA program managers and validated with FAA funding schedules in March 1987.

Our work was performed at FAA's headquarters, Washington, D.C.; NWS, Silver Spring, Maryland; the National Severe Storms Laboratory, Norman, Oklahoma; and the FAA Technical Center, Pomona, New Jersey. In addition, we visited FAA contractor facilities, including Martin Marietta, FAA's NAS plan System Engineering and Integration Contractor; and Lincoln Laboratory, Lexington, Massachusetts. We interviewed officials at the NEXRAD Joint System Program Office and the National Center for Atmospheric Research concerning the terminal NEXRAD and terminal Doppler weather radars. We also interviewed contract officials at Westinghouse Electric Corporation, manufacturer of the airport surveillance radar. We used information contained in prior GAO reports and statements before Congressional Committees concerning FAA air traffic controller activities and aviation weather systems capabilities and limitations.

Our review was conducted primarily from June through December 1986, and we updated the systems' implementation schedules and costs as of March 1987. We performed our review in accordance with generally accepted government auditing standards.

DOT and FAA officials with whom we discussed this report, generally agreed with our findings, conclusions, and recommendations. At the request of the Chairman's office, however, we did not obtain written agency comments on this report so that it could be issued before a scheduled September 1987 hearing before the Subcommittee on Transportation, Aviation, and Materials, House Committee on Science, Space, and Technology.

Unresolved Issues Relating to FAA's New Hazardous Weather Detection and Dissemination Systems

FAA's planned wind-shear detection systems will provide progressively better wind-shear protection than is presently available with LLWAS. However, FAA's optimal ground-based wind-shear detection system—the terminal Doppler weather radar—has several unresolved technical issues that could reduce its anticipated effectiveness and/or increase its cost.

Similarly, FAA's ASR-9 radar provides improved weather detection over that of existing airport surveillance radars. The usefulness of the ASR-9 data is clouded, however, because FAA is uncertain of how the radar is to be monitored by air traffic controllers and what information they are to disseminate to pilots.

Finally, while FAA intends to improve the timeliness of weather information dissemination, its current NAS plan states that hazardous weather information from the new detection systems will not be sent directly to pilots for at least a decade. Until its hazardous weather communication system is implemented, FAA will continue to use its busy controllers to disseminate this information.

FAA's Performance Objectives for an Optimal Ground-Based Wind-Shear Detection System

FAA and its wind-shear researchers have identified performance objectives that they believe an optimal ground-based wind-shear detection system should meet. These objectives are formalized in FAA's May 28, 1987, Order 1812.9, System Requirements Statement for the terminal Doppler weather radar. They include (1) accurately measuring a wind shear's headwind-tailwind component, (2) forecasting the development of microbursts by detecting wind-shear precursors, (3) scanning all airport runways and flight paths, (4) having at least a 90-percent probability of detecting all microbursts while having a 10-percent or less false alarm rate, and (5) being fully automated whereby radar signals are automatically translated into useful information. The purpose of these performance objectives is to assure accurate detection and useful information to pilots.

Accurately Measuring the Headwind-Tailwind Component

The National Center for Atmospheric Research has identified the headwind-tailwind component of wind shear as the one most critical to aircraft performance. The quick change from an increasing headwind to an increasing tailwind is the single factor most likely to cause a wind-shear accident. Without accurately measuring the headwind-tailwind component, pilots will not have the information they need to decide whether to abort a takeoff or landing, or what actions to take to best recover from wind shear should one be encountered.

Forecasting Microbursts Development

An optimal ground-based wind-shear detection system should also be able to scan the area above an airport to detect clues or precursors of microbursts. The National Transportation Safety Board has urged positive identification of conditions conducive to microbursts and FAA warnings to pilots when these conditions exist. Through earlier detection, pilots would have more time to avoid the wind shear, thereby possibly reducing the number of wind shears encountered. Without such a capability, the early warning that pilots need before taking off or landing will not be available.

Scanning All Runways and Flight Paths

According to the official in charge of FAA's terminal Doppler weather radar research at Lincoln Laboratories, scanning all airport runways and flight paths is important to maximize the area covered, thereby minimizing the service disruptions created by potential wind-shear conditions. At most large airports, this objective creates siting problems for the radar because few locations have an unobstructed view of all runway approaches.

Detecting Most Microbursts While Having a Low False Alarm Rate

The importance of the 90-percent detection and 10-percent false alarm rates concerns the need for system credibility among pilots and controllers. Pilots must decide what action to take on FAA's warnings. If the system fails to detect most microbursts or false alarms frequently, pilots are not likely to have faith in the system and may even ignore its warnings. System credibility has been a major problem with the existing LLWAS. It could also become an issue with the terminal Doppler weather radar.

A Fully Automated System

Because of the rapidity with which wind shears develop, the detection and accompanying dissemination of warnings must also be rapid—there is no time for evaluations by a meteorologist. Accordingly, the wind-shear detection and dissemination systems must be completely automated and generate a simple, easily understood message. The message must reliably indicate the existence, location, and severity of the wind shear.

Research on Certain Terminal Doppler Weather Radar Performance Objectives May Not Be Completed Before FAA's Planned Production Contract Date

Even though FAA is planning to award a procurement contract for 100 terminal Doppler weather radars in 1988, research on certain performance objectives will still be continuing. Thus, in 1988 FAA will not have determined whether the radar can meet all of its performance objectives.

For example, FAA researchers have identified several weather features that are believed to be indicators of developing microbursts; but it is not known whether a reliable precursor detection technique is possible, and research on the detection of microburst precursors is to continue at the National Center for Atmospheric Research in fiscal years 1987 and 1988. Similarly, FAA researchers question whether the 90-percent detection and 10-percent false alarm rates are attainable, and further testing is planned through fiscal year 1988.

As of now, an automated system for detecting wind shears and disseminating warnings has not been developed, and until operationally tested, its success is unknown. Research officials at the National Center for Atmospheric Research have stated that the development of the final user product and its automated delivery system may be more difficult than the development of the radar. Research on the development of an automated system is also to continue in fiscal years 1987 and 1988.

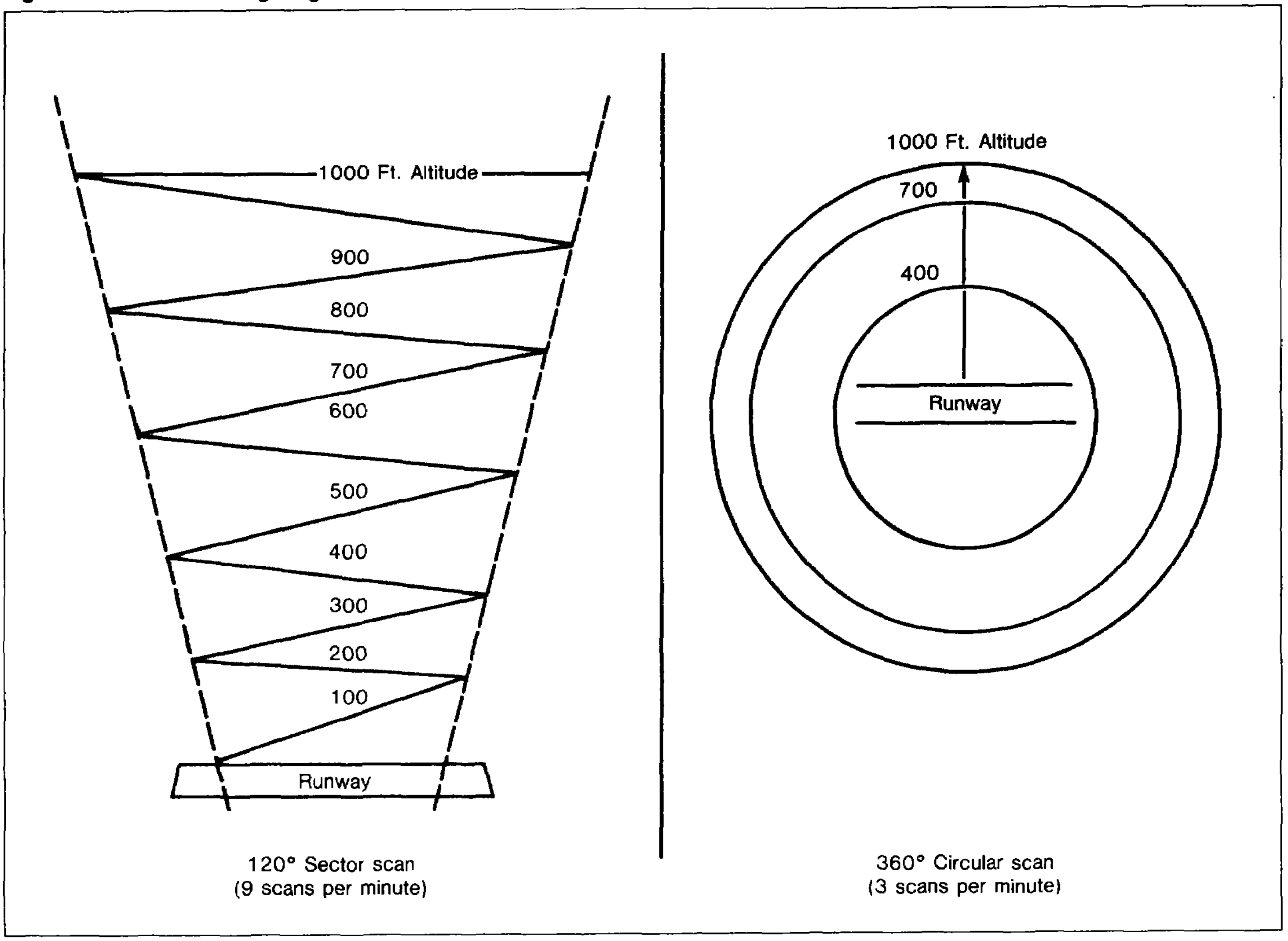
The Terminal Doppler Weather Radar's Competing Performance Objectives May Require Different Siting and Scanning Strategies

When FAA's research on all the performance objectives is completed, certain trade-offs among the various performance objectives may have to be made. Different system siting and scanning strategies may meet some performance objectives while reducing the effectiveness of others.

For example, as illustrated in figure 2.1, FAA is considering both a full-circle scan in which the radar antenna rotates 360 degrees, and a sector scan in which the antenna rotates back and forth at a 120-degree angle. According to the official in charge of FAA's terminal Doppler weather radar research at Lincoln Laboratories, the advantage of the sector scan is that it can make more scans and produce more data quicker than the 360-degree scan, thereby increasing the probability and accuracy of wind-shear detection. The advantage of the 360-degree scan is that the entire airport area can be observed. This could include the identification and location of incoming wind shears that have not yet reached the airport runways and flight paths.

FAA is also considering various radar siting strategies. The National Center for Atmospheric Research has concluded that to best measure

Figure 2.1: Radar Scanning Diagram

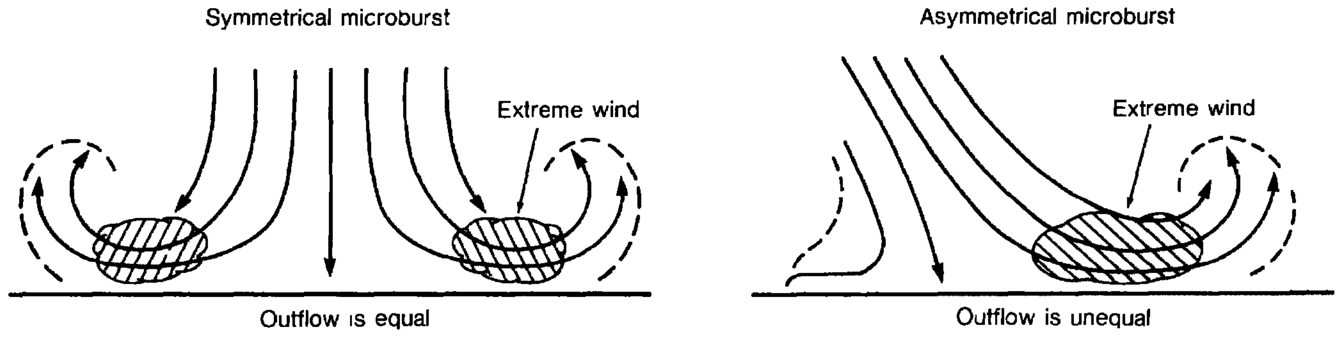


Source GAO on the basis of NCAR data

the headwind-tailwind component, the radar should look straight down a particular runway to detect the speed of wind moving toward and away from the radar. This is particularly true when measuring asymmetrical microbursts, illustrated in figure 2.2, where the wind outflows are much greater on one side than the other.

According to FAA researchers, a radar that does not look straight down a particular runway may greatly underestimate or not detect the severity of asymmetrical microbursts. Conversely, that same radar looking

Figure 2.2: Symmetrical and Asymmetrical Microbursts



Source: T. Theordore Fujita, "Microburst As An Aviation Wind Shear Hazard," University of Chicago.

straight down a runway may miss weather movements or precursors aloft that will ultimately result in microbursts.

Reliably measuring diverging winds along the flight path or detecting microbursts before they enter the flight path will probably depend on the radar-scanning strategy FAA decides to use. On-airport siting may provide more accurate headwind-tailwind measurements for at least one runway while off-airport siting may provide better detection of wind-shear precursors. Research on both the radar's scanning and siting strategies is to continue at least through fiscal year 1988.

Siting Two Radars at Each Airport May Be an Effective but Costly Alternative

In reporting on test results from its Joint Airport Weather Studies project in October 1984, the National Center for Atmospheric Research found that the performance objectives of an optimal ground-based wind-shear detection system can best be met by installing two terminal Doppler weather radars at each airport. On the basis of its research, the Center found that a dual-Doppler radar system, using two radars placed at 90-degree angles to the center of the airport, is the only way of providing accurate measurements of all winds along all runways and flight paths. In addition, two Doppler radars could also facilitate the scanning for microburst precursors if a reliable detection technique can be developed.

Uncertainty Exists About How to Use the Airport Surveillance Radar's Weather Data

In addition to the terminal Doppler weather radar, FAA is also installing the ASR-9 radar capable of distinguishing between six levels of precipitation and, thus, the likelihood that the precipitation is associated with lightning, hail, or turbulence, which are hazardous to aviation. While FAA officials told us that they plan to provide some of the ASR-9 weather information to pilots, the agency has not developed guidance for controllers on how the levels of weather are to be monitored and what information is to be disseminated to pilots.

NWS has categorized the six precipitation levels that the ASR-9 can distinguish between and the phenomena that are likely to be associated with them as shown in table 2.1. FAA and NWS have determined that each of the six levels can contain phenomena strong enough to crash an aircraft.

Table 2.1: NWS Definition of Six Weather Levels

Level 1 (WEAK)	Light to moderate turbulence is possible with lightning
Level 2 (MODERATE)	Same as Level 1
Level 3 (STRONG)	Severe turbulence possible lightning
Level 4 (VERY STRONG)	Severe turbulence likely lightning
Level 5 (INTENSE)	Severe turbulence lightning, organized wind gust Hail likely
Level 6 (EXTREME)	Severe turbulence large hail, lightning and extensive wind gust

Source NWS

FAA has decided to disseminate the ASR-9 weather information directly to air traffic controllers, who will relay the information to pilots. It may be difficult for controllers, however, to explain to pilots the airspace covered by the different levels of precipitation. For example, it will be difficult for a controller to explain to a pilot the airspace that is covered by level-3 type weather versus the airspace that is covered by level-5 type weather. This problem is compounded by the fact that only two of the six levels of precipitation can be displayed on a controller's radar screen at one time. Thus, it will be particularly difficult to explain to a pilot the levels within the same geographical boundary that appear on different channels, which would require the controller to switch from channel to channel.

Status of FAA's Efforts to Send Hazardous Weather Data Directly to Pilots

In a March 1987 hearing before the Subcommittee on Transportation, Aviation, and Materials, House Committee on Science, Space, and Technology, FAA stated that wind-shear information will be disseminated to pilots via the Mode S data link. However, current NAS plan projections indicate that automatic dissemination of hazardous weather data, such as wind shear, will not occur for at least a decade. FAA recently began research and development on how to send terminal NEXRAD wind-shear data directly to pilots.

In October 1985 hearings before the Subcommittee on Aviation, House Committee on Public Works and Transportation, FAA officials said that ASR-9 precipitation data would be available in the cockpit via the Mode S data-link system by the early 1990's. This does not comport with FAA's current intentions, which are to rely on controllers to provide pilots with ASR-9 data. FAA officials recently told us that the agency does not plan for in-flight aircraft to directly access ASR-9's precipitation data. According to program officials, uplinking such radar data would be an enormous undertaking requiring considerable data processing.

Controllers Often Lack Time to Disseminate Weather Information

Switching from channel to channel to monitor and disseminate ASR-9 data as well as providing pilots with wind-shear information from FAA's enhanced LLWAS, terminal NEXRAD, and/or terminal Doppler weather radar takes time. On the basis of past GAO reviews of controller activities, there will be times when controllers will not be able to monitor the radar displays or disseminate hazardous weather information to pilots.

In our April 22, 1986, report on FAA's current system for disseminating hazardous weather information,[1] we found that two-thirds of the controllers at the nation's five busiest airports occasionally delay or do not give weather information to pilots. In addition, when weather information is given, it may not be given as soon as possible because controllers are too busy performing their primary duty of separating aircraft. For example, we found that 19 percent of controllers responding to our 1985 air traffic control work force survey[2] reported they often decline to provide weather advisories while working daily traffic peak periods. Another 34 percent said they occasionally decline to give weather advisories.

[1]See GAO/RCED-86-152BR, Apr 22, 1986.

[2]See GAO/RCED-86-121, Mar. 6, 1986.

Conclusions

As planned, the terminal Doppler weather radar will improve wind-shear detection, but all research on the radar's scanning and siting strategies, detection accuracy and reliability, automation, and wind-shear precursors will not be completed by FAA's planned fiscal year 1988 production contract date. While it is important for FAA to proceed as quickly as possible in developing and deploying an optimal ground-based wind-shear detection system, we believe it is also important that the system's capability to perform effectively be demonstrated before it is purchased and that the effects of unmet performance objectives be clearly assessed before awarding a production contract.

The new airport surveillance radar presents significant improvements in detecting airport-area weather hazards, but FAA has not determined how the ASR-9 information is to be monitored by controllers or what weather information is to be disseminated to pilots.

Until FAA can send information from its new ground-based hazardous weather detection systems directly to pilots via the Mode S data link, we believe that it will not be in a position to meet its objective of providing timely hazardous weather information to pilots. Controllers will continue being the primary source of hazardous weather information dissemination.

Recommendations to the Secretary of Transportation

We recommend that the Secretary of Transportation direct the Administrator, FAA, to

- inform the Department and the Congress of any performance objectives that the terminal Doppler weather radar cannot meet and their impact on safety and cost before committing funds for a procurement contract and
- develop guidance on how air traffic controllers are to monitor the ASR-9 weather display and what hazardous weather information they are to disseminate to pilots.

Views of FAA Program Officials and GAO's Response

We discussed the content of this report, our findings, and recommendations with senior FAA program officials, including the Associate Administrator for Development and Logistics. These officials agreed to inform DOT and the Congress of any unmet performance objectives and their impact on safety and cost before committing funds to procure a terminal Doppler weather radar. They expressed concern, however, that our conclusion and recommendation may understate the very positive progress and safety improvements the system will achieve. The fact that the system cannot meet all of its objectives at the time a procurement decision is made, they said, must not overshadow its very real accomplishments or suggest future solutions to unresolved problems will not be forthcoming.

We agree that unresolved technical problems at the time of procurement should not obscure what the radar can do, nor suggest that future solutions will not be forthcoming. Our recommendation seeks to achieve an informed decision by decision makers of a very expensive and important procurement by making them aware of what the system can and cannot do at the time of their decision as well as the cost and safety implications of any unmet performance objectives.

FAA officials also agreed with our recommendation to develop guidance for controllers to monitor and disseminate ASR-9 weather data to pilots. They said such guidance will be developed by FAA before the first commissioning of the ASR-9 radar, now scheduled for July 1988.

FAA officials agreed with the importance of sending hazardous weather data directly to pilots. They emphasized that research is underway, but cautioned that at the present time there is not sufficient information to know exactly how data links can be most effectively developed and implemented. We believe that uplinking hazardous weather information is an integral part of the usefulness of the Mode S data link and is important to the success of the detection systems.

Estimated Cost of FAA's Aviation Weather Systems

Dollars in millions

	Cost
Detection systems:	
1. Automated weather observing system	$208 5
2. LLWAS	56.2
3. NEXRAD	164.6
4. Terminal NEXRAD	103 0
5. Terminal Doppler weather radar	562 4
6. ASR-9	(a)
Processing systems	
7. Central weather processor	168 0
8. Weather communications processor	98 6
9. Flight service data processing system	31 0
10. Aviation weather processor	2.5
Communication Systems·	
11. National airspace data interchange network	83 6
12 Weather message switching center	22 9
13. Mode S data link	47 8
Total	**$1,549.1**

[a]The cost of the ASR is $575 million We did not include any of this cost in FAA's weather systems because the radar's primary purpose is to monitor air traffic and FAA could not segregate the cost of the weather detection system from that of air traffic surveillance

Source FAA's March 1987 Project Resume Report and FAA program officials

Estimated Implementation Schedule of FAA's Aviation Weather Systems

Aviation Weather Systems	First system operational	Last system operational
Detection systems:		
1. Automated weather-observing system	Dec. 15, 1988	Apr. 21, 1993
2 Enhanced LLWAS	Jan. 29, 1988	Aug. 31, 1992
3. NEXRAD	June 30, 1989	Jan. 31, 1994
4 Terminal NEXRAD	May 30, 1990	Mar. 31, 1992
5 Terminal Doppler weather radar	Sept. 2, 1992	May 24, 1995
6 ASR–9	June 30, 1988	May 30, 1991
Processing systems		
7. Flight service data processing system	Feb 12, 1986	Apr. 18, 1994
8 Aviation weather processor	May 2, 1990	Apr. 18, 1994
9 Central weather processor	Dec. 16, 1993	Mar. 22, 1995
10 Weather communications processor	Aug. 27, 1990	Apr. 28, 1992
Communication systems		
11. National airspace data interchange network	Sept. 25, 1990	July 29, 1994
12. Weather message switching center	Aug. 15, 1991	Oct. 15, 1991
13. Mode S data link	Mar. 5, 1990	July 29, 1994

Source FAA's March 1987 NAS Program Master Schedule Baseline Report

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