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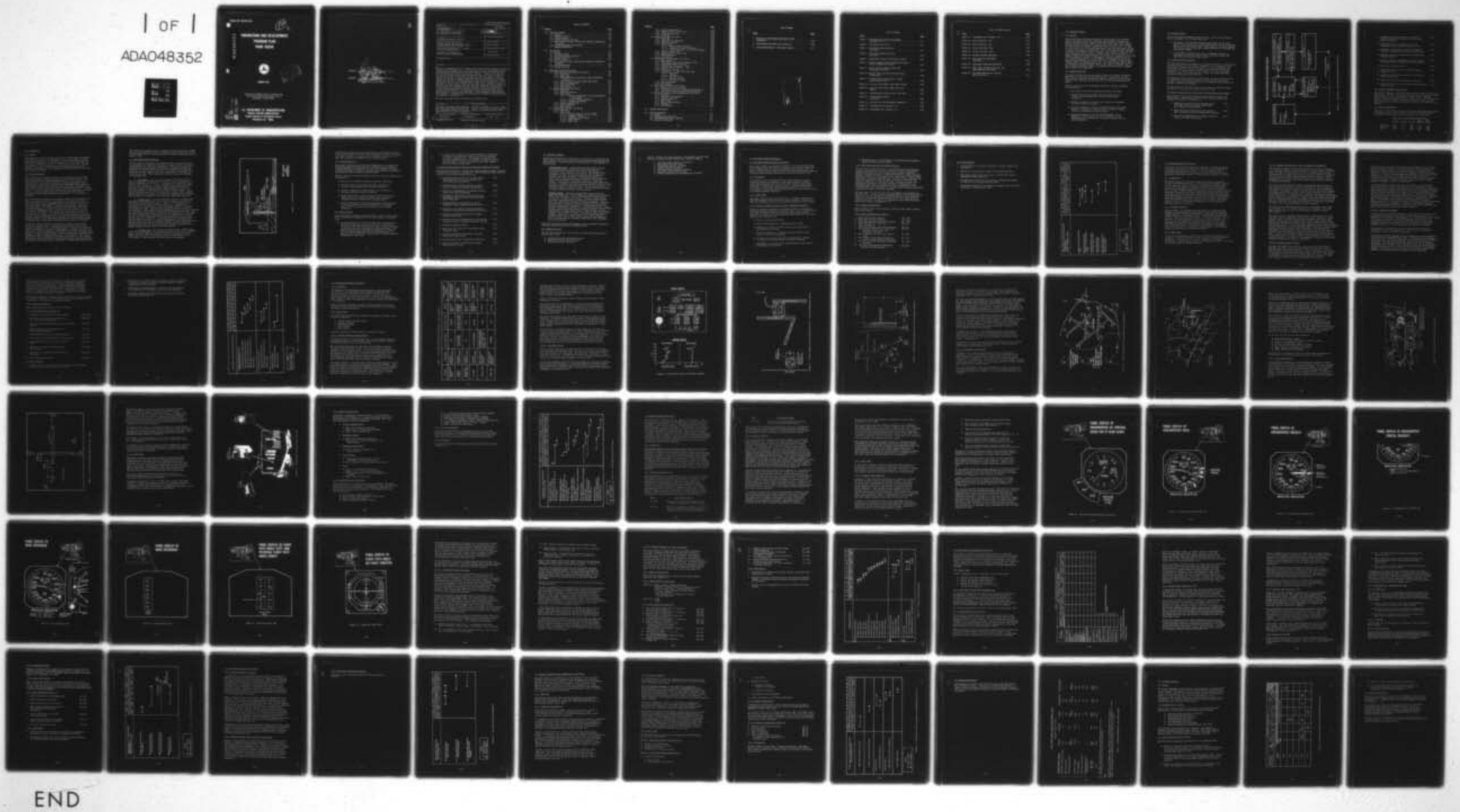

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ENGINEERING AND DEVELOPMENT PROGRAM PLAN - WIND SHEAR

AUGUST 1977

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

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16. Abstract

This is a development plan for solutions to the aviation hazards created by low-level wind shear in the terminal area. It describes the four-year development program to satisfy National Airspace System (NAS) user needs for current and predicted information concerning wind shear at the Nation's airports. Included in the plan are: (1) efforts to better characterize low-level wind shear, (2) plans to define the hazards of wind shear for the aviation community, (3) tasks required to develop ground-based devices for hazardous wind shear detection and movement, (4) investigations into the use of airborne equipment to detect hazardous wind shear and then either warn the pilot of its presence and/or assist him in coping with it, (5) a description of how the data collected on wind shear will be processed, analyzed and reported, (6) plans to improve low-level wind shear predictions are presented, and (7) provisions for integrating wind shear data into the NAS by developing data formats and displays suitable to users (air traffic controllers, pilots and the National Weather Service). The FAA groups and other Federal Government agencies participating in this effort are identified. Program management responsibilities are addressed. A program schedule with milestones is presented and program funding requirements are identified.

This plan supersedes Report No. FAA-ED-15-2 dated March 1976.

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1.0 Executive Summary

1.1 Problem

Severe wind shear conditions occurring at low altitudes in the terminal area are hazardous to aircraft operations during takeoff, approach and landing, as indicated in a number of accidents in the past several years. When an aircraft is flying only slightly above stall speed a major change in wind velocity can lead to a significant gain or loss of lift. If there is a loss and it is of sufficient magnitude so that the power and/or control response is inadequate to immediately correct the energy deficient condition, it results in an excessive rate of descent. The altitude at which the wind shear encounter occurs, the pilot's reaction time, and the aircraft's response capability, determine whether the descent can be slowed in sufficient time to prevent an accident. For example, if there is a gain and it is of sufficient magnitude so that the response is inadequate to correct the energy excessive condition, it will result in an aircraft excursion significantly above the intended glide slope. This condition may cause a resultant overshoot or missed approach, but may also cause an excessive rate of descent during the latter phase of the approach when the pilot is attempting a return to the glide path.

1.2 Program Objectives

The overall objective of the Wind Shear Program is to examine the hazards associated with wind shear in the terminal area, characterize the wind shear problem, establish required work needed to arrive at solutions; and implement and integrate such solutions into the National Airspace System (NAS).

Specific objectives of the development plan are to innovate equipments and techniques to:

- Warn pilots of potential hazardous wind shear encounters.
- Provide pilots with in-flight wind shear detection and aircraft control guidance for coping with wind shear encounters.
- Provide a capability to predict the occurrence of hazardous wind shear events at airports.
- Provide information to Flight Standards describing wind shear hazard as it relates to aircraft type or category, airspeed, altitude, configuration and gross weight.
- Furnish information to the ATC System management on the magnitude of wind shear hazards in the terminal area for subsequent relay to pilots at a rate and in formats that are easily understood.

1.3 Critical Issues

As the wind shear development program proceeds, certain critical issues must be considered. Two of these issues are:

- Solutions to the wind shear problem using cockpit derived information versus that obtained from ground equipment has been evaluated. Results of the evaluation support continuation of concurrent development in both areas to determine optimum capabilities of airborne and ground-based systems.

- An assessment of benefits and costs of candidate solutions is necessary to support decisions on which wind shear systems will most effectively enhance flight safety.

1.4 Program Technical Approach

The Wind Shear Program is designed to investigate solutions to terminal area wind shear hazards in three general categories: (1) through the use of ground-based equipment, (2) through the use of airborne equipment, and (3) by improving the accuracy of terminal area wind shear forecasting techniques. It is most probable that elements of all three categories will be included in the final solution. Figure 1 outlines wind shear subprogram relationships and work flow.

The program has been structured to provide near-term and interim products for operational application, when such products can provide a safety increase. Longer term program tasks will be integrated with the near term outputs as they become available.

For the purpose of this effort, near term products are defined as those scheduled for field test and evaluation prior to 1978.

1.5 Major Decision Points, Products and Estimated Completion Schedule

Major decision points for the seven wind shear projects (tasks) are outlined below. Individual wind shear project (task) milestones are presented in Sections 3.1 through 3.7.

• Establish future direction of airborne system development based on critical aircraft and pilot response characteristics.	5/77
• Adopt wind shear profiles that can be used in pilot training and aircraft engineering simulators.	10/77
• Decision on implementation of expanded low-level frontal wind shear forecasting.	11/77

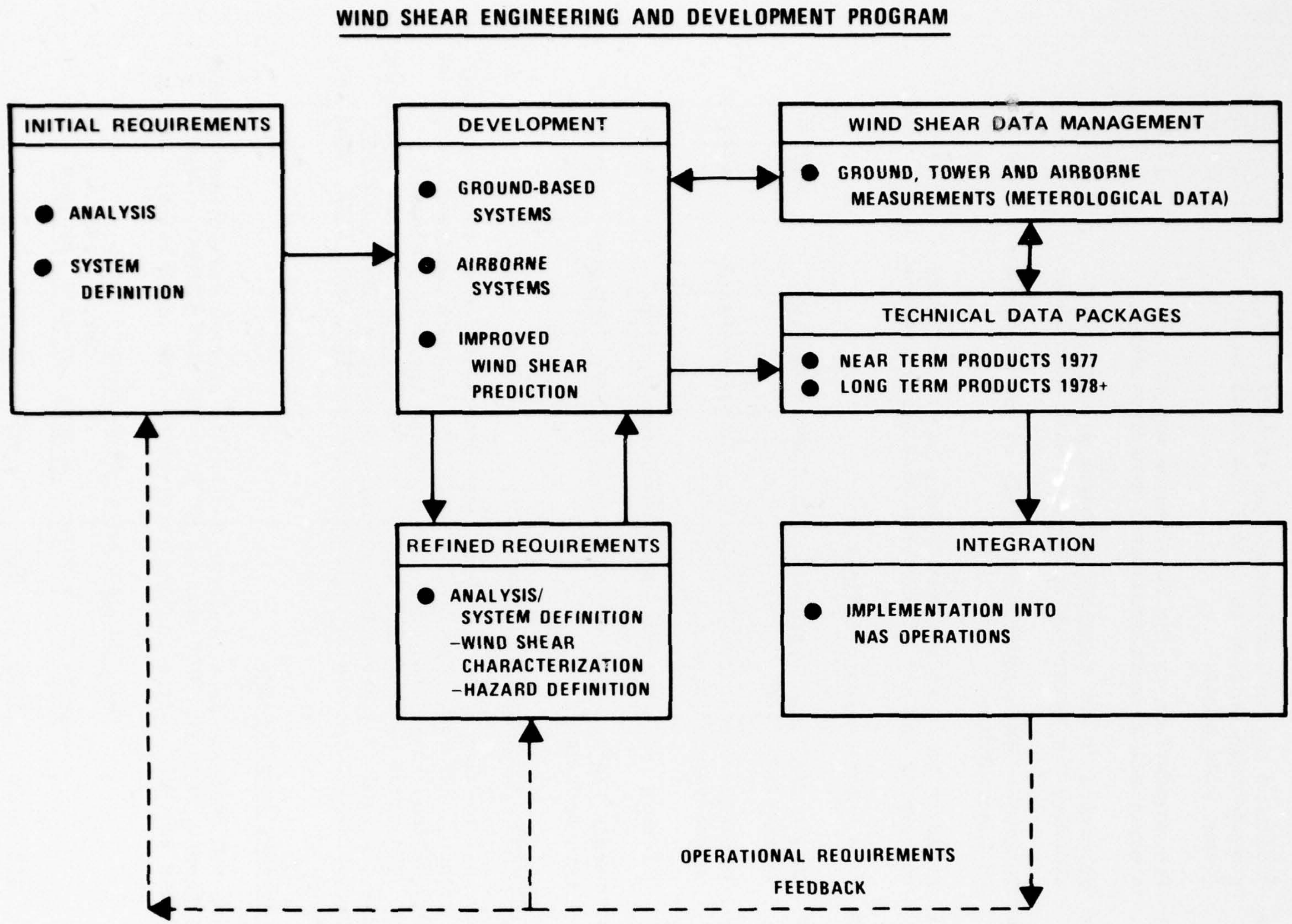


Figure 1. Wind Shear Functional Relationships and Work Flow

● Recommend to the Services siting criteria for ground-based sensors to detect and track significant wind shear.	12/77
● Recommendations to the Services on use of operational airport anemometer sensor system.	12/77
● Recommend to the Services airborne procedures/ avionics for detecting and coping with wind shear.	1/78
● Determine operational feasibility of ground-based CW Laser system.	3/78
● Evaluate and make recommendations to the Services concerning the use of airborne wind shear systems.	7/78
● Wind Shear language refined.	11/78
● Obtain FAA final approval of Wind Shear System Integration Plan.	1/79
● Determine operational feasibility of ground-based pulsed laser system.	4/79
● Determine pulsed radar operational feasibility.	4/79
● Obtain FAA approval for Wind Shear Systems Implementation Criteria.	11/79

1.6 Program Management and Interface

The overall management of the Wind Shear Program is under the Wind Shear/ WVAS Branch, ARD-740. The Program utilizes a matrix management approach wherein various functional SRDS groups manage specific projects/ tasks. The major participants within the FAA include: the FAA Operating Services, Office of Systems Engineering, Logistics, SRDS, and NAFEC. Participating groups outside the agency include TSC, DOD, NASA, NOAA and industry.

1.7 Funding Requirements

Section 4.0 contains past, current and future program development funding requirements from FY 1976T through FY-1979 for each project (task). Total R&D and F&E program funding requirements are shown below:

Wind Shear Funding Requirements ($000)

	FY-1976	FY-1976T	FY-1977	Est. FY-1978	Est. FY-1979
R&D Funds	2597	948	4297	4561	2194
F&E Funds	800	-	700	30	2000
Totals	3397	948	4997	4591	4194

2.0 Introduction

2.1 General

Sharp gradients in the wind field referred to as wind shears, encountered by aircraft on takeoff or final approach, have caused serious accidents. Wind shear is any change in wind speed and/or direction through any thin layer of the atmosphere. It can be gradual; e.g., 4 knots per 500 feet in altitude, or it can be abrupt; i.e., 10 knots per 100 feet. For the purpose of this plan, low-level wind shear is defined as that shear occurring in the layer of the atmosphere between the surface and 1500 feet above ground level (AGL).

2.2 Problem Statement

Severe wind shear conditions occurring at low altitudes in the terminal area are hazardous to aircraft during final approach and takeoff. Any wind shear produces an immediate dynamic effect on the aircraft. This dynamic effect is particularly noticeable during an approach because the airplane is being flown at relatively low airspeeds along a precise three-dimensional path with relatively small operational tolerances. Airflow over the wing is effectively changed without either thrust or attitude change. In its very basic form, there are two shear conditions to consider. In one, the effective airflow over the wing is increased during the transition period between changing wind conditions. It is decreased in the other.

Effective airflow is increased in any shear condition of increasing headwind or decreasing tailwind. If an aircraft is on glide path with a stabilized approach, this <u>increased</u> effective airflow over the wing will cause an airspeed increase and the aircraft will initially tend to go above glide path. The reverse is true when encountering a condition of decreased headwind or increasing tailwind, then the effective airflow over the wing <u>decreases</u>. Again, in the latter case at least two things will happen: the airspeed will decrease and the airplane will tend to go below the glide slope. If the magnitude of this shear is severe, an excessive rate of descent can occur. The altitude at which the wind shear encounter occurs, the airspeed of the aircraft, the pilot's reaction time, and the aircraft's power and control response capability determine whether the descent can be controlled in sufficient time to prevent an accident.

A number of wind shear-related accidents and incidents have occurred in the past several years. An often referenced incident of wind shear occurred on January 4, 1971. Measurements showed, for aircraft approaching from the Southwest and landing to the Northeast, a tailwind of 70 knots at 3,000 feet, a 25-knot crosswind at 1,000 feet, and a 10-knot headwind on the surface. During a two-hour period, 9 aircraft consecutively executed missed approaches to John F. Kennedy's Runway 04R. On December 17, 1973, Iberia Flight 993, a DC-10, crashed short of Runway 33L at Boston's Logan Airport. The National Transportation Safety Board concluded that excessive wind shear was a major factor in the crash. Furthermore, investigations indicate that wind shear was the probable cause of Eastern's Flight 066 (B-727) accident while on final approach at John F. Kennedy Airport, June 24, 1975, as well as Continental's (B-727) crash after takeoff at Denver (Stapleton Airport), August 7, 1975.

2.3 Wind Shear Hazard Conditions

For most major air terminals, the hazardous shear can seriously disrupt air operations on a scale from 10 minutes to several hours. Fortunately, strong shears occur relatively infrequently. The major terminals may experience strong wind shears in and around the approach and departure corridors up to about 50 hours per year. The reason that stronger wind shears are not more common is that the meteorological conditions that cause them are rare. These conditions, in their order of the severity, are discussed below.

A. Gust Fronts. Gust fronts are normally formed from mature, severe thunderstorms and when located in the vicinity of airports can be extremely hazardous to air traffic. A schematic of a generalized gust front is shown in Figure 2. A zone of maximum hazard precedes the radar echo and is not identified by current airport surveillance radars or adequately detected by today's airport weather sensors. Only on very rare occasions has it been located and tracked by weather radar. It is usually determined after the fact by analysis of airport surface weather observations and pilot reports. The gust front phenomenon has a maximum frequency which is coincident with the maximum thunderstorm frequency.

B. Frontal Zones. The second mechanism capable of causing strong wind shears are frontal zones. These zones are routinely identified by conventional meteorological analysis. However, identification of the shear associated with them is much more difficult. Throughout the continental U.S., there exists a relatively meager network of 150 upper-air observing stations. They routinely collect data twice a day at 12-hour intervals. To determine the wind immediately near and over the collection site requires tracking a balloon located in the low-level wind field. Over the first 1,000 feet above the tracking site, if winds are not too strong, only two low-level wind measurements are usually obtained; i.e., one at 500 feet and one at 1,000 feet. Often when the type of winds that cause hazardous shear are present, an accurate measurement of the wind other than the surface wind, is not presently available for the altitude levels at which hazardous wind shear most seriously affects aircraft operations. Hazardous wind shears associated with frontal movement typically reach a maximum frequency between late Fall and early Spring.

C. Low-Level Jet. The last general meteorological condition that creates wind shear hazards, and perhaps the rarest of all, is the condition where a low-level temperature inversion forms near the surface with a warmer, low-level wind of considerable magnitude, immediately on top of the inversion. This situation typically occurs after midnight.

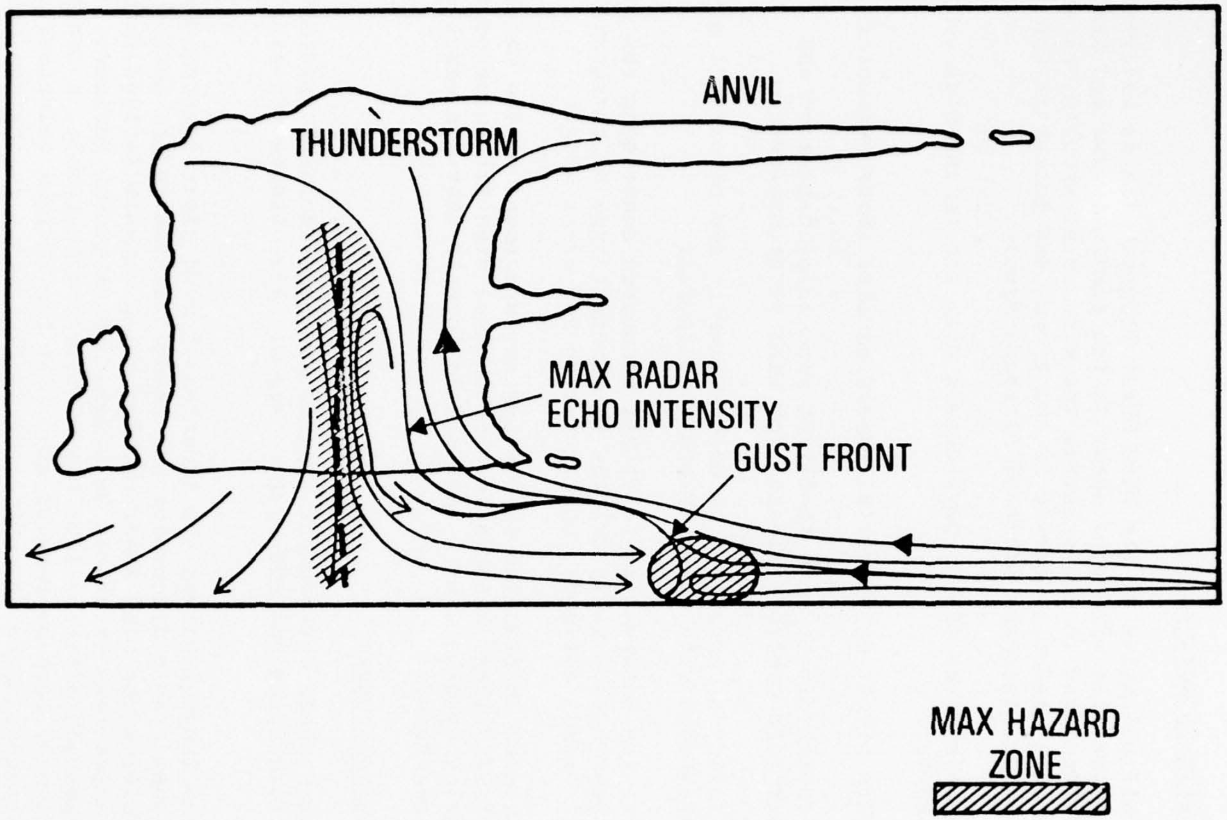


Figure 2. Generalized Gust Front

To summarize, hazardous low-level wind shear can be generally characterized as a rare event that is not easily identified or tracked. It occurs year round, and when it is detected it is normally after the fact, by past event analysis or through the pilot reporting system.

2.4 Program Objectives

The overall objective of the Wind Shear Program plan is to examine the hazards associated with wind shear in the terminal area and structure a program designed to characterize the wind shear problem, establish required work needed to arrive at solutions, and integrate and implement such solutions into the National Airspace System.

Specific objectives of the development plan are to innovate equipments and techniques to:

- Warn pilots of potential hazardous wind shear encounters.
- Provide pilots with in-flight wind shear detection and aircraft control guidance for wind shear encounters.
- Provide a capability to better predict the occurrence of hazardous wind shear events at airports.
- Provide information to Flight Standards describing the wind shear hazard as it relates to aircraft type or category, airspeed, altitude, configuration and gross weight.
- Furnish information to ATC System management on the magnitude of wind shear hazards in the terminal area for subsequent relay to pilots at a rate and in formats that are easily understood.

2.5 Critical Issues

As the wind shear development program proceeds, related critical issues must be identified and addressed. Two of these issues are discussed below:

- One issue involves the location of wind shear instrumentation. Considerable discussion has taken place as to the merits of solving the wind shear problem using cockpit derived information versus that which can be obtained from ground equipment. Each approach offers unique capabilities; conceivably, a combination of both approaches may offer the optimum solution. At present, there is sufficient justification to perform concurrent development in both areas.

- A second issue concerns the cost-effectiveness of alternative solutions to the wind shear problem as it affects decisions on systems implementation. An assessment of benefits and costs of candidate solutions is necessary to support decisions for selection of the most cost-effective wind shear systems that will enhance flight safety.

2.6 Major Decision Points, Products and Estimated Completion Schedule

Planned decision points for the Wind Shear Program projects (tasks) (154-740) are detailed in Sections 3.1 through 3.7. The following are major decisions critical to the overall Program Plan action.

• Establish future direction of airborne system development based on critical aircraft and pilot response characteristics.	5/77
• Adopt wind shear profiles that can be used in aircraft training and engineering simulators.	10/77
• Decision on implementation of expanded low-level frontal wind shear forecasting.	11/77
• Recommend to the Services siting criteria for ground-based sensors to detect and track significant wind shear.	12/77
• Recommendations to the Services on use of operational airport anemometer sensor system.	12/77
• Recommend to the Services airborne procedures/ avionics for detecting and coping with wind shear.	1/78
• Determine operational feasibility of ground-based CW Laser system.	3/78
• Evaluate and make recommendations to the Services concerning the use of airborne wind shear systems.	7/78
• Wind Shear language refined.	11/78
• Obtain FAA final approval of Wind Shear System Integration Plan.	1/79
• Determine operational feasibility of ground-based pulsed laser system.	4/79
• Determine pulsed radar operational feasibility.	4/79
• Obtain FAA approval for Wind Shear Systems Implementation Criteria.	11/79

2.7 Technical Approach

Considerable discussion has taken place on the merits of solving the wind shear problem using cockpit-derived information versus that obtained from ground sensors. A brief discussion of the potential of each approach is provided below.

Ground-based Systems. Ground-based wind shear sensor systems have the potential to provide data from forecasting the occurrence of and pinpointing the location and intensity of wind shears in the vicinity of an airport. The systems may be configured to alert the controller and the pilot to expect a hazardous wind shear encounter. Ground-based equipment can also be used to provide information to general aviation aircraft which have no dedicated wind shear avionics due to economic reasons. Additionally, ground-based detection systems could alert the pilot to possible wind shear encounters prior to takeoff to avoid conditions similar to those involved in the accident at Denver (Stapleton Airport) on August 7, 1975. In this particular accident, an airborne system would have been ineffective.

Airborne Systems. Airborne instrumentation could provide the necessary guidance and control information required by pilots during strong shear encounters. The information may be ground-derived, air-derived, or combinations thereof. Obviously, ground-derived wind shear information must be transmitted to the pilot in real-time, but could be done in advance of a shear encounter. The pilot could then make a decision as to the corrective action required. Air-derived techniques, independent of ground-based sensors, could provide considerable flexibility on a worldwide basis in that on-board equipment would provide wind shear detection instantly and with comparatively no communications delay. However, there is no advance warning of the presence of shears. Airborne wind shear detection equipment coupled to a flight director could provide guidance for the correct pilot action required during the shear encounter while the ground-derived information would have to be interpreted by or for the pilot.

Both airborne and ground-based developments include desirable features for potential problem solutions and are being pursued.

2.8 Program Structure

The wind shear program plan is structured to provide concurrent development in three areas:

- Ground-Based Sensor and Warning Systems
- Airborne Sensor and Warning Systems
- Improved Wind Shear Prediction

Figure 1 outlines wind shear functional relationships and work flow. The plan is based on seven essential major projects (tasks):

1. Wind Shear Characterization (154-740-1)
2. Hazard Definition (154-740-2)
3. Ground-Based Systems (154-740-3)
4. Airborne Systems (154-740-4)
5. Wind Shear Data Management (154-740-5)
6. Wind Shear Prediction (154-740-6)
7. Systems Integration and Implementation (154-740-7)

3.0 Wind Shear Program Description

3.1 Wind Shear Characterization (154-740-1)

Before major progress can be made in several of the other program areas, it is essential that wind shear be understood in much greater depth and detail. Meteorological research laboratories were therefore asked to assist the FAA in characterizing low-level wind shear using their expertise to better understand why, when and where wind shear manifests itself.

3.1.1 Objective

The objective of the wind shear characterization effort is to substantially increase our knowledge of what meteorological conditions cause significant wind shear and how the shear associated with those conditions is distributed in space and time. A greater understanding of the above, coupled with improved hazard definition, will lead to specifications for ground-based sensors and avionics that will warn pilots of impending hazardous wind shear.

3.1.2 Major Tasks

Wind shear characterization includes efforts to compile, analyze and model meteorological situations which cause significant low-level wind shear and recommend sensors for its detection, evaluation, and tracking.

3.1.3 Wind Shear Characterization by Wave Propagation Laboratory

Results of research performed by the National Oceanic and Atmospheric Administration's Wave Propagation Laboratory (WPL), over a one-year period that began in February 1976, have been published in Report Number FAA-RD-77-33, "Wind Shear Characterization", dated May 1977. The report addresses the following areas:

- Causes of low-level wind shear.
- General characteristics of thunderstorm gust fronts.
- Comparison of laboratory model flows with those observed in and around the gust front.
- Statistical analysis of atmospheric pressure jumps as they relate to low-level wind shears.
- Discussions of vertical wind shear distribution as observed in Spring of 1976 thunderstorms near Norman, Oklahoma.
- Development of a source-driven, density-current, model and its application to gust fronts.

- Recommendations on the deployment of ground-based meteorological sensors to detect low-level shear.

3.1.4 Wind Shear Modeling for Hazard Definition

This task is to develop families of wind shear profiles representative of shear created by low-level jets, frontal wind shear conditions and thunderstorm outflows for use in manned and/or computer simulation studies. National Aeronautics & Space Administration's (NASA) Aerospace Environment Division of the Marshall Space Flight Center's Space Sciences Laboratory is providing these profiles. An interim report, FAA-RD-77-36, "Wind Shear Modeling for Aircraft Hazard Definition," dated May 1977 reviews the work done in this area to date. The report reviews: the influence of wind shear on aircraft operations, characteristics of thunderstorm gust fronts in graphical as well as mathematical models of nominal wind shear conditions, and the wind shear conditions encountered during several recent air carrier accidents.

The final report for work in this area is scheduled to be published in September 1977. It will contain an expanded number of wind shear profiles that can be used in training and engineering aircraft flight simulators along with a recommended turbulence model which can be superimposed on the basic profiles. A review of FAA simulations using these wind shear profiles is offered in paragraph 3.2.3.1.

3.1.5 Support Organizations

NOAA's National Severe Storms Laboratory (NSSL) and WPL, NASA's Marshall Space Flight Center.

3.1.6 Major Milestones (See Figure 3)

1.	Begin WPL Wind Shear Analysis	Feb. 1976
2.	Begin NSSL Gust Front Analysis	Apr. 1976
3.	Begin NASA Wind Shear Profile Development	Apr. 1976
4.	Report FAA-RD-77-33 "Wind Shear Characterization"	May 1977
5.	Begin 1977 NSSL Gust Front Data Collection	May 1977
6.	Interim Report FAA-RD-77-36, "Wind Shear Modeling for Aircraft Hazard Definition" Published	May 1977
7.	Report FAA-ED-77-40, "Gust Front Analytical Study:	Jun. 1977
8.	Final report on Wind Shear Modeling for Aircraft Hazard Definition Published	Nov. 1977
9.	NSSL 1977 Gust Front Modeling Verification Published	Feb. 1978
10.	Gust Front and Warm Front Sensitivity Analysis with NASA Complete	Mar 1978

3.1.7 End Products

1. Characterization of low-level wind shear by cause, severity and distribution.
2. Modeling of the three major causes of low-level wind shear.
3. Wind Shear profiles that can be used in training and aircraft engineering flight simulators.
4. Recommendation on the choice and siting of ground-based sensors to detect and track significant wind shear.
5. Recommended modeling of the atmospheric boundary layer for better prediction of low-level wind shear.

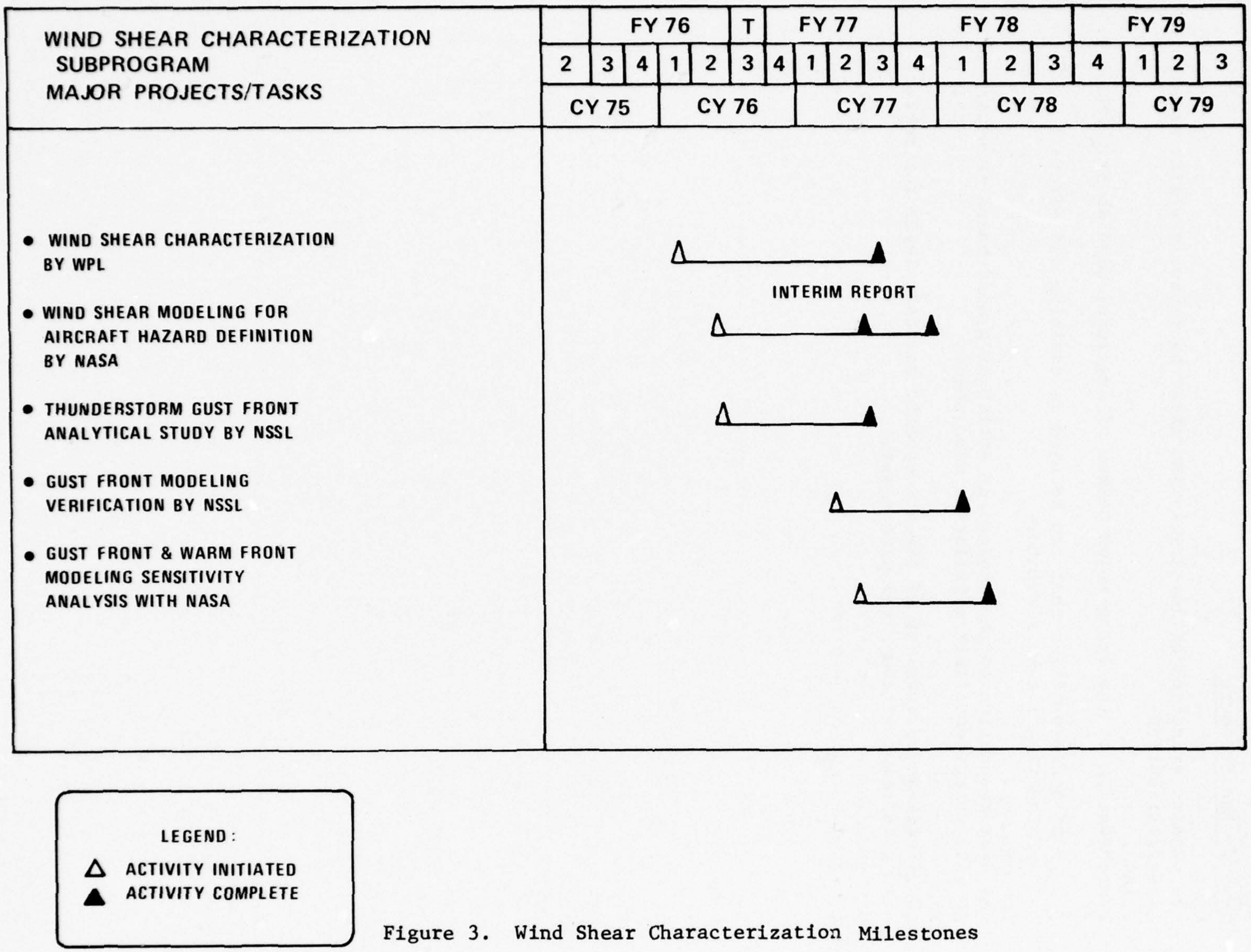


Figure 3. Wind Shear Characterization Milestones

3.2 Hazard Definition (154-740-2)

A basic part of solving the wind shear problem is to define the hazard; the primary need being to establish the wind shear hazard potential in terms that meet the needs of pilots. It is also essential that a standardized methodology for wind shear detection be developed and an appropriate operational language to express hazard potential be refined.

3.2.1 Objectives

The general objective of the hazard definition effort is to define the wind shear hazard potential in terms of altitude, airspeed, severity of shear, aircraft type (or category), configuration and gross weight, and to refine the capability to express the hazard in comprehensive terms that are meaningful and useful to pilots. Specific objectives are as follows: Conduct computer simulation studies to determine aircraft performance characteristics under various wind shear encounter profiles. Investigate the factors involved in wind shear accidents/incidents and their relationship to the severity of the hazard, and evaluate procedures designed to increase operational tolerance to wind shear. Refine terms used operationally during radio communications to describe wind shear hazards, as well as the technical language used in forecasting and reporting wind shear conditions.

3.2.2 Technical Approach

The main thrust of the hazard definition effort is to quantitatively define the wind shear hazard as it applies to air carrier and general aviation aircraft. This objective will be accomplished via fast-time computer simulation of various aircraft. The aircraft response characteristics when encountering wind shears of different magnitudes will be measured. It is also planned to analyze aircraft (air carrier, air taxi, business and general aviation) accident reports in an attempt to establish a correlation of the existence and severity of wind shear with the type of aircraft. This effort also embodies a requirement to express the hazards in a standardized language based on the knowledge gained from the analysis and simulation efforts.

3.2.3 Major Tasks

To aid in the development of solutions to the wind shear problem, it is necessary to define the hazards as they may exist for different types or categories of aircraft and to be able to communicate information pertaining to these hazards in effective and unequivocal terms. To this end, the following tasks are being undertaken.

3.2.3.1 Computer Simulations of Aircraft Response to Wind Shear

The limitations imposed by wind shear encounters on aircraft performance are an important aspect of hazard definition. Digital computer simulation offers a timely and cost-effective option in determining the response characteristics of various aircraft as a function of wind shear parameters. In a joint effort between FAA and NASA/Ames Research Center, a comprehensive review of aircraft response data was made to determine critical aerodynamic characteristics and pilot response characteristics important in wind shear encounters.

The effects of wind shear were studied by developing computer models of four significantly different aircraft, developing a digital non-linear pilot model for closed-loop control of each aircraft, and investigating two distinct wind shears. Since it was felt that the longitudinal degrees of freedom were the most critical during a shear encounter, the lateral-directional degrees of freedom were not simulated. An unmanned simulation with a digital pilot controlling the aircraft was chosen since the simulation could be done more quickly and more cheaply than with a manned simulation. Also, it eliminated human pilot variability which would have made aircraft comparison difficult, and avoided the problem of a human pilot "learning" the shear. Only landing approaches have been simulated.

The four aircraft simulated consisted of (1) a twin-engine, short-range jet transport, (2) a four-engine, wide-body jet transport, (3) a light swept-wing business jet, and (4) a twin-engine, turbo-prop commuter STOL aircraft.

The results of this simulation indicate that, in the presence of closed-loop pilot control, significant aircraft-to-aircraft variations in shear hazard do exist. The key vehicle-related parameters which affect shear response are approach speed, engine thrust lag and engine thrust offset. The key pilot parameters affecting shear response are glide slope control and airspeed control. Follow-on fast-time simulation of wind shear encounters will be conducted by FAA using additional models of specific aircraft types. Modeling of specific aircraft will be dependent on the availability/obtainability of performance, stability and control data for the various aircraft. Both air carrier and general aviation aircraft models will be used. Results of the computer simulation study will be the determination of wind shear hazard in terms of shear velocity gradient and direction vs. critical altitude. Development of requirements for flight test and manned simulation validation is a part of this effort.

3.2.3.2 Accident/Incident Analysis

Although some research has been done in the past on the meteorology of low-level wind shear, little data is currently available on aircraft encounters with wind shear conditions. Pilots may encounter a low-level shear leading to an unstablized approach (with a resultant missed approach or undershoot/overshoot accident) without being aware of the role played by the shear. In many past accident investigations, findings of "pilot error" may have resulted from an unrecognized shear condition.

The objective of this task is to examine a broad segment of the existing aviation accident records to identify wind shear factors which may have been a contributing factor to an accident/incident in terminal area operations. These factors will be used to establish a wind shear hazard profile. At the time of this writing approximately 25 large aircraft (over 12,500 lbs.) accidents and 2495 small aircraft (under 12,500 lbs.) accidents have been identified that may be wind shear-related in terminal area type operations. However, additional analysis of these accident reports is necessary and will be accomplished.

This investigation is being conducted in two phases. The first phase consists of identification of the significant wind shear factors which may contribute to an accident and an analysis of the National Transportation Safety Board (NTSB) accident data base for wind shear involvement potential. The second phase consolidates the identified factors associated with wind shear accidents into a wind shear hazard profile. NAFEC has conducted a literature search and analysis of possible wind shear influence on approach and landing accidents. For details see Report No. FAA-RD-76-44, "Wind Shear: A Literature Search, Analysis, and Annotated Bibliography", dated February 1977. In addition, efforts will be made to define significant wind shear factors contributing to accidents by simulating documented accidents and accident scenarios to determine which factors contribute to operational sensitivity during wind shear encounters.

3.2.3.3. Language Development

At present there are misinterpretations of the technical terminology used by engineers, meteorologists and pilots to describe wind shear. For example, in the literature some engineers call a horizontal wind which changes as a function of altitude a "vertical" wind shear and some call it a "horizontal" wind shear. Pilots and controllers require clearly understandable terms for a shear which causes a decrease in the aircraft's airspeed as opposed to a shear which causes an increase in airspeed.

The objective of this task is to refine terms used operationally to communicate the necessary information to assist pilots in avoiding or coping with a shear on approach or departure.

A prototype wind shear language has been developed by the Wind Shear/WVAS Branch and Flight Standards Service (AFS). In determining the language to be evaluated in the flight simulator, various user groups (Air Transport Association, Air Line Pilots Association, Aircraft Owners and Pilots Association, National Business Aircraft Association, and the Department of Defense) were consulted. After coordination with user groups and AFS, manned simulation was used to evaluate the effectiveness of the proposed language. Deficiencies as they are identified are being brought to the attention of interested groups and changes are being developed.

The special objective of the sub-task is to refine terms to be used operationally to communicate the necessary information to assist pilots in avoiding or coping with a shear on approach or departure. The language was used in the Phase I manned simulation survey (see Section 3.4.3) and revised and reevaluated in the Phase II manned simulation evaluation (see Section 3.4.3). Additional use of this language is planned for the follow-on manned simulations and flight tests, and eventual operational evaluation.

The resultant operational language should clearly reflect the type of wind shear that is reported. Beyond this evolution, little additional effort is expected to be required for language refinement.

3.2.4 Support Organizations

NAFEC, NASA/Ames Research Center, DOD, AFS and AAT.

3.2.5 Major Milestones (See Figure 4).

1.	Development of Prototype Wind Shear Language	April 1976
2.	Determination of Critical Aerodynamic and Pilot Response Characteristics	Mar 1977
3.	Complete Accident Data Base Review for Air Carrier Aircraft	Apr 1977
4.	Complete Accident Data Base Review for General Aviation Aircraft	Jul 1977
5.	Development/Acquisition of Simulation Models	Aug 1977
6.	Final Report and Accident/Incident Analysis Comp.	Dec 1977
7.	Simulation of Specific Air Carrier Aircraft Types	Dec 1977
8.	Simulation of Specific General Aviation Aircraft Types	June 1978
9.	Final Report to Establish Wind Shear Hazard Definition	Aug 1978
10.	Wind Shear Language Refined	Nov 1978

3.2.6 End Products

1. Identification of the most critical aircraft and pilot response characteristics during wind shear encounters.

2. Definition of wind shear hazard for different types or categories of aircraft in terms of altitude, airspeed, severity of shear, configuration and gross weight.

3. Determination, through analysis of aircraft accident/incidents, of the importance of wind shear to safe aircraft operations.

4. Wind shear language and terminology refined and tested through simulation and in-flight use.

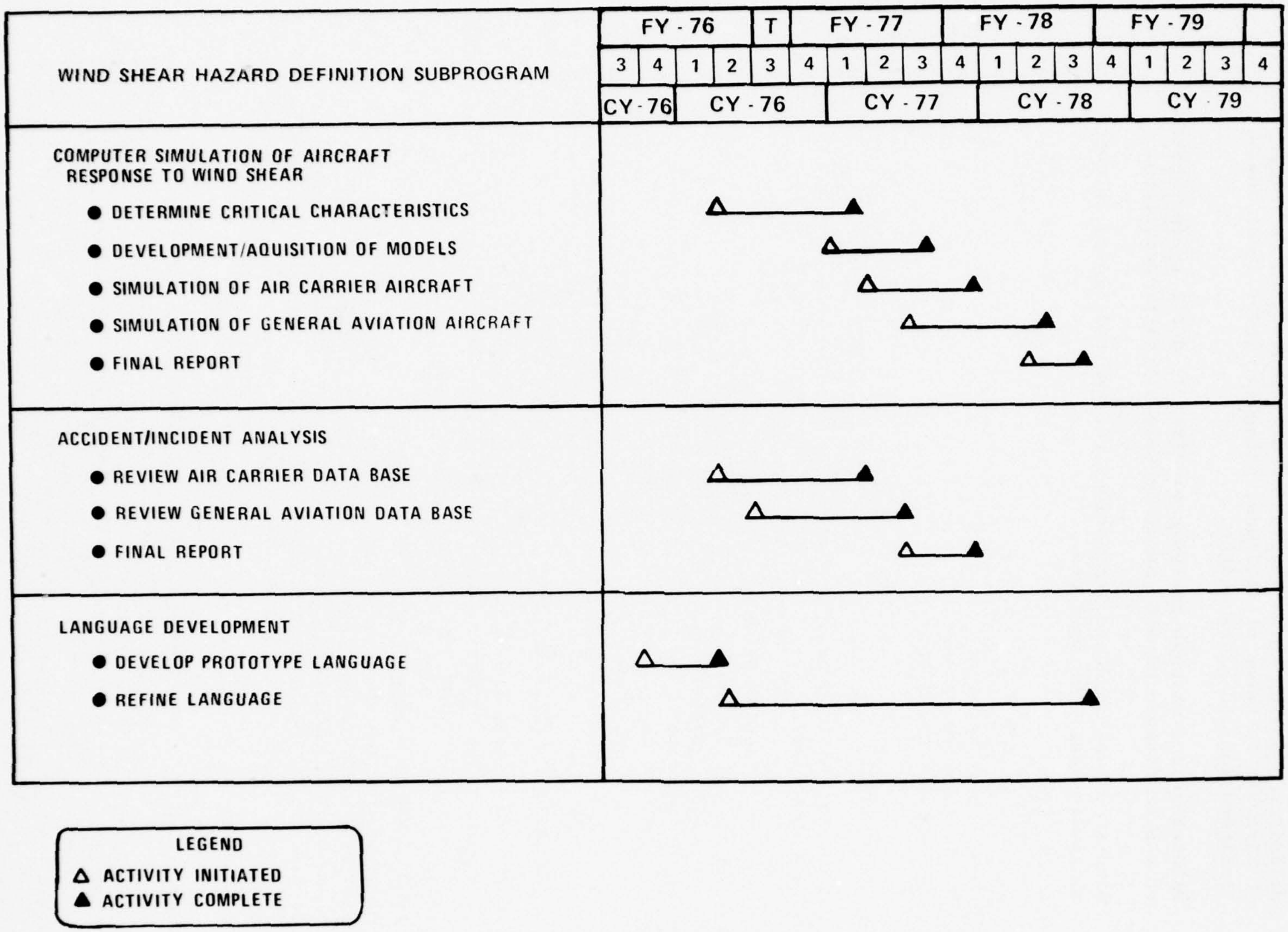


Figure 4. Wind Shear Hazard Definition Milestones

3.3 Ground-Based Systems (154-740-3)

3.3.1 Objective

The objective of the ground-based systems effort is the development and evaluation of ground-based systems capable of detecting and measuring low-level wind shear on or around an airport with sufficient lead time to permit alerting pilots to the potential hazard. This information would be used by the pilot to execute a missed approach, delay takeoff, or take other appropriate actions to permit safe continuation of the operation.

Various technical approaches are being investigated and data is being collected on which to assess the merits of each approach. Each of these approaches are discussed below:

3.3.2 Major Tasks

The ground-based systems being investigated are generally classed in the following categories:

1. Acoustic Doppler Systems (SODAR)
2. Barometric Systems
3. Anemometer Systems
4. Laser Systems
5. Radar Systems

A general comparison of these systems in contained in Table 1.

3.3.2.1 Acoustic Doppler Systems (SODAR)

This task provides for the development of an acoustic Doppler system with an engineering model of the resulting design to be installed at Dulles International Airport for test and evaluation.

When the FAA was reviewing the approaches and technologies available for remote wind measurement in 1971, the acoustic Doppler technique appeared to offer the most promise. For this reason the acoustic Doppler system was a prime candidate for accelerated development when wind shear was identified as a major cause of two air carrier accidents in 1975. Accordingly, the FAA entered into an interagency agreement with the Wave Propagation Laboratory (WPL) of NOAA to conduct tests and develop system concepts based upon a acoustic Doppler technique.

The system consists of a central audio transmitter which transmits a series of acoustic pulses into the air volume directly over the equipment. Wind speed and direction is determined by measuring the frequency shift (Doppler effect) in signals reflected by the atmosphere at three receivers distributed about the central transmitting site. Additionally, one smaller satellite transmitter is associated with each receiver site to ensure adequate coverage in the lower 300 feet of the atmosphere.

TABLE 1. WIND SHEAR GROUND-BASED MEASUREMENT SYSTEM COMPARISON

SYSTEM	COVERAGE	"ALL WEATHER"	RELATIVE COST	RANGE	DEVELOPMENT STATUS
ANEMOMETER ARRAY	LOCALIZED (GROUND EFFECTS)	YES	MEDIUM	NOT APPLICABLE	ENGINEERING MODEL BEING DEVELOPED
ACOUSTIC DOPPLER	LOCALIZED (VERTICAL PROBE)	NO (REQUIRES DUAL SYSTEM)	HIGH WITH OR WITHOUT DUAL SYSTEM	500-1500 FT MAXIMUM ALTITUDE	ENGINEERING MODEL UNDER TEST
BAROMETRIC SENSOR ARRAY	LOCALIZED (GROUND EFFECTS)	YES	LOW	NOT APPLICABLE	ENGINEERING MODEL BEING EVALUATED
CW LASER	LOCALIZED (VERTICAL PROBE)	TO BE DETERMINED	MEDIUM	500-1500 FT MAXIMUM ALTITUDE	PROTOTYPE BEING EVALUATED
PULSED LASER	AREA SCAN WITH GLIDE SLOPE EMPHASIS	UNKNOWN (DEPENDING ON ATTENUATION DUE TO FOG, RAIN, LOW CLOUDS, ETC.)	HIGH	1-8 MILES	EXPLORATORY DEVELOPMENT
RADAR (EM)	AREA SCAN WITH GLIDE SLOPE EMPHASIS	UNKNOWN	HIGH	1-8 MILES	EXPLORATORY DEVELOPMENT

Sophisticated software is used to control the system operation, calculate the wind speed and direction based upon data inputs, filter out system and environmental noise and drive a number of test displays. The output formats used in the current system design are illustrated in Figure 5. Figure 6 depicts the location and relative size of the acoustic test site at Dulles International Airport.

Figure 7 illustrates the Dulles acoustic Doppler System layout and wind measurement techniques.

The acoustic system is supplemented by a co-located X-Band Radar which provides the same type of data under conditions of heavy precipitation. This supplemental sensor radar was implemented since it was predicted that the range and sensitivity of the acoustic system would be severely limited by high ambient noise levels; i.e., heavy rain on the receiver and high surface winds.

The system developed has been installed at Dulles and is currently being evaluated. The evaluation period will be used to establish the accuracy of the acoustic sensor concepts, and collect data on the wind shear phenomenon. However, it is not anticipated that the acoustic Doppler system, in its current configuration, will be implemented nationwide as an operational system.

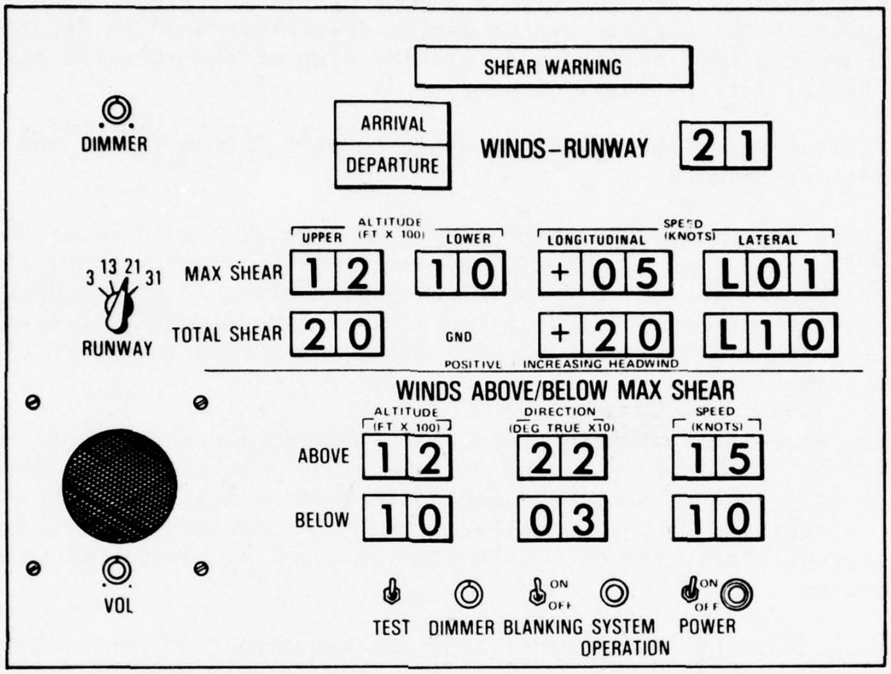
To be effective, the system requires a sizable amount of real estate in an area of very low ambient noise level. This requirement will be difficult to meet in many large hub airports. In addition, since the system only measures the wind field directly above the transmitter, large scale homogeneity of the air mass is required for the measurements to be valid over the entire airport. This latter restriction eliminates this approach for thunderstorm gust front detection which has been identified as the major contributing cause in a large percentage of wind shear accidents.

3.3.2.2 Barometric System

One of the most dangerous and insidious sources of wind shear is the gust front associated with thunderstorms. The gust front, which is not detectable with existing ATC surveillance radar, can precede the thunderstorm center by as much as 18 miles. A simple method of detecting the passage of a gust front is to monitor the rapid changes in pressure or wind velocity which occur at or near the surface with the passage of the gust front.

Of the three parameters which vary with the passage of a gust front (pressure, wind velocity and temperature), a system which measures the pressure change has the advantage of providing a passive device which is quiescent until triggered by a rapid pressure change. This approach minimizes data processing requirements and hardware costs.

DIGITAL DISPLAY



GRAPHIC DISPLAY

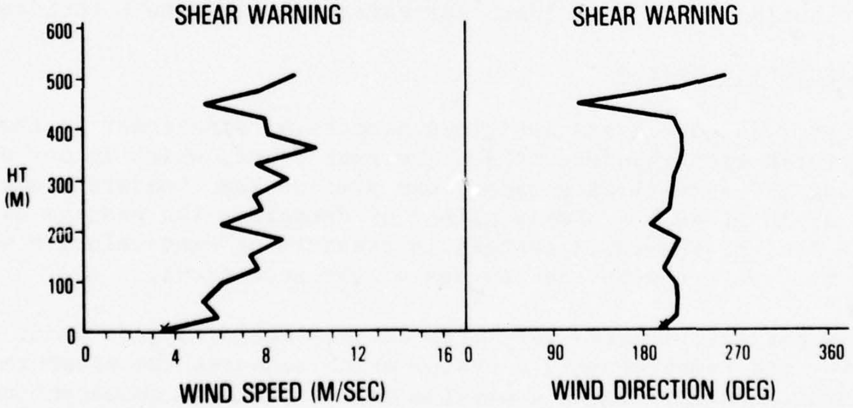


Figure 5. Experimental Forms of Wind Shear Displays

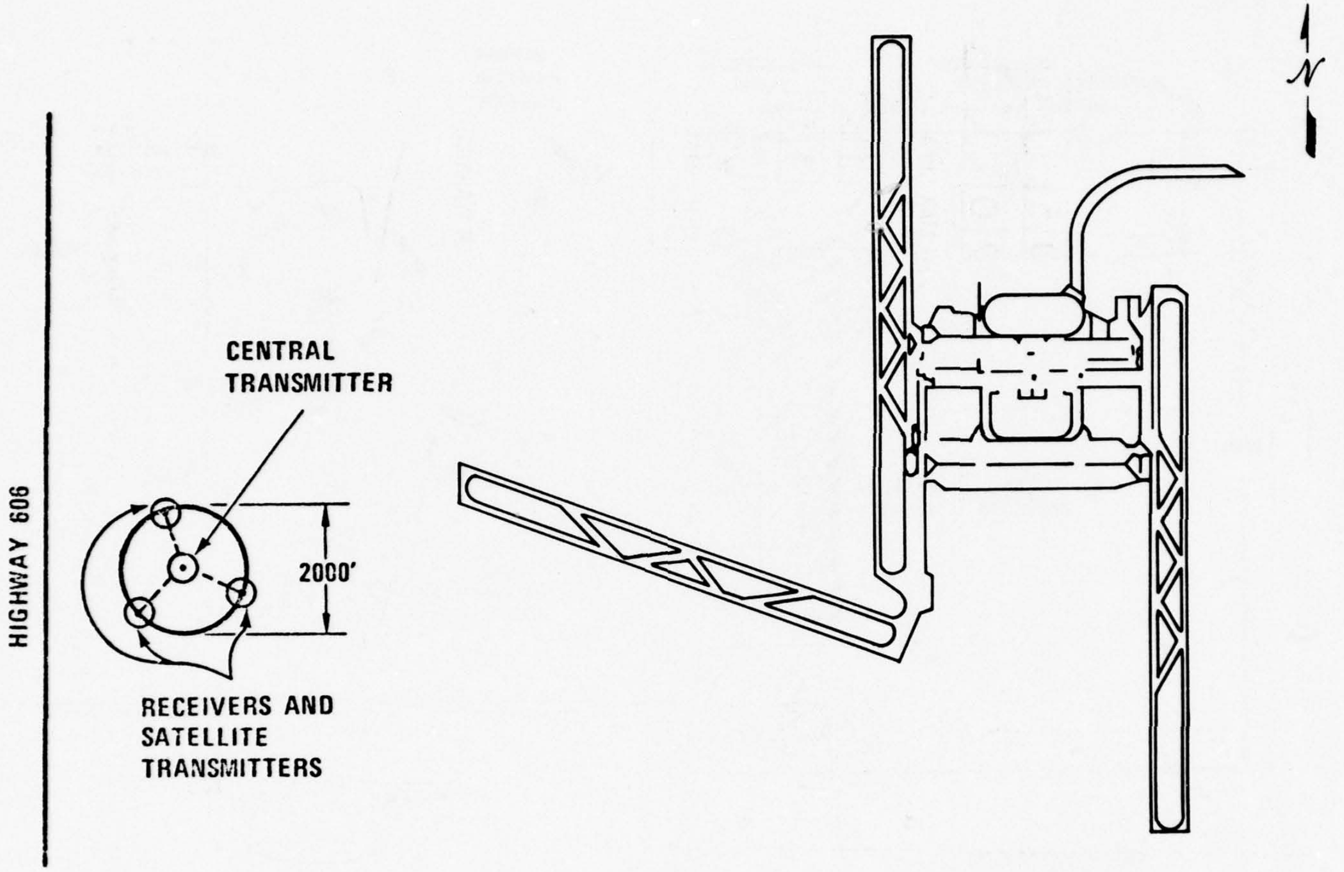


Figure 6. Acoustic Doppler System Installation Layout - Dulles International Airport

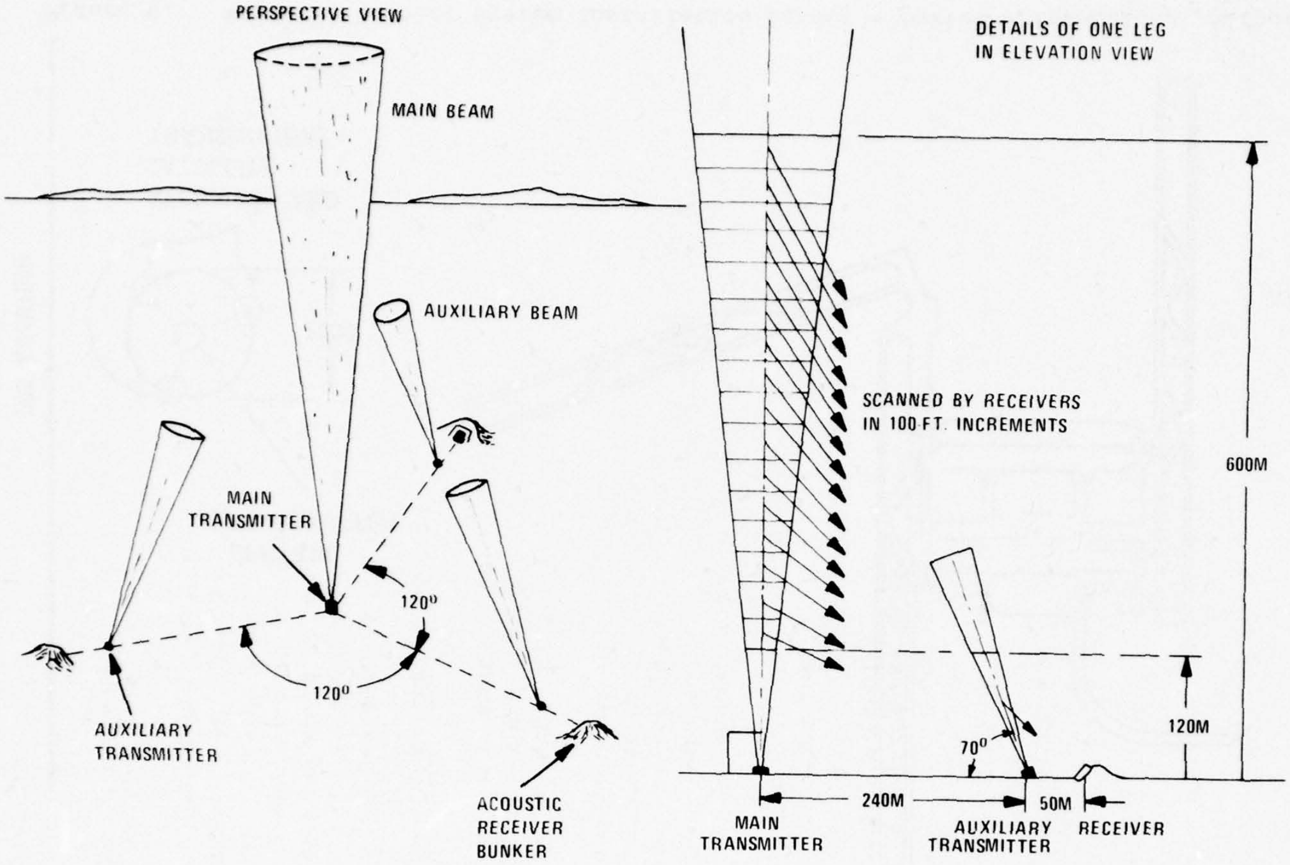


Figure 7. Dulles Acoustic Doppler Layout and Measurement Technique

Utilizing an array of such devices, it is possible to determine the speed and direction of the gust front movement. When integrated with a suitable display, the array can provide advanced warning of the front's impingement into the operating corridors.

There are also some disadvantages to this technique which are being addressed. They include: false alarms due to the passage of strong cold fronts and gravity waves traveling overhead at high altitudes and the fact that the sensor, by itself, does not determine when it is safe to operate again adding to the complexity of the system. In addition, the relationship between pressure increases over short time intervals and the magnitude of the shear contained within the thunderstorm outflow area (gust fronts) has not been clearly established and is still being investigated.

To collect data aimed at answering these questions, a small array (18 sensors) of pressure-jump detection sensors have been installed at Chicago O'Hare Airport and data collection began in the Summer of 1976 (See Figure 8). This array has detected the passage of several gust fronts through the airport complex. The O'Hare test system will continue to collect data through the Summer of 1977 to evaluate the total system performance and determine if the pressure-jump sensor technique is a viable method for gust front detection.

In addition to the above, a more automated and much larger array of pressure-jump sensors (over 100) have been deployed on and around Dulles Airport for the purpose of optimizing the location and number of devices that must be sited for high reliability detection of gust fronts. (See Figure 9).

Evaluation of the gust front warning system at Dulles will also continue through 1977 in conjunction with the Dual Sensor, Acoustic Doppler/ Pulsed Doppler radar systems evaluation.

3.3.2.3 Anemometer Array System

Analogous to the pressure jump (Barometric) devices discussed in paragraph 3.3.2.2 is the concept of making direct measurements of the wind direction and speed at various points on and around the airport with an array of anemometers. This system is relatively inexpensive to install, is reliable since it provides direct wind measurement, and with proper processing, is capable of detecting the presence of severe horizontal wind shears near the airport surface.

The major disadvantage to the use of anemometers is that the output must be constantly monitored and compared with other anemometer outputs to effectively determine the presence of a significant horizontal wind shear condition.

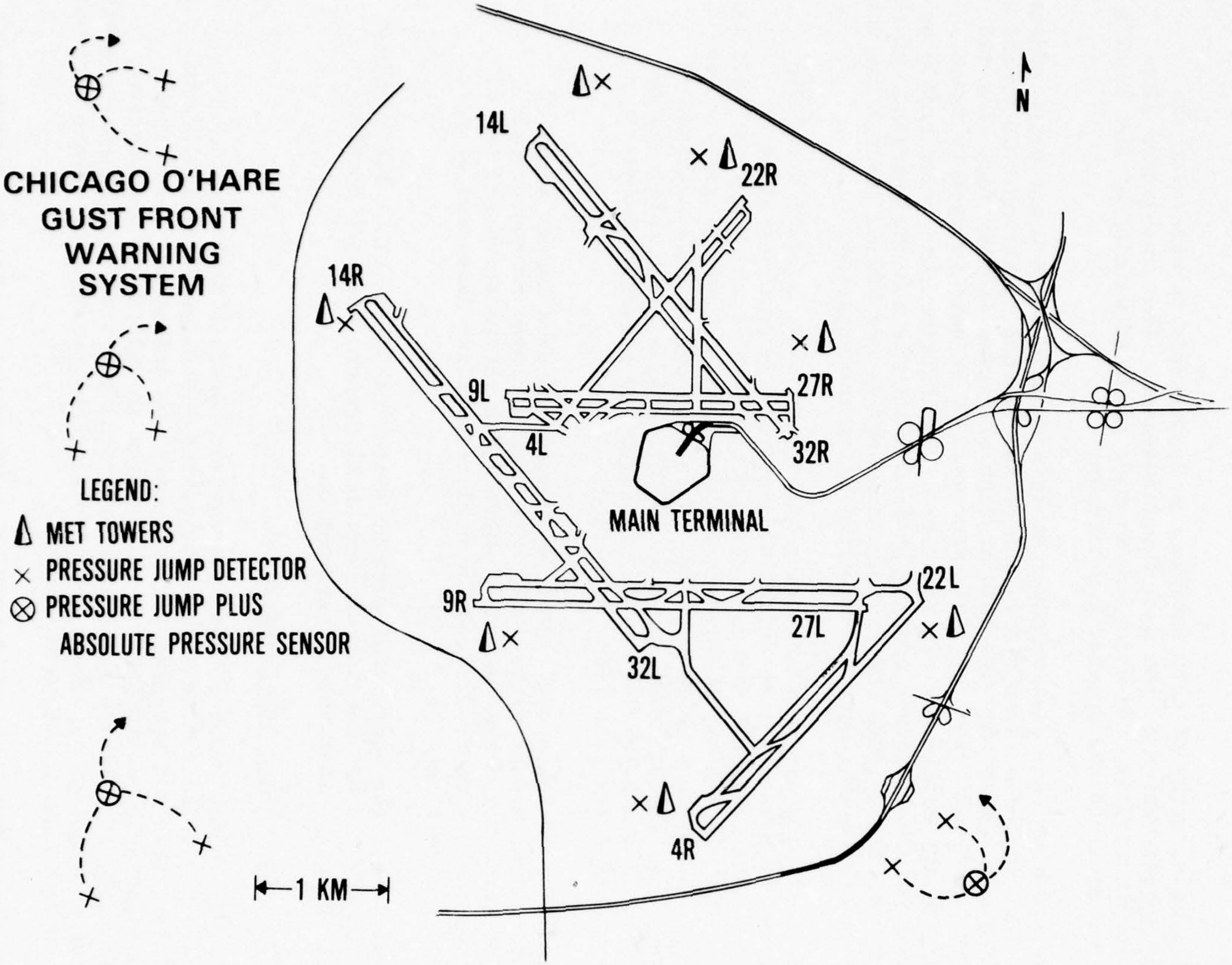


Figure 8. Chicago O'Hare Gust Front Warning System Configuration

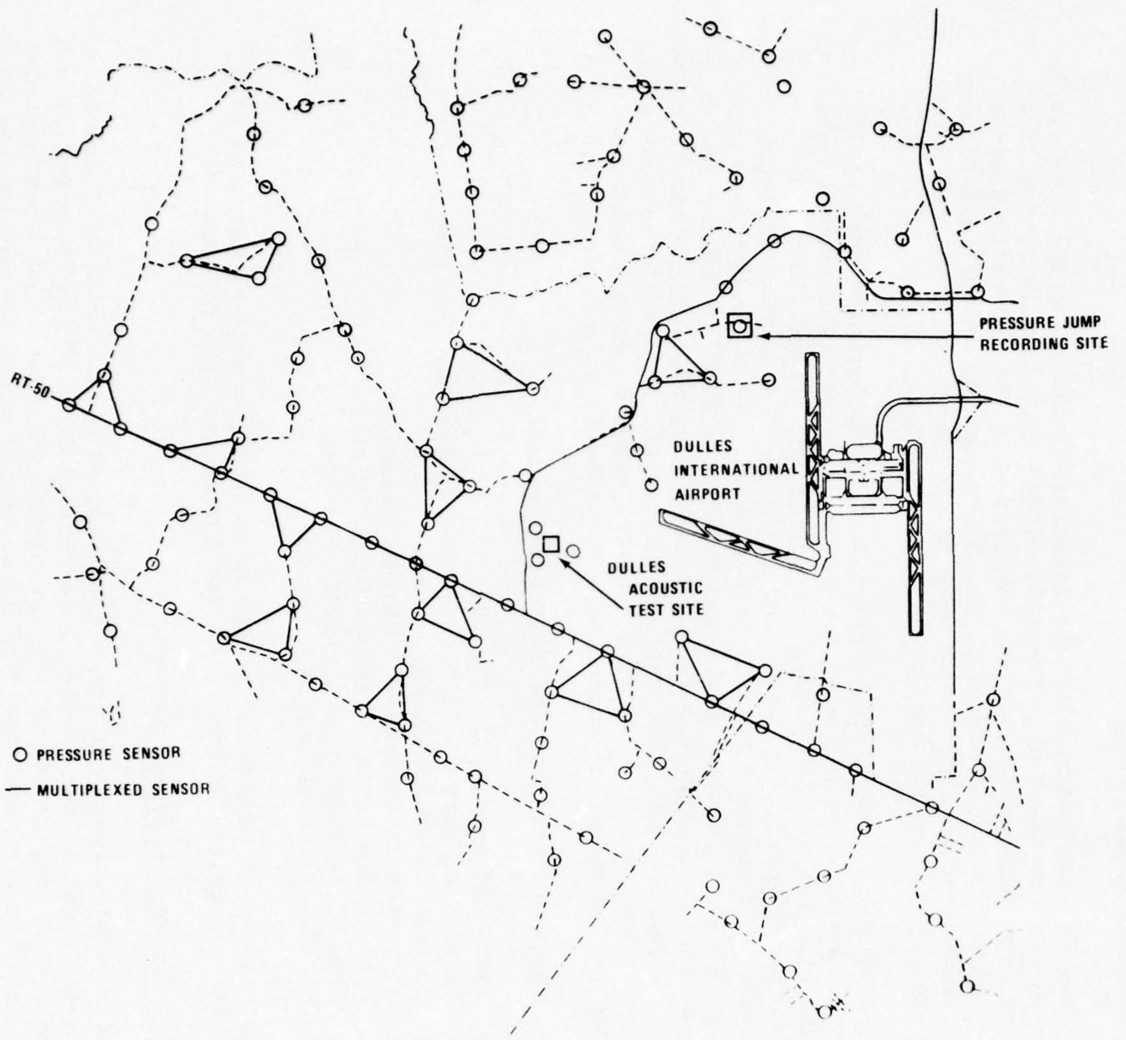


Figure 9. Pressure Sensor Installation - Dulles International Airport

Based on an FAA decision in October 1976, arrays of anemometers are being installed at six airports throughout the U.S. to collect data on the effectiveness of this system concept in detecting the passage of thunderstorm gust fronts.

The array of anemometers with its associated processing and displays is known as the Low Level Wind Shear Alert System. In this system, the outputs from each anemometer are compared with the centerfield sensor. When a significant difference is noted between the centerfield and any other anemometer an alert is sounded in the tower cab. The Low Level Wind Shear Alert system concept is shown in Figure 10.

Data collected at these six airports during the Spring/Summer of 1977 will be used in conjunction with experimental test results from NAFEC to determine the threshold levels required for declaration of a hazardous horizontal wind shear and to verify the number and locations of anemometers required for reliable detection of a thunderstorm gust front. The basic design of the tower cab test display and the needed information for operational language tests have been determined in cooperation with AAT and AFS. The test site at NAFEC, Figure 11, is configured to permit evaluations of various types of anemometers and determine numbers and locations of anemometers required at an airport.

The airports selected for the test program are:

- Tampa International, Florida
- William B. Hartsfield International, Atlanta, Georgia
- Houston Intercontinental, Texas
- Stapleton International, Denver, Colorado
- Will Rogers World, Oklahoma City, Oklahoma
- John F. Kennedy International, New York
- NAFEC, Atlantic City, New Jersey

Implementation of anemometer arrays at a larger number of airports will be predicated on the success achieved during the test program.

3.3.2.4 Laser Sensor System

A most promising technique for a ground-based sensor capable of remote wind measurement is the Doppler laser velocimeter, which is an out-growth of the wake vortex and clear air turbulence programs. The laser approach makes possible very accurate wind measurements which are not limited by ambient audio noise and high surface winds that degrade the acoustic system. Two forms of laser systems are being developed. The most mature design is a Continuous Wave (CW) laser Doppler system which provides a vertical probe with a range capability comparable to the Acoustic Doppler System.

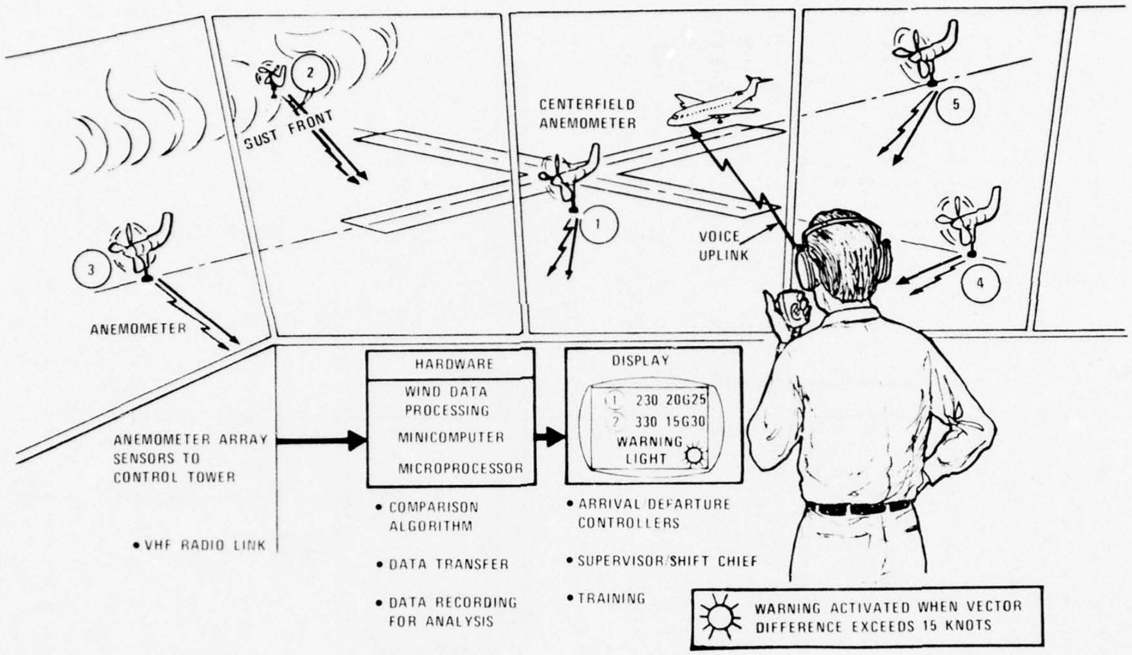


Figure 10. Low Level Wind Shear Alert System Concept

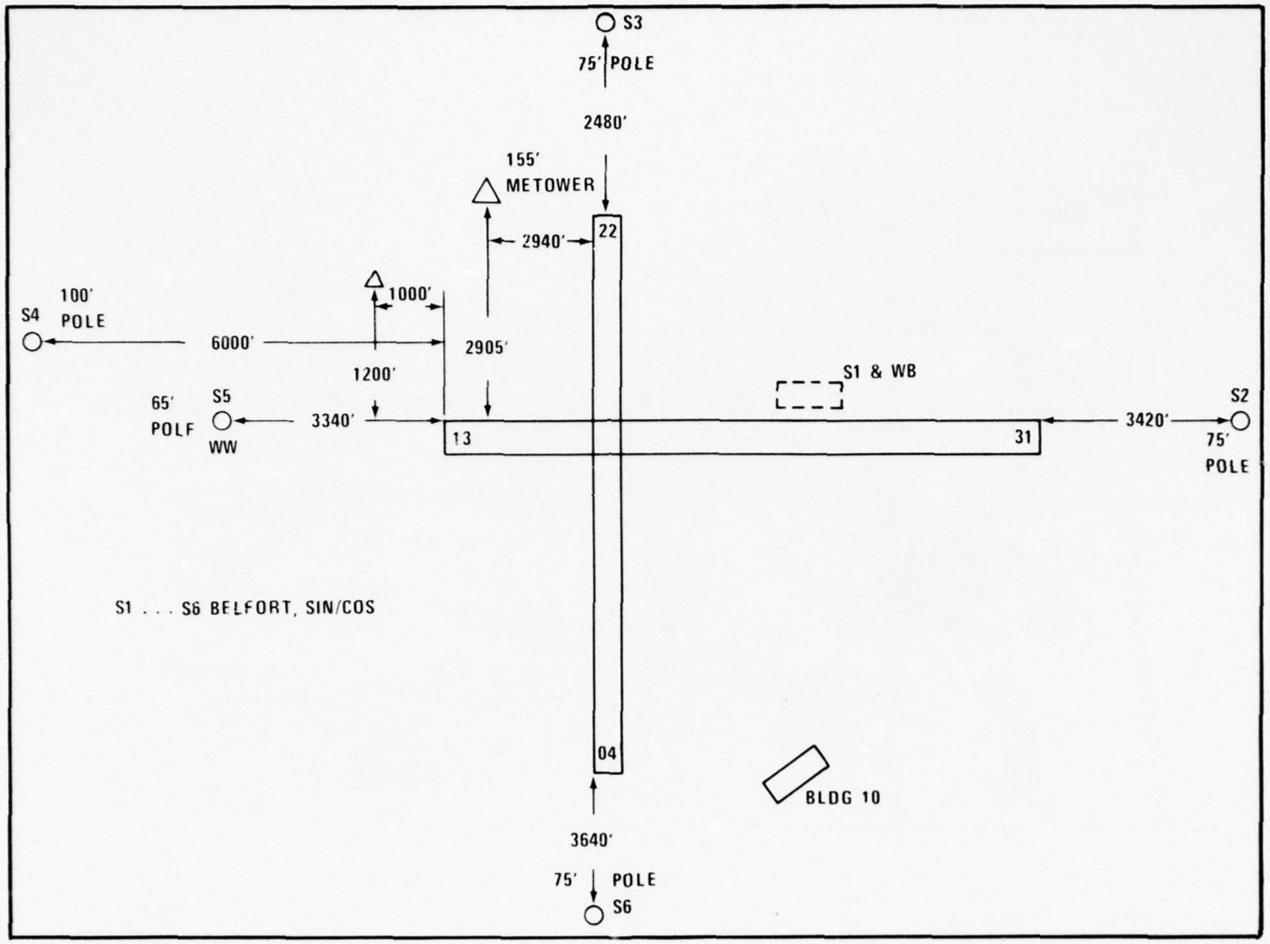


Figure 11. Low Level Wind Shear (LLWS) Test Site - NAFEC

The CW laser approach is more accurate than the acoustic Doppler approach according to tests conducted with the mobile laser Doppler system at the Boulder, Colorado test site. Much less real estate for installation is required for the CW laser. However, the CW laser system, like the acoustic system, detects only that wind field directly over the sensor. A transportable version of the CW laser (Figure 12) has been delivered to the Transportation System Center (TSC) for detailed technical evaluation and use as a test comparison device for other systems.

The approach which offers an even greater promise is a pulsed Doppler laser which has the potential for scanning up the glide slope and covering the departure corridors at ranges up to 12 kilometers (7.5 miles) thereby measuring the most probable wind conditions that an aircraft will encounter in either approach or departure.

The schedule for the development of such a laser system calls for a three phase project which develops a prototype, field tested, system by mid to late 1979.

An on-going activity leading to the prototype development of the pulsed laser system is the joint FAA/TSC/NASA test of a pulsed laser under various environmental conditions to establish required relationships between range, power and weather.

3.3.2.5 *Radar Task*

Experiments conducted by the Wave Propagation Laboratory and the National Severe Storms Laboratory with CW and pulsed radars have demonstrated that high power radars with appropriate processing techniques can detect variations in the atmospheric refractive index which can be used to make remote measurements of wind direction and speed. Radar offers the advantage of long range detection capability, improved performance as atmospheric moisture and aerosol levels increase, and a potential for multifunction airport applications.

The major technical unkowns are ground clutter returns in an operational environment and the performance in optically clear air when return signal levels would be minimum.

A program was initiated in 1977 to collect data to resolve the above questions. Antennas with beamwidths typical of those used for Airport Surveillance Radar (ASR) applications will be merged with an ASR transmitter and improved ASR processing techniques (Moving Target Detector) to collect data on clutter and clear air performance.

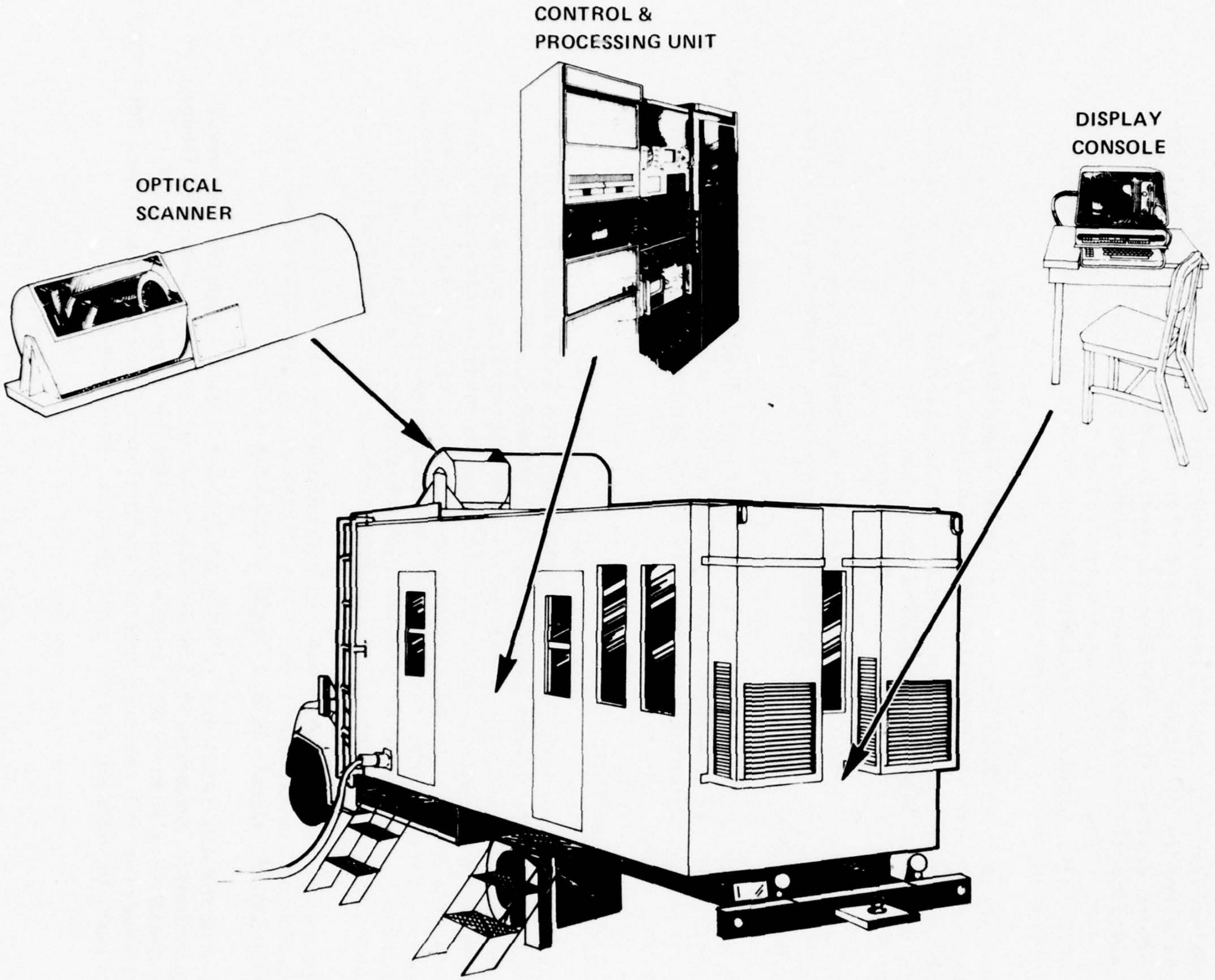


Figure 12. Transportable Continuous Wave (CW) Laser

3.3.3 Support Organizations

In addition to industrial contractor support in the design and fabrication of R&D hardware, the following Government organizations are supporting the ground-based equipment development under interagency agreements or project assignments.

A. Acoustic Doppler System

- NOAA, Wave Propagation Labroatory
  Boulder, Colo. - Design and Development
- NAFEC - Test and Evaluation

B. Barometric System

- NOAA, Wave Propagation Laboratory
  Boulder, Colo. - Design, Development, Test and Evaluation

C. Anemometer Array System

- NAFEC - Design, Development, Test and Evaluation

D. Laser Sensors

- Transportation System Center - Design, Development, Test and Evaluation
- NASA - Huntsville, Marshall Space Flight Center

E. Radar

- NOAA - Wave Propagation Laboratory
  Boulder, Colo. - Design and Development
- Lincoln Laboratories - Consulting Engineering Services
- NAFEC - Test and Evaluation

3.3.4 Identification of Test Sites

Since wind shear is an infrequently occurring phenomena, test sites have been selected on the basis of the frequency at which thunderstorms occur in the area or the quality of instrumentation available for measurement of metorological parameters. The following sites have been so identified.

- Table Mountain, Boulder, Colorado
- National Severe Storm Laboratory, Norman, Okla.
- Dulles International Airport
- Tampa International Airport, Florida

- W. B. Hartsfield International Airport, Atlanta, Georgia
- Houston Intercontinental Airport, Texas
- Stapleton International Airport, Denver, Colorado
- Will Rogers World Airport, Oklahoma City, Oklahoma
- J. F. Kennedy International Airport, New York City, New York
- O'Hare International Airport, Chicago, Illinois
- NAFEC, Atlantic City, New Jersey

3.3.5 Critical Technology

The major technology which is considered critical to a successful ground-based system is the signal processing associated with acoustic, laser and radar sensors. In addition, the need for a reliable high power pulsed laser is essential to a viable pulsed laser system.

3.3.6 Milestones

The major milestones for ground-based system projects/tasks are shown in Figure 13.

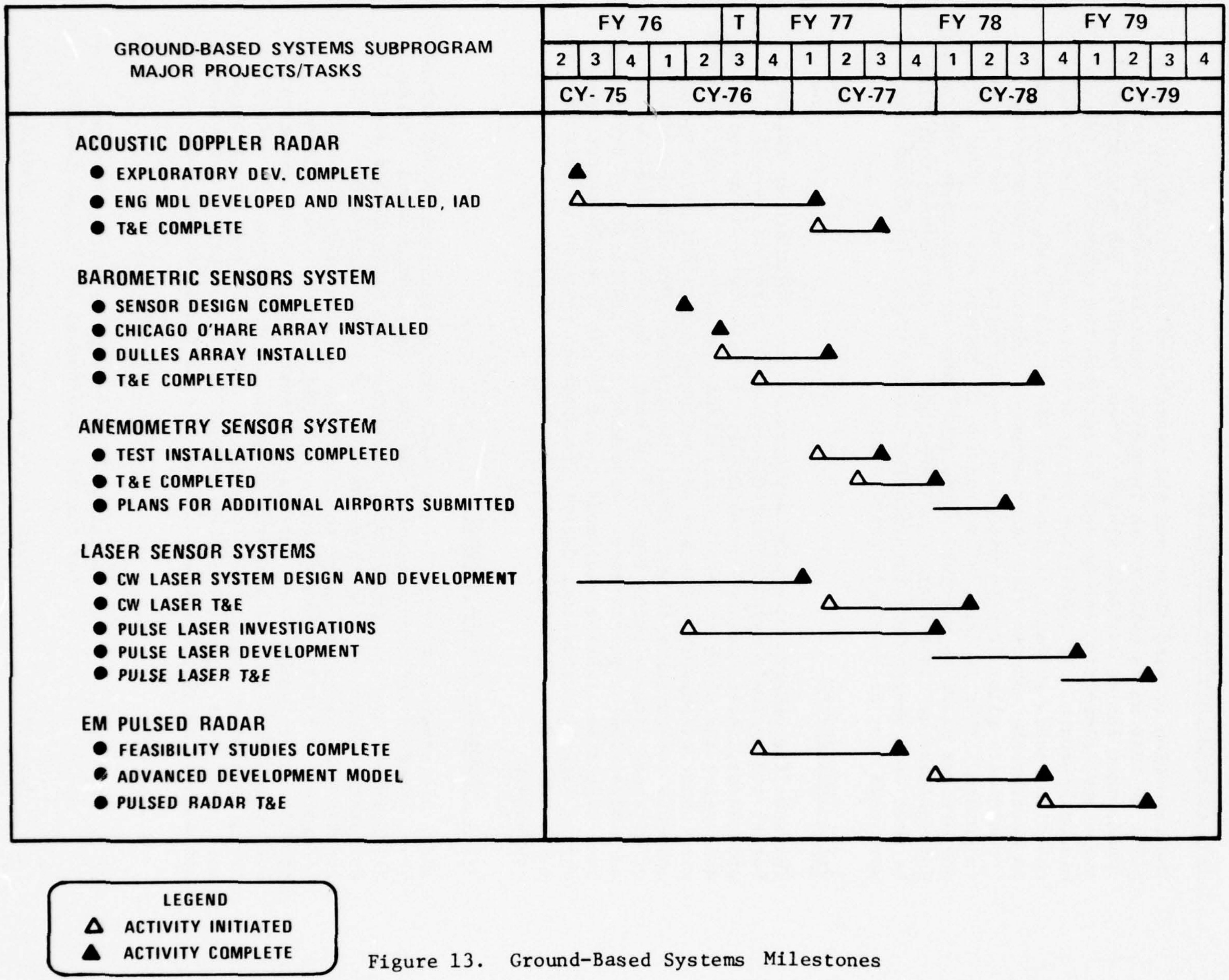


Figure 13. Ground-Based Systems Milestones

3.4 Airborne Systems (154-740-4)

The detection of wind shear and the transfer of information to the pilot so that he is aware of an impending shear encounter is the basic requirement for an airborne system. Then, based on the severity of the shear, a decision can be made to continue the approach or make a missed approach. If conditions permit a continuation of the approach, the pilot needs guidance to determine the proper flight control input to counter the adverse wind shear effects. Ideally, such a system for aiding a pilot to cope with wind shear effects should be predictive in nature. This is especially true for the severe shears where aircraft performance might be marginal. The timeliness of wind shear information for inflight use is a basic consideration. The information must also be free from ambiguous interpretation and its impact on flight crew workloads must be carefully considered.

3.4.1 Objectives

The specific objectives of the airborne system effort are as follows: Survey and evaluate existing and developmental airborne systems, procedures, techniques and capabilities to detect wind shear conditions and assist the pilot in safely controlling the aircraft during low-level wind shear encounters. Develop and evaluate additional pilot aiding concepts for coping with wind shear conditions. Evaluate the impact of advanced display technology in the resolution of wind shear effects on aircraft/pilot performance. Determine the feasibility of developing cost-effective airborne equipment to aid flight crews in detecting and coping with wind gradients during the approach phase of flight. Provide performance specifications for the development of airborne wind shear equipment.

3.4.2 Important Considerations

There are several critical issues which must be resolved before actual development of airborne equipment for wind shear can proceed. After all airborne systems, procedures, techniques and capabilities are evaluated using cost-effective computer and manned simulation experiments, it is necessary to choose the optimum pilot aiding concepts for further development and flight testing. In addition, it will be necessary to decide what engineering prototypes, studies and/or modifications of airborne or ground equipment must be undertaken to support the further development and flight testing of these concepts. Also, a decision must be made as to the optimum locations and methods of displaying wind shear information in the cockpit.

Date	Key Decision Points
Apr 1977	Decision on optimum pilot aiding concepts for further development and flight testing.
Jun 1977	Decision on engineering studies, modifications and/or development of airborne prototype equipments for wind shear detection/display.

Date	Key Decision Points
Jun 1978	Decision on optimum methods and locations for in-cockpit wind shear displays.

Factors which will influence these decisions are: cost of implementing the system to air carrier and general aviation operators and owners: cost of implementing the systems in the National Aviation System (NAS); and the degree to which the systems solve the wind shear problem.

3.4.3 Technical Approach

Prior to any decision to develop new avionic equipment for wind shear detection/display it is necessary to evaluate pilot response to wind shear encounters using procedures and techniques based on currently available instrumentation and any feasible additional pilot aiding concepts. To accomplish this, a series of manned flight simulation experiments were performed to evaluate these concepts and procedures. These flight simulations were conducted through an Engineering Services Support Contract (DOT-FA75WA-3650) with Stanford Research Institute and through an Interagency Agreement with the National Aeronautics and Space Administration (NASA/Ames Research Center). Two phases of manned flight simulation were conducted to survey and evaluate various systems and techniques to detect and cope with shear conditions during takeoff, approach and landing. An in-depth analysis and statistical validation of pilot/simulator performance was not required during the survey tests (Phase I); however, the most promising systems/concepts/procedures were examined in depth during the more rigorous evaluation program (Phase II).

Follow-on manned simulation efforts will be necessary as a cost-effective adjunct to support the planned flight test program and to validate the results of the hazard definition efforts. These simulations will be directed toward the optimization and evaluation of the most promising airborne wind shear detection and display systems selected. The work will consist of manned flight simulation experiments to document pilot performance using the selected systems in conjunction with a variety of wind shear profiles and terminal flight operations scenarios. In addition, manned simulations will be used to determine the optimum systems/concepts/procedures which are necessary for use by general aviation aircraft as well as air carrier operations.

As a result of the wind shear simulation experiments completed to date, it has become apparent that the most promising concepts are dependent upon groundspeed information being available in the cockpit. For this reason, several commonly used types of avionics and airborne equipments will be evaluated to determine the optimum technique of providing this groundspeed information. Engineering studies, modifications and tests of existing hardware will be performed to arrive at the least costly methods for providing accurate, timely groundspeed in the cockpit.

Before any devised wind shear detection systems can be recommended for general applications to the aviation industry, their performance and characteristics must be validated in actual flight tests. Following tests in a simulated environemnt, selected systems will be installed in an aircraft and adequately instrumented for follow-on flight tests. As airborne techniques and equipments are refined, flight tests will be conducted to determine specific performance requirements and capabilities that are necessary for airborne wind shear systems.

The information gained during manned simulations, groundspeed sensor development and in-flight testing will allow the selection, identification and description of those systems/procedures/equipments which can be used aboard the aircraft by the flight crew to detect and cope with wind shear. The program will permit complete performance specifications to be written for the development of airborne equipment, will permit detailed operational procedures to be recommended, and will assure that the selected systems are cost effective.

3.4.4 Major Tasks

To aid in the selection of specific wind shear related avionics, it is necessary to identify the various roles which an airborne wind shear detection and/or information system could fulfill and to conduct an evaluation of the most promising approaches. In support of the above overall objectives the following tasks are being undertaken.

3.4.4.1 Manned Flight Simulation

A series of flight simulation experiments were conducted to identify and refine the most effective pilot-aiding concepts. The first simulation effort was designed to provide an early determination of the potential operational effectiveness of candidate systems and techniques that could be used to guide in-depth studies and system refinement. These experiments were conducted in a DC-10 training simulator at the Douglas Aircraft Company Flight Crew Training Center in Long Beach, California. The simulator was equipped with a full complement of controls and instruments for all flight crew member postions and was capable of simulating all flight guidance and control modes available on the aircraft in service use.

In Phase I of the simulation effort, pilot performance data and subjective pilot opinions were recorded on eight highly experienced pilots most of whom held DC-10 pilot qualifications. The pilots were subjected to various flight scenarios and wind shear combinations while being aided by the following discrete concepts:

- Wind Shear Advisories based on ground sensor data;
- Panel display of groundspeed versus vertical speed for a 3° glide slope; (See Figure 14)
- INS wind speed and direction;
- Panel display of groundspeed integrated with conventional airspeed indicator (ΔV); (See Figures 15, 16, 17)
- Panel and simulated head-up display of difference between along-track wind component at surface and aircraft altitude (ΔW), and; (See Figures 18, and 19).
- Panel and simulated head-up display of flight path angle and potential flight path angle (See Figures 20 and 21).

The results of these experiments indicate the groundspeed/airspeed comparison (ΔV) ranked as the best aiding concept by pilot subjective opinions and by the comparison of recorded landing performance.

The second ranking aiding concept was found to be the along-track wind component comparison (ΔW), either head-up or head-down, but particularly when presented in a head-up display. There is also an indication that the head-up displayed flight path angle has some merit.

The top ranking aiding concepts were reexamined in the Flight Simulator for Advanced Aircraft (FSAA) and NASA/Ames Research Center using a Boeing 737 airplane model. The results of this simulator experiment verified the findings from Phase I simulation efforts.

A Phase II simulation activity was also completed in the Douglas DC-10 simulator to provide an evaluation of improved ΔV, ΔW, and flight path angle (both air and ground derived) displays. This activity also evaluated a modified flight director developed by Collins Radio.

The results of the more detailed evaluations in the Phase II simulations have confirmed that the groundspeed/airspeed comparison (ΔV) provides significant aid to the pilot and the along-track wind component comparison (ΔW) provides some aid to the pilot in detecting and coping with wind shear. In addition, it was also shown that the modified control laws (algorithms) for flight director/thrust commands also significantly increased the pilots ability to handle wind shear encounters. Pilot acceptance of each of these concepts was high. Pilot performance and acceptance using flight path angle information was no better and, in some cases, worse than baseline, where no aiding concepts were used.

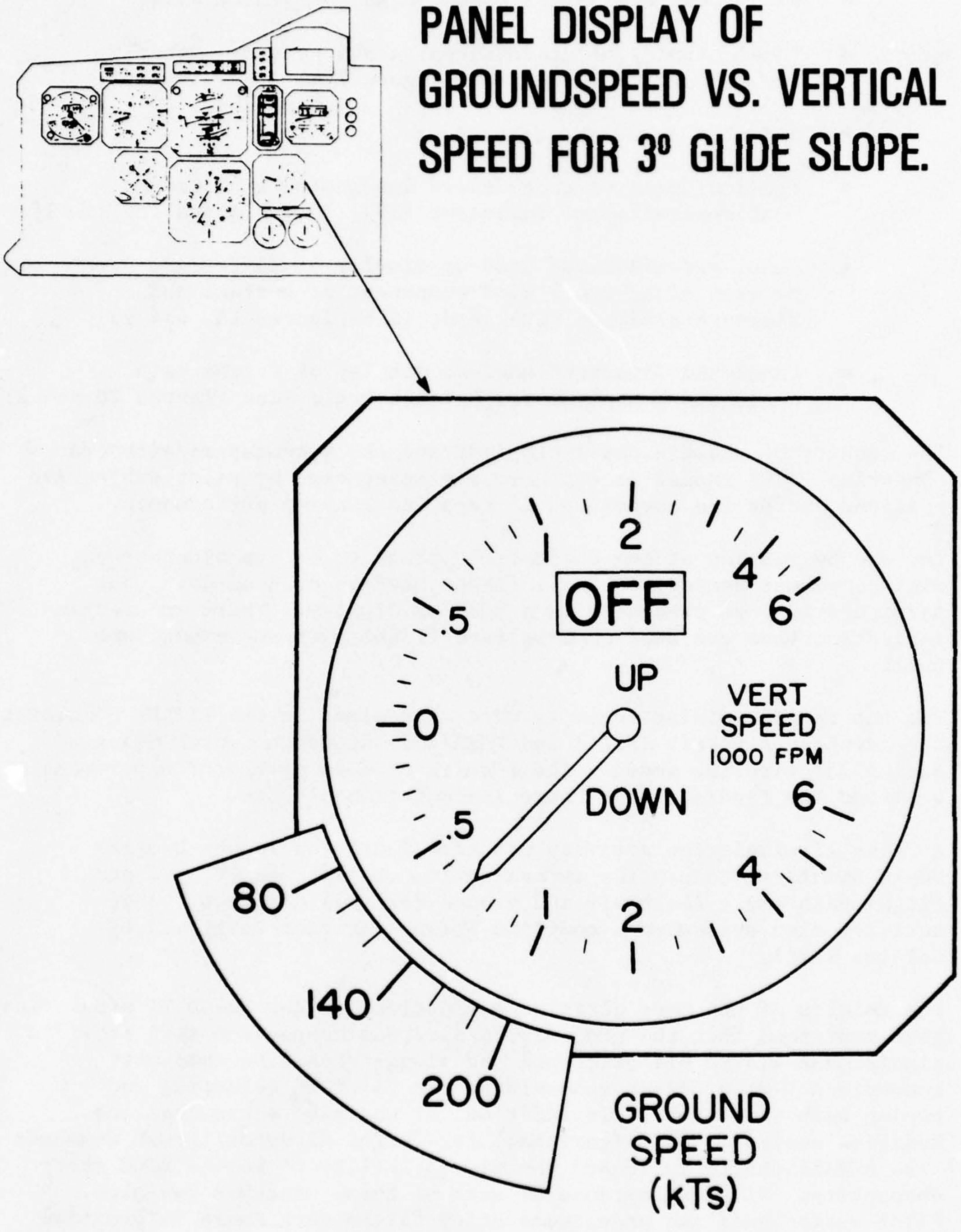
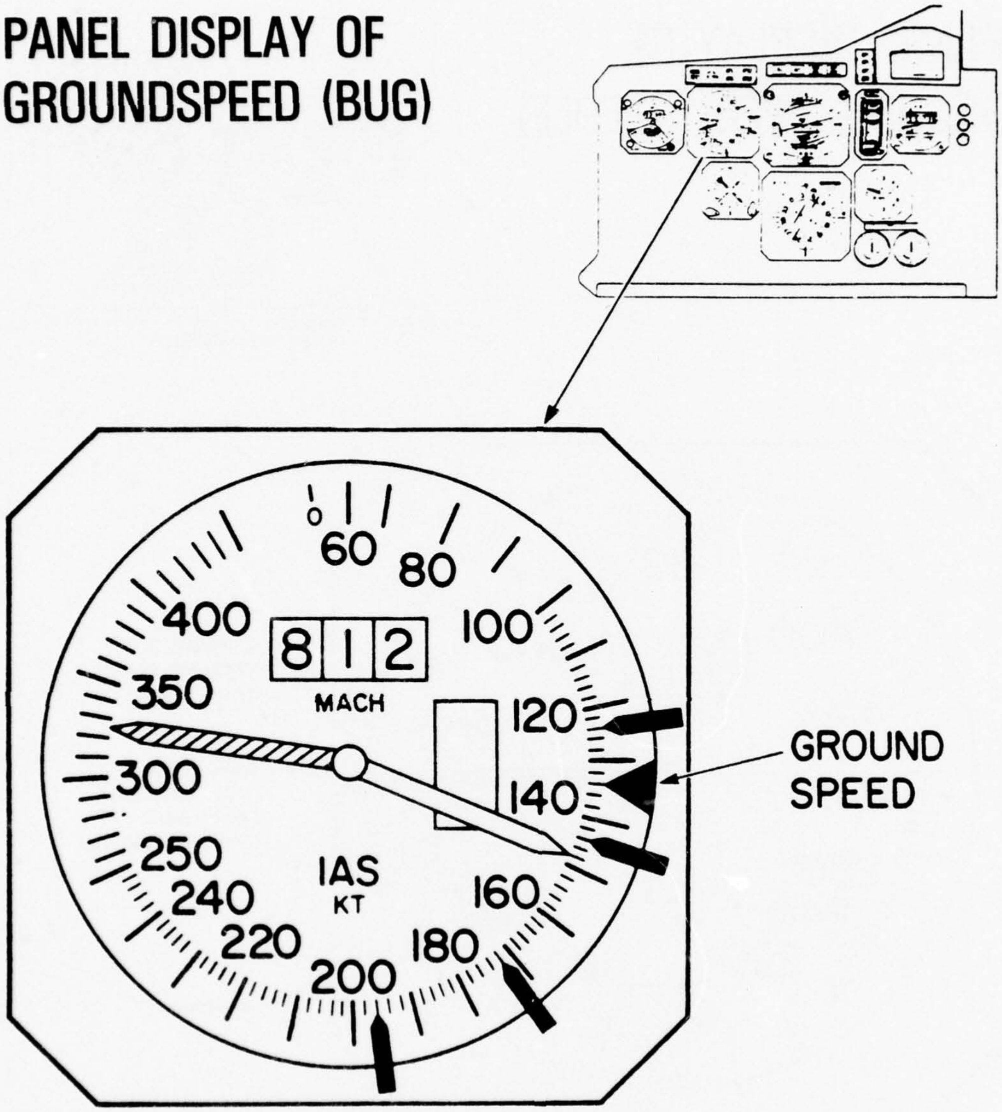


Figure 14. Vertical Velocity/Groundspeed Comparator



PANEL DISPLAY OF GROUNDSPEED (BUG)

MACH/AS INDICATOR

Figure 15. Groundspeed With Airspeed (ΔV)

PANEL DISPLAY OF GROUNDSPEED (NEEDLE)

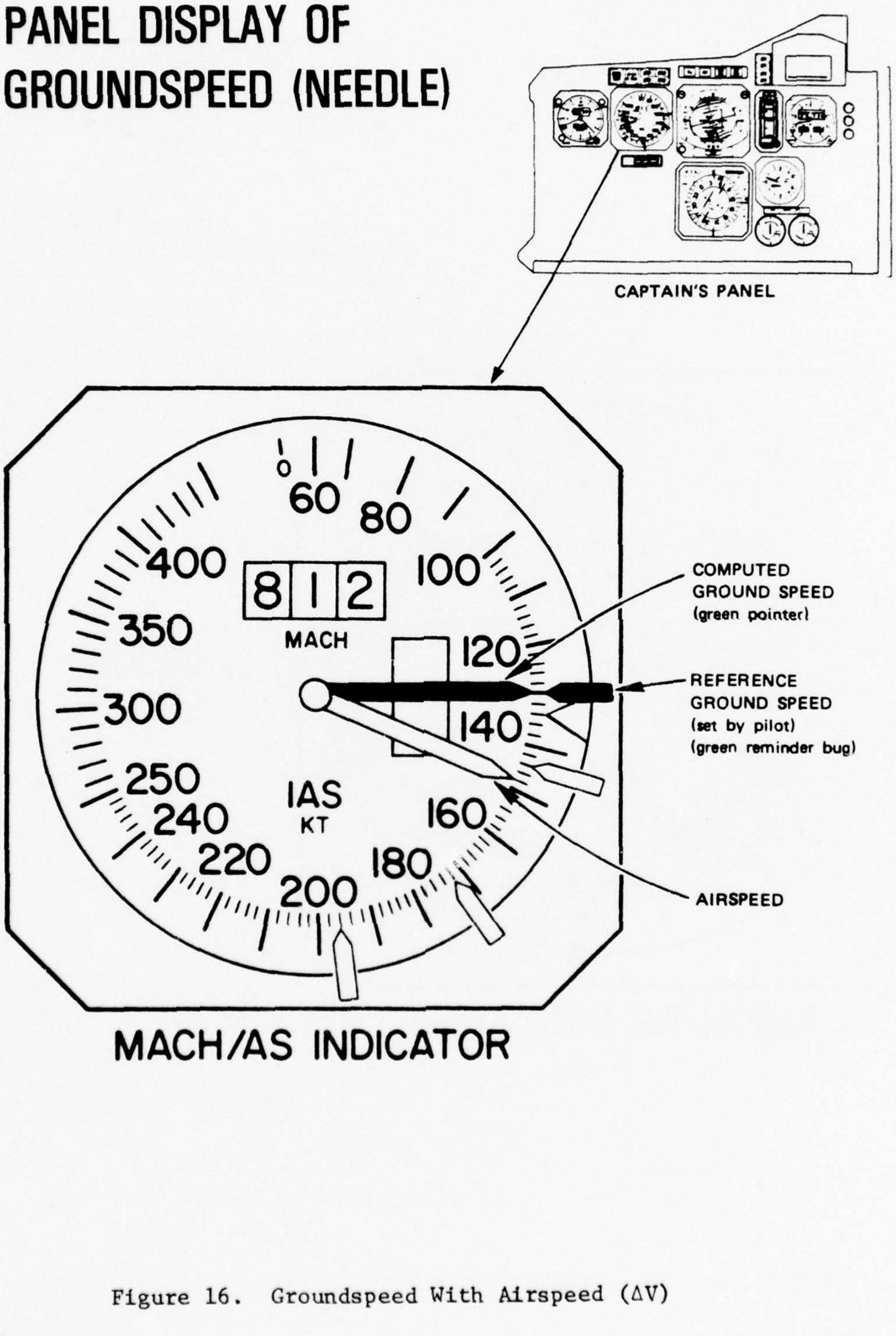


Figure 16. Groundspeed With Airspeed (ΔV)

PANEL DISPLAY OF GROUNDSPEED (DIGITAL READOUT)

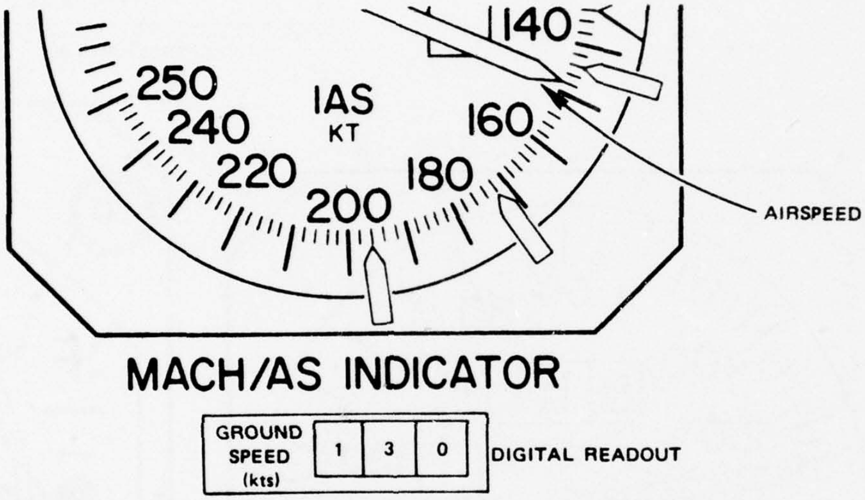


Figure 17. Groundspeed With Airspeed (ΔV)

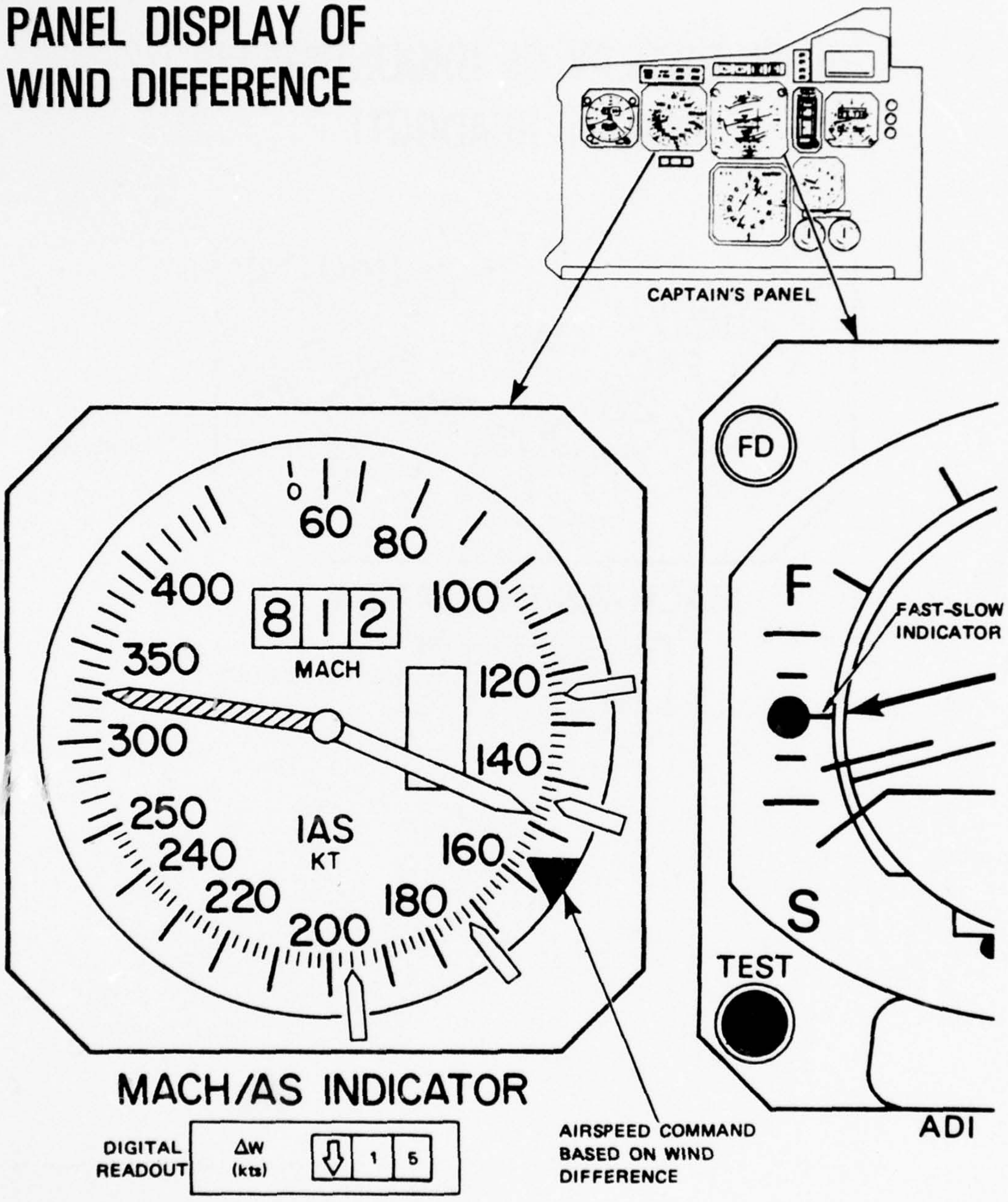


Figure 18. Wind Difference (ΔW)

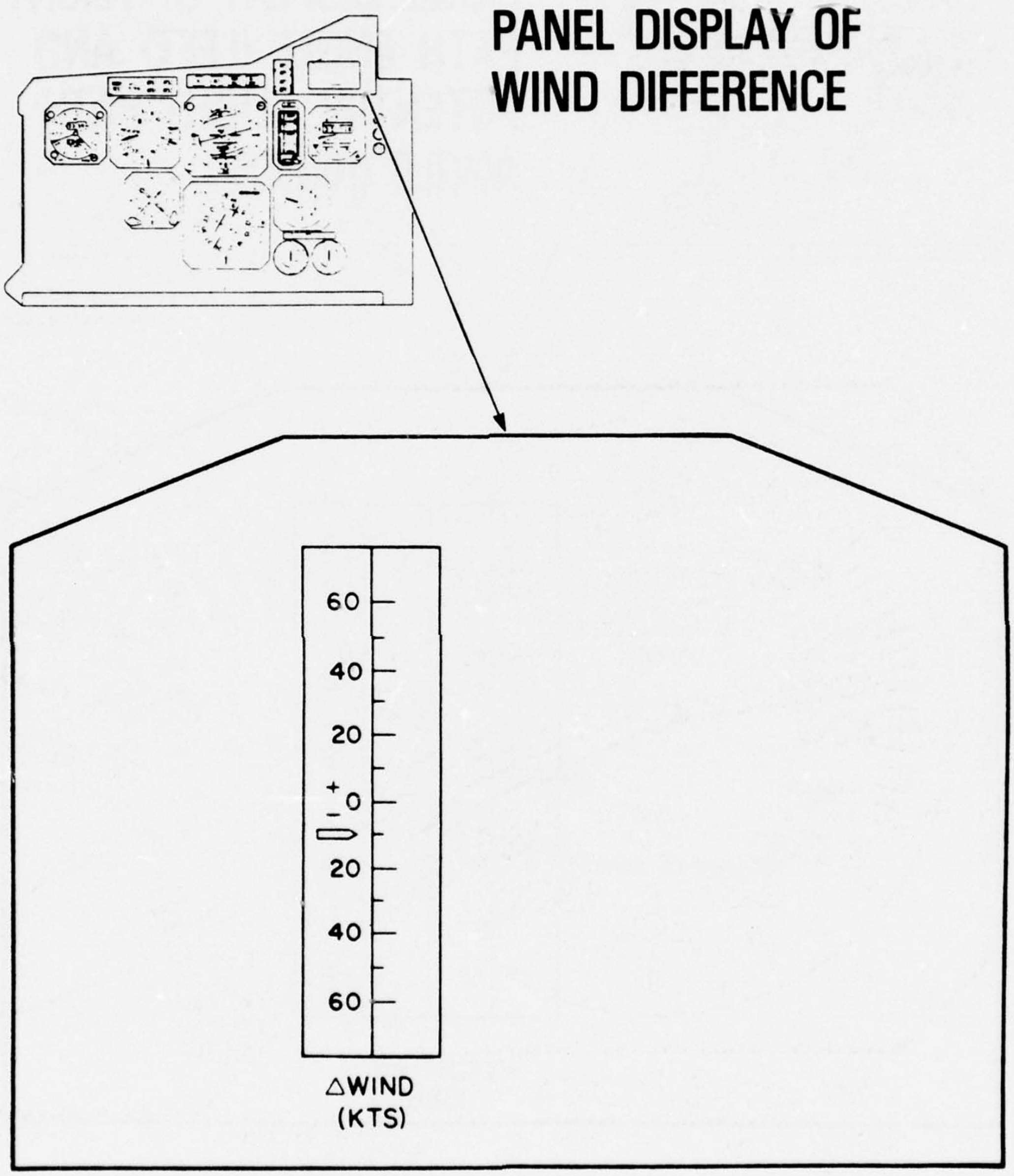
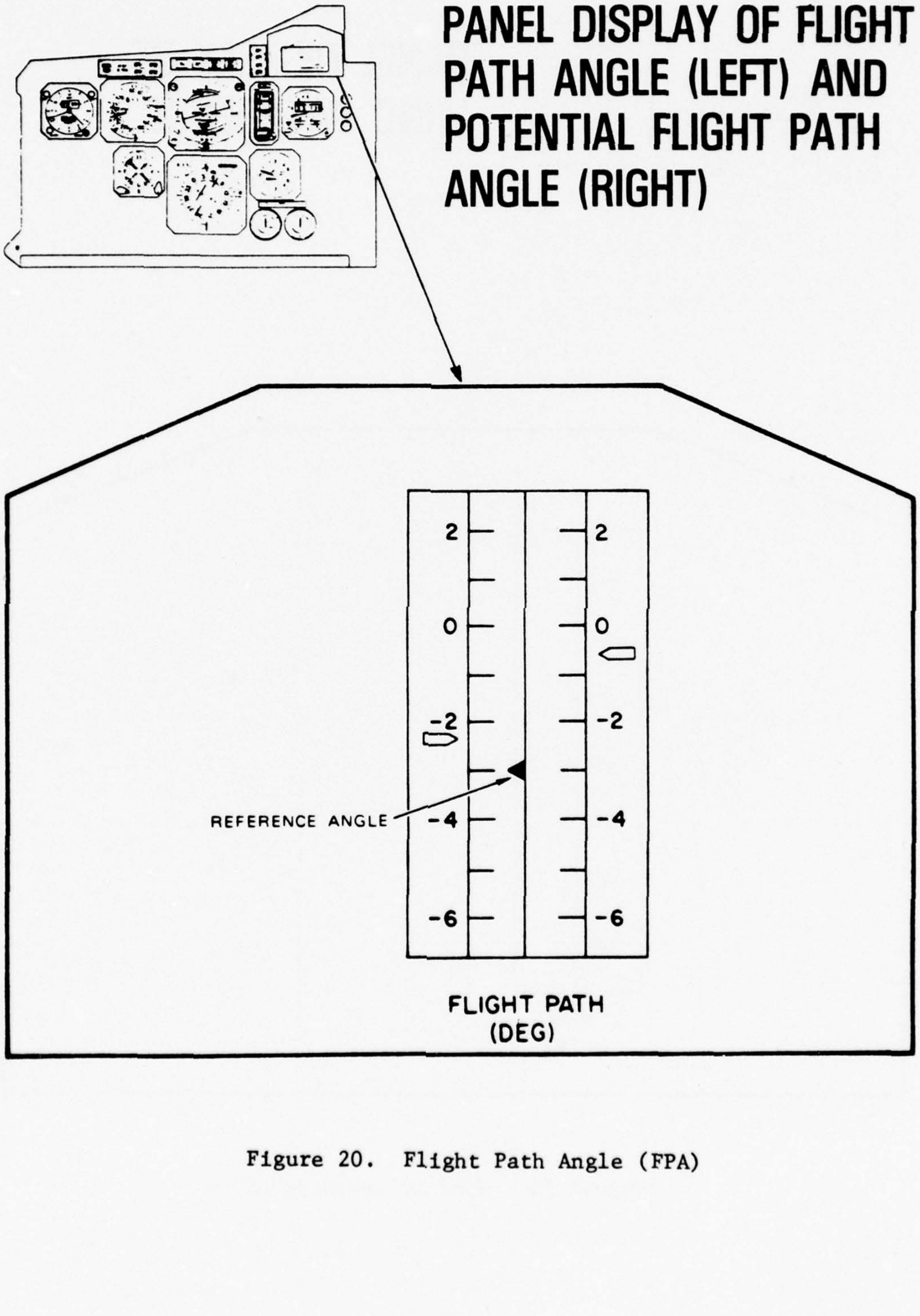
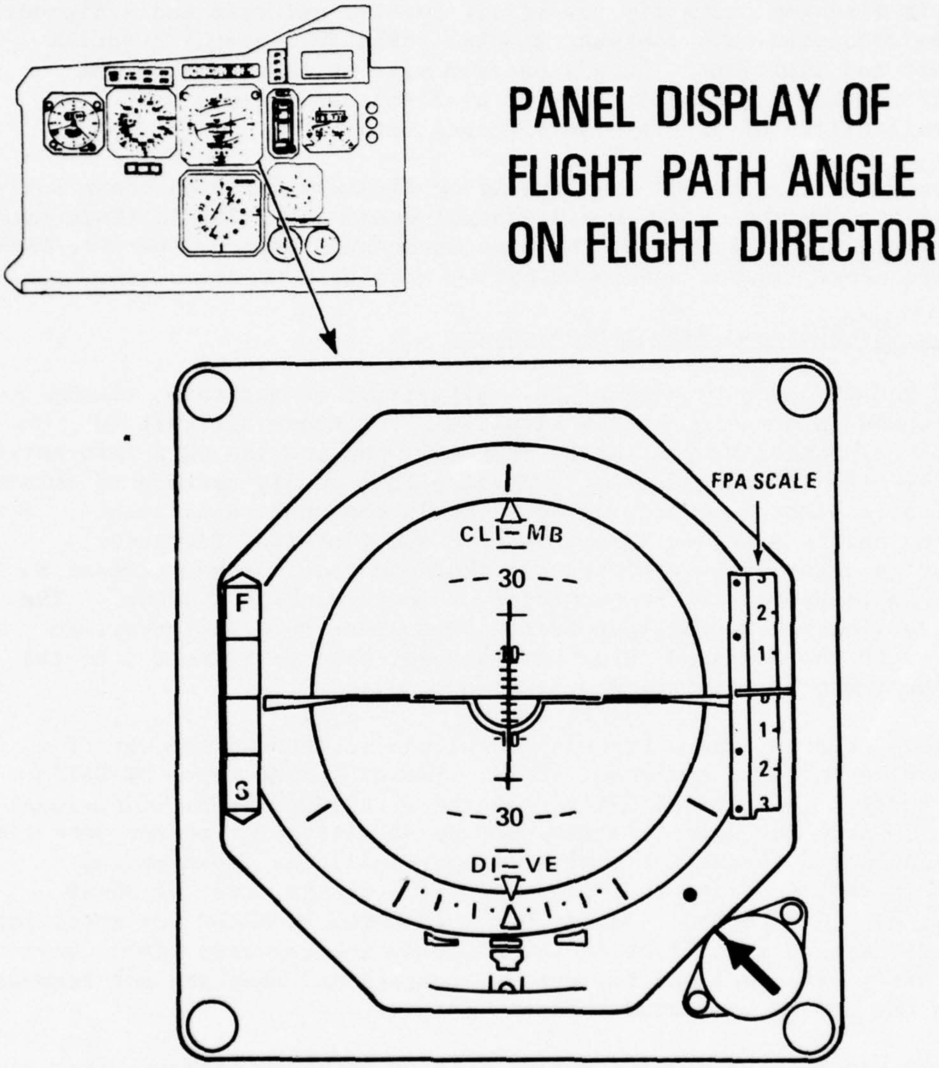


Figure 19. Wind Difference (ΔW)



PANEL DISPLAY OF FLIGHT PATH ANGLE (LEFT) AND POTENTIAL FLIGHT PATH ANGLE (RIGHT)

Figure 20. Flight Path Angle (FPA)



PANEL DISPLAY OF FLIGHT PATH ANGLE ON FLIGHT DIRECTOR

Figure 21. Flight Path Angle (FPA)

Additional manned simulation experiments will be conducted to support the flight test program and to determine the feasibility/necessity of applying the selected aiding concepts to general aviation aircraft. It is anticipated that a program similar to that described above, which is directed primarily toward air carrier aircraft and equipment, will be conducted on a somewhat simpler scale for general aviation aircraft and equipment. Such a program will be dependent on the characteristics and capabilities of available simulators and the availability of aircraft performance data.

Further evaluation of the use of head-up displays for wind shear will be conducted by the Guidance and Control Branch, ARD-730 in their program, Head-Up Display Evaluation. The Wind Shear/WVAS Branch, ARD-740, will maintain close liaison and coordination with this program.

3.4.4.2 Groundspeed Sensor Development

The ΔV and ΔW concepts assume the availability of accurate, timely groundspeed information in the airplane. For those aircraft so equipped, Inertial Navigation Systems (INS) can provide this information. Priority efforts are underway to develop less costly methods of obtaining groundspeed within the accuracy and timely response requirements. For the four shears examined in both manned and fast-time (computer) simulation experiments, the results indicate that a sensor lag of no more than 5-seconds can be permitted on the groundspeed signal. The accuracy limits have not been established since velocity errors in addition to the 5-second delay have not yet been programmed into the wind shear manned simulation experiments.

One means of providing a groundspeed signal is through the use of distance measurement equipment (DME). Two different types of DME's exist today. The digital DME's (covered by ARINC 568 specifications) meet a 2% accuracy specification, but no specification on response time. Tests conducted by the National Aviation Facilities Experimental Center (NAFEC) indicate that response times on the order of 30-40 seconds can be expected. Analog DME's (covered by ARINC 521 specifications); however, have no specification for accuracy nor response time. Obviously, since DME's were designed for enroute operations, they are not responsive enough for coping with wind shears.

The task was then to develop a family of groundspeed sensors which would be add-ons to existing airborne equipment used in the terminal environment (an altitude range from 0 to 2000 feet above ground level, and groundspeed from 0 to 250 knots). Five systems were considered:

(1) Instrument Landing System (ILS). A groundspeed sensor using Doppler techniques, which utilizes the RF carrier of the localizer;

(2) ILS. A groundspeed sensor using doppler techniques, which utilizes the audio subcarrier of the localizer;

(3) DME. Develop equipment to optimize the groundspeed output;

(4) Weather Radar. A groundspeed sensor which tracks a specially coded reflector on the ground; and,

(5) Radar Altimeter. A system which correlates in time the transmitted radar altimeter signal that is received by two along-track antennas.

Each of these ground speed sensors should emulate an INS groundspeed signal, with response times on the order of 1 second, accuracies on the order of 1 knot. and a resolution of 0.1 knots.

As a result of preliminary tests, the ILS localizer RF and audio concepts are considered successful and are undergoing optimization of the concept evaluation models. The digital and analog DME optimization is also successful. These systems would require only an add-on black-box, and no modification to existing equipment. From preliminary analyses both systems emulate an INS in the terminal environment.

Efforts are being initiated to develop weather radar and radar altimeter groundspeed sensors.

In order to rigorously test the capabilities of the different groundspeed sensors, NAFEC will build a groundspeed sensor flight test package for use in the NAFEC Gulfstream I. Part of this package will include an INS to be used as a reference for testing the groundspeed sensors. Results of these flight tests will indicate the accuracy and responsiveness of the various groundspeed sensors compared to an INS, and will be made available to Flight Standards Service (AFS) as significant results present themselves. A final letter report to AFS at the conclusion of the tests will outline the results of the flight tests and the performance of the various groundspeed sensors.

A cost impact study will be initiated to analyze the impact that the various groundspeed sensors will have on the FAA and various user groups. This cost impact study will not make recommendations as to which system should be adopted by the FAA since the capabilities and requirements may be vastly different from one user group to another.

In conjunction with the Hazard Definition effort, where an attempt will be made to define which types of wind profiles are most hazardous to various types of aircraft, a specification for accuracy and response time for groundspeed sensors will be developed. As a further fallout of this project, a candidate standard wind shear profile, or a set of profiles, will be developed to test the performance of future aircraft systems to cope with wind shears.

3.4.4.3 Flight Evaluation of ΔV and ΔW Displays

These two displays are being installed in the NAFEC Gulfstream I for flight evaluations along with wind shear data collection activities. The INS installed in the Gulstream I will provide the groundspeed input to these display concepts. Evaluation is expected to begin in July 1977. Improvements in the ΔV and ΔW displays developed in simulation experiments will also be installed in a flight test aircraft for flight evaluation. The NAFEC Gulfstream I appears to be the best candidate for this task as well as its use as a flight test bed for the groundspeed sensor development efforts. These concepts and displays will also be validated in an aircraft typical of the civil air carrier fleet, such as the Boeing 727.

3.4.5 Support Organizations

NAFEC, NASA/Ames Research Center, DOD/Air Force Flight Dynamics Laboratory and FAA/ARD-740.

3.4.6 Identification of Test Sites

Simulation: NAFEC - General Aviation Simulators
NASA/Ames - Flight Simulator for Advanced Aircraft
Douglas Aircraft Corp. - DC-10 Simulators
Air Force Flight Dynamics Laboratory (AFFDL) - Various Simulators
Other Locations (To be determined) - General Aviation Simulators

Flight Test: NAFEC
AFFDL

3.4.7 Major Milestones (Figure 22)

1.	Test Plan Complete/Begin Phase I Simulation	Apr 1976
2.	Complete Phase I Simulation	May 1976
3.	Test Plan Complete/Begin Phase II Simulation	Nov 1976
4.	Complete Phase II Simulation	Feb 1977
5.	Interim Report of Simulation Results and Recommendations Published	June 1977
6.	Test Plan Complete/Begin Phase III Simulation	Aug 1977
7.	Complete Phase III Simulation	Sept 1977
8.	Complete Engineering Studies of Most Promising Systems for Airborne Determination of Groundspeed	Jan 1978
9.	Complete Hardware Development of Selected Groundspeed Systems	Jan 1978
10.	Final Report of Phase I, II and III of Manned Simulation	Jan 1978
11.	Test Plan Completed/Begin General Aviation Simulation (Phase IV)	Feb 1978
12.	Complete General Aviation Simulation (Phase IV)	Mar 1978

13.	Complete Flight testing of Pilot Aiding Concepts/Systems	May 1978
14.	Complete Flight Testing of Prototype Groundspeed Equipment	May 1978
15.	Final Report of General Aviation Simulation and Recommendations	Jun 1978
16.	Develop Performance Specifications for Airborne Groundspeed Systems	Jun 1978
17.	Develop Recommendations for Use of Airborne Wind Shear Systems	July 1978

3.4.8 End Products

1. Determination of optimum pilot aiding concepts for detecting and coping with wind shear.

2. Complete performance specifications for cost-effective airborne equipment to display accurate and timely groundspeed information in the cockpit.

3. Selection of and recommendations for use of airborne wind shear systems.

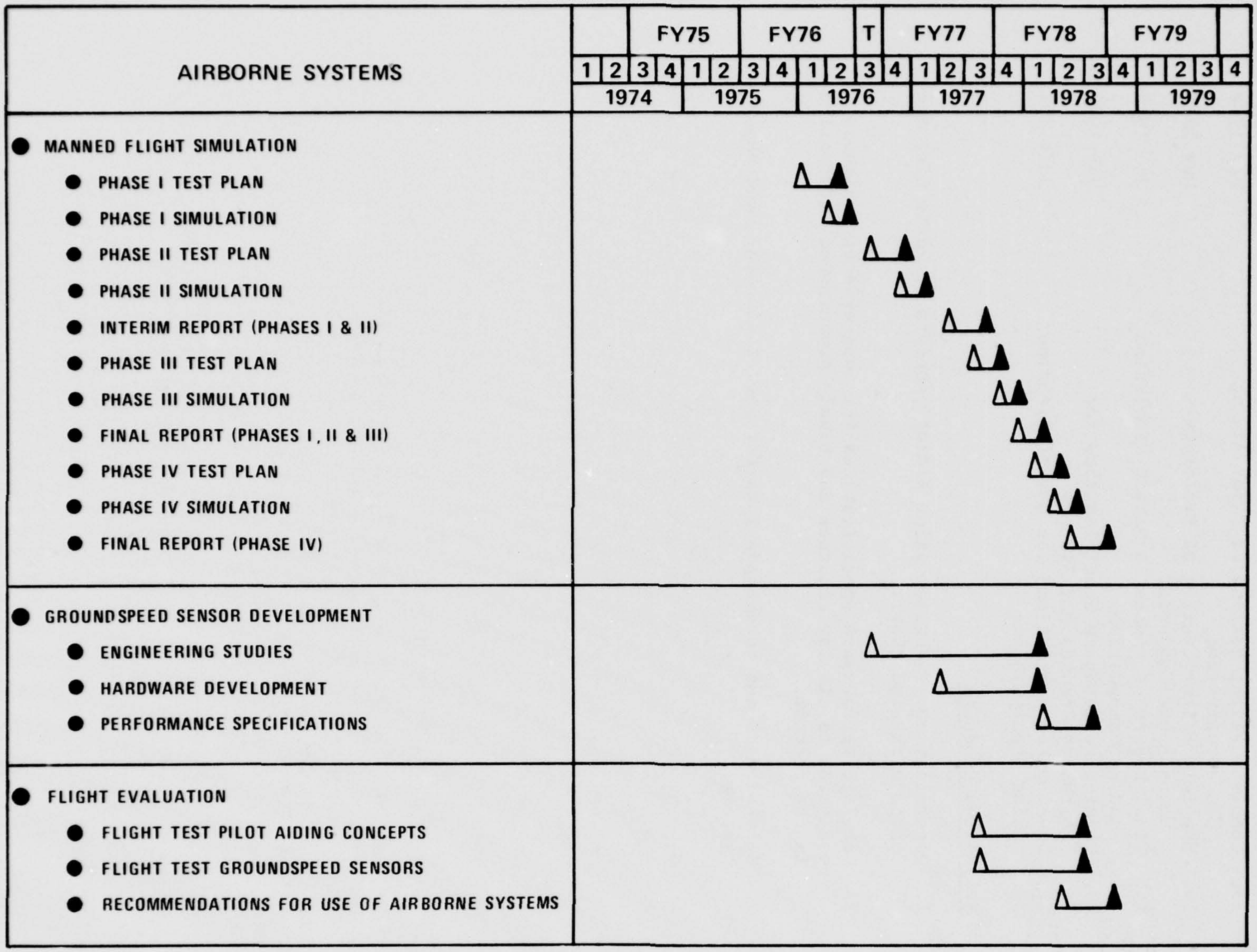


Figure 22. Airborne Systems Milestones

3.5 Wind Shear Data Management (154-740-5)

The effective acquisition, processing and analysis of wind shear meteorological data and subsequent distribution of wind shear technical reports is important to the success of program objectives. Since data on low-level wind shear will be collected in the program from a wide range of instrumentation, it is essential that those data are normalized so that meaningful comparisons can be made between data sets. This portion of the plan describes data management activities underway and scheduled.

3.5.1 Major Tasks

The data management effort is composed of the following tasks.

A. Develop a wind shear management plan.
B. Collect and organize ground-based data.
C. Collect and organize airborne data.
D. Analyze and evaluate data collected.
E. Develop a wind shear data base for use by the aviation community.

3.5.2 Wind Shear Program Data Management Plan

The Wind Shear Program Data Management Plan, Report No. FAA-RD-76-25, was published in May 1976. It describes the metoeological data collection efforts associated with the program and provides a set of data processing and analysis guidelines to be followed by data collection participants. It also contains the wind shear data base functional requirements and a brief description of the characteristics of the meteorological sensors being used in the program.

The following paragraphs will briefly review the data management tasks.

3.5.3 Ground-Based Data Collection

The collection of ground-based wind shear data specifically for use in the program began in the Spring of 1976 at National Severe Storms Laboratory (NSSL). By the Summer of 1977, data collection will have expanded to 14 test sites or airports. Much of the data being processed is used in sensor development studies, wind shear forecast verifications and wind shear profile development prior to becoming part of the wind shear data base which is being developed at NAFEC.

Table 2 contains a listing of the types of data collected and identifies the class of sensors used to acquire the data by location. Data collection is not continuous at all sites at all times. At those sites where surface wind is being monitored, data are logged continuously

TABLE 2. GROUND-BASED WIND SHEAR DATA COLLECTION

TEST SITES AND AIRPORTS	DATA TYPES AND CLASS OF SENSORS							
	ADDITIONAL SURFACE WIND ANEMOMETERS	TOWER WINDS MULTI-LEVEL	PRESSURE *DP/DT & P_O**	SURFACE TEMPERATURE	MICROWAVE RADAR	DOPPLER RADAR	ACOUSTIC SONAR	CW*** LASER
NORMAN, OK. (NSSL)	X	X	X	X	X	X		X
PHILADELPHIA, PA. (DREXEL)		X						
AIKEN, S. C. (SAV. RIVER)		X						
MT. SUTRO, CA. (NEAR SFO)		X						
STERLING, VA. DULLES INTERNATIONAL	X		X	X		X	X	X
CHICAGO, Ill. O'HARE INTERNATIONAL	X		X	X	X			X
ATLANTIC CITY, N. J. (NAFEC)	X	X		X	X	X		
CAPE KENNEDY, FLA.	X	X		X	X			
J. F. KENNEDY, N. Y.	X							
STAPLETON, DENVER, CO.	X							
HARTSFIELD, ATLANTA, GA.	X							
HOUSTON INTERCON, TX.	X							
TAMPA INTER. FLA.	X							
OKLAHOMA CITY, OK.	X							

SURFACE WIND MONITORING SYSTEM (SWIMS) TESTING

* PRESSURE JUMP SENSOR TESTING

** P_O CONTINUOUS MICROBAROGRAPH SENSING

*** CONTINUOUS WAVE

except for equipment outage. At three of the four towers where data have been taken at multiple levels, the data is pre-1976. Only at the KTVY-TV tower, near Norman, Oklahoma, have data been logged continuously since April 1976 and that is scheduled to end by the Fall of 1977. The processing of wind data from the other three towers will be discussed in Section 3.5.7.

With the exception of Dulles Airport, the rest of the data acquisition will be done as the more exotic sensor and wind shear detection systems are tested. This means that some signficant wind shear events may not be sampled because prototype equipment is either not scheduled to operate or is in a modification or repair status. Ground-based data collection, with the exception of those sites where sensor development work will continue (Chicago, Dulles and NAFEC), will begin phase-out in late 1977. By early 1978, sufficient ground-based data will have been collected, archived and in most cases analyzed to provide sufficient meteorological data to meet program objectives.

3.5.4 Airborne Data Collection - 1976

A considerable amount of airborne data have already been collected, processed and plotted in altitude, time and data point cross sections. The data logging techniques, sampling frequencies and wind shear events sampled are discussed in reports FAA-RD-76-25, FAA-RD-77-33 and FAA-RD-77-40. A brief summary of the work done thus far follows.

In the Spring of 1976, the Air Force provided a C-141 which flew four missions in response to forecasts of wind shear associated with frontal situations. Data were collected during a total of 32 approaches at three different airports. The C-141 is equipped with two Inertial Navigation Systems, data processing and recording equipment. Data collected include windspeed and direction, temperature, aircraft heading, altitude and other aircraft performance parameters. The maximum wind shear and most hazardous conditions encountered were associated with warm front penetrations at altitudes below 800 feet above ground level.

An FAA Aero Commander based at NAFEC continued the data collection efforts started by the C-141. The aircraft was launched in response to forecasts made by NWS meteorologists participating in a wind shear forecast experiment (See Section 3.6 for forecast details). The NAFEC Gulfstream I is being modified to support this task and is expected to be available for data collection by August 1977.

The Aero Commander was also used during August 1976 in Project Thunderstorm II at Cape Kennedy, Florida, to collect data on thunderstorm inflow characteristics and the shear associated with sea-breeze fronts near the Cape. In addition, as part of the testing of the Acoustic Doppler System, the Aero Commander has flown approaches into Dulles to collect comparative wind data for use in ground-based wind sensor development.

Royal Dutch Airlines (KLM) has provided the FAA with data on 190 approaches collected at John F. Kennedy and Chicago, O'Hare airports. These data were collected during the Summer of 1976 from a B-747 and a DC-10-30 equipped with Aircraft Integrated Data Systems capable of high speed inertial wind detection and processing. Data collected was on a random basis with respect to weather events.

In addition to the above, an Air Force F4C was used to collect thunderstorm gust front data as part of the Spring Thunderstorm Project conducted in 1976 by NSSL near Norman, Oklahoma. The data collected will be discussed in Report FAA-RD-77-40.

3.5.5 Airborne Data Collection - 1977

During 1977, the Aero Commander continued to be used in the forecast verification task and to collect wind data used in ground-based sensor testing at Dulles. By Summer, the Aero Commander will be replaced by the better instrumented, more durable and longer ranged Grumman Gulfstream which will also have weather radar on board. Sea-breeze frontal data will be collected at east coast airports that border the Atlantic Ocean, i.e., Logan-Boston; J.F. Kennedy and La Guardia, New York and Norfolk, Virginia.

Under consideration is the use of KLM again to provide approach data on low-level wind conditions but on a world-wide basis. Aside from a small sampling of data on wind conditions in the United States, no international or world-wide distribution data on the intensity or frequency of low-level wind shear are available to the aviation community. It is difficult to envision low-level wind shear as being a hazard unique to the United States.

F4C missions at Norman are also scheduled again for the 1977 thunderstorm season. The 1976 airborne data sampling in this area was quite small because nearly all the 1976 thunderstorms occurred at night. Nighttime penetrations of thunderstorm gust fronts are considered too dangerous for any type aircraft.

3.5.6 Analysis of the Data

Participating research groups such as WPL, NSSL, NASA-Marshall Space Flight Center are analyzing recent data (1975 and 1976) for both wind shear characterization and modeling purposes. Other efforts by these groups include:

- WPL - Long term pressure and surface wind records for Chicago, O'Hare.
- NSSL - Long term surface, tower and airborne data from Norman, Oklahoma on gust fronts caused by Oklahoma thunderstorms.
- NASA - Previous low-level shear and turbulence modeling of the atmospheric boundary layers.

In addition to the above, the FAA has sponsored Drexel University (Philadelphia) to examine six years of meteorological data (1964-70) collected on their five-level tower for significant wind shear frequency and cause of occurrence. Drexel's records appear to be one of the few long-term records of low-level shear in the United States that can be related to nearby airport activities. The results of their studies are scheduled to be published in November 1977.

3.5.7 Development of a Wind Shear Data Base

3.5.7.1 Objectives

The objective of the data base development effort is to provide for the systematic storage, retrieval, analysis and distribution of wind shear and associated meteorological data collected during the Wind Shear Program. *Specifically, the data* base will fulfill the following requirements:

- Provide the basic data for the statistical computations to characterize the general wind shear problem.
- Provide the basis data for the statistical computations to characterize the wind shear problem for selected sites.
- Provide for the selective retrieval and distribution of basic data and statistical computations.

3.5.7.2 Contents

The data base will incorporate data from surface, tower, airborne and remote sensors.

3.5.7.3 Data Retrieval

The data base will provide for the selective retrieval of stored data. General retrieval keys will include site, weather conditions (fronts, thunderstorm and low-level jet), magnitude of event, date and time, etc. Both raw data and statistical summaries will be available.

3.5.7.4 Requests for Data

Beginning in January 1978, a summary of the data base content will be available from the Wind Shear/WVAS Branch (ARD-740). Requests for data should be addressed to the Wind Shear/WVAS Branch (ARD-740), 2100 Second Street, S.W., Washington, D.C. 20591.

3.5.7.5 Data Base Schedule

Data collected during 1976 is currently being entered into the data base. Data of 1977 should be available in processed form by the Spring of 1978. Data Collection for use in the data base will begin phase-out in early 1978 with the exception of data collected for ground-based sensor or airborne systems development.

3.5.8 Major Milestones (Figure 23)

1.	Complete Wind Shear Data Management Plan	Feb 1976
2.	Begin airborne data collection	May 1976
3.	Begin ground-based data collection	Apr 1976
4.	Begin software development to process wind shear data for data base construction	Aug 1976
5.	Initial tabulations of wind shear data base available	Aug 1977
6.	Drexel Technical Report on wind shear distribution and intensity complete	Nov 1977
7.	Wind Shear data base complete	Jun 1978

3.5.9 End Products

1. Technical Report on distribution and intensity of significant wind shear by cause as derived from long-term tower data.

2. Accessible wind shear data base for use by aviation interests for training, design, and research purposes.

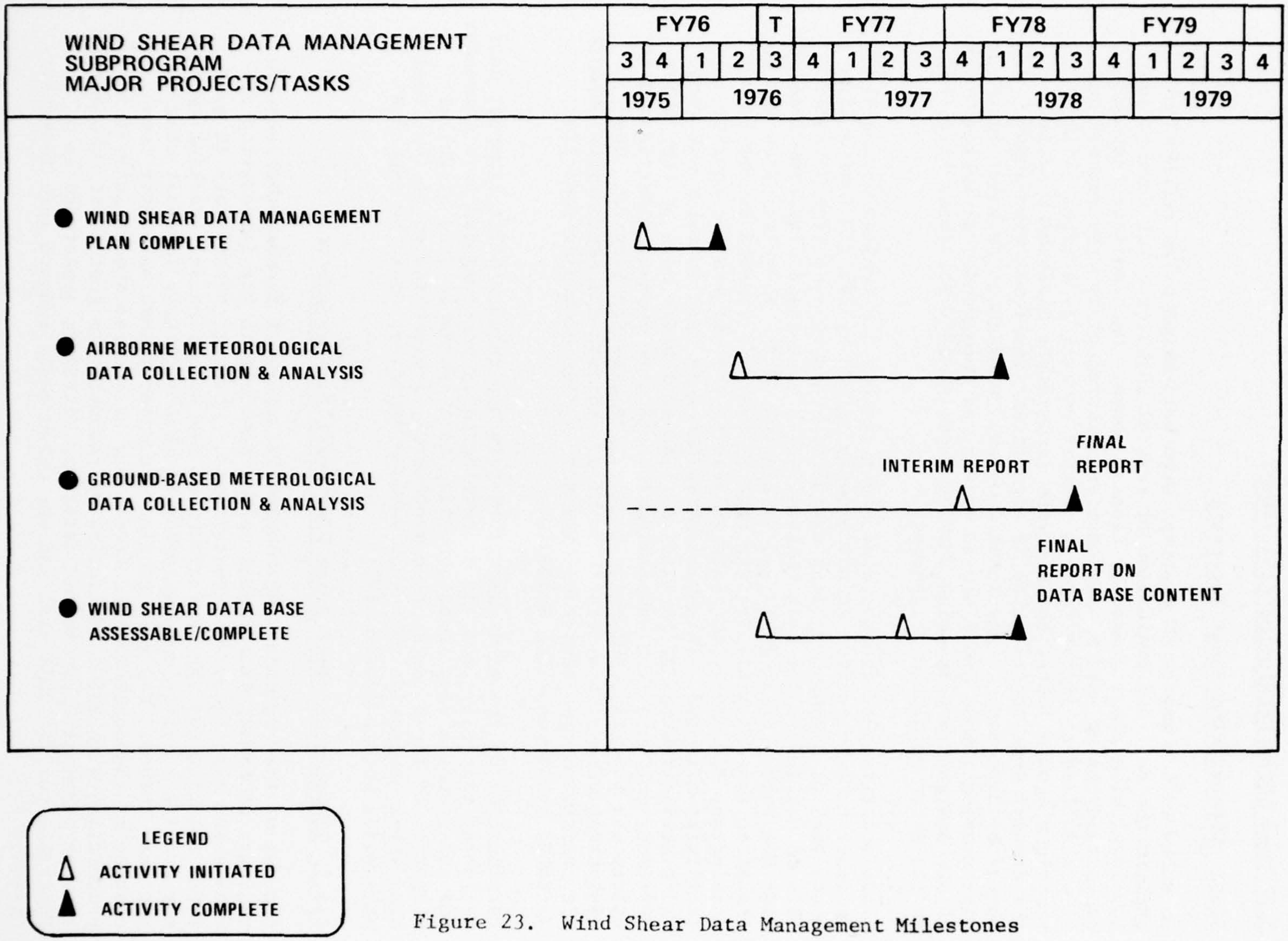


Figure 23. Wind Shear Data Management Milestones

3.6 Wind Shear Prediction (154-740-6)

3.6.1 Frontal Wind Shear Forecasts

In early 1976 a series of meetings were held between FAA and NWS to explore the test and evaluation of several techniques for forecasting low-level wind shear caused by frontal zones. One candiate technique was already being used by air carrier meteorologists with success and it was decided to investigate it further as well as others. This technique uses a fontal speed versus temperature difference across the frontal zone to determine if significant low-level wind shear should be forecast. Significant low-level wind shear or shear intensity greater than 8 knots per 30 meters, as recommended in Appendix B of Air Navigation Commission Working Paper AN-WP/4498, dated 11/25/75, is the shear magnitude of concern.

Since occurrence of frontal wind shear reaches its maximum during the December - March period, it was jointly agreed by NWS/FAA that a six-month test of techniques being evaluated would be made from November 1976 to May 1977. The test included seven east-coast airports, located near New York, Philadelphia and Washington, D.C. Forecasts from NWS were issued to the FAA's Air Traffic Control System's Command Center in Washington, D.C. where they are relayed to the air traffic control facilities affected. Telephone hot-lines were used to relay the wind shear advisories to ATC facilities. The advisories were of very short duration, not more than several hours, and were further disseminated to pilots via the FAA's Automatic Terminal Information Service. The advisories were also available to pilots through the appropriate enroute air traffic control center and the air carrier communications link operated by Aeronautical Radio Inc.

Verification of the wind shear forecasts was through pilot reports, data collected initially from the meteorologically instrumented Aero Commander and the acoustic wind shear detection test system located at Dulles airport. If these tests prove successful, implementation of low-level wind shear advisories (or other warning vehicles) could be expanded nationwide before Winter 1977.

3.6.2 Thunderstorm Gust Front Wind Shear Forecasting

Because of the transient and complex structure of thunderstorm outflow regions, no immediate advances appear possible in the forecasting of wind shear associated with gust fronts. However, recent work in gust front modeling and the development of new detection and tracking systems may provide a better understanding of this difficult forecast area in the near future. FAA will continue to sponsor work on better forecasting of thunderstorm gust fronts and associated shears in 1978 in cooperation with NWS. Advisories of thunderstorm gust front movement through terminal approach and departure corridors appears to be a desirable goal in this area and one which would enhance safe terminal operations.

3.6.2 Wind Shear Prediction Milestones

Milestones for the Wind Shear Prediction effort are shown in Figure 24.

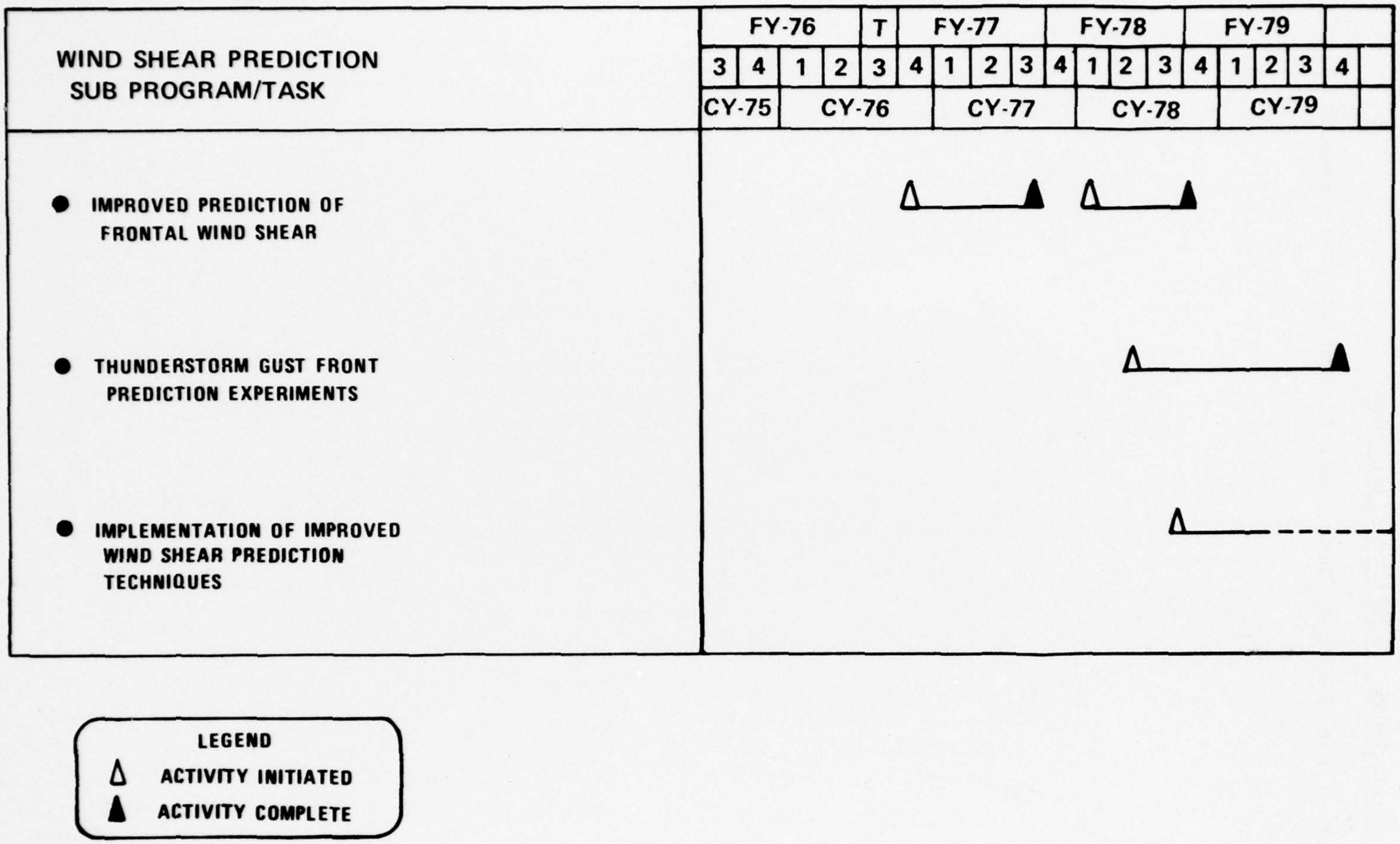


Figure 24. Wind Shear Prediction Milestones

3.7 Systems Integration and Implementation (154-740-7)

The final aspects to be addressed in the development of the Wind Shear Systems are the operational integration and implementation of sensors, displays, avionics, and procedures in order to effectively and efficiently meet the overall objectives of the program. This final phase of the Wind Shear Program is important and must be accomplished in a timely manner since the ultimate success of the program requires the implementation of systems which provide an identified functional utility in addition to a demonstrated technical capability.

3.7.1 Objective

The objective of the wind shear systems integration and implementation effort is the development of a plan, with supporting rationale, for the efficient and economical integration of the Wind Shear Systems into the National Airspace System (NAS).

3.7.2 Important Considerations

The nature of the National Airspace System is such that it contains a broad spectrum of users, airport configurations, and a variety of Air Traffic Control services. The planned integration must account for this diversity during its development.

To accommodate this variety of users, the analysis must address all categories of aircraft, from the smallest general aviation aircraft to the largest wide-body air carrier type. It can be expected that the acceptability of equipping the various categories of aircraft with the avionics which are developed in the Wind Shear Program will be inversely proportional to the cost of those packages and the complexity of their use.

Similarly, the categories of airports extend from the single, grass runway configuration to the multi-runway, highly complex international airport . A rationale must be established to rank airports for implementation of wind shear systems based upon appropriate factors such as operations, passenger enplanements, and probability of hazard due to wind shear phenomena. This analysis shall specifically identify the weightings to be employed to facilitate management decision, whether equipments so identified are procured through the Airports Development program or through the FAA Facilities and Equipments program.

Finally, the Air Traffic Control services must be considered, which range from none to the enhanced Automated Radar Terminal System (ARTS-III). The integration design must allow for maximum useage of existing hardware and communication facilities not only for cost-effectiveness, but also because physical space is extremely limited in many terminal facilities.

3.7.3 Technical Approach

The Systems Integration Plan and Implementation Analysis efforts will be accomplished by in-house, FAA organizations and a contractor chosen thru a competitive bid process.

The work includes refinement of the operational requirements, a detailed definition of systems interfaces, establishment of a data format compatible with other elements of the Upgraded Third Generation ATC System, and determination of the optimum display techniques. This effort also encompasses those activities required to provide a detailed implementation plan including cost/benefit studies, environmental impact assessment, and recommended system architecture for each designated airport category.

The system integration, relative to this effort, is intended to include the integration, into the National Airspace System, of the various hardware components, air traffic control procedures, pilot techniques, etc., which will comprise the Wind Shear System.

While this effort does not specifically address tasks directly related to Wake Vortex Systems it is recognized that many similarities do exist between certain elements of the Wind Shear System and the Wake Vortex System. A closer examination of these commonalities may lead to the requirement for a detailed study to determine the feasibility of combining elements of both systems (e.g. Surface Wind Monitoring System (SWIMS) combined with the Vortex Advisory System (VAS). The resultant systems integration and systems implementation considerations would then be analyzed in order to insure the most efficient and effective combined Wind Shear/Wake Vortex System.

3.7.4 Major Tasks

The wind shear systems integration and implementation effort shall be conducted in two phases:

Phase I - Wind Shear Systems Integration Plan

A. Study of User Requirements
B. Systems Integration Definition
C. Establish Data Format
D. Determination of Optimum Displays

Phase II - Wind Shear Systems Implementation

A. Systems Implementation

1) Impact on NAS
2) Determination of Priorities

3) Time Table

B. Benefit/Cost Study

1) Airborne vs Ground
   Systems vs Forecasting

2) Interim vs Long Term

C. Environmental Impact Assessment

D. Spares, Maintenance, and Training Requirements

3.7.5 Support Organizations

Transportation Systems Center, (TSC), National Aviation Facilities Experimental Center (NAFEC), ARD-100, Office of Systems Engineering Management (Benefit/Cost Study).

As an initial effort on the systems integration tasks, requirements will be provided to ARD-100 for consideration in new tower cab studies. TSC is to analyze wind shear systems requirements in the context of the Upgraded Third Generation ATC System to determine if common processing and display requirements could be developed.

3.7.6 Schedule and Milestones (Figure 25)

1. Engineering Requirement Prepared	Jul 77
2. Contract Award	May 78
3. User Requirements	Nov 78
4. Phase I Completion	May 79
5. Phase II Completion	Dec 79
6. Final summary report published on Wind Shear Systems Integration and Implementation	Mar 80

3.7.7 End Products

The end products of this effort include the following: Wind Shear warning system integration plan, implementation analysis and schedule, total funding estimate and a summary report on the results of the system analysis study.

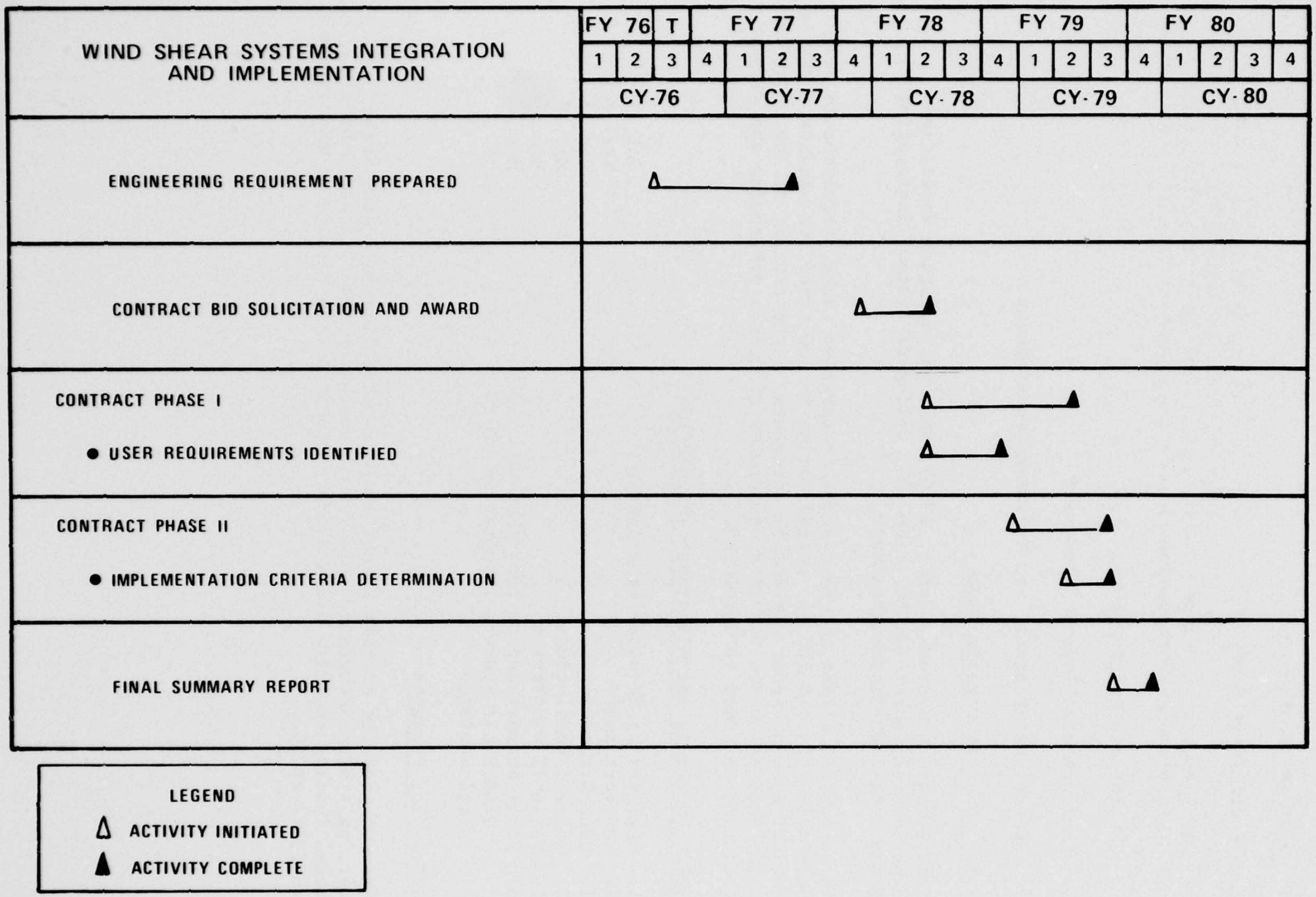


Figure 25. Wind Shear Systems Integration and Implementation Milestones

4.0 Funding Requirements

Funds required to provide timely solutions to the wind shear problem are identified in Table 3. Allocation of funds by major project (task) is geared to promote priority effort for operational implementation of short term, interim, products or services capable of enhancing air safety.

WIND SHEAR PROGRAM FUNDING REQUIREMENTS ($000)

(Program Code 154-740)

MAJOR PROJECTS (Tasks)	FY-1976	FY-1976T	FY-1977	FY-1978(EST.)	FY-1979 (EST.)
1. Wind Shear Characterization	225	76	195	180	-
2. Hazard Definition	130	-	295	180	-
3. Ground-Based Systems	1240 800 A/	359	1504 700 A/	1840 30 A/	707 2000 A/
4. Airborne Systems	962 B/	447 B/	2050	1852	1082
5. Data Management	40	66	195	149	100
6. Wind Shear Prediction			44	210	100
7. Systems Integration/ Implementation			14	150	205
R&D Funds	2597	948	4297	4561	2194
F&E Funds	800	-	700	30	2000
Total	3397	948	4997	4591	4194

A/ F&E Funds, including existing and planned demonstration sites.
B/ Includes 073 R&D Funds and prior year obligations.

NOTE:

Availability of estimated funds is subject to OST/OMB/Congressional actions.
Funding estimates reflect planned program milestones subject to availability of funds.
Current year estimates are consistent with the Wind Shear Fiscal Program.

TABLE 3. FUNDING REQUIREMENTS--WIND SHEAR PROGRAM

5.0 Program Management

5.1 General

The overall management and direction of this program is the responsibility of the Wind Shear/WVAS Branch, ARD-740, Systems Research and Development Service (SRDS). The Program is conducted under a matrix managment concept (Figure 26) through which other internal SRDS groups may be requested by ARD-740 to handle specific project or task assignments. These assignments, made through established procedures, outline the work to be accomplished, work schedules and define project-specific funding authorizations within the total Wind Shear Program.

5.2 Program Office Structure

The Wind Shear Program, under the supervision of the Wind Shear/WVAS Branch Chief, is structured into seven major projects (tasks):

1. Wind Shear Characterization (154-740-1)
2. Hazard Definition (154-740-2)
3. Ground-Based Systems (154-740-3)
4. Airborne Systems (154-740-4)
5. Data Management (154-740-5)
6. Wind Shear Prediction (154-740-6)
7. Systems Integration and Implementation (154-740-7)

The individual projects (tasks) are assigned to and managed by a member of the Wind Shear/WVAS Branch, ARD-740. Each project/task is directed toward satisfying a specific functional requirement and producing a service or end item within a specified time frame.

5.3 Wind Shear/WVAS Branch (ARD-740)

ARD-740 exercises management responsibility in the following areas:

- Review all wind shear proposals and assign specific projects or tasks, subject to the approval of the Chief, Approach and Landing Division (ARD-700) and Director, Systems Research and Development Service (ARD-1).

- Establish and authorize all project/task funding levels. Approve all Procurement Requests, Inter-Agency Agreements, Project Plan Agreements (PPA's) and NAFEC Program Documents (NPD's) before issuance.

- Monitor and evaluate project/task progress. Participate in all intra- and interagency coordination and review meetings.

SYSTEMS RESEARCH AND DEVELOPMENT SERVICE/APPROACH AND LANDING DIVISION, ARD-700	WIND SHEAR/WVAS BRANCH, ARD-740						
PROJECTS/ TASKS	1. WIND SHEAR CHARACTERIZATION	2. HAZARD DEFINITION	3. GROUND-BASED SYSTEMS	4. AIRBORNE SYSTEMS	5. DATA MANAGEMENT	6. WIND SHEAR PREDICTION	7. SYSTEMS INTEGRATION AND IMPLEMENTATION
PROJECT/TASK MANAGER	PROJECT/TASK/SUPPORT ACTIVITY – WIND SHEAR						
ARD-150							TSC NAFEC
ARD-243			NOAA/ WPL NAFEC				
ARD-330				NAFEC			
ARD-450	NOAA/ WPL NOAA/NSSL	NASA/ HUNTSVILLE	NOAA/ WPL		NAFEC	NOAA/ NWS	
ARD-730		NAFEC NASA		NAFEC NASA			

Figure 26. Wind Shear/ WVAS Branch (ARD-740) Matrix Structure

- Modify or cancel projects/tasks when appropriate.
- Act as the SRDS central clearing point to approve all major SRDS briefings and releases of information pertaining to the Wind Shear Program.

5.4 Program Coordination

Because of the substantial interest and involvement of many diverse groups in the wind shear problem, close coordination between the Wind Shear/WVAS Branch, ARD-740, and other concerned elements is essential for program success.

The time-critical nature of this program requires a close working relationship with FAA's Flight Standards Service, Air Traffic Service and Airway Facilities Service. This relationship serves to keep the Services informed of program progress and minimize leadtime required for integration of adopted products into the National Airspace System (NAS).

Additional support to ARD-740 will be provided through appropriate planning groups to be established "as needed" to perform certain tasks requiring expertise in specific areas.