NASA/CR-2000-210288

Aviation Weather Information Requirements Study

Byron M. Keel, Charles E. Stancil, Clifford A. Eckert, Susan M. Brown, Gary G. Gimmestad, and Mark A. Richards
Georgia Tech Research Institute, Atlanta, Georgia

June 2000

The NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA STI Help Desk at (301) 621-0134
- Phone the NASA STI Help Desk at (301) 621-0390
- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/CR-2000-210288

Aviation Weather Information Requirements Study

Byron M. Keel, Charles E. Stancil, Clifford A. Eckert, Susan M. Brown,
Gary G. Gimmestad, and Mark A. Richards
Georgia Tech Research Institute, Atlanta, Georgia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under Contract NAS1-99073

June 2000

Available from:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

Contents

1 Study Overview

The White Commission on Aviation Safety and Security, chaired by Vice President Al Gore, issued its final report to President Clinton on February 12, 1997. One of the key recommendations of that report was to reduce the rate of aviation accidents by 80% within the next five years. As a result, the National Aeronautical and Space Administration (NASA) and the Federal Aviation Administration (FAA) have teamed to form the NASA-led Aviation Safety Program (AvSP). The goal of the AvSP is to develop and demonstrate technologies that will contribute to an increase in aviation safety by a factor of 5 in the next 10 years and by a factor of 10 in the next 20 years [1-1]. This increase in safety is to be achieved in parallel with a goal of tripling the aviation system capacity, under all weather conditions, within the next 10 years [1-2]. The first phase of the program will focus on the 10 year goal of increasing aviation safety by a factor of 5. This first phase of the program is designed to take place between fiscal years 2000 and 2004. The AvSP is divided into a number of level 2 programs, as shown in Figure 1-1. Since weather is a factor in 30% of all aviation accidents, a significant portion of the AvSP program is focused on weather-related accident prevention. This level 2 element, entitled "Weather Accident Prevention," is being led by Goddard Research Center (GRC). The goal of this element of the program is to develop enabling technologies which will contribute to a reduction in aviation weather-related accidents. This element of the program contains a number of level 3 projects, one of which is the Aviation Weather Information (AWIN) Distribution and Presentation project led by Mr. Paul Stough at the Langely Research Center (LaRC). This level 3 project is further subdivided into four level 4 tasks: Enhanced Weather Products (ExWP), Data Communication/Link (DCL), Operator Support (O/S), and Systems Engineering (SE). The ExWP task is led by Mr. Phil R. Schaffner at LaRC. The objective of the ExWP task is to "develop new and derivative weather products, complementing existing weather sources with *in situ* and remote sensing capability where necessary, to provide the necessary information at appropriate temporal and spatial resolution for both tactical and strategic decision making for aviation users" [1-3].

In aviation, knowledge of the existing conditions and those forecast along the flight path are critical to operating the aircraft in a manner so as to avoid or mitigate the affects of hazardous atmospheric events. The aviation community relies on weather products prepared by the Federal Aviation Administration (FAA), National Weather Service (NWS), and commercial vendors who add value to NWS products. Under the Enhanced Weather Product task, a study, entitled "Aviation Weather Information Requirements," was defined to investigate present applications of aviation weather information and to develop weather information requirements for operators and weather products. The study was broken into three phases.

In the first phase of the subtask, the current set of aviation weather products were examined and cataloged. An analysis was performed to identify deficiencies in this set of weather products. The second phase of the subtask focused on recommending weather information requirements for each category of user (*e.g.,* Parts 121, 135, and 91) during each phase of flight. Recommendations were made to support both strategic and tactical decisions in the presence of atmospheric hazards. In the third phase of the subtask, sensor technologies (existing, modified, fused, or new) were assessed in terms of their ability to fill the weather information gaps defined in phases I and II.

This report captures the findings of the three phases of the study. The individual phases of the study were originally captured in separate reports. These reports were combined to form this composite report. This report is divided into three major sections each one corresponding to a particular phase of the study. Because the phases did not overlap and the individual reports were written at separate times, the phases may contain some overlapping information or in some cases, the latter two sections may build upon or contain additional information not found in the first section related to the weather products and sensors.

The first phase of the study examined the current set of weather products. The findings were compiled in a database for ease of access and analysis. The present applications of the weather products and their usefulness were examined through a limited survey and interviews with a number of the users and suppliers of aviation related weather information. Through an analysis of the weather products and opinions of current users and suppliers of weather information, deficiencies were identified. The deficiencies identified under this study are described in Section 2.7.

The second phase of the study focused on the defining weather information requirements for each phase of flight in support of both strategic and tactical decision making. The requirement recommendations are given in Section 3.9. The third phase of the study included an assessment of existing sensors that either directly or indirectly support the collection of weather information in support of aviation. Recommendations were given for existing, modified, or new sensors that could help fill in the gaps identified in Sections 2 and 3. These recommendations are given in Section 4.5. Included in phase III of this study was an analysis of potential onboard sensors that could be included in an electronic pilot report (EPIREP). Recommendations for sensors in support of EPIREPS are given in Section 4.6.

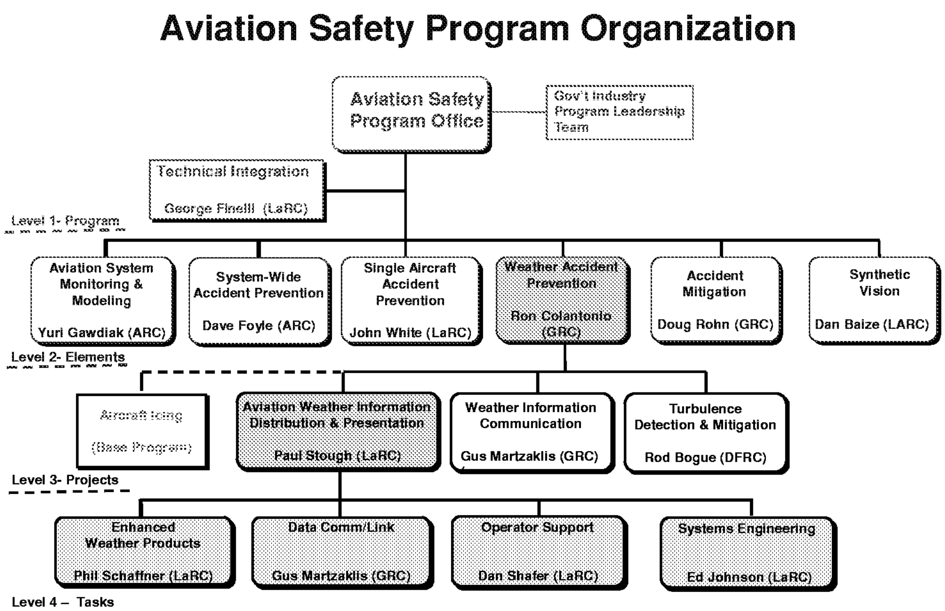


Figure 1-1. An organization chart for the Aviation Safety Program

References

1-1. NASA Aviation Safety Program, Program Plan, Draft Copy, March, 1999

1-2. http://www.aero-space.nasa.gov/goals/iindex.thm

1-3. Aviation Weather Information Distribution and Presentation, Level 3 Plan, NASA LaRC, 1999

2 Aviation Weather Data Product Investigation

2.1 Task Summary

Under the first phase of this study, an analysis of weather products and how they are applied toward aviation safety was performed by the Georgia Tech Research Institute (GTRI). The analysis included a review of relevant documentation, surveys, and one-on-one interviews. Based on this analysis, GTRI has identified four areas where deficiencies exist. The four areas are data format, support systems, sensors, and forecasting and modeling. In the area of data format, the lack of a graphical display capability in the cockpit limits the pilot's ability to consume and interpret weather products as they become available. A low cost graphical display system is needed for Parts 121, 135, and 91 operators. In the area of weather information support systems, an identified deficiency is the shortfall in tailoring weather products to the spatial and temporal needs of the aviation community. For the air traffic control system to function properly, weather information must be distributed in a common format that permits the individual parts of the system to work together.

Weather products are, in most cases, derived from sensor outputs. There are five areas related to the current set of sensors where deficiencies have been identified: lack of availability, lack of confidence, loss of capability, lack of capability, and a need for required tuning to meet the needs of the aviation community. The low number of runway visual range sensors is a major safety concern for some members of the aviation community. There exists a perception that the Low Level Wind Shear Alert System (LLWAS) is associated with a high false alarm rate, resulting in a lack of confidence in the system. There exists the potential loss of the Geostationary Operational Environmental Satellite (GOES) as an asset in detecting volcanic ash after the year 2002. There are a number of atmospheric hazards (*e.g.*, turbulence, in-flight icing, hail, and ceilings/visibility) for which sensor suites have not been developed that can detect and quantify these hazards on a regular basis.

In the area of mesoscale forecasting deficiencies have also been identified. To support the forecasting spatial resolution needs of the aviation community, higher fidelity mesoscale models and closer spaced sensors are required.

2.2 Introduction

This study is funded as a subtask under the AvSP's Enhanced Weather Products (ExWP) task. The focus of the subtask is "to examine present applications for aviation weather information and, from that perspective, to develop weather information requirements for operators and weather products in order to highlight deficiencies and to identify requirements for new or enhanced weather products or sensors. Future work will be directed at developing the necessary weather products, presentations, and sensors to improve aviation safety in accordance with the AvSP goals." The subtask is divided into three phases. In this first phase of the subtask, an investigation of the existing weather products is performed. The investigation identifies current aviation weather products and their attributes (*e.g.*, update rate) and identifies deficiencies associated with the weather products. Weather product information is captured in a database which will a provide tool for further investigation. This report provides an overview of the current set of aviation weather products and how they are applied to impact aviation safety. This report goes on to discuss deficiencies associated with the weather products based on surveys and interviews with users of the products and on analysis of the available data.

2.3 Atmospheric Hazards

Weather impacts aviation in a number of different areas including safety and efficiency/cost. In terms of efficiency, commercial airlines use winds aloft information to their advantage during flight planning to reduce fuel consumption and to provide their passengers with a safer and smoother ride. Weather information is also required by the pilot and/or air traffic control system during all phases of flight to make both strategic and tactical decisions impacting flight safety. The detection of a windshear event during or prior to the arrival and departure phases of a flight is an example of where weather information may directly impact flight safety.

The atmosphere, which provides the aerodynamic forces needed for flight, is an ever-evolving system of complex structures defined over large and small temporal and spatial scales. This complex system is defined by a number of variables (*e.g.*, wind speed and direction, temperature, and phase of water) whose absolute value or relative change temporally or spatially may have a major impact on an aircraft's performance. Without going into an in-depth discussion of the individual hazards and the physics behind their development, this section is intended to give a general overview of some of the more common atmospheric hazards.

The phase and concentration of water molecules in the atmosphere impacts aviation in a number of different ways. Visibility is often limited by clouds, fog, rain, and snow. To the pilot flying under visual flight rules (VFR), ceiling and visibility information is critical in all phases of flight. Even in the case of instrumented flight rules (IFR) certain minimums must exists for safe landing and take-off. Icing can dramatically impact aircraft performance by changing the shape of the aerofoils and by adding additional weight to the aircraft. Large hail represents a dangerous impact hazard to aircraft, which are generally moving at speeds between 100 and 1000 km/hr during the cruise phase of flight. Hail stones may range in size from 5 mm in diameter (pea size) to 60 mm in diameter (tennis ball size). Hail has been known to crack windshields and to damage the surface structures of an aircraft.

Temperature, besides playing a significant role, in combination with other variables (*e.g.*, moisture) in the development of atmospheric hazards, has a direct impact on aircraft safety in the area of fuel capacity and performance. For non-stop trips between continents, the outside temperature at the airport during fueling may impact the fuel storage capacity of the aircraft since fuels tend to expand as the temperature rises. Also, in extreme cases, fuels may gel or freeze in extremely low temperatures.

The movement of air in the atmosphere is both beneficial and hazardous to aircraft performance. Turbulence (random motion) and wind shear (a more systematic motion) are both known to impact aircraft performance. Turbulence may originate from a number of different sources including thunderstorms, strong surface winds, and mountain waves. Clear air turbulence (CAT) is often associated with turbulence at high altitudes and is generally not associated with thunderstorms. CAT is a product of both wind and temperature gradients that result in turbulence at the boundaries between the two air masses. Severe turbulence may damage the structural integrity of an aircraft. To aid other pilots in avoiding CAT, pilots often report turbulence as light, moderate, severe, or extreme via pilot reports (PIREPS). Gust fronts, which are outflows from thunderstorms, may impact aviation safety in the terminal area. These transitory cross-winds may cause an unsuspecting pilot to deviate from his approach or landing causing him to miss the runway.

Wind shear involves a more systematic variation of wind speed and direction both temporally and spatially. Wind shear events include, for example, high winds and microburst. A microburst is a localized downdraft, which may or may not contain a large number of precipitants (dry or wet microburst). As the downdraft encounters the ground, an outflow is developed in all directions. The horizontal and vertical wind components may cause a deflection of the aircraft from its ascent or descent trajectory. At low altitudes, wind shear may cause an aircraft to lose altitude and result in an impact with the ground.

Volcanic ash and lightning are phenomena that also pose a hazard to aviation. Cloud to cloud lightning poses a threat to aircraft since the skin of the aircraft serves as a conductor. Lightning may damage critical digital and analog components. This electrical activity is most often associated with thunderstorms. Volcanic ash is a threat to aviation because it contains glass shards that may damage aircraft engines [2-1].

Aircraft also induce variations in the atmosphere that may impact safety. The angle of attack during take off and landing induces a turbulent flow along the wing tips of the aircraft. This turbulent flow results in horizontally oriented trailing vortices. The vortices pose a problem to smaller, trailing aircraft on landing or take-off from the same or an adjacent runways. The vortex (or horizontal tornado) may cause a smaller aircraft to flip.

Cyclic atmospheric phenomena including tornadoes, hurricanes, and tropical cyclones may also pose a severe threat to aviation. Hurricanes and tropical cyclones represent large scale cyclonic events with strong steady wind fields over large extents. Whereas, tornadoes exhibit extreme winds on a much smaller scale. However, the probability of an aircraft encountering a tornado is rather small.

This section has summarized the significant atmospheric hazards. For a more detailed examination of each of the hazards see [2-2,2-3].

2.4 Aviation System Components

2.4.1 Aircraft Operators

All pilots need the same basic weather information for safe operation. How the aircraft performs in adverse conditions is a function of the type of aircraft, the equipment, and the pilot's training/certification. However, FAA weather information requirements vary depending upon the category of operation: Parts 121, 135, and 91. Similar weather information is needed for each type of operator, but the Federal Aviation Regulation (FAR) requirements differ on how that information is to be obtained. The following paragraphs provide an overview of FAR requirements for weather information by category of operator. However, this study does not go on to define requirements for weather information in terms of category of operator. There is such a significant overlap between categories, in terms of weather information needs for safe flight, that to do so would be redundant. Any exceptions will be stated in the text.

There are various civilian categories of aircraft operators identified by the FAA. Each category has its own set of requirements under the Federal Aviation Regulations. The largest segment of operators falls under the following three categories:

- Part 91 - General Operating and Flight Rules
- Part 135 – Air Taxi Operators and Commercial Operators
- Part 121 – Domestic Commercial Operators

2.4.1.1 Part 91 - General Operating and Flight Rules

The Part 91 segment of civilian aviation constitutes more than half of the domestic operations. In 1996, there were 35.2 million general aviation operations representing almost 60% of all operations. Part 91 flight operations include personal flights, business and corporate flights, training flights and special operations, (*e.g.,* flight-tests, glider towing, parachuting, *etc.*). As a general rule, Part 91 operations do not include flights for compensation or hire. Under Part 91 operations, aircraft types range in complexity, equipage, and sophistication from the smallest single engine aircraft to large commercial jets (operating during maintenance and ferry flights).

Weather information requirements are relatively lenient under Part 91. FAR 91.103 states, "Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight. This information must include--For a flight under IFR or a flight not in the vicinity of an airport, **weather reports and forecasts**, fuel requirements, alternatives available if the planned flight cannot be completed, and any known traffic delays of which the pilot in command has been advised by air traffic control (ATC)…other reliable information appropriate to the aircraft, relating to aircraft performance under expected values of airport elevation and runway slope, aircraft gross weight, and **wind** and **temperature**" [emphasis added].

The FAR does not state what types of weather reports or forecasts are required or information about their timeliness. Since the FARs are not specific on how weather information is to be obtained, many Part 91 pilots obtain weather information from TV, radio, and the Internet.

2.4.1.2 Part 135 – Air Taxi Operators and Commercial Operators

Part 135 operations represent the smallest of the three segments with approximately 17% of all operations in 1996. From a regulatory perspective, it is a step up from Part 91 operations.

Generally, Part 135 operations include:

- Commuter (scheduled passenger-carrying operations in airplanes that have passenger-seating configurations of less than 10) or on-demand (charter) operations, and

- Nonstop sightseeing flights for compensation or hire that begin and end at the same airport, and are conducted within a 25 statute mile radius of that airport [2-4].

Aircraft operating under Part 135 are generally more sophisticated than many Part 91 operated aircraft and are required to have certain communication and navigation equipment, flight instruments, electrical power generating sources, and approved thunderstorm detection equipment or approved airborne weather radar equipment. Under Part 135 operations, there are also extensive administrative, maintenance, and flight crew requirements.

Weather requirements under Part 135 are more stringent than Part 91. FAR 135.213 states: "Whenever a person operating an aircraft under this part is required to use a weather report or forecast, that person shall use that of the **U.S. National Weather Service, a source approved by the U.S. National Weather Service, or a source approved by the Administrator**. However, for operations under VFR, the pilot in command may, if such a report is not available, use weather information based on that pilot's own observations or on those of other persons competent to supply appropriate observations…weather observations made and furnished to pilots to conduct IFR operations at an airport must be taken at the airport where those IFR operations are conducted, unless the Administrator issues operations specifications allowing the use of weather observations taken at a location not at the airport where the IFR operations are conducted" [emphasis added].

2.4.1.3 Part 121 – Domestic Commercial Operators

Part 121 operations are the second largest segment of operations with approximately 23% of operations in 1996. Part 121 operations include:

- Passenger and cargo domestic, flag (international), and supplemental operations (*e.g.*, operating aircraft with 10 or more seats or more than 7,500 pounds payload capacity), and
- Nonstop sightseeing flights conducted with airplanes having a passenger-seat configuration of 30 seats or fewer and a maximum payload capacity of 7,500 pounds or less that begin and end at the same airport, and are conducted within a 25 statute mile radius of that airport [2-4].

Part 121 operating requirements are more rigorous than Part 135 operations with extensive requirements related to route approvals, operating limitations, instrument and equipment requirements, maintenance, preventive maintenance and alterations, airman and crew member requirements, training, dispatcher functions, records, and reports.

Part 121 operators conducting domestic or flag operations must have sufficient dispatch centers located at points necessary to ensure proper operational control of each flight.

Weather service requirements under Part 121 are extensive. FAR 121.101 states in part: "domestic or flag operations must show that enough weather reporting services are available along each route to ensure weather reports and forecasts necessary for the operation. (b) Except as provided in paragraph (d) of this section, no certificate holder conducting domestic or flag operations may use any weather report to control flight unless--

(1) For operations within the 48 contiguous States and the District of Columbia, it was prepared by the **U.S. National Weather Service or a source approved by the U.S. National Weather Service**; or

(2) For operations conducted outside the 48 contiguous States and the District of Columbia, it was prepared by **a source approved by the Administrator**.

(c) *Each certificate holder conducting domestic or flag operations that uses forecasts to control flight movements shall use forecasts prepared from weather reports specified in paragraph (b) of this section and from any source approved under its system adopted pursuant to paragraph (d) of this section.*

(d) *Each certificate holder conducting domestic or flag operations shall adopt and put into use* ***an approved system for obtaining forecasts and reports of adverse weather phenomena****, such as clear air turbulence, thunderstorms, and low altitude wind shear, that may affect safety of flight on each route to be flown and at each airport to be used."*

FARs further specify weather reporting information be required at all airports used by Part 121 operators. This includes runway visual range information and prevailing wind information under low visibility conditions. Part 121 airline operation centers may be supported by FAA certified enhanced weather information systems (EWINS) (see Appendix A). In addition, dispatchers may be FAA certified as having flight movement forecast (FMF) authority. For additional information on Part 135 and Part 121 weather information requirements, see Appendix B.

2.4.2 Aviation Weather Information Support System

2.4.2.1 Federal Aviation Administration

The current system which provides weather information to the aviation community is a partnership between the FAA and the National Oceanic and Atmospheric Administration (NOAA). The FAA-administered national air traffic control system's central office is located in Herndon, Virginia. This facility manages the nation's airspace in an effort to maximize efficiency and safety. Since weather plays a major role in aviation safety, the center employs weather unit specialists who provide weather information updates to aid in local and national traffic management flow and safety.

An aircraft's flight phases can be grouped into two general categories: en route and terminal area. The national air traffic control system has been designed to support the specific needs of these two phases of flight. The air route traffic control centers (ARTCC) provide air space management to aircraft operating under IFR flight plans. The ARTCC are nominally assigned 150 nautical mile jurisdictions. A center weather service unit (CWSU), composed of both NWS meteorologists and FAA support personnel, is associated with each of the ARTCCs. The weather service units provide up-to-date weather information based on analysis of weather products obtained from a number of different sources.

The terminal area is managed by the airport traffic control tower (ATCT). Weather information is provided to the tower from a number of sources. In turn, the tower serves as one potential source of weather information for arriving and departing aircraft. At some airports, an automated system is in place to provide up-to-date weather information to arriving and departing pilots. This automated system is termed the automatic terminal information service (ATIS). ATIS provides weather information as well as other pertinent information related to the airport's operation.

Another component of the FAA weather information support system is the FAA Flight Service Stations (FSSs) and the Automated Flight Service Stations (AFSSs) which serve as the primary providers of flight information services throughout the U.S. Although both types of stations serve the same purpose, AFSSs serve a broader area, usually an entire state, and are equipped with more advanced electronic services to allow for more efficient planning of weather and flight information. FSSs and AFSSs provide pilots with pre-flight weather briefings, flight planning assistance, weather and en route flight information, and airport terminal advisory services.

In an effort to modernize the FAA's weather processing system, the FAA is sponsoring the Weather and Radar Processing (WARP) program. WARP is being developed by Harris Corp. with development slated for completion in June 2000. The new system will ingest weather information from a number of sources (including radar, lightning detection, satellites, gridded forecast) and process and analyze the data for dissemination to air traffic controllers and managers [2-5].

2.4.2.2 National Oceanic and Atmospheric Administration

The National Weather Service, under the National Oceanic and Atmospheric Administration (NOAA), measures, analyzes, forecasts, and distributes weather information to the different FAA centers and to pilots as official FAA approved weather products. The NWS is organized into a number of offices and centers which serve the meteorological and hydrological needs of the nation. In this report, the discussion will be limited to those parts of the NWS that provide direct information to the aviation community. The NWS contains nine National Centers for Environmental Prediction (NCEP). The nine centers are listed in Table 2-1. The last four centers in Table 2-1 (highlighted in bold) provide services to the aviation community.

Table 2-1. A Listing of the Different Centers Associated with the NCEP

National Centers for Environmental Prediction
Climate Prediction Center
Space Environment Center
Marine Prediction Center
Hydrologic Prediction Center
Environmental Modeling Center
National Center Operations
Storm Prediction Center
Aviation Weather Center
Tropical Prediction Center

Table 2-2 contains a summary of some of the products [2-3] the centers provide. Another agency under NOAA that provides weather information to the aviation community is the National Environmental Satellite, Data, and Information Service (NESDIS). NESDIS provides satellite images of the atmosphere, which are used in modeling and forecasting. The main research arm of NOAA is the office of Oceanic and Atmospheric Research (OAR). This office is further divided into a number of laboratories including the Environmental Research Laboratory, which houses the National Severe Storms Laboratory and the Forecast Systems Labs.

The National Centers for Environmental Prediction supports several mesoscale models. A few of the current and future models are described here. The Eta-32 model produces 48 hour forecast twice a day at 0000 and 1200 UTC, a 33 hour forecast at 0300 UTC, and a 30 hour forecast at 1800 UTC [2-6]. In support of shorter range forecast, the NCEP supports the Rapid Update Cycle (version 2) (RUC-2) model. The RUC forecasts are unique in that they are initialized with very recent data. The RUC-2 produces updated forecast every hour [2-7]. A third mesoscale model that has found acceptance in the modeling community is the fifth-generation National Center for Atmospheric Research (NCAR)/Penn State Mesoscale Model (MM5). This mesoscale model is a limited-area, nonhydrostatic or hydrostatic terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation [2-8]. The NCEP is also currently overseeing the development of the next generation in mesoscale modeling termed the Weather Research and Forecast (WRF) model. This collaborative effort is scheduled to produce a product by the end of 2003. The model will provide a common tool for both research and operations [2-9].

Table 2-2. A Cursory Overview of the Aviation Specific Weather Products Provided by the NWS

NWS Products Supporting Aviation	
Provider	**Weather Product**
National Center Operations (Washington, DC)	1. Serves as focal center for the nations weather processing 2. Measures winds and temperatures aloft
Storms Prediction Center (Norman, Oklahoma)	1. Generates convective outlooks and forecast 2. Issues severe weather watches
Aviation Weather Center (Kansas City, Missouri)	1. Identifies hazardous weather to aircraft and issues warnings 2. Produces 48 hour operational forecast 3. Prepares and issues aviation area forecasts 4. Prepares and issues in-flight aviation weather advisories
Tropical Prediction Center (Miami, Florida)	1. Issues hurricane advisories
NWS Weather Forecast Office (Regional)	1. Provides route forecast 2. Provides terminal area forecasts

The NWS also has Weather Forecast Offices (WFO) located in each state. The NWS WFO provides up-to-date information on weather in its assigned region. The NWS WFOs also provide route forecast and terminal area forecast.

2.5 A Review of Weather Products and Delivery Systems

This section of the report summarizes the major weather products and gives the reader an overview of the major delivery systems. In this report, weather products are defined as information (measured data, processed data, forecasts) that have been packaged for interpretation by the recipient to aid in making both strategic and tactical decisions affecting aviation safety. Where as, delivery systems are defined as the communications paths over which weather products are delivered to the user.

2.5.1 Summary of Aviation Weather Products

The intent of this section of the report is to give the reader a summary overview of the major weather products and to illustrate how weather products are designed to address the specific phases of flight and to address specific coverage areas. The weather product information was captured in a database for ease of retrieval and analysis. Table 2-3 contains a listing and brief description of 23 of the 45 weather products contained in the database. A more detailed description of each of the weather products can be found in Appendix C.

Table 2-4 contains information, extracted from the database, on 23 of the weather products. The example query provides weather product source, coverage area, update rate, and product life information. Table 2-5 has been color coded to illustrate how different weather products have been tailored to specific portions of the flight phase. Note that the METAR, SPECI, TAF, TDWR, LLWAS, and WSP are all localized measurements or forecast for the terminal area. For the en route phase of flight, weather products may provide information on atmospheric events that are affecting a very large area or the weather product may address events on a much smaller scale or along a specific route. For example, the AIRMETs and SIGMETs are inflight advisories provided by the Aviation Weather Center which warn

Table 2-3. A Summary of some of the Weather Products Contained in the Database

Weather Product	Description
Aviation Routine Weather Report (METAR)	A METAR contains information on surface conditions at the airport.
Aviation Selected Special Weather Report (SPECI)	A SPECI is an unscheduled METAR warranted by degrading weather conditions.
Terminal Area Forecast (or Aerodrome Forecast) (TAF)	A forecast prepared by the NWS for an airport
Area Forecasts (FA)	An area forecast is issued by the AWC and contains information on cloud cover (visual meteorological conditions) and general weather conditions for six regions in the U.S.
Airman's Meteorological Advisory (AIRMET)	An advisory issued by the AWC to warn of atmospheric conditions that may be hazardous to the pilots flying VFR, or light or single engines planes. The AIRMET advisory is divided into three categories: - Sierra – issued concerning ceiling and visibility - Tango – issued concerning moderate turbulence and surface winds - Zulu – issued concerning moderate icing and freezing levels
Domestic Significant Meteorological Information (Domestic SIGMET)	Domestic SIGMETs are issued by the AWC to alert all user categories of conditions that may be hazardous to flight. The domestic SIGMET does not contain information related to events associated with convective activity.
Convective Significant Meteorological Information (Convective SIGMET)	Convective SIGMETs are issued by the AWC to alert pilots of convective activity that may be hazardous to all categories of pilots.
International Significant Meteorological Information (International SIGMET)	International SIGMETs are issued by NWS Meteorological Watch Offices (MWO) and contain information on atmospheric hazardous that may impact international flights en route along the coastal areas of the U.S.
Low Level Significant Weather Charts (LLSWC)	LLSWC are charts provide by the NWS to aid in the VFR briefing. The charts contain information on freezing levels, turbulence, ceilings, fronts, and precipitation.
High Level Significant Weather Charts (HLSWC)	The high level significant weather charts are designed to provide forecasts during the en route phase of international flights. These charts contain information on thunderstorms, tropical cyclones, squall lines, turbulence, icing, sand and dust storms, convergence zones, surface fronts, jet streams, and volcanic eruptions.
Winds and Temperatures Aloft (WA and TA)	The NCEP provides winds and temperature aloft information at 9 discrete elevations (3,000, 6,000, 9,000, 12,000, 18,000, 24,000, 30,000, 34,000, and 39,000 feet).
Route Forecast (RF)	Route forecasts are issued by the NWS forecast offices for some 300 selected routes over the continental U.S.

Table 2-3. A Summary of some of the Weather Products Contained in the Database

Weather Product	Description
Meteorological Impact Statement (MIS)	The meteorological impact statement (MIS) is issued by the CWSU at the ATRCC to provide unscheduled weather information to aid in flow control, flight operations, and planning. The forecasts are targeted at events that will initiate beyond a 2 hour window not to exceed 12 hours after the MIS is issued.
Center Weather Advisory (CWA)	Center weather advisories are issued by the CWSU at the ATRCCs. CWA are nowcasts that aid flight crews in avoiding hazardous conditions en route and in the terminal area.
Severe Weather Watch (WW)	Severe Weather Watches (WW), which are unscheduled, are issued by the Storms Prediction Center in Norman, Oklahoma. The severe weather watches define areas with possible severe storm or tornadic activity.
Pilot Reports (PIREPS)	Pilot reports (PIREPs) are direct observations of the atmosphere by either instruments on board the aircraft (*e.g.*, temperature probes) or by the pilot.
Satellite Imagery (SI)	Satellites provide visible and infrared images that can be analyzed to estimate the type of cloud, the temperate of the cloud (which can be related to cloud height), the thickness of the cloud layers.
Radiosonde Additional Data (RAD)	Radiosonde provide information on freezing levels and relative humidity.
Convective Outlook	Convective outlooks are issued by the Storm Prediction Center in Norman, Oklahoma. The convective looks are a two-day forecast of severe and non-severe thunderstorms across the country.
Next Generation Weather Surveillance Radar (NEXRAD)	The national weather service provides some 18 products dealing with precipitation and velocity estimates that are generated by the NWS WSR-88D radars (or Next Generation Weather Surveillance Radars (NEXRAD)).
Terminal Doppler Weather Radar (TDWR)	The Terminal Doppler Weather Radars (TDWR) are installed at 36 major airports through the country to aid in the detection of wind shear (microburst), gusts, and heavy precipitation in the terminal area.
Low Level Wind Shear Alert System (LLWAS)	The Low Level Wind Shear Alert System (LLWAS) is a relatively inexpensive systems of anemometers to detect the presence of wind shear and microburst in the terminal area.
Weather Systems Processor (WSP)	The Weather Systems Processor (WSP) detects the presence of wind shear and microburst in the terminal area. The WSP taps data for the existing airport surveillance radars (ASR-9).

Table 2-4. A Summary of some of the Weather Products Contained in the Database

Weather Product	Description
Aviation Routine Weather Report (METAR)	A METAR contains information on surface conditions at the airport.
Aviation Selected Special Weather Report (SPECI)	A SPECI is an unscheduled METAR warranted by degrading weather conditions.
Terminal Area Forecast (or Aerodrome Forecast) (TAF)	A forecast prepared by the NWS for an airport
Area Forecasts (FA)	An area forecast is issued by the AWC and contains information on cloud cover (visual meteorological conditions) and general weather conditions for six regions in the U.S.
Airman's Meteorological Advisory (AIRMET)	An advisory issued by the AWC to warn of atmospheric conditions that may be hazardous to the pilots flying VFR, or light or single engines planes. The AIRMET advisory is divided into three categories: - Sierra – issued concerning ceiling and visibility - Tango – issued concerning moderate turbulence and surface winds - Zulu – issued concerning moderate icing and freezing levels
Domestic Significant Meteorological Information (Domestic SIGMET)	Domestic SIGMETs are issued by the AWC to alert all user categories of conditions that may be hazardous to flight. The domestic SIGMET does not contain information related to events associated with convective activity.
Convective Significant Meteorological Information (Convective SIGMET)	Convective SIGMETs are issued by the AWC to alert pilots of convective activity that may be hazardous to all categories of pilots.
International Significant Meteorological Information (International SIGMET)	International SIGMETs are issued by NWS Meteorological Watch Offices (WMO) and contain information on atmospheric hazardous that may impact international flights en route along the coastal areas of the United States.
Low Level Significant Weather Charts (LLSWC)	LLSWC are charts provide by the NWS to aid in the VFR briefing. The charts contain information on freezing levels, turbulence, ceilings, fronts, and precipitation.
High Level Significant Weather Charts (HLSWC)	The high level significant weather charts are designed to provide forecasts during the en route phase of international flights. These charts contain information on thunderstorms, tropical cyclones, squall lines, turbulence, icing, sand and dust storms, convergence zones, surface fronts, jet streams, and volcanic eruptions.
Winds and Temperatures Aloft (WA and TA)	The NCEP provides winds and temperature aloft information at 9 discrete elevations (3,000, 6,000, 9,000, 12,000, 18,000, 24,000, 30,000, 34,000, and 39,000 feet).
Route Forecast (RF)	Route forecasts are issued by the NWS forecast offices for some 300 selected routes over the continental U.S.

Table 2-4. A Summary of some of the Weather Products Contained in the Database

Weather Product	Description
Meteorological Impact Statement (MIS)	The meteorological impact statement (MIS) is issued by the CWSU at the ATRCC to provide unscheduled weather information to aid in flow control, flight operations, and planning. The forecasts are targeted at events that will initiate beyond a 2 hour window not to exceed 12 hours after the MIS is issued.
Center Weather Advisory (CWA)	Center weather advisories are issued by the CWSU at the ATRCCs. CWA are nowcast that aid flight crews in avoiding hazardous conditions en route and in the terminal area.
Severe Weather Watch (WW)	Severe Weather Watches (WW), which are unscheduled, are issued by the Storms Prediction Center in Norman, Oklahoma. The severe weather watches define areas with possible severe storm or tornadic activity.
Pilot Reports (PIREPS)	Pilot reports (PIREP) are direct observations of the atmosphere by either instruments on board the aircraft (*e.g.*, temperature probes) or by the pilot.
Satellite Imagery (SI)	Satellites provide visible and infrared images that can be analyzed to estimate the type of cloud, the temperate of the cloud (which can be related to cloud height) , the thickness of the cloud layers.
Radiosonde Additional Data (RAD)	Radiosonde provide information on freezing levels and relative humidity.
Convective Outlook	Convective outlooks are issued by the Storm Prediction Center in Norman, Oklahoma. The convective looks are a two-day forecast of severe and non-severe thunderstorms across the country.
Next Generation Weather Surveillance Radar (NEXRAD)	The national weather service provides some 18 products dealing with precipitation and velocity estimates that are generated by the NWS WSR-88D radars (or Next Generation Weather Surveillance Radars (NEXRAD)).
Terminal Doppler Weather Radar (TDWR)	The Terminal Doppler Weather Radars (TDWR) are installed at 36 major airports through the country to aid in the detection of wind shear (microburst), gusts, and heavy precipitation in the terminal area.
Low Level Wind Shear Alert System (LLWAS)	The Low Level Wind Shear Alert System (LLWAS) is a relatively inexpensive systems of anemometers to detect the presence of wind shear and microburst in the terminal area.
Weather Systems Processor (WSP)	The Weather Systems Processor (WSP) detects the presence of wind shear and microburst in the terminal area. The WSP taps data for the existing airport surveillance radars (ASR-9).

Table 2-5. Weather Product Attributes Extracted from the Database

Weather Produce	Source	Coverage Area	Update Rate	Product Life
METAR	ASOS, AWOS, HO	Terminal	1 hour	1 hour
SPECI	ASOS, AWOS, HO	Terminal	As conditions warrant	< 1 hour
TAF	NWS WFO	Terminal	4 hours	24 hours
FA	AWC	6 regions	8 hours	12 hours
AIRMET – Sierra	AWC	3000 square miles	6 hours	6 hours
AIRMET – Zulu	AWC	3000 square miles	6 hours	6 hours
AIRMET – Tango	AWC	3000 square miles	6 hours	6 hours
SIGMET – Domestic	AWC	3000 square miles	As conditions warrant	4 hours
SIGMET – Convective	AWC	3 Regions (E, C, W)	1 hour	2 hours
SIGMET – International	NWS WMO	3000 square miles	As conditions warrant	4 hours
LLSWC	NWS	U.S. region	4 times per day	12 to 24 hours
HLSWC	NWS	U.S. region	4 times per day	6 hours
Winds and Temperatures Aloft	NCEP	U.S. region	12 hours	6 l 12 l 24 hours
Route Forecast	NWS WFO	Route specific	3 times per day	15 hours
MIS	CWSU	Regional	As conditions warrant	12 hours
CWA	CWSU	Regional	As conditions warrant	2 hours
WW	SPC	Variable	As conditions warrant	
PIREPS	Pilots	Localized	As conditions warrant	variable
Satellite Imagery	GOES/NOAA	National	15 min – 1 hour	
Radiosonde	NWS	National	12 hours	current conditions
Convective Outlook	SPC	National	5 l 2 times per day	24 l 48 hours
NEXRAD	NWS	~200 mile radius	6 – 12 minutes	now cast
TDWR	FAA/NWS	Terminal	As conditions warrant	now cast
LLWAS	FAA/NWS	Terminal	As conditions warrant	now cast
WSP	FAA/NWS	Terminal	As conditions warrant	now cast

pilots of hazardous conditions that are affecting or will be affecting an area of at least 3,000 square miles at any one instant in time. Route forecasts, issued by the NWS WFOs, provide pilots forecast information for more than 200 specific routes over the contiguous United States. Weather products also are designed to provide the pilots with information that is very location specific. For example, pilot reports (PIREPS) are issued by pilots who have experienced adverse weather conditions in flight. This information provides other pilots with a snap shot of potential adverse conditions that may lie along his route.

2.5.2 Sensors

Sensors provide the means of measuring a property of the atmosphere either remotely or *in situ*. In this report, sensor outputs are considered, in most cases, weather products. A complete analysis of sensor systems is given in Section 4 of this report.

2.5.3 Delivery Systems

Pilots rely on a number of different delivery systems to receive weather and flight information during the en route and terminal phases of flight.

In the terminal area, pilots may receive weather and forecast information from a number of different sources. The Automated Weather Observing System (AWOS) and Automated Surface Observation System (ASOS) broadcast local weather information directly to pilots via discrete very high frequency (VHF) transmissions or as the voice portion of a local navigational aid (NAVAID). The Automatic Terminal Information Service (ATIS) is a continuous broadcast of recorded weather and runway conditions of importance to arriving and departing aircraft. ATIS is also broadcast over discrete VHF radio channels or the voice portion of a local NAVAID. The Aircraft Communications Addressing and Reporting System (ACARS) is a VHF air/ground datalink that relays weather information to the cockpit in a digital format. Both Terminal Weather Information for Pilots (TWIP) and the Digital Automated Terminal Information Service (D-ATIS) are available through ACARS.

In the domestic en route flight phase, pilots have direct access to weather information and flight planning assistance via Flight Service Stations (FSSs) and Automated Flight Service Stations (AFSS). If available, an En Route Flight Advisory Service (EFAS) (Flight Watch) provides weather updates and advisories by providing pilots direct access to weather specialists. FSSs, AFSSs and EFASs all transmit data directly over VHF radio. For short or local flights, pilots can use the Transcribed Weather Broadcast (TWEB), which provides continuous, up-to-date, recorded weather information. Pilots can also receive or request weather information directly from their operation centers over VHF radio through ACARS. Air Route Traffic Control Centers (ARTCCs) are capable of direct communications with IFR air traffic on specific frequencies. If hazardous weather conditions develop, pilots will be advised to tune into the Hazardous In-Flight Weather Advisory Service (HIWAS) for a continuous broadcast of recorded in-flight weather advisories. For oceanic flights, pilots can receive updated weather information via ACARS. The Lockheed Martin report [2-10] provides additional incites into the current set of delivery systems.

The main conclusion of this discussion is that a number of systems have been developed to provide pilots with the latest weather information. However, the majority of these systems require the pilot to manually request information. In some cases, the pilot may not know what information to request since conditions may have changed considerably since initiating flight. For all of the delivery systems, except ACARS, voice is the only means of receiving information during flight. For the high-end aircraft, ACARS provides the capability to support both text and voice.

At the time of this reporting, the FAA seems to be moving in a direction that will support information presentation to the pilot in a graphical format, making it easier to interpret and making possible additional information to aid the pilot in making both strategic and tactical decisions. The FAA has agreed to establish a partnership with industry to make available to the general aviation community Flight Information Services via Data Link. The FAA/Industry partnership includes NavRadio Corp. and ARNAV Systems Inc. This system will allow pilots to display both text and graphical weather information. Full national deployment is scheduled for the year 2000 [2-11].

2.6 Database Development and User Feedback

GTRI used two information sources, user surveys and visits, to investigate how weather products are applied in the aviation community. Due to time and resource constraints, the number of surveys and visits was limited to a small sampling of the cross section of the user community.

2.6.1 Survey

GTRI developed a survey (see Appendix D) containing questions that focused on user operational parameters, weather product utilization as a function of the phase of flight, and user opinion of weather product attributes (*e.g.*, utilization, accuracy, constraints, utility, and price). Results from these surveys provided insights into how, when, and where weather products are used as well as how the aviation community perceives these weather products.

Table 2-6 indicates to whom the surveys were sent and the role of the respondent under each of the FAR categories. Multiple entries in the table indicate more than one respondent from a given company. Three of the surveys were not returned as noted in Table 2-6. The results of the surveys were recorded in a relational database for both current and future analysis. For example, a rank ordering of the most frequently used weather products by flight phase is shown in Table 2-7. This type of information can easily be extracted from the database to aid in current and future analysis.

2.6.2 Weather Product Database

2.6.2.1 Overview

A Weather Product Database was developed as a requirement under this subtask for the purpose of compiling information about current information products and sources in a format that provided ready access to the information. Guidelines for the database were specific in that the database should include information about the weather information source, the route from origin to user, the method of application, related economics, the extent of use, latency, adequacy, criticality, information format, displays, availability, and required hardware and software. Weather information was also to be categorized by user type (*e.g.*, Part 91, Part 135, Part 121, AOC, ATC, etc.)

GTRI chose to implement the database using Microsoft Access ("Access"), a relational database application, for two primary reasons. First, a relational database has the ability to integrate or link data from various data tables by using common attributes (columns of information). Thus the information in one table may be related to the information in another. Relational databases also help eliminate redundant information, reduce storage retirements, and heighten data integrity and consistency. Second, Access is a widely used, user friendly database application that will allow users to develop tables, forms, reports, and queries without requiring programming skills.

Table 2-6. A List of Survey Participants

	user_name	Role	FAR Part	Comments
1	Tri-Star	Pilot	135	
2	Epps Aviation (Charter)	Pilot	135	
3	Epps Aviation (Charter)	Pilot	135	
4	United Parcel Service	Pilot	121	
5	United Parcel Service	Dispatcher	121	
6	United Parcel Service	Meteorologist	121	
7	United Parcel Service	Meteorologist	121	
8	United Parcel Service	Meteorologist	121	
9	Southern Company	Pilot	91	
10	Southern Company	Pilot	91	
11	Southern Company	Pilot	91	
12	Southern Company	Pilot	91	
13	Delta Airlines	Dispatcher	121	
14	Delta Airlines	Dispatcher	121	
15	Delta Airlines	Dispatcher	121	
16	Northern Air Cargo (Alaska)	Pilot	121	survey not received
17	Northern Air Cargo (Alaska)	Pilot	121	survey not received
18	Northern Air Cargo (Alaska)	Pilot	121	survey not received

Table 2-7. Frequency of Weather Product Use by Phases of Flight

Flight Phase	Weather Product (Most Frequent)
Preflight Planning	TAF, Winds Aloft, METAR
Taxi Out and Takeoff	ATIS
Departure Operations	Weather Radar (Airborne)
Initial Climb	Weather Radar (Airborne)
Cruise	Winds Aloft, Weather Radar (Airborne)
Approach Operations	ATIS, Weather Radar (Airborne)
Landing Operations	Weather Radar (Airborne)
Taxi In and Park	ATIS
Alternate Airport Operations	METAR, TAF

There are three primary purposes for the database:

(1) The database will allow users to easily access information about the various weather products and the characteristics of the weather products. Once the data are entered, questions can be asked of the weather products by using queries into the various tables.

(2) The data obtained from the surveys provides insight into who, what, when, and where weather products are used. While the survey data are not a true statistical sampling of weather product users, the survey respondents do represent a meaningful segment of users and provide a realistic view of how weather products are used and the perceived value of the weather products.

(3) The database can be used as a tool for determining weather requirements and deficiencies. By linking the survey tables to the weather product and weather element tables, the database can provide insightful information. For example, time constraints faced by the different pilot and aircraft categories can be uncovered by querying weather products by weather element, product information, duration, and frequency.

The database was populated with data obtained from the surveys and from sources listed in the reference section of this report. The survey participants are described in Table 2-6.

2.6.2.2 Future Capabilities

The Weather Products Database is capable of providing more than just summary and detail information queries. With additional development, algorithms can be built and incorporated into queries that when linked to the various tables could be used for scenario or "what if" analysis. For example, an algorithm that incorporates the temporal and spatial coverage of the various weather products and then links them to a flight scenario reflecting a given type of aircraft, time of day, and weather condition could reveal where the weather product has limitations, deficiencies, or is more than adequate under the scenario.

Also, additional weather element attributes or characteristics could be developed for the weather element table that would make the database more useful. For example, by adding intensity levels, hazard ranges, and concentration levels as weather element attributes, the database would reveal associations between weather element characteristics, flight phases, aircraft classes, and weather products. Additional features of the database could also include a more comprehensive definition of the weather products and links to selected Internet sites that provide additional weather product information.

2.6.3 User Inputs

GTRI made four formal visits and conducted one phone call interview as a part of the survey process. Table 2-8 lists the operators that were visited. Results from these interviews are summarized in the following sections.

Table 2-8. Companies that Participated in Formal Interviews

Operator	Department
FAA Southeast Region	Terminal Radar Approach Control (TRACON)
Delta Airline Systems	Operations Control Center
FAA Headquarters	FIS Project Office
National Weather Service	Peachtree City NWC
United Parcel Service	Flight Operations

2.6.3.1 United Parcel Service (UPS)

GTRI selected two 121 Part operators to interview on a more formal basis (face-to-face interviews with key operations personnel) in addition to the informal weather product surveys sent to the two companies. UPS was selected because of its status as the world's largest package distribution company. UPS has 224 jet aircraft in its fleet and charters another 302 aircraft. UPS flies 995 domestic segments and 559 international segments on a daily basis into 391 domestic airports and 219 international airports. In support of its operations, UPS maintains a well equipped and staffed meteorological department at its aviation headquarters in Louisville, Kentucky. GTRI's point of contact at UPS is Randy Baker, Chief Meteorologist for Flight Operations.

The purpose of the interview was to gather information from UPS on how they applied weather information in regard to safety and day to day operations (cost/efficiency). The following is a summary of those discussions. UPS also provided additional information in their response to the survey. This information in partially captured in the text and the full content of the survey response is captured in the database.

In the interview, UPS was asked to elaborate on which components of the aviation weather information system (dissemination, sensors, weather products) needed improvement. UPS's response can be grouped into two main areas: sensor capabilities/support and weather product dissemination/ availability.

For UPS, the reduction in the number of runway visual range (RVR) sensors providing real-time updates across the country has had an impact on their operations in terms of both safety and economics. Besides providing a tactical sensor on approach, RVR trend monitoring permits one to predict changing conditions at an airport. This type of information allows the pilot to make an informed decision about changing conditions at the destination and alternate airports. UPS's perception of a reduction in RVR support needs to be investigated further.

UPS also noted that the Low Level Wind Shear Alert System (LLWAS) is reported to have a high false alarm rate. This high false alarm rate may reduce pilot confidence in the system, resulting in "go" decisions when conditions are marginal. LLWAS is a relatively inexpensive system of anemometers, positioned around the terminal area, that are integrated as a system to provide microburst, gust front, and windshear information. Over a hundred airports were equipped with the original system during the 1977-1987 time frame. A LLWAS enhanced network (LLWAS-NE) is being developed that will be deployed at 39 airports across the country [2-3]. Gleim [2-3] notes that the original LLWAS will eventually be phased out at the remaining 61 airports. In addition to the problem of a high false alarm rate, LLWAS is a surface level sensor, which does not provide information needed to characterize conditions along the glide slope. The terminal Doppler weather radar (TDWR) was developed to aid in the characterization of higher level winds in the terminal area. UPS's comment needs to be investigated in light of the advances of the LLWAS-NE and the potential reduction in the number of LLWAS sites.

UPS is also concerned with the potential lack of a satellite to detect the presence of volcanic ash. The perceived situation, by UPS (and Delta), is that the existing GOES asset used to detect volcanic ash will not be available after the year 2002. This is a perceived gap that needs to be investigated further. The duration of this study did not permit GTRI to validate this assertion, but two sources (Delta and UPS) seem to confirm that it is a potential issue and one that has the aviation community concerned.

UPS meteorologists have also identified the need for a water vapor sensor to predict icing and fog conditions. Water vapor is a key variable in attempting to define a number of weather conditions, including: ceiling and visibility, turbulence, icing, thunderstorms, precipitant type and amount. UPS is involved in a joint program with NOAA and American Airlines to investigate the use of an airborne water vapor sensor to provide real-time data collection. The current developmental system provides real-time display of water vapor, temperature, and wind information as it is being collected. The display is available on a limited access internet site. The airborne system would provide a finer sampling of the atmosphere than the current system of radiosonde. Water vapor data are used in conjunction with winds and temperature information as an input to mesoscale models (*e.g.*, the rapid update cycle (RUC) model) to predict atmospheric conditions on both a large and small scale. The quality of the forecast is a function of both the model fidelity and the quality of the data input to the model. Incorporation of sensors on aircraft in conjunction with radiosonde and additional ground based sensors (*e.g.*, wind profilers and Differential Absorption Lidar (DIAL) water vapor profiles) would lead the way to improved forecasting on the scale required for aviation. Mesoscale modeling and sensor capabilities and spacings need to be investigated in terms of their potential impact on aviation safety.

Prediction of icing conditions is another area of major concern for both UPS and Delta. Icing impacts both safety and operations (cost/efficiency). The predicted level of icing will determine what procedures a company will follow to prevent ice buildup (*e.g.*, type of de-icing solvent). Delays and costs due to icing can impact the parallel goal of increasing the aviation system capacity while improving safety. UPS considers this as an area where more can be done to improve safety and efficiency.

Pilot reports (PIREPS) are an integral part of UPS's flight planning and hazardous weather avoidance system. PIREPS are a very useful aviation safety tool (*e.g.*, notification of unforecasted severe turbulence in an area). UPS collects PIREPS from their pilots on a regular basis. However, UPS perceives a reduction in the number of reports and a lack of dissemination of PIREPS between Part 121 operators. Delta also employs pilot reports on a regular basis. The movement toward electronic PIREPS (EPIREPS) will help in increasing the number of reports and the quality of the information. In parallel with defining sensors for EPIREPS, dissemination networks, with sufficient bandwidth, need to be identified to support the increased amount of information to be down linked and distributed to user community.

UPS made the statement that it would like to see new products or those under development be made available to all members of the aviation community as soon as possible. In particular, UPS would like to see as many products as possible made available to both the pilot and dispatchers. One example of moving in the right direction is the integrated terminal weather support system (ITWS) that is currently being developed to integrate weather products generated by LLWAS, TDWR, ASOS, and other sensors in the terminal area. The terminal weather information for pilots (TWIP) digital communications system is an example of a parallel effort to provide TDWR and ITWS in text and character graphic messages. Limiting a product's dissemination or data format reduces the product's ability to aid the pilot in making both tactical and strategic decisions. In this same spirit, UPS would also like to see more of the weather products formatted to directly support the aviation community.

2.6.3.2 Delta Airlines

GTRI also selected Delta Airlines to participate in a formal interview. Delta Airlines represents one of the top five commercial airlines in the Nation and is a 121 Part certificate holder. GTRI's contacts at the Atlanta based Delta Airlines Flight Operations and Weather Center are Mr. Hank Echols, Manager and Chief Dispatcher, and Mr. Joe Luisi, Chief Meteorologist.

Delta Airlines' operations center is supported by a staff of 18 meteorologists and is equipped with some of the most modern weather information systems. Weather information plays a major role in flight safety and operations. In the case of Delta, a performance degradation due to winds, equivalent to a one cent increase in fuel cost, amounts to a loss of $25 million dollars over the course of a year. Delta is continually applying weather information to identify optimum routes in order to take advantage of tail winds and to reduce the effects of head winds. Delta is also very concerned with weather's impact on safety. For example, Delta is concerned with identifying regions that may contain severe turbulence.

Severe turbulence is a hazard to both passengers and equipment. To support hazardous weather avoidance, Delta dispatchers are Enhanced Weather Information Systems (EWINS) certified (see Appendix E) which permits them to make and issue flight movement forecast to avoid hazardous areas. Appendix F contains a job description for a Delta aircraft dispatcher. In should be noted, that the dispatcher shares the responsibility for flight safety with the pilot. In addition, the major hubs receive weather briefings from the Atlanta-based Delta Airlines operation center four times a day.

Delta places a high value on accurate forecasting of winds and temperature aloft information. As noted, these forecasts are currently based on mesoscale models with input from sensors (radiosonde) whose spacings are on the order of 200 nautical miles apart. Delta would like to see improvements in these forecasts both from a safety and economic stand point. Delta noted that trans-Atlantic flights require accurate winds aloft information due to the close spacing between the flights in this crowded corridor. Only a finite set of economically efficient tracts exists in the corridor. Approximately 300 flights enter this corridor once a day with most of the flights confined within a 12 hour window. The aircraft are stacked vertically and temporally with 10 minute spacings. In addition, mountain waves from Greenland are known to induce turbulence in this region. Delta has also identified turbulence detection and mitigation as an area where they would like to see improvements.

Delta pointed out their concern that much of the weather information collection in the terminal area is being obtained through an automated system (*e.g.*, ASOS). Delta's chief meteorologist expressed his view that the man-in-the-loop is still required to convey accurate information concerning certain atmospheric conditions, for example, ceilings and visibility. Sensors tend to look through a straw when observing the environment and tend not to provide a composite view of the terminal area.

Delta points out that hail continues to be a significant hazard to aviation. Delta's operating procedures call for their aircraft to stay at least 20 miles from thunderstorms. Thunderstorms produce a number of hazards including hail. The ability to distinguish hail from other precipitant types is an area where research into improved sensor systems (*e.g.*, radars employing polarization diversity) may benefit the aviation community.

One of the concerns voiced by Delta is the apparent move by the NWS away from supporting the spatial resolution needs of the aviation community. NWS forecasts tend to characterize weather events over large regions, whereas, the aviation community would like to have more localized forecasts. On a similar note, there is currently a bill in Congress to take the NWS out of the aviation weather information provider role. Aviation weather information would be obtained directly from commercial suppliers. Delta currently purchases enhanced weather information from a number of providers including Braknel Winds, Suitland Winds, and Litton Weather Services International (WSI). Delta and WSI have jointly been developing an advanced weather information system termed DWINS which will be installed in the latter part of 1999.

As a final note, Delta pointed out that the electro-optic and infrared imaginary supplied by WSI is not capable of providing water vapor information at the lower altitudes. This may be significant in forecasting potential icing conditions.

2.6.3.3 National Weather Service Weather Forecast Offices

As one of the key components in the NWS and FAA aviation weather information support system, the National Weather Service Weather Forecast Offices (NWS WFO) provide a number of products to support the aviation community. As an example, the NWS WFOs provide both route and terminal area forecasts. NEXRAD radars located at the NWS WFO sites generate some 18 weather products providing information on precipitation levels and weather movement and development. These products are provided to four commercial vendors who add value and market them commercially. A direct feed from the NWS WFO is also made available to a number of government agencies within the FAA/NWS support system. The FAA-sponsored NEXRAD product development team is investigating a number of possible upgrades to the NEXRAD radar that may directly impact the aviation community. These include:

- Development and enhancement of the damaging downburst detection and prediction algorithm
- Polarization algorithm development
- Enhancement of NSSL's mesocyclone detection and tornado detection algorithms
- Rapid update, improving the update rate from the current 5 to 6 minute rate
- Integration of the storm cell identification and tracking
- High resolution layered composite reflectivity
- Develop and implement volume coverage patterns

The enhancements will provide scanning patterns and update rates commensurate with aviation weather information needs. The enhancements will also improve storm tracking and identification and precipitant type discrimination. These enhancements can improve the quality and timeliness of information. However, the infrastructure to support aviation weather information dissemination and interpretation must also be in place to take advantage of these enhancements as they come on-line.

GTRI visited the NWS WFO in Peachtree City, Georgia to get an overview of how this office supports the aviation community. GTRI's point of contact at the NWS WFO in Peachtree City is Chief Meteorologist Gary Bealy. One of the main observations extracted from that interview was the fact that the NWS WFO's role in providing weather information to the aviation community has changed. The role has shifted away from being a provider of weather briefings directly to pilots. This role of interfacing with the general aviation pilot has been assumed by the Flight Service Stations who provide pre-flight briefings and en route information.

The NWS WFO are official sites for administering radiosonde observations. These soundings are taken twice a day at 0000Z and 1200Z. These observations are used as inputs to mesoscale models. Radiosonde observations are taken at 102 discrete locations across the country with an approximate spacing of 200 nautical miles. This sparse network of observations is the focal point of Delta's and UPS's concerns in the previous sections.

2.6.3.4 Southern Region Air Traffic Control

To get a perspective from the air traffic control community, GTRI contacted the FAA Air Traffic Control Southern Region Headquarters in Atlanta, Georgia. The primary contact at the Southern Region Headquarters is Ms. Nancy Shelton. Ms. Shelton focused her comments on the role of Flight Service Stations (FSS) in providing updated weather information to the Part 91/135 operator.

Ms. Shelton provided the following commentary on the role of the FSS in support the PIREP program. A key feature of the FSS activity is responding to requests from pilots in flight and during the planning phase. This includes the function of receiving and processing PIREPS. The point was made that the PIREP process depends on the individual skill and proficiency of the person handling the report. The process is described as "manual" by Ms. Shelton. The PIREP is received and must be manually recorded and then entered into the system. It is immediately apparent that this can become labor intensive when conditions are severe and changing rapidly and air traffic is dense. Nevertheless the "Flight Watch" activity within the FSS is a very important function, and under the present system, it is the primary mode of update for the general aviation Part 91 aviation consumer and for some 135 operators.

2.6.3.5 Flight Information Systems – Dean Resch

The National Aeronautics and Space Administration (NASA), in partnership with the Federal Aviation Administration (FAA), is conducting research and development programs to modernize the National Airspace System (NAS). Advanced Air Transportation Technologies (AATT) is one effort, under this program, developing concepts and decision support tools for eventual deployment and implementation by the FAA and the private sector. A major objective of the NASA AATT project is to understand and promote the needs of all aviation user categories (Parts 91, 121, and 135). The Gulf of Mexico presents some challenging NAS opportunities that will impact all three categories of users.

There is a large region over the middle of the Gulf of Mexico where no communication with aircraft flying above 18,000 feet is possible due to inadequacies in the communication network. This area is referred to as the "doughnut." Understandably, this presents a problem in providing weather information to aircraft at these flight levels. The FAA is addressing this high altitude communication problem by using four communication relay buoys designed to serve as radio relay stations. These stations will be strategically placed in the Gulf "doughnut" to support continuous communication with aircraft in this area. FAA funds have already been allocated for this project, and the buoys are undergoing tests at the present time. When the tests are completed, the buoys will be deployed with a spare ready to take the place of any station that experiences problems or needs periodic maintenance.

For low altitude operations, below FL180, a similar communication and weather information problem exists. Due to the large number of helicopters operating in the Gulf (more than 600 helicopters supporting 35,000 offshore workers) and the extreme weather elements associated with the Gulf, a similar program of deployed buoys is being considered.

Helicopters normally operate at low altitudes; however, in the Gulf, there is an issue of VFR/IFR operations, which is being addressed by the Flight Information Systems (FIS) program headed by Dean Resch. VFR operations are normally conducted at 3,500 feet or below, and IFR operations are normally conducted at 7,000 feet or below. Helicopters typically operate in the Gulf under VFR without ATC separation services. During inclement weather when flights cannot be conducted under VFR conditions, the low operating altitudes and line-of-sight limitations on communication and radar signals limit FAA surveillance and make mandatory the use of non-radar separation standards. These are very inefficient in terms of traffic throughput.

Specialized pilot training and flight procedures are utilized for IFR flights in the Gulf. IFR flights begin with pilots receiving weather information from company dispatchers and AWOS or certified weather observers. Flight plans are filed with the FSS via commercial telephone, VHF voice communications, Direct user access terminal (DUAT), or with Houston ARTCC via VHF voice communications. IFR clearances are relayed through company dispatchers and pilots via commercial telephone. Dispatchers and FSS may issue weather updates. Radar and communication coverage at the platform level is limited with limitations extending to the onshore hubs as well. As a result, IFR service to helicopters operating in the region is based on the rule commonly referred to as the "one in/one out" rule. This can generate delays of one or more hours during instrument meteorological conditions.

Consequently, the FAA FIS program is also looking at solutions for the helicopter IFR problem. To date, there is not a formal program such as that for the above FL 180 situation. The program director has held meetings with the Gulf region helicopter community, and it appears that a program is taking shape. The oil industry is considering donating at least two offshore platforms that could serve as sites for weather observation and communication equipment to better support helicopter IFR operations. NEXRAD like radars are being consider for placement on these platforms to aid in obtaining a composite view of weather in the Gulf.

2.7 Deficiencies in the Current Set of Weather Products

2.7.1 Introduction

This phase of the subtask has focused on collecting a body of information characterizing the current set of aviation weather products. The information was collected from a number of sources including the world wide web, literature, surveys, and interviews. This information was then captured in a database and in text format (within this report). The last portion of this phase of the subtask is to identify any deficiencies in the current set of weather products. The approach taken was to combine the opinions of the user community (albeit limited within the scope of this task) with GTRI's assessment, based on the collected information, to develop an overview of where the deficiencies lie.

GTRI identified four key areas that contain components that are deficient in some qualitative way. The four key areas are data format, support systems, sensors, and forecasting and modeling as shown in Figure 2-1. Each of these areas will be expanded upon in the following sections.

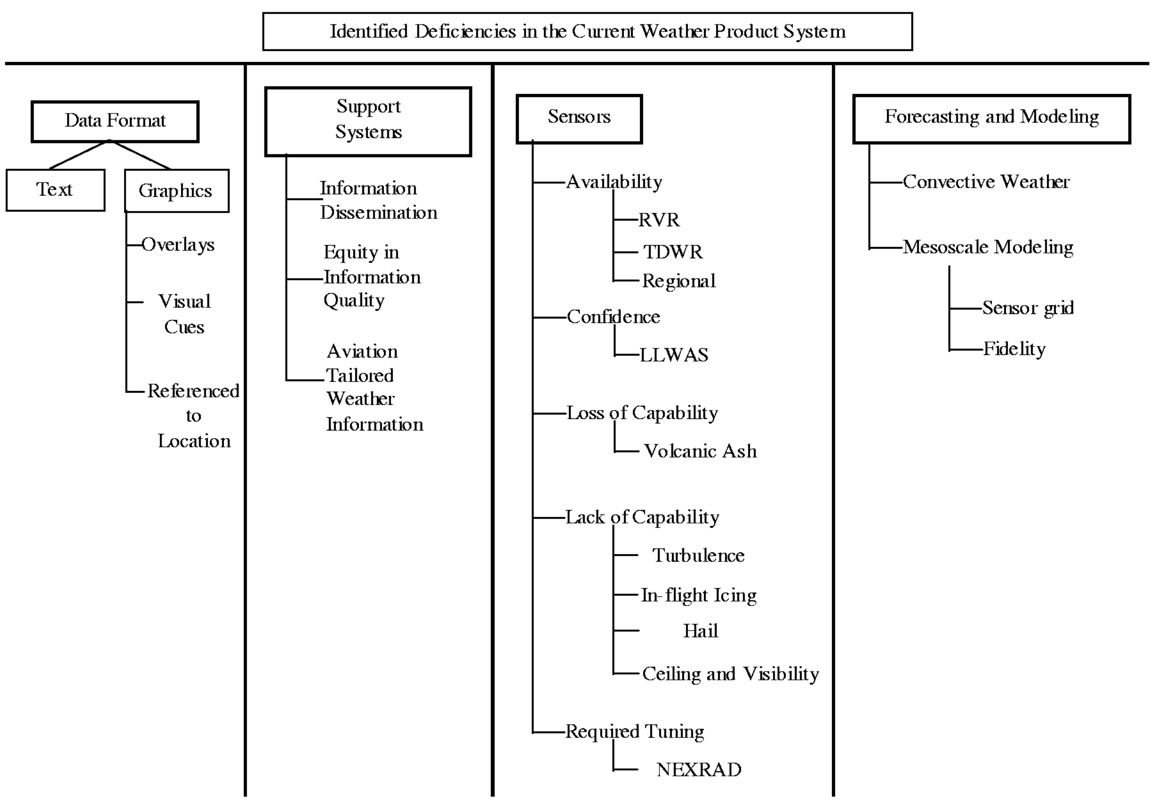


Figure 2-1. Identified deficiencies in the current weather product system

2.7.2 Data Format

The utility of a weather product, in many cases, depends on the delivery system's ability to provide the information in a timely manner and in a format that can be easily interpreted. With the amount of information and the format of some of the information (*e.g.*, radar products) currently available to the pilot, a graphical display is needed to reduce the pilot's workload and to aid in the interpretive process (*e.g.*, a coordinate overlay with hazard areas defined). A graphical display system permits the pilot to switch between a number of different data sources (provided the communication bandwidth is available) and to overlay the information in order to obtain a composite view of the current or forecasted conditions. There exists the need to develop low cost communication and display systems that can provide current weather products to the pilot during the en route flight phase to aid him/her in making both tactical and strategic decisions. The content of the weather products should be correlated with the aircraft's position. This ability to receive regularly scheduled updates (without operator intervention) in a format that can be quickly and easily interpreted is paramount to enhancing safety.

The timeliness of a weather product also impacts its usefulness. One case in point is the NEXRAD radar, which has a 5 to 6 minute update rate. The NEXRAD products are updated after all the data has been collected from each of the elevation scans. An effort is underway to develop the necessary algorithms to process the data on a scan by scan basis. The faster update rate may benefit the aviation community. The ability to provide timely updates need to be addressed along with the enhanced data format to provide the pilot with quality information.

2.7.3 Support System

Both Part 121 operators interviewed under this subtask observed deficiencies in the "system" designed to provide weather information to the aviation community. One area of concern, expressed by those interviewed, is the slow process in which new products are introduced. In addition, regional, and not national, implementation limits access to the entire community. This concern is being addressed as one of the goals under the FAA's Aviation Weather Research Program (AWRP). However, as new products are proposed under AWIN, a path for distribution to the end users should be defined.

The FAA depends on the NWS to provide weather information that can be tailored to the needs of the aviation community. However, as stated previously, the NWS often provides weather information on a much coarser grid than that required for aviation. For example, a number of the in-flight advisories are issued for events that are affecting or will affect an area of at least 3,000 square miles at any one time. In some cases, an event over a much smaller area may have a significant impact on safety. The aviation community would like to continue to see weather products that are designed for aviation. This may require input earlier in the weather product development process, starting even at the sensor level. AWRP is one FAA program tailored to focus research in those areas that will directly impact flight safety and to tailor products that will meet the needs of the aviation community. The Aviation Gridded Forecast System product develop team, under AWRP, is an example of an effort to move in that direction.

During this investigation, GTRI received comments from at least two sources that the NWS may be moving in a direction away from supporting the weather information needs of the aviation community. The idea would be to turn the role of providing aviation weather information over to the private sector. This would have both positive and negative impacts, and would need to be investigated more closely from an aviation safety and regulatory standpoint if this idea moves forward.

From the Part 121 operator's viewpoint, the air traffic control system depends on a cooperative working relationship between the FAA, NWS, and the airlines. However, in some cases there seems to be a perceived difference in the "quality" of weather information available to the ATC and that available and used by commercial airlines through private vendors. Delta supplied the following example: on the 9th of August, 1999, at the Hartsfield International Airport, it was reported that Atlanta traffic was being vectored over Nashville because of weather affecting the normal feeder fix to Hartsfield International. However, Delta's weather support system and staff indicated no reason to divert traffic flow. Delta receives its value added weather information from WSI, whereas the ATC depends on the NWS. The FAA has the regulatory authority to make the call, but in many cases will consult with Delta for their view on developing weather conditions. There is, at least in this case, a perception that the weather products made available to the airlines through private companies are in some ways superior to those provided by the NWS.

The issues discussed in this section are very sensitive in nature and require a joint effort between the FAA, NWS, and industry to develop an infrastructure/support system that can supply the best available weather products to all parties involved to meet the goals of the AvSP.

2.7.4 Sensors

Sensors were identified as having deficiencies in a number of areas. The deficiencies have been grouped into five categories: lack of availability, lack of confidence, loss of capability, lack of capability, and required tuning. These are illustrated in Figure 2-1.

The dream is to have a full suite of weather sensors at every airport, but from an economics standpoint, this is not feasible. Trades must be made in the allocation of resources. The ability to proliferate radars throughout the country continues to be limited by cost. These sensors provide a unique, remote capability to sense wind conditions along the glide slope. The LLWAS and the ASR-9 WSP are lower cost systems that are intended to provide some of the capability that is afforded by the TDWR. The development of lower cost systems would provide the opportunity to place sensors at more sites around the country. A region not supported by weather systems is the Gulf of Mexico. This is an area of dense helicopter traffic used to support the offshore oil industry. The Flight Information Systems program is investigating the possibility of siting weather radars on oil platforms in the Gulf to provide the needed information to support IFR flight. Finally, during this investigation the lack of runway visual range sensors at some airports was identified as a key area of concern.

There also exists a lack of confidence in some of the weather products. In particular, UPS has noted a high false alarm rate associated with LLWAS. Further analysis is required to confirm or refute this perception.

Loss of any support function is always viewed as a step backwards. The reported scheduled loss of a volcanic ash detection capability from GOES satellites after the year 2002 has a number of members of the aviation community concerned.

Currently, there are a number of hazards that are not detectable/predictable on a regular and consistent basis using existing deployed sensor suites. Without the necessary sensor capability, the current set of weather products cannot provide sufficient information to support turbulence detection, in-flight icing prediction, hail detection, and ceiling and visibility measurements.

During this weather product investigation, the suggestion was made that a sensor or suite of sensors should be developed to provide visibility and ceiling conditions along the glide slope. The sensors would provide information about conditions at airports prior to the pilot initiating the approach phase. A go-around, due to ceilings and visibility below minimums, places the pilot in a higher stress condition that could be avoided if conditions at the airport could be known in advance.

As noted in the previous section, deficiencies also exist in some of the weather products when the sensor is not designed to meet the spatial and temporal needs of the aviation community. One example of this is the NEXRAD product update rate.

2.7.5 Forecasting and Modeling

The fourth area where deficiencies have been identified is in the area of forecasted weather products. Mesoscale modeling is required to forecast winds and temperatures aloft. However, the model's forecast products are a function of the model's fidelity and the sensor data input to the model. As noted in this analysis, a finer spaced grid of sensors (*e.g.*, radiosonde or wind profilers) is required to provide the level of forecast needed to support the aviation community.

2.8 A Look Forward to Requirements

This section is intended as a look forward into phase 2 of this subtask. As a reminder, phase 2 focuses on developing weather information requirements for users during each phase of flight. There exists a number of reports [2-12, 2-13] written in the early 1990's that look at the weather information requirements of the aviation community. These reports will be used as a starting point in the phase II analysis so as not to re-invent the wheel. Crabill [2-13] addresses the weather information needs of the pilot in each phase of twelve phases of flight. These phases of flight are depicted in Figure 2-2. A summary of the weather information requirements, as identified in Crabill's report, are given in Table 2-9.

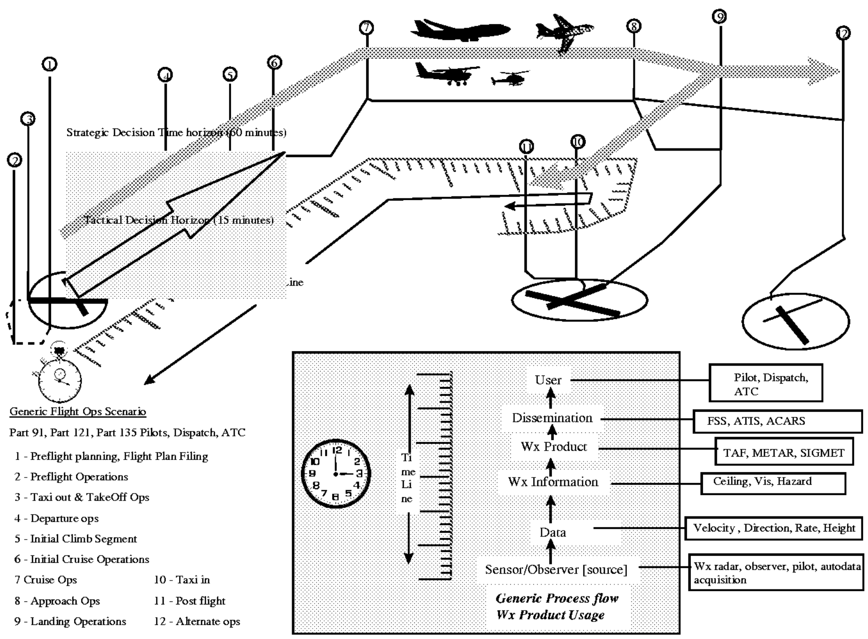


Figure 2-2. An illustration of the twelve phases of flight

Phase II of this subtask will seek to define both tactical and strategic weather information requirements to support the goals of the aviation safety program. Tactical weather information is defined as weather information required to support hazard avoidance/mitigation within a window of 0 to 15 minutes prior to encountering the hazard. Strategic weather information can be broken into two categories: near term strategic and far term strategic. Near-term strategic weather information supports hazard avoidance/mitigation in the 15 to 60 minute time interval, and the far-term strategic weather information support avoidance/mitigation beyond 60 minutes. These categories of information are defined in the AWIN Data and Communication Link (DCL) report [2-10]. In the DCL report, the description of the various phases of flight includes a concept for near term decision making in the cockpit based upon a supposition that 15 minutes is sufficient lead time to respond to most weather hazards. The 15 minute tactical and 60 minute strategic criteria facilitate a very useful analytical tool to be applied in phase II of the analysis. These criteria will be used to time step through a representative flight scenario and to ask questions about weather information requirements in the presence of atmospheric hazards encountered in the various phases of flight.

Table 2-9. Weather Information Requirements based on Phase of Flight

Activity	Surface Weather Information Required	Aloft Weather Information Required
Preflight	• Summary statement of current and forecast surface conditions along route • Time phased terminal forecasts along route • Comparisons of terminal forecasts and surface observations along route for last 3 hours • Location of acceptable alternate airport	• Summary statement of current and forecast aloft weather conditions along route • Time phased area forecasts along route • Comparison of area forecasts and aloft observations along route for last 3 hours
Taxi-Out	• Current taxiway and runup area conditions	
Take-Off	• Current runway surface conditions	• Hazardous weather elements aloft in departure terminal area updated since preflight briefing

Activity	Surface Weather Information Required	Aloft Weather Information Required
Departure	• Current surface conditions at departure terminal area airports	• Hazardous weather elements aloft in departure terminal area updated since take-off
En route	• Current and forecast surface conditions at suitable accessible airports along route, including destination and alternates	• Actual and time-phased forecast aloft conditions along the route with emphasis on location and intensity of hazardous weather to be expected
Descent	• Current and forecast surface conditions at destination airport and alternates	• Current and forecast aloft conditions in destination terminal area with emphasis on location and intensity of hazardous weather to be expected
Landing	• Current runway surface conditions	• Current aloft conditions in destination terminal area with emphasis on location, intensity, and movement of hazardous weather
Taxi-In and Parking	• Current taxiway and parking area conditions	
Post flight	• Current and forecast surface conditions for the stay time	

References

2-1. Marshall, R. E., Richards, M. A., and et al., "Advanced Microwave Sensing Technology Study for Civil Aviation Atmospheric Hazards," Research Triangle Institute, Final Technical Report, NAS1-18925, February 1993.

2-2. Mahapatra, Pravas, "Aviation Weather Surveillance Systems," The Institution of Electrical Engineers, Michael Faraday House, United Kingdom, 1999.

2-3. Gleim, I. N., "Aviation Weather and Weather Services," Gleim Publishing, Inc., March 1998.

2-4. www.landings.com/_landings/pages/fars.html

2-5. www.govcomm.harris.com/environmental/ programs/warp/

2-6. www.comet.ucar.edu/nwplessons/etalesson2/

2-7. maps.fsl.noaa.gov/ruc2.tpb.html

2-8. www.mmm.ucar.edu/mm5/overview.html

2-9. www.emc.ncep.noaa.gov/mmb/wrf/

2-10. Ball, J. W., et al., "Aviation Weather Communication Requirements," Lockheed Martin Aeronautical Systems, Phase I Report for Glenn Research Center, June 1999.

2-11. http://www.arnav.com/prFIS01.htm

2-12. Air Traffic Weather Requirements Report, by the Air Traffic Weather Requirements Team (ATWRT), February 11, 1993.

2-13. Crabill, N. L., and Dash, E. R., "Pilot's Automated Weather Support System (PAWSS) Concepts Demonstration Project," DOT/FAA/RD-91-9.

3 Aviation Weather Information Requirements Recommendations

3.1 Task Summary

This section of the report contains recommendations for new or modified aviation weather information requirements that have been developed during the second phase of the Aviation Weather Requirements Study under the Enhanced Weather Products task. The requirements are derived to meet the stated objective of increasing flight safety under the auspices of National Aeronautics and Space Administration (NASA's) Aviation Safety Program. The requirements put forth in this report were developed under a study performed by the Georgia Tech Research Institute (GTRI), which included the following components:

(1) An overview of weather phenomena and their impact on aviation;

(2) A grouping of atmospheric phenomena, that may pose a hazard to aviation, into eight categories: weather systems, air motion, precipitation, icing, visibility/ceilings, lightning, volcanic ash, and wake vortices;

(3) An analysis of twelve phases of flight (the analysis identified requirements for weather information content, coverage, and timeliness while addressing the eight categories of weather phenomena defined in item 2);

(4) An evaluation of the existing weather products and their ability to support each phase of flight; and

(5) A review of National Transportation Safety Board (NTSB) accident data. The NTSB review is restricted to those accidents where weather was either a cause or factor. The NTSB data were applied in identifying deficiencies in the existing weather products. These deficiencies signal the need for new or modified requirements.

This analysis also included a review of studies performed in the early 1990s that addressed weather information requirements as a function of the phase of flight. The recommendations included in these studies, where appropriate, were folded into the requirements developed under this task.

A cooperative decision making relationship must exist between the pilot, air traffic control, and the dispatcher. However, under this study an explicit assignment of common and distinct requirements between the users was not developed. The requirements focus more on the weather information needed during each phase of flight and the hardware/communication equipment required to disseminate and interpret the information. It is assumed that the partitioning of the information between pilot, ATC, and dispatcher will be developed at a later date and will require input from all three groups in order to satisfy regulatory, commercial, and personal (pilots versus air traffic control) views of weather information.

The following bullets provide a summary overview of the recommended requirements developed under this study.

- A requirement for aviation weather products to address the eight categories of weather phenomena defined in the report (reference Tables 3-2, 3-3, 3-4, 3-5, 3-6, and 3-7)

- A requirement for aviation weather products to address hazards in terms of forecasted conditions, current conditions (observations/measurements), intensity, location, extent, movement, and life cycle

- A requirement for aviation weather products to provide both strategic and tactical (for forecasted and current conditions) information as a function of the phase of flight (reference Tables 3-13, 3-14, 3-15, and 3-16)

- A requirement for more accurate, localized descriptions of forecasted and current conditions tailored to the needs of the aviation community

- A requirement for integration/fusion of weather sensors to develop an improved composite view of the weather conditions in the terminal area

- A requirement to support three-dimensional wind sensing in the terminal area

- A requirement to support detection of wind phenomena that contain low levels of precipitants (*e.g.*, dry microburst and gust fronts)

- A requirement for lower cost systems to support wind sensing in the terminal area; this is intended to increase the number of airports having this capability

- A requirement for wake vortex detection and tracking in the terminal area under all weather conditions

- A requirement for a sensor system to provide real-time slant range visibility conditions along the glide slope

- A requirement for improvements in ceiling and visibility forecast

- A requirement for an automated system allowing a user to enter route and aircraft specific information that would then provide the pilot with tailored weather products to aid in preflight planning

- A requirement for a real-time system providing current information on visual meteorological conditions (VMC) and instrument meteorological conditions (IMC) (*e.g.*, cloud ceilings and coverage) on a finer time and spatial scale than currently exists

- A requirement for an increase in the update rate associated with a number of weather products used in pre-flight planning

- A requirement for a finer time and spatial spacing between radiosonde measurements

- A requirement for an automated system, requiring little pilot interaction, to deliver updates to the pilot as weather conditions change

- A requirement for a standardized three dimensional coordinate system (*e.g.*, GPS coordinates) in which to describe a hazard's position, extent, and movement

- A requirement for on-board equipment to interpret position and movement of hazardous conditions (based on a three dimensional coordinate system) in relation to the aircraft's current position and intended route

- A requirement for an autonomous, on-board, expert system providing weather information in the cockpit in a graphical format; the expert system should be capable of handling and interpreting large amounts of data and should provide specific options for the pilot based on current and forecasted weather information

- A requirement for on-board sensors to address in-flight icing

- A requirement for on-board sensors to address turbulence

- A requirement for lower cost, on-board weather systems to support the smaller aircraft that fall under Part 91 operations

- A requirement for a reduction in the number of airports where the pilot is required to rely solely on personal observation or PIREPs to obtain local information

- A requirement for on-board sensors to provide inputs for EPIREPS

- A requirement for a system to sense and report runway surface conditions (*e.g.*, runway coefficient of friction) that relate to the pilots ability to stop or main control of the aircraft while the aircraft is on the runway

- A requirement for a replacement sensor (due to a loss of the GOES split channel) to detect volcanic ash

3.2 Introduction

This section of the report contains recommendations for weather information requirements developed under the second phase of the Aviation Weather Information Requirements Study. These requirements are designed to support the National Aeronautics and Space Administration's Aviation Safety Program (AvSP) goal of improving aviation safety by a factor of five in the next ten years. The requirements focus on weather information needs as a function of the category of user and the phase of flight in support of both strategic and tactical decisions. The supporting analysis includes a review of weather phenomena and their impact on aviation, a categorization of atmospheric phenomena based on their impact on aviation, a flight phase analysis of weather information needs, an assessment of existing weather products, and a review of National Transportation Safety Board accident data.

3.3 Fundamentals of Weather Phenomena

This section provides a basic overview of weather phenomena which may pose a threat to aviation. This overview is derived from three excellent references [3-1,3-2,3-3] that address weather's impact on aviation. In this study, weather information requirements are formulated to address some of the threatening weather conditions covered in this section.

3.3.1 The Atmosphere

The atmosphere nearest the earth is divided into three basic layers: the troposphere, the tropopause, and the stratosphere. The troposphere is the layer that extends between 25,000 to 30,000 feet at the poles and 55,000 to 65,000 feet at the equator. The troposphere is characterized by a general decrease in temperature with increasing altitude and contains the highest concentration of water vapor of the three layers. The tropopause extends above the troposphere and is characterized by a constant temperature versus elevation profile. The tropopause serves as a boundary layer trapping most of the moisture in the troposphere. The stratosphere exists above the tropopause and is characterized by an inversion in the temperature gradient. Table 3-1 contains minimum and maximum cruise altitudes [3-1] for different types of aircraft. Note that the majority of commercial and general aviation cruise operations take place in the troposphere.

Table 3-1. Approximate Minimum and Maximum Cruise Altitudes for Some Basic Types of Aircraft

Aircraft Type	Cruise Altitude (minimum/maximum), feet
Propeller-driven	2000 – 15,000
Subsonic airliners and transport aircraft (turbojet and turbofan engines)	20,000 – 40,000
Supersonic transport	60,000 – 70,000

The earth's atmosphere is a complex system that is composed mostly of oxygen and nitrogen. Temperature around the globe varies as a function of altitude, season, latitude, topography, and time of day. Heating and cooling of the land and sea has a direct impact on the atmosphere. These changes in temperature directly affect atmospheric pressure. Atmospheric pressure is a measure of the weight of the atmosphere at a given altitude. Temperature and pressure differences are a major source of the complex system of winds observed around the globe. Differences in temperature drive circulatory motion (termed convection) as the warmer air ascends and the cool air descends. Pressure gradients result in movement of air from high pressure to low pressure. The spherical shape and rotation of the earth also plays a major role in the movement of winds as evidenced by the Coriolis forces [3-2]. Topography also plays a major role in defining wind patterns. The heating and cooling of mountain surfaces causes temperature gradients between the air near the surface of the mountain and the surrounding air. The result is a flow of air along the mountain's face as the temperature gradients cause warm and cold air to rise and fall. Land and sea interfaces also produce winds due to the fact that the land is warmer than the sea during the day and the reverse is true during the night. As will be seen, winds have a direct impact on the aerodynamic performance of an aircraft and can present a lethal hazard to aircraft under certain conditions.

3.3.2 Moisture

Water vapor exists in the atmosphere as a gas. Two terms are often used to characterize water vapor in the atmosphere: relative humidity and dew point. Relative humidity is defined as the ratio of the amount of water vapor currently in the atmosphere to the amount that would present if the atmosphere were saturated. Dew point is the temperature to which the air must be cooled in order for the current level of water vapor in the air to result in saturation. The current temperature and dew point spread near the surface of the earth is an indicator of the potential development of fog. Fog tends to result when the dew point is less than 3° C.

Precipitation requires condensation of water vapor on what are termed condensation nuclei (*e.g.*, small solids in the atmosphere). As the water vapor condenses, the nuclei grow, forming liquid or ice particles. In some cases, "super cooled" water droplets may exist between 0° C and –20° C [3-1, page 67]. These super cooled water droplets are a major contributor to in-flight icing. Sublimation defines the direct conversion of water vapor (a gas) to ice (a solid) skipping the water phase entirely. Precipitation results when precipitants (*e.g.*, rain, snow, hail, sleet) are sufficiently heavy that the atmosphere can no longer support them. It should be noted that the precipitants are not stationary during this growth process. Horizontal and vertical winds carry the precipitants aloft, resulting in additional condensation, evaporation, freezing, and melting as the precipitants grow and shrink in size. Precipitation may occur at high altitudes but may never be observed on the ground due to evaporation as the precipitants descend through the atmosphere (*e.g.*, Virga).

3.3.3 Air Masses

Air masses are often termed stable or unstable. A stable air mass resists upward or downward displacement, whereas an unstable air mass may permit an upward or downward movement of air or both (*e.g.*, a convective process). The structure of clouds may be used by pilots to sense the presence of certain atmospheric phenomena. Layered or "stratiform clouds" are indicative of a stable air mass whereas unstable air masses exhibit cumuliform clouds that extend upward due to vertical air movement. The structure of clouds may also be an indicator of the presence of ice crystals, water and super cooled liquids, and convection. Pilots may use the structure of a cloud as an aid in interpreting current atmospheric conditions in a local area [3-2].

The term "air mass" is used to describe a body of air that exhibits a fairly uniform temperature and moisture profile. The origins of air masses tend to be stationary or slowing moving air that acquires its properties by association with a particular geographic region (*e.g.*, polar regions or tropical oceans). Fronts define the boundaries between differing air masses. A cold front defines the leading edge of an advancing cold air mass as it overtakes warmer air. At low altitudes, the cold air replaces the warm air. A warm front defines the leading edge of an advancing warm air mass as it moves over the denser cold air. A stationary front is a stalemate between a cold and warm air mass where neither is replacing the other. Air masses may also be influenced by the geographic regions over which they move. A cold air mass moving over a warm region may experience instabilities as the warmer air, near the earth's surface, rises through the air mass. In addition, air masses may add or loss water vapor to due evaporation or precipitation as the air mass moves along. The weather associated with a front is a function of the moisture in the atmosphere and the stability or instability of the air mass.

3.3.4 Thunderstorms

As pointed out by a number of authors [3-4,3-5], thunderstorms are a primary source of many of the weather related aviation hazards. Thunderstorm life cycles are characterized by three stages: the cumulus stage, the mature stage, and the dissipating stage. The cumulus stage consists of cumulus clouds that are a result of convective processes. The clouds tend to extend less than a few kilometers across and have large vertical extents. These clouds may experience stronger convective forces as they pass over warmer regions. The stronger convective forces in combination with the cooler temperatures in the upper atmosphere result in the formation of both updrafts and down drafts that coexist within the cell. The storm tops are generally between 25,000 feet and 40,000 feet [3-1] and in extreme cases extend to 65,000 feet (above sea level). The storm top may take on a characteristic anvil shape due to the prevailing winds. Single cell thunderstorms are typically several kilometers across and have a life cycle between 20 minutes and 1.5 hours. The updrafts in a storm cell may reach 25 m/s at heights of 25,000 feet [3-1]. Storm cells may also move at speeds up to 50–70 m/s in the upper atmosphere. Super cells are a class of severe thunderstorms that exhibit giant hail, strong surface winds, and strong updrafts and down drafts. Super cells are also known to spawn tornadoes. Super cells may exist up to 6 hours. A squall line is a linear arrangement of single storm cells that extend over hundreds of kilometers. Squall lines are associated with violent rain, hail, and strong winds.

All thunderstorms contain moderate turbulence and may also be the source of severe/extreme turbulence in a number of cases. Thunderstorms may also produce mesocyclones which exhibit a circular rotation over a large area. The rotation generally has little impact on aviation since the variation in wind speed changes slowly over a large region; however, mesocyclones are known to produce tornadoes. Tornadoes have an average diameter of 100 meters and typically travel less than 2 kilometers [3-1]. Maximum wind speeds can reach 110–125 m/s in extreme cases [3-1]. Large amounts of rain are also associated with thunderstorms. The amount of precipitation varies with altitude with the heaviest amounts of precipitation found in the higher altitudes. Hail is also associated with most thunderstorms since the cells generally extend above the freezing level. Hail size varies between less than 5 millimeters (shot size hail) to greater than 60 millimeters (tennis ball size hail). Hail is generally localized in what are termed hail shafts that may appear offset from the storm cell. The typical cross section of a hail shaft has an area of approximately 1 km^2. Hail is most often encountered at altitudes between 10,000 and 25,000 feet [3-1]. Hail stones have been found to be carried by updrafts and cross winds for distances up to 20 kilometers from the center of the storm cell. Thunderstorms are also known to harbor supercold liquids which support icing conditions. In addition, thunderstorms produce electrical discharges known as lightning that are hazardous to aviation. Cloud to cloud and cloud to ground lightning strikes are good indicators of convective activity.

3.3.5 Gust Fronts

Gust fronts are thunderstorm related phenomena that are particularly hazardous to aircraft at low altitudes. Gust fronts are the leading edge of a divergent outflow near the earth's surface that is generated by strong down drafts within a thunderstorm. The cold denser air moves out away from the thunderstorm causing the surrounding warm air to rise above it. Gust fronts may move at speeds up to 25 m/s [3-1]. Large velocity gradients are observed as the airspeed changes by tens of meters/sec over relatively short distances. High levels of turbulence also exist behind the gust front. Gust fronts are known to propagate significant distances. In some cases, gust fronts may be found several tens of kilometers away from the parent thunderstorm. One problem in detecting gust fronts is the fact that they may be characterized as "dry" or containing little precipitant. The low precipitant levels correspond to low reflective properties in the case of remote sensing.

3.3.6 Downbursts

Downbursts are strong downdrafts which cause a divergent flow of wind in all directions. The diverging winds represent a velocity gradient which may be hazardous to aircraft at low altitudes. Macrobursts are defined as downbursts whose maximum radial components of wind velocity are spaced by more than 4 kilometers. Microbursts exhibit a separation, between radial wind velocity maxima, that is less than 4 kilometers and exhibit a differential radial velocity maxima that exceeds 10 m/s. Radial wind components in a microburst may exceed 75 m/s. The maximum wind speeds tend to occur at the lowest altitudes (< 100 feet above ground level (AGL)). This low altitude wind shear is hazardous to aircraft during take-off and landing. Microbursts can be characterized as either wet or dry depending upon the amount of precipitation they contain. For microbursts, the dimensions of the downburst are, on average, approximately 1 km across at the outflow. The outflow tends to start less than 1 km above the ground. Studies have shown that average lifetime for a microburst is approximately 13 minutes with maximum wind speeds lasting 2 to 5 minutes [3-1]. The short life cycle, small dimension, low altitude, and potentially low reflective properties of the microburst combine to make it a difficult condition to predict and detect.

3.3.7 Wind

Wind motion may be characterized in a number of different ways. However, two terms are often used to describe wind motion that may be hazardous to aircraft: turbulence and wind shear. Turbulent air motion (*i.e.*, turbulence) is characterized by variations in wind speed over small spatial extents (*i.e.*, random motion). The term wind shear describes a more systematic variation of wind speed and direction in both spatial and temporal domains. Turbulence tends to excite the dynamics of the aircraft body, resulting in oscillations in the aircraft, which may induce a loss in performance and a bumpy and potentially hazardous ride for passengers. An example of wind shear is a variation in wind speed versus altitude. On landing, if the aircraft experiences head winds which then transition to strong tail winds as the aircraft descends through a shear layer, the aircraft may experience a loss in altitude and deviation from the intended flight path. Turbulence is associated with a number of atmospheric events including thunderstorms, mountain waves, wind shear layers (or boundaries), convection, and topographic features affecting wind flow. Clear air turbulence (CAT) is a term used to describe turbulence that is not associated with clouds or thunderstorms and generally takes place above 15,000 feet. Efforts are under way, under the FAA sponsored Product Development Teams and the Aviation Safety Program, to develop sensor systems that may aid in the detection of CAT, but none are fielded at this time. Meteorologists do have the ability to forecast turbulence, but the forecasts tend to be issued for a generally large area even though the turbulence may only be present in a smaller sub-region of the forecasted area. Turbulence is characterized as either light, moderate, severe, or extreme. These categories of turbulence can be related to the vertical acceleration experienced by the aircraft [3-1]. Aircraft should avoid areas of severe or extreme turbulence. Wind gusts are also a hazard to aircraft during landing and take-off and are characterized by a transitory burst of wind.

3.3.8 Icing

Icing is a major threat to aviation in that icing increases drag, reduces thrust, reduces lift, and increases the weight of the aircraft. Icing is also known to clog carburetors and Pitot tubes. All clouds above the freezing level have the potential to exhibit icing conditions. Icing tends to occur more often in the presence of supercooled water droplets. As an aircraft moves through the supercooled liquids, the water droplets impact the wings of the aircraft and freeze almost instantaneously. Icing is also an issue in the terminal area since icing may occur while an aircraft is waiting for taxi and take-off [3-1].

3.4 Categories of Weather Hazards

Weather, as described in the previous section, is a complex system driven by winds, temperature, pressure, and moisture. To try and enumerate or describe all of the atmospheric conditions that could eventually lead to a hazardous condition impacting flight safety is a monumental task. However, atmospheric events can be placed into categories based on their impact on aviation. This approach permits one to compartmentalize atmospheric events in a way that an analysis of weather information requirements may be handled within the scope of this task.

In this study, GTRI has grouped weather phenomena into eight categories that may contribute to or are, in themselves, hazardous conditions impacting flight safety. These categories are similar to the five categories proposed by Mahapatra [3-1]. Mahapatra groups weather phenomena into the following categories: (1) "phenomena involving the physical motion of air," (2) "hydrometeorological phenomena," (3) "phenomena inducing and facilitating ice formation on aircraft surfaces," (4) "phenomena causing low visibility," and (5) "phenomena involving atmospheric electricity." The eight categories of weather applied in this analysis are: weather systems, air motion, icing, visibility/ceiling, precipitation, volcanic ash, wake vortices, and lightning. These categories include the service areas identified in the National Aviation Weather Initiatives report prepared by the Joint Action Group for Aviation Weather [3-6].

Since air masses and convective systems are the source of many of the atmospheric hazards, a category, entitled "Weather Systems," is defined. Table 3-2 contains a listing of some of the types of systems include in this category. Weather products that address these systems need to include information about their location, intensity, extent, movement, and life cycle. Specific atmospheric phenomena/conditions that are a product of these weather systems will be included in separate categories based on their impact on aviation.

Table 3-2. A Listing of Some the Weather Phenomena Contained in the Category "Weather Systems"

Weather Systems
Thunderstorms
Single Cells
Super Cells
Squall Lines
Mesoclyclones
Tornadoes
Hurricanes
Pressure Systems
Warm and Cold Fronts

As noted in the previous section, air motion has a significant impact on aviation safety. Table 3-3 contains a listing of the significant atmospheric phenomena that are included in the category "air motion." This category is divided into two sub-categories: flight level phenomena and terminal area phenomena (including take-off and landing). The phenomena contained in the two sub-categories are not exclusive, but a distinction is made in order to address the differing requirements for the terminal and en route phases of flight.

In the terminal area, microbursts and gust fronts are significant hazards at low altitudes. At flight level, clear air turbulence (CAT) is a significant hazard. Currently, the are no fielded systems to detect the presence of CAT with sufficient time for the pilot to react. Requirements developed in the later sections will focus on a number of the air motion related hazards.

Since precipitation may impact aircraft performance in a number of different ways, precipitation is assigned a separate weather hazard category. Table 3-4 contains a list of some of the types of precipitation included in this category. Precipitation may impact visibility, but it may also result in other hazardous conditions that impact flight safety. For example, hail is a real threat to aircraft due to the high speeds at which hail impacts the surface of the aircraft during flight.

Table 3-3. Potential Hazardous Conditions Associated with Air Motion

Air Motion	
Terminal Area	**Flight Level**
Microburst (wet and dry)	Clear Air Turbulence
Gust Fronts	Mountain Waves
Low Level Wind Shear (non-convective)	Convective Turbulence
Sustained Surface Winds	Strong Updrafts
Gusts	Strong Downdrafts
Low Level Turbulence (convective)	Jet Stream
Low Level Jets/Nocturnal Jets	Frontal Shear
Land and Sea Breeze	Winds Aloft
Cross Winds	
Topographically Induced Winds	

Table 3-4. Phenomena Associated with Precipitation

Precipitation Type
Rain
Snow
Hail
Sleet
Virga

As noted in the previous section, icing may occur near the surface or at altitudes above the freezing level. While in-flight, super cooled liquids are the major contributing factor to the formation of ice on aircraft surfaces. On the ground, precipitation and temperatures at or below 0° C, result in the formation of ice on the surfaces of aircraft. Table 3-5 provides a summary of some of the factors that contribute to icing both in the terminal area (near or on the ground) and while in flight.

Table 3-5. Phenomena Contributing to the Formation of Ice on Aircraft Structures

Icing	
Terminal Area	**Flight Level**
Temperature	Super Cooled Liquids
Precipitation	Temperature / Freezing Level

Visibility and ceiling conditions are important to pilots under both instrument flight rules (IFR) and visual flight rules (VFR). For the VFR pilot, visibility and ceiling minimums are required during all phases of flight whereas the IFR pilot is concerned with these conditions only in the terminal area for take-off and landing. Table 3-6 contains a list of some of the atmospheric conditions that impact visibility and ceiling.

Table 3-6. Phenomena Contributing to Hazardous Visibility and Ceiling Conditions

Visibility/Ceilings	
Terminal Area	**Flight Level**
Low Level Clouds	Cloud Ceilings
Fog	Cloud Cover
Rain	Rain
Snow	Snow
Dust/Sand Storms	
Smoke/Pollution	
Runway Visual Range Conditions	

Three other categories (Table 3-7) have been defined in this analysis: lightning, volcanic ash, and wake vortices. Lightning is an electrical discharge that is generally associated with thunderstorms. The metal surface of the aircraft serves as a conductor, which permits electrical currents to damage sensitive aircraft components. Volcanic ash is the result of volcanic eruptions which spew large amounts of glass and acidic compounds into the atmosphere. Wake vortices are "horizontal tornadoes" induced by airflow along the tips of the aircraft wings during take-off and landing. Smaller aircraft are at a particular risk to the effects of wake vortices.

Table 3-7. Additional Categories of Weather Phenomena Impacting Aviation Safety

Additional Categories
Lightning
Volcanic Ash
Wake Vortices

These eight categories of weather phenomena will be used in the following sections to define information requirements for each phase of flight.

3.5 VFR and IFR Flight

Aircraft may operate under one of two sets of flight rules: visual flight rules and instrument flight rules. Under visual flight rules, the pilot is required to maintain minimum flight visibility conditions and minimum distances from clouds during all phases of flight. These minimums are given in Section 91.155 of the Federal Aviation Regulations (FAR) and are provided in Table 3-8 as a reference. The requirements are defined in terms of the airspace in which the aircraft is operating. All flights under VFR conditions must occur below 18,000 feet. For the VFR pilot, ceiling and visibility information plays a major role in his ability to remain VFR and to perform safe flight operations during all phases of flight.

Instrument flight rules permit en route operations in instrument meteorological conditions (IMC). During the approach phase of flight, a pre-defined altitude is reached at which the pilot must be able to make visual contact with the runway or abort the approach. For precision approaches, the minimum altitude is referred to as the decision height (DH), and for non-precision approaches, the minimum altitude is referred to as the minimum descent altitude (MDA). At the decision height, the pilot must be able to see the runway environment. The measure of visibility along the runway is termed the "runway visual range" (RVR). Table 3-9 contains decision heights and RVR requirements for different categories of landing. Weather products, tailored to inform the pilot of visibility conditions before reaching the DH, aid in reducing the number of missed approaches which may jeopardize the safety of the air space.

Table 3-8. FAR VFR Requirements for Visibility and Distance from Clouds

Airspace	Flight Visibility	Distance from Clouds
Class B	3 statute miles	Clear of clouds
Class C	3 statute miles	500 feet below 1,000 feet above 2,000 feet horizontal
Class D	3 statute miles	500 feet below 1,000 feet above 2,000 feet horizontal
Class E (< 10,000 ft. mean sea level (MSL))	3 statute miles	500 feet below 1,000 feet above 2,000 feet horizontal
Class E (> 10,000 ft. MSL)	5 statute miles	1,000 feet below 1,000 feet above 1 statute mile horizontal

Table 3-9. Decision Heights and RVR Requirements for IFR Flight

Landing Type	Decision Height, feet (not less than)	Runway Visual Range, meters (not less than)
CAT I	200	550
CAT II	100	350
CAT IIIA ('see to land')	100	200
CAT IIIB ('see to taxi')	50	50
CAT IIIC ('zero visibility')		

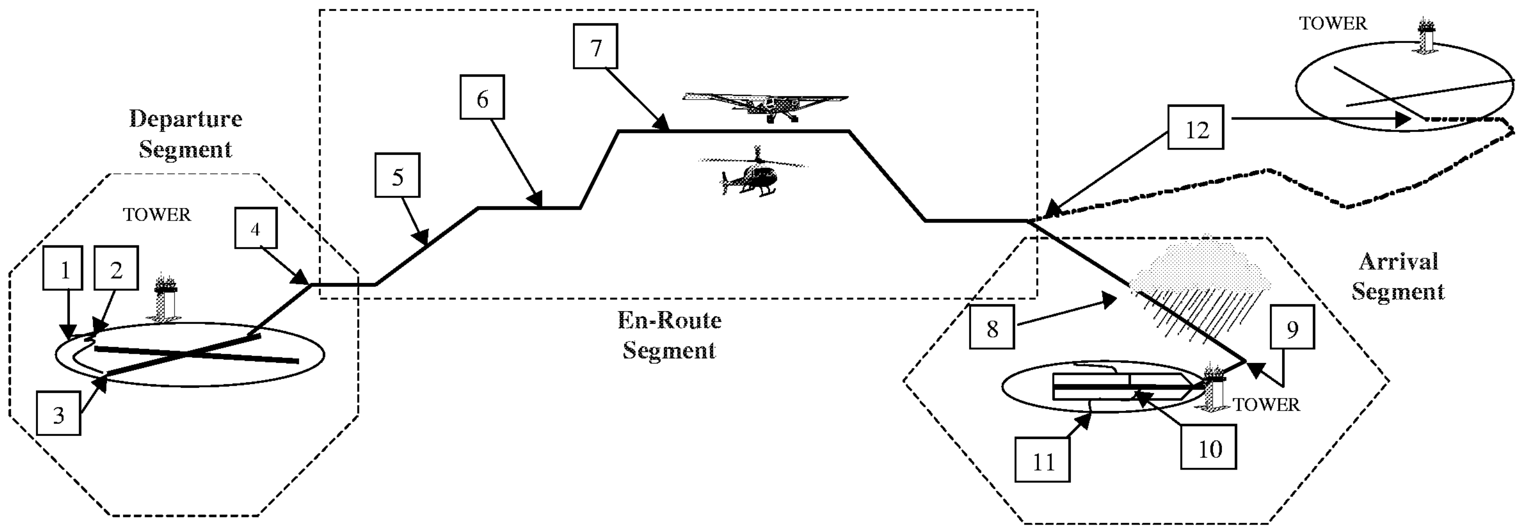
3.6 Weather Product Requirements as a Function of Phase of Flight

A number of studies [3-8, 3-9, 3-10] were performed during the early 1990s that specified weather information requirements for each phase of flight. This study seeks to consolidate those requirements and expand upon them to reach the goals set forth by the AvSP of improving aviation safety. In reviewing and assessing the weather information needs of the aviation community, it was seen that the different FAR categories (*e.g.*, Parts 121, 135, and 91) all require similar weather information to perform safe flight. However, a difference in weather information requirements does exist between VFR and IFR operations. These differences will be expanded upon as weather information requirements are developed in the following sections. The term “requirements” in this study should be viewed from the standpoint of meeting the AvSP goal of improving flight safety and should not be viewed as a FAR or regulatory requirement. When this study refers to existing FAR requirements, the term “FAR” will be included in the text.

The effect of weather on an aircraft is a function of the type of aircraft, its equipment, and the capabilities of the pilot. The minimum equipage requirements for an aircraft are defined by the FAR categories of operation. An example of a piece of equipment that is required to support operation in inclement weather is the airborne weather radar. This radar is required for Part 121 operators but is not required for Part 91 operators. However, both the Part 91 and Part 121 aircraft need to be aware of the presence of hazardous weather conditions while in flight. The differences in the requirements are a function of the relationship between the operator and his passengers and cargo. Part 121 operators are carrying passengers for hire and many lives are at stake. In contrast, Part 91 operators are not for hire and carry few passengers. The following analysis does not address weather information requirements from a regulatory (FAR) standpoint. If safety is to be improved, specific pieces of weather information are needed by all operators. Whether this information will be required from a regulatory standpoint is an issue to be resolved after the needed improvements have been identified.

In the most general sense, the term “weather product” may contain weather information at different stages of processing/interpretation: raw, measured data (*e.g.*, temperature), processed data (*e.g.*, a microburst hazard alert obtained from processing range gated velocity profiles), and forecast data (*e.g.*, winds aloft forecast). The term “weather product” may also encompass the sensor, the processor, the meteorologist/forecaster/observer, and/or the delivery system (communication/data link). Aviation weather products are, in general, tailored to convey information about events within a defined region of space. Aviation weather products also have a temporal factor associated with them that denotes current or forecast conditions and an interval of time over which the weather product is valid. The weather information requirements defined in this study focus on weather information content (*e.g.*, temperature, dewpoint, and microburst conditions), spatial coverage (*e.g.*, en route and terminal area), and timeliness (*i.e.*, supporting tactical versus strategic decisions). The data and communication requirements needed to support new weather products are addressed in a separate effort and documented in reference [3-7].

Figure 3-1 illustrates the 12 phases of flight as defined in the Crabill [3-8] report. The 12 phases of flight begin with preflight planning and flight plan filing at the departure airport and end with post flight operations at the destination airport. The time an aircraft spends in each phase of flight is a function of the flight plan (route and purpose of flight). Also, in some cases, there may not be a clear boundary between when an aircraft transitions from one phase of flight to the next. The altitude at which the different phases of flight are performed is a function of the aircraft’s and pilot’s certification and the flight plan. The 12th phase of flight is included to illustrate the fact that certain conditions may require that an alternative airport be used for landing. In general, phases VIII–XI would need to be repeated when diverting to an alternative airport. In this analysis, the first 11 phases of flight are grouped in three major segments: departure (D), en route (E), and arrival (A). These segments are denoted in Figure 3-1. The departure segment includes preflight planning and operations, taxi and take-off operations, and departure operations (phases I-IV). The departure segment should not be confused with the fourth phase of flight termed “departure operations.” The en route segment includes climb and cruise operations (phases V-VII), and the arrival segment includes approach, landing, and taxi in operations (phases VIII-XI).



Phases of Flight	
1. Preflight Planning; Flight Plan Filing	7. Cruise Operations
2. Preflight Operations	8. Approach Operations
3. Taxi Out and Take Off Operations	9. Landing Operations
4. Departure Operations	10. Taxi In and Parking Operations
5. Initial Climb Segment Operations	11. Post Flight Operations
6. Initial Cruise Operations	12. Alternate Operations (if required)

Figure 3-1. The 12 phases of flight applied in defining weather information requirements

In Section 3.4, weather phenomena which are potential hazards to aviation were grouped into eight major categories. In addition, some of the categories are further subdivided into terminal and flight level phenomena in order to distinguish the altitudes at which the phenomena pose a hazard. The aviator is required to have a working knowledge of meteorology as it applies to aviation and the ability to compile and interpret weather information in order to gain a "picture" of the current and forecasted conditions which may occur during each phase of flight. Some of the information provided to the pilot or user is in the form of a "warning" to indicate the presence of a hazardous condition that should be avoided. An example of a warning is a wind shear alert on approach which may be issued either by the tower or an airborne weather radar. However, other weather information is provided to the pilot to aid him in monitoring conditions with no action to be taken at the present time. Examples of weather information that may used to monitor changing conditions are temperature and dew point. The current set of weather products are designed to provide both "warning" type information and information that serves to monitor changing weather conditions over time. The eight major categories of weather phenomena, defined in Section 3.4, contain elements that can be observed/measured to monitor and warn of hazardous conditions.

The eight categories of weather contained in Tables 3-2, 3-3, 3-4, 3-5, 3-6, and 3-7 define, at a high level, the types of hazards weather products are required to address. The following analysis correlates these eight categories of weather with the different phases of flight. As the pilot transitions from one phase of flight to the next, his weather information needs change. At each stage, the pilot is assessing current conditions in order to make tactical decisions concerning safety and is assessing forecasted conditions for strategic planning either en route or during the pre-flight planning stage. The Lockheed Martin report [3-7] defines tactical information as information required within a 15 minute window to support real-time decisions and short term strategic information as information that would impact flight safety beyond the 15 minute interval but within a 60 minute interval. These are good rules of thumb, but the pilot may have less than 15 minutes to be warned of and react to hazardous conditions. For example, the average microburst may form and dissipate within 13 minutes, with the strongest wind shear conditions lasting only 2-5 minutes.

In most scenarios involving weather, the pilot makes a decision that is supported by input from dispatch and air traffic control. Therefore, even though the focus tends to be on the pilot in this analysis of weather information requirements, what one should be aware of is that all parties involved may require all or a subset of the weather information to aid the pilot in making an informed decision and to manage the composite air space. ATC also needs weather information to anticipate pilot actions supported by airline operation centers and flight service stations.

In this analysis, the timeliness of weather information is broken into two categories: current (C) and forecasted (F). "Current" weather information provides an assessment (in most cases, based on measured data) of the atmospheric conditions that the pilot will encounter during the current phase or segment of flight. This information may be applied by the pilot in making tactical decisions. Forecasted weather information is a statement about expected conditions that the pilot may encounter in the next phase or segment of flight. As noted previously, weather conditions may change dramatically over short intervals of time. This puts some restrictions on the application and age of forecasted weather information.

The following subsections contain an assessment of the tactical (*i.e.*, current) and strategic (*e.g.*, forecasted) weather information requirements for each phase of flight. The information content requirements are defined in terms of one of the eight major categories of weather phenomena presented in Section 3.4. The tables are used to correlate weather information requirements to phases of flight. During each phase of flight, the pilot needs an awareness of what is happening during his current phase of flight and what may occur during the next phase or segment of flight. The tables define weather information requirements as current or forecasted and identify which segment of flight (departure, en route, or arrival) the weather information should address. The tables also contain an additional row labeled “alternate.” This row is used to indicate when current or forecasted information is required for the alternate airport. The following sections step through each phase of flight commenting on weather information requirements for that phase of flight.

3.6.1 Preflight Planning and Flight Plan Filing

Preflight planning involves an assessment of current and forecasted conditions at the departure and destination airports and along the intended route. This assessment is initially performed to determine if the trip is feasible. The assessment is made by first examining the weather’s history over the area encompassing the intended flight. Crabill’s study [3-8] states that an assessment of significant weather for the past 3 hours is needed over an area encompassing 150 nautical miles on either side of the route. This assessment should be validated by comparing forecasted information with observed weather reports to identify discrepancies in the forecasted data. This is intended to provide some level of confidence or validity to the forecast data which will be used during the planning stages. Table 3-10 contains the required weather information by flight segment (D,E,A) for the planning phase. Note that both current (C) and forecasted (F) information is required for each segment of flight. The only category of information that is not required during this phase of flight is wake vortex information. Wake vortex information is required in real-time during the taxi and take-off phases and the landing phase. Forecasted ceiling and visibility (C&V) conditions should be collected for the departure airport, along the route, and for the destination and alternate airports. In order to account for conditions below minimum at the destination airport, Crabill [3-8] states that the C&V forecast should be obtained for the estimated time of arrival (ETA) plus one hour. The C&V conditions should also be estimated at the alternate airport taking into account this one hour delay.

Table 3-10. Weather Information Required During the Planning, Preflight, and Taxi and Take-Off Phases of Flight

	Planning						Preflight Ops						Taxi and Take-off					
	D		E		A		D		E		A		D		E		A	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Weather Systems	x	x	x	x	x	x	x	x										
Air Motion																		
Flight Level	x	x	x	x	x	x												
Terminal	x	x	x	x	x	x	x	x						x				
Precipitation	x	x	x	x	x	x	x	x						x				
Icing																		
Flight Level	x	x	x	x	x	x												
Terminal	x	x	x	x	x	x	x	x						x				
Visibility																		
Flight Level	x	x	x	x	x	x												
Terminal	x	x	x	x	x	x	x	x						x				
Lightning	x	x	x	x	x	x	x	x										
Volcanic Ash	x	x	x	x	x	x	x	x						x				
Wake Vortices														x				
Alternate																		
Route	x	x	x	x	x	x												
Terminal	x	x	x	x	x	x												

D = Departure Segment, E = Enroute Segment, A = Arrival Segment, F = Forecasted, C = Current

Flight planning involves assessing the impact of current and forecasted weather conditions on the different aspects of flight. Table 3-11 contains a number of the aspects of flight planning that must be assessed in terms of the available weather information [3-8].

Table 3-11. Flight Plan Components that May be Impacted by Weather

Flight Plan Considerations	
VMC/IMC	Ground Speeds
Departure Time	Trip Time
Take-off and Climb Performance	Fuel Burn
Route	Arrival Time at Destination
Altitudes	Daylight/Darkness
Airspeeds	Alternate Conditions

3.6.2 Preflight Operations

Preflight operations require a check-out of equipment for proper operation. Past, current, and forecasted weather information [3-8] is required to assess the need for de-icing and engine and carburetor heating. Preflight operation is also a time for validating weather information collected during the planning phase for the departure area. Personal observation of prevailing conditions (*e.g.*, ceiling, visibility, and winds) is the method most often applied. Prevailing conditions may require the pilot to revisit the flight plan. The focus is on conditions at the departure airport at the estimated time of departure (ETD). Table 3-10 contains the categories of weather information required during this phase of operation. The focus is on the current and forecasted conditions in the terminal area. In this analysis, the terminal area is included in the departure segment of flight.

3.6.3 Taxi and Take-Off

During taxi and take-off, the focus is on tactical information required to execute a taxi-out onto the runway and a take-off operation. Low altitude air motion information is critical in this phase of flight. Types of low altitude air motion include: microburst, non-convective wind shear, gust fronts, wind gust, surface winds, and turbulence. Section 3.3 provides an explanation of these low-level phenomena. Additional types of low altitude air motion are included in Table 3-3. Icing and visibility conditions are also tactical considerations. Of additional concern during this phase of flight is the presence of wake vortices produced by arriving and departing aircraft.

3.6.4 Departure, Initial Climb, and Initial Cruise

The departure phase is the last phase in the departure segment. During this phase the pilot needs tactical (*i.e.*, current) weather information associated with this phase of flight. The pilot is also starting to focus on weather information that he will need to make strategic decisions during the en route segment of flight. During the initial climb and initial cruise phases of flight, the pilot's weather information requirements are focused on the en route segment of flight from both a tactical and strategic decision perspective. In all three phases of flight, the required weather information transitions from information about conditions near the surface to flight level condition information. During these phases of flight, weather information and aircraft performance are assessed to determine if the flight plan needs to be updated to account for current and forecasted conditions. Table 3-12 contains a listing of the weather information required for each phase of flight.

Table 3-12. Weather Information Required During the Departure, Initial Climb, and Initial Cruise Phases of Flight

	Departure						Initial Climb						Initial Cruise					
	D		E		A		D		E		A		D		E		A	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Weather Systems		x	x	x					x	x					x	x		
Air Motion																		
Flight Level			x	x					x	x					x	x		
Terminal		x																
Precipitation		x	x	x					x	x					x	x		
Icing																		
Flight Level			x	x					x	x					x	x		
Terminal		x																
Visibility																		
Flight Level			x	x					x	x					x	x		
Terminal		x																
Lightning		x	x	x					x	x					x	x		
Volcanic Ash		x	x	x					x	x					x	x		
Wake Vortices																		
Alternate																		
Route																		
Terminal																		

D = Departure Segment, E = Enroute Segment, A = Arrival Segment, F = Forecast, C = Current

3.6.5 Cruise

During the cruise phase, the VFR pilot needs current and forecasted weather information to stay clear of clouds and to maintain visibility requirements. Both the IFR and VFR pilot also require wind information to assess fuel burn rates. The pilot must be updated with current or forecasted hazardous weather conditions (*e.g.*, CAT, hail, thunderstorms, *etc.*) along the intended route. It is during the cruise phase of flight that the pilot needs current and forecasted weather information about the destination and alternate airports in order to make an intelligent decision to proceed to the alternate or to continue to the destination airport to attempt a landing. Table 3-13 contains the categories of weather information required during the cruise phase.

Table 3-13. Weather Information Required During the Cruise, Approach, and Landing Phases of Flight

	Cruise						Approach						Landing					
	D		E		A		D		E		A		D		E		A	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
Weather Systems			x	x	x	x					x	x						x
Air Motion																		
Flight Level			x	x														
Terminal					x	x					x	x						x
Precipitation			x	x	x	x					x	x						x
Icing																		
Flight Level			x	x														
Terminal					x	x					x	x						x
Visibility																		
Flight Level			x	x														
Terminal					x	x					x	x						x
Lightning			x	x	x	x					x	x						x
Volcanic Ash			x	x	x	x					x	x						x
Wake Vortices																		x
Alternate																		
Route					x	x												
Terminal					x	x												

D = Departure Segment, E = Enroute Segment, A = Arrival Segment, F = Forecast, C = Current

3.6.6 Approach

The approach phase represents the transition phase between the cruise and landing phases. The current conditions during the final portion of the cruise phase and the current and forecasted conditions for the arrival segment are required by the pilot. During the approach phase, the pilot is correlating current weather conditions with those forecasted for the destination airport. At this point in the flight, the pilot's options continue to narrow as the aircraft transitions into a more confined air space and a lower altitude. The aircraft may be placed in a holding pattern prior to starting the approach if conditions are below minimums or hazardous weather conditions exist. A possible holding pattern and unexpected winds experienced during flight may result in an in-flight emergency as a result of fuel starvation. Table 3-13 contains the categories of weather information required during the approach phase.

3.6.7 Landing

During the landing phase, VFR pilots must achieve minimum visibility and ceilings conditions with an uncompromised visual reference of the runway. For the IFR pilot, the approach end of the runway must be visible at the decision height (DH) for precision approaches and at the MDA for non-precision approaches. In addition, runway visual ranges (RVR) must be met by IFR pilots for the different IFR landing categories (CAT I, II, and III). At the altitudes associated with landing, low level wind and wind shear information is critical in making a safe landing. The focus of the weather information during the landing phase is on the current weather conditions (*i.e.*, tactical information). As in the take-off phase, information on wake vortex movement and strengths becomes a critical piece of information in an airport environment supporting all aircraft types. In addition, both precipitation and icing change the coefficient of friction of the runway which may impact the aircraft's ability to decelerate or to maintain position in the desired direction along the runway. Table 3-13 contains the categories of weather information required during the landing phase.

3.6.8 Taxi In and Post Flight Operations

During taxi in operations, the pilot needs to be aware of taxi way and ramp conditions. Winds, surface conditions (*e.g.*, snow on the ground), visibility, and other hazardous conditions may impact the aircraft as it moves from the runway to the ramp. Post flight operations should be supported by forecast information covering the remainder of the time the aircraft is in the terminal area. This weather information will be used by the pilot to assess actions to be taken before continuing flight or to be taken in securing the aircraft. The weather information required during these two phases of flight is given in Table 3-14.

3.7 Existing Weather Products

The current system of aviation weather products is designed in such a way that individual weather products are tailored to address specific hazards or to monitor specific atmospheric conditions. Aviation weather products are also tailored to address current and forecasted conditions and to address weather conditions in the terminal area and along specific air routes. Specific weather products are designed to alert pilots in real-time of changing conditions that are deemed hazardous to aviation. A number of the current weather products are described in Appendix G.

Table 3-15 contains a listing of weather products that are directed at current and forecasted conditions along specific air routes and at specific airports. The aviation routine weather report (METAR) describes current conditions at an airport and is updated on an hourly basis. A non-routine aviation weather report (SPECI) may be issued between METAR reports if changing conditions warrant. The terminal aerodrome forecast (TAF) is a forecast issued by the NWS WFO about conditions within a five mile radius of the terminal area. This forecast is issued every six hours or as changing conditions warrant. It should be noted that a METAR and TAF may not be available for every airport. Some 300 routes are supported by route forecasts which are issued by the NWS WFO. A route forecast is issued every 8 hours and describes expected conditions within a corridor 50 miles wide along the specified route. These products are available to the pilot en route (via voice or digitally) for use in making both strategic and tactical decisions. However, their application depends greatly on the time of issuance. These products may also be used in the flight planning phases. The aviation forecast (FA) is a more widespread forecast (generally addressing expected conditions over an area the size of several states) which is updated on an eight hour basis or as conditions warrant. The FA describes visual meteorological and general weather conditions.

Table 3-14. Weather Information Required During the Taxi In and Post Flight Phases of Flight

	Taxi In						Post Flight Ops					
	D		E		A		D		E		A	
	F	C	F	C	F	C	F	C	F	C	F	C
Weather Systems						x					x	
Air Motion												
Flight Level												
Terminal						x					x	
Precipitation						x					x	
Icing												
Flight Level												
Terminal											x	
Visibility												
Flight Level												
Terminal						x						
Lightning												
Volcanic Ash												
Wake Vortices												
Alternate												
Route												
Terminal												

D = Departure Segment, E = Enroute Segment, A = Arrival Segment, F = Forecast, C = Current

A pilot needs to be made aware of weather conditions that have reached a level that is deemed hazardous to aviation. This information needs to be available both while en route and during flight planning. In-flight weather advisories, issued by the Aviation Weather Center and the Center Weather Service Units, serve this role. Table 3-16 lists properties associated with the in-flight weather advisories. Each weather product is tailored to address specific weather hazards. The Significant Meteorological Information (SIGMET) and Airman's Meteorological Information (AIRMET) are issued by the Aviation Weather Center (AWC) for the entire U.S. airspace; while, the meteorological impact statement (MIS) and center weather advisory (CWA) address hazards that may impact air traffic flow associated with a particular air route traffic control center (ARTCC). These weather products tend to be updated on a regular basis, but all are amendable based on changing conditions. One should note that a number of the in-flight advisories use VHF omnidirectional range (VORs) locations, airports, or well known geographic areas as landmarks in referencing areas containing hazardous conditions.

Table 3-15. A Listing of Aviation Weather Products Addressing Airport and Route Specific Conditions

Aviation Routine Weather Report (METAR)	**Content:**	Terminal area conditions: wind, visibility, runway visual range (RVR), weather phenomena, sky condition, temperature, dewpoint, altimeter
	Issued by:	FAA, NWS, or contract personnel at the airport or by an automated system (*e.g.*, AWOS or ASOS)
	Update:	1 hour
	Area:	Terminal
	Type:	Current conditions
Terminal Aerodrome Forecast (TAF)	**Content:**	Wind, visibility, weather, sky condition, and wind shear (non-convective)
	Issued by:	NWS WFO
	Update:	6 hours (or as conditions warrant)
	Area:	Within 5 miles of the terminal area
	Type:	Forecast
	Requires:	Two consecutive METARs are required for the TAF to be issued.
Route Forecast	**Content:**	Sustained surfaced winds, visibility, weather, thunderstorms, volcanic ash, sky conditions, mountain obscurements, non-convective low-level windshear
	Issued by:	NWS WFO
	Update:	8 hours
	Area:	25 miles on either side of some 300 routes
	Type:	Forecast
	Requires:	A TAF must be issued for the airport for a route forecast to be issued
Aviation Area Forecast (FA)	**Content:**	Visual meteorological conditions, clouds, and general weather
	Issued by:	Aviation Weather Center
	Update:	8 hours (as conditions warrant)
	Area:	area the size of several states
	Type:	Forecast

Table 3-16. A Listing of In-Flight Weather Advisories Issued by the AWC and CWA

In-Flight Weather Advisories		
Convective SIGMET	**Issued for:**	Thunderstorms (TS): severe, embedded, and line of, heavy precipitation affecting 40% of 3,000 square mile area.
	Issued by:	Aviation Weather Center
	Update:	Hourly (or as conditions warrant)
	Reference:	VORs, airports, or well known geographic areas
Domestic SIGMET	**Issued for:**	Non-convective phenomena: severe icing, extreme or severe turbulence or CAT, dust and storms, volcanic ash
	Issued by:	Aviation Weather Center
	Update:	As conditions warrant
	Reference:	VORs, airports, or well known geographic areas; generally widespread forecast
International SIGMET	**Issued for:**	Thunderstorms, tropical cyclones, severe icing, severe or extreme turbulence, dust and sand storms, volcanic ash
	Issued by:	ICAO Meteorological Watch Offices
	Update:	As conditions warrant
AIRMET Sierra	**Issued for:**	IFR weather conditions (< 1,000 ft. and 3 miles) affecting a large area, extensive mountain obscuration
	Issued by:	Aviation Weather Center
	Update:	6 hours (as conditions warrant)
AIRMET Tango	**Issued for:**	Moderate turbulence, 30 knot surface winds, low-level wind shear
	Issued by:	Aviation Weather Center
	Update:	6 hours (or as conditions warrant)
AIRMET Zulu	**Issued for:**	Moderate icing, freezing-level heights
	Issued by:	Aviation Weather Center
	Update:	6 hours (or as conditions warrant)
Meteorological Impact Statement (MIS)	**Issued for:**	Convective SIGMET criteria, icing, turbulence, surface winds, wind shear, volcanic ash, sand and dust storms
	Issued by:	Center Weather Service Unit at ARTCC
	Update:	As conditions warrant– event to begin beyond 2 hours
Center Weather Advisory (CWA)	**Issued for:**	Weather phenomena that will impact air traffic flow within the next 2 hours.
	Issued by:	Center Weather Service Unit at ARTCC
	Update:	As conditions warrant; event to begin within less than 2 hours
Severe Weather Watch Bulletin	**Issued for:**	A watch issued for areas where expected severe thunderstorms or tornadoes may exists.
	Issued by:	Storms Prediction Center in Norman, Oklahoma
	Update:	As conditions warrant

A number of the weather products are designed to support pre-flight planning and strategic decisions. These are captured in Table 3-17. Their applicability to tactical decision making is limited due to the update rates which vary from 1 hour to 12 hours.

There are a number of sensors that have been developed to aid in characterizing weather conditions in the terminal area. Table 3-18 contains a list of these sensor systems. Currently, three sensors are employed in the terminal area to address microburst and gust front detection. The low level wind shear alert system consists of an integrated set of anemometers placed along a runway to alert of potentially hazardous conditions. The terminal Doppler weather radar (TDWR) and the ASR-9 retrofitted with a weather systems processor (WSP) serve as remote sensors for the detection of wind shear conditions in the terminal area. The ASR-9 WSP is a lower cost alternative to the TDWR, which was designed specifically as a weather radar for the terminal area. Automated systems have also been developed to provide the measurements needed to file a METAR. Two systems, the Automated Weather Observation System (AWOS) and the newer Automated Surface Observation System (ASOS), provide continuous broadcast of measured conditions in the terminal area. The integrated terminal weather system (ITWS) is a system being developed by Massachusetts Institute of Technology (MIT) Lincoln Laboratories to combine measurements from a number of systems (*e.g.*, TDWR, next generation radar (NEXRAD), AWOS/ASOS, PIREPS). This integration of resources makes possible a more complete picture of current and forecasted conditions in the terminal area. Even though these systems exist and are fielded at a number of airports, cost currently limits the number of airports which can be supported by these systems. It should be pointed out that the NEXRAD (WSR-88D) radar provides input to a number of the weather products listed in Tables 3-15, 3-16 , and 3-17. The WSR-88D provides three moment data to the FAA/NWS support system (*e.g.*, AWC, CWSU, ATCT, *etc.*) to aid in the analysis of current and forecasted conditions. In general, NEXRAD radars are not located in the terminal area but provide wide area coverage out to approximately 200 nautical miles. There are approximately 162 WSR-88D installations located throughout the U.S.

Pilots do have some options in terms of on-board weather sensors (see Table 3-19). The most basic instrument is the pitot tube which measures flight speed and from which prevailing wind speeds may be derived. This information can be used in real-time to estimate fuel burn rates. A storm scope is available for the detection of lightning, which is an indicator of severe weather. The storm scope provides lightning strike intensity and direction information. Airborne weather radars are available and required for Part 121 operators. The airborne weather radar serves as a remote sensor to aid the pilot in identifying regions which may contain hazardous weather. Airborne weather radars have also been developed that can detect the presence of wind shear conditions during take-off and landing. However, current versions of airborne weather radars are not capable of distinguishing between different forms of precipitations, (*e.g.*, rain, snow, and hail) and are not capable of detecting phenomena containing low levels of precipitants (*e.g.*, clear air turbulence).

In a number of cases, the first level of defense for many pilots is personal observation. However, visual range is limited and many phenomena cannot be identified through visual observation. A final weather product that is used by many pilots is the pilot report or PIREP. This is a verbal description of conditions the pilot has experienced during flight that may be of interest to other pilots (*e.g.*, moderate to severe turbulence).

Table 3-17. Aviation Weather Products Used During Preflight Planning and in Making Strategic Decisions

Winds and Temperature Aloft Forecast	**Content:**	Winds and temperature
	Update:	12 hours
	Elevations:	3,000, 6,000, 9,000, 12,000, 18,000, 24,000, 30,000, 39,000, 45,000, and 53,000 ft (pressure alternate)
Radiosonde Additional Data	**Content:**	Freezing level and relative humidity
	Update:	12 hours
Constant Pressure Analysis Charts	**Content:**	Temperature, wind, dew point
	Update:	12 hours
	Elevations:	1,500, 3,000, 18,000, 30,000, 34,000, and 39,000 ft (pressure altitude)
Composite Moisture Stability Chart	**Content:**	Stability, freezing levels, precipitation water, and relative humidity
	Update:	12 hours
	Elevations:	Surface, 1,000, 850, 700, and 500 b/hPa
U.S. Low-level Significant Weather Prognosis	**Content:**	Fronts, pressure centers, precipitation, TS, IMC, VMC, turbulence, freezing levels
	Update:	6 hours
	Elevations:	Surface to 24,000 feet
High Level Significant Weather Prognosis	**Content:**	TS, turbulence, fronts, jet stream, tropopause, volcanic activity
	Update:	6 hours
	Elevations:	25,000 to 60,000 ft (pressure altitude)
Convective Outlook	**Content:**	Forecast of areas at risk for severe thunderstorms over the next 24-48 hours
	Update:	5 times per day
Surface Analysis Charts	**Content:**	Pressure systems, isobars, and observable weather at reporting stations
	Update:	3 hours
	Elevation:	Surface
Weather Depiction Chart	**Content:**	Summary of METAR reports
	Update:	3 hours
Radar Weather Report	**Content:**	Precipitation information
	Update:	1 hour
Radar Summary Chart	**Content:**	Precipitation information
	Update:	1 hour
Satellite Weather Pictures	**Content:**	Clouds: type and height
	Update:	0.25 to 1 hour
Hurricane Advisory	**Issued for:**	Hurricanes 300 nm offshore
	Issued by:	Tropical Prediction Center (Miami)
	Update:	As conditions warrant
Volcanic Ash Forecast and Dispersion Chart	**Issued for:**	Ash concentration forecast at different altitudes
	Issued by:	NOAA Air Resources Laboratory (ARL)
	Update:	6, 12, 24, and 36 hours after a volcanic eruption

Table 3-18. A Listing of the Major Terminal Area Ground Based Sensor Systems

Terminal Area Ground Based Sensor Systems
Microburst and Gust Front Detection
Low Level Wind Shear Alert Systems (LLWAS)
Terminal Doppler Weather Radar (TDWR)
ASR-9 with Weather Systems Processor (WSP)
Automated Surface and Terminal Area Observations
Automated Weather Observation System (AWOS)
Automated Surface Observation System (ASOS)
Runway Visual Range
Combined Systems
Integrated Terminal Weather System (ITWS)

Table 3-19. A Listing of On-Board Weather Sensors

On-board Weather Sensors
Pitot Tube
Storm Scope
Airborne Weather Radar

3.8 National Transportation Safety Board (NSTB) Data

In this analysis, the development of requirements for new or improved weather products is partially based on the use of NTSB accident data as an indicator of possible deficiencies in the current system. A study [3-11] has been conducted by the NTSB that identifies weather as either a cause or factor in some 3,978 accidents between 1989 and 1997. The study groups weather phenomena into eight categories: turbulence, visibility/ceiling, winds, wind shear, density altitude, icing, precipitation, and thunderstorms. The accident data are also partitioned by FAR Parts: 121, 135, 137, and 91. Part 137 is associated with those operating agricultural aircraft.

Figures 3-2, 3-3, 3-4, and 3-5 contain graphics showing the percentage of accidents indexed by weather and FAR category (121, 135, 137, and 91, respectively). Table 3-20 contains a summary of the total number of accidents and the total number of weather events that may have been either a cause or a factor in these accidents.

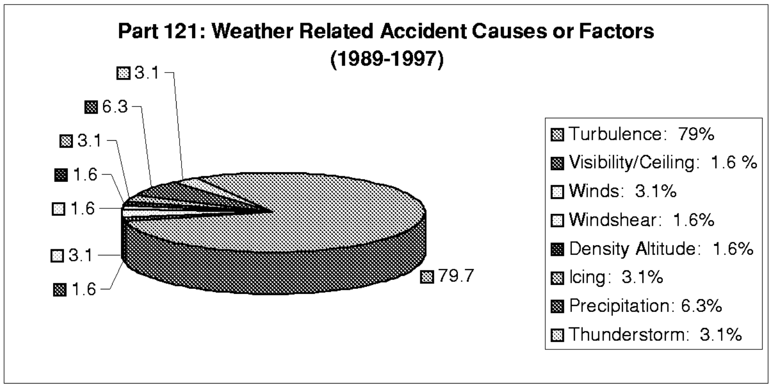


Figure 3-2. Results of an FAA study on weather related causes or factors in aircraft accidents between 1989 and 1997 for Part 121 operators

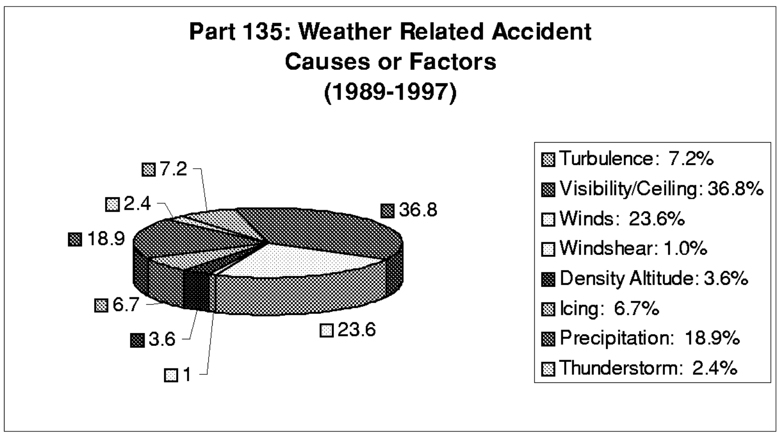


Figure 3-3. Results of an FAA study on weather related causes or factors in aircraft accidents between 1989 and 1997 for Part 135 operators

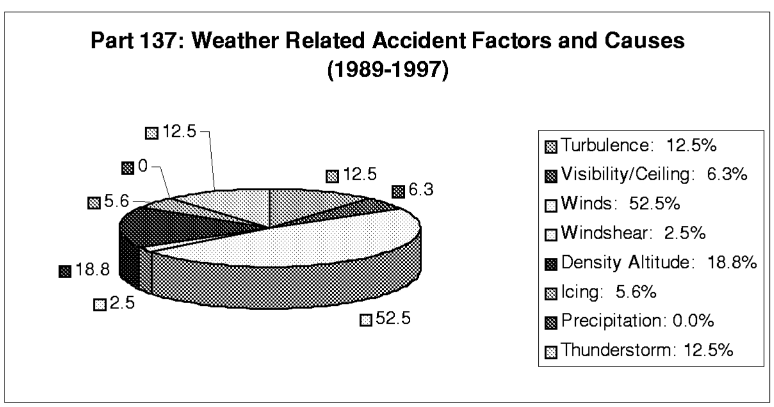


Figure 3-4. Results of an FAA study on weather related causes or factors in aircraft accidents between 1989 and 1997 for Part 137 operators

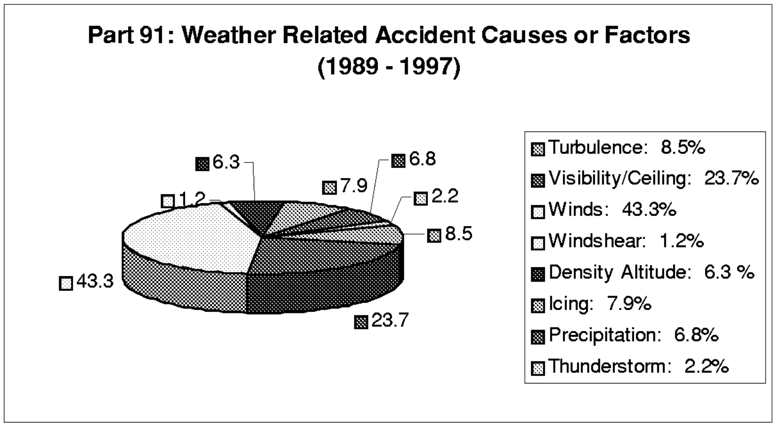


Figure 3-5. Results of an FAA study on weather related causes or factors in aircraft accidents between 1989 and 1997 for Part 91 operators

Table 3-20. A Listing of the Number of Weather Related Causes or Factors by FAA Category

Part	Number of Accidents	Weather Related Causes or Factors
121	60	64
135	249	419
137	128	160
91	3,510	5,231

Table 3-21 provides a comparison of the accident data by FAR category, and Table 3-22 provides a rank ordering of the weather events based on the percentages in descending rank order. Based on the study, the majority of the weather related accidents for Part 121 operators involved some form of turbulence. For Parts 135/137 and Part 91 operators, the majority of weather related accidents involved winds and visibility/ceiling conditions.

Table 3-21. A Comparison of the Weather Related Accident Causes or Factors by FAA Category

Weather Category	Part 121	Part 135	Part 137	Part 91
Turbulence	79.7	7.2	12.5	8.5
Visibility/Ceiling	1.6	36.8	6.3	23.7
Winds	3.1	23.6	52.5	43.3
Windshear	1.6	1	2.5	1.2
Density Altitude	1.6	3.6	18.8	6.3
Icing	3.1	6.7	5.6	7.9
Precipitation	6.3	18.9	0.0	6.8
Thunderstorm	3.1	2.4	12.5	2.2

Table 3-22. A Listing of the Weather Categories in Descending Order that Have Contributed to Aircraft Accidents

Part 121	Part 135	Part 137	Part 91
Turbulence	Visibility/Ceiling	Winds	Winds
Precipitation	Winds	Density Altitude	Visibility/Ceiling
Winds	Precipitation	Turbulence	Turbulence
Icing	Turbulence	Thunderstorm	Icing
Thunderstorm	Icing	Visibility/Ceiling	Precipitation
Visibility/Ceiling	Density Altitude	Icing	Density Altitude
Windshear	Thunderstorm	Windshear	Thunderstorm
Density Altitude	Windshear	Precipitation	Windshear

In cases where visibility/ceiling conditions are a cause or factor, fog, haze/smoke, and low ceilings were the major contributors. The data supporting this analysis are shown in Figure 3-6. Figure 3-7 contains a break out of the different categories of wind that either caused or were a factor in these accidents. The categories of winds used in this study do not correlate directly to the atmospheric conditions that produced them. However, it should be noted that winds are a major contributing factor in accidents for Part 135 and Part 91 operators.

The NTSB study provides an indicator of the types of weather phenomena that continue to contribute to weather accidents. In some cases, the percentage of accidents is small, but for the Part 121 or 135 operator, a single accident may put a number of lives at risk. A number of the existing weather products address weather phenomena in the NTSB report; however, the accident data indicate that room exists for improvements. The NTSB study is used in this analysis to provide the basis for some of the weather requirements defined in the next section.

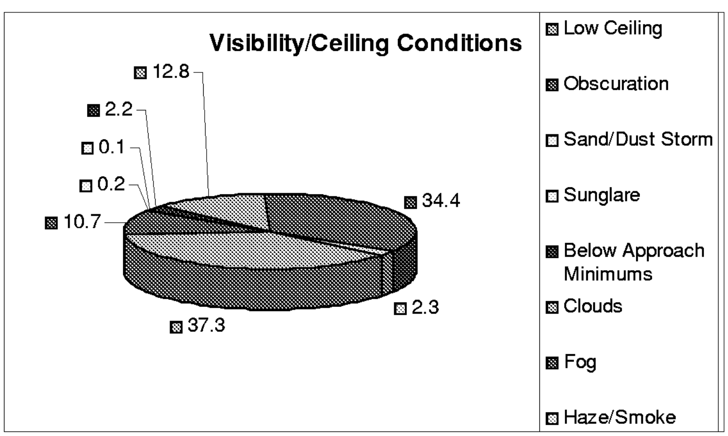


Figure 3-6. A summary of the conditions leading to visibility/ceiling related accidents

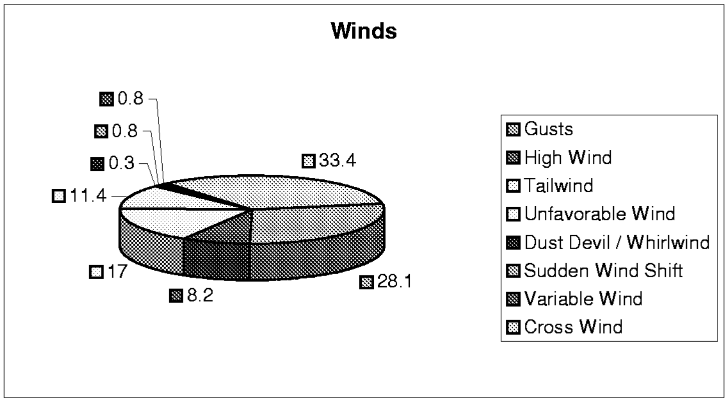


Figure 3-7. A summary of the conditions leading to wind related accidents

3.9 Weather Product Requirements Recommendations

The goal of this study is to define recommendations for weather information requirements that will result in improved aviation safety. These requirements are developed within a framework that simultaneously supports an increase in aviation system capacity. The recommended requirements are based on an analysis of weather hazards, phase of flight weather information requirements, current weather products, and NTSB data discussed in the previous sections. A number of the weather information requirements defined in studies performed in the early 1990s [3-8, 3-9, 3-10] still hold true in the year 2000 and are also included in this analysis.

A cooperative decision making relationship must exist between the pilot, air traffic control, and the dispatcher. However, under this study, an explicit assignment of common and distinct requirements between the users was not developed. The requirements focus more on the weather information needed during each phase of flight and the hardware/communication equipment required to disseminate and interpret the information. It is assumed that the partitioning of the information between pilot, ATC, and dispatcher will be developed at a later date and will require input from all three groups in order to satisfy regulatory, commercial, and personal (pilot and ATC) views of weather information.

In Section 3.4, the weather hazards were grouped into eight major categories: weather systems, air motion, precipitation, icing, visibility and ceiling, lightning, volcanic ash, and wake vortices. The atmospheric conditions that are potential hazards to aviation could be grouped in a number of ways with acknowledged overlaps between categories. However, the categories provide a mechanism for defining the types of atmospheric conditions that impact aviation safety without the need to list all of the possible conditions and the sources of those conditions, for fear of omitting one. There is a general requirement that aviation weather products address each of the weather hazards in terms of: forecast, observations, intensity, location, extent, movement, and life cycle. Based on an assessment of aviation weather hazards, GTRI proposes the following general requirements:

- A requirement for aviation weather products to address the eight categories of weather phenomena defined in the report (reference Tables 3-2, 3-3, 3-4, 3-5, 3-6, and 3-7)
- A requirement for aviation weather products to address hazards in terms of forecasted conditions, current conditions (observations/measurements), intensity, location, extent, movement, and life cycle

The phases of flight analysis, described in Section 3.6, includes the forecasted or current weather information required by the pilot as a function of the departure, en route, and arrival segments. In general, forecasted weather information is applied in making strategic decisions; whereas, information on current weather conditions is required to make real-time tactical decisions. Tables 3-13, 3-14, 3-15, and 2-16 define the required weather information on a per-phase of flight basis using the eight categories of weather hazards defined in Section 3.4. The timeliness of the weather information is grouped into two categories: forecast and current. Based on GTRI's analysis of the 12 phases of flight, GTRI proposes the following requirement:

- A requirement for aviation weather products to provide both strategic and tactical (for forecasted and current conditions) information as a function of the phase of flight (reference Tables 3-13, 3-14, 3-15, and 3-16)

Based on a review of the current weather products and interviews with users, GTRI proposes the following requirement:

- A requirement for more accurate, localized descriptions of forecasted and current conditions tailored to the need of the aviation community

The terminal area has been identified as the area where weather may have the most impact in terms of flight safety. The dense aircraft environment, reduced airspeeds, and low altitudes combine to intensify the effects of weather on the pilot and aircraft. New requirements for the terminal area are focused on hazards associated with winds and ceiling/visibility. As noted in the previous sections, low altitude winds (wind shear and turbulence) can result in an aircraft deviating from the intended flight path, which at low altitudes, may result in impact with the ground or low trajectories on take-off.

Current sensor systems in the terminal area include Terminal Doppler Weather Radars (TDWR), Low Level Wind Shear Alert System (LLWAS), and ASR-9 radars equipped with a weather systems processor (WSP). A capability to support three-dimensional wind sensing in the terminal area is desired to maximize safety. However, to date, system cost and complexity have placed a limit on the number of field systems that may be used to address this requirement. There are some 45 TDWRs located across the country. However, the TDWR also has its limitations [3-2]. The TDWR does not provide warnings of wind shear conditions outside the alert boxes on the approach and departure ends of the runway. The TDWR does not report wind shear conditions that are not associated with a microburst or gust front. The TDWR does not detect turbulence and cross or gusty winds.

The low level wind shear alert system (LLWAS) consists of anemometers placed on poles (as high as 150 feet above the surface) which are located around the runway environment. The sensors provide input to a processor that is used to detect wind shear conditions. The LLWAS was originally located at 110 airports. These systems are being phased out and are being replaced by an upgraded system termed the LLWAS-NE (network expansion) which will be located at 39 airports. In general, the LLWAS is restricted to *in situ* measurements of low level phenomena.

The ASR-9 radar retrofitted with a weather systems processor is used at airports where financial constraints do not permit the installation of a TDWR. The ASR-9 is scheduled for deployment at 34 airports across the continental U.S. The integrated terminal weather support system (ITWS) is a system designed to combine the inputs from a number of sensors including TDWR, LLWAS, ASOS, and WSR-88D in order to develop a better composite picture of conditions in the terminal area. On board weather radars also serve a major role in providing a pilot real-time information on microburst conditions.

An analysis of the aforementioned systems and the weather hazards found in the terminal area led to the following set of requirements:

- A requirement for integration/fusion of weather sensors to develop an improved composite view of the weather conditions in the terminal area
- A requirement to support three-dimensional wind sensing in the terminal area
- A requirement to support detection of wind phenomena that contain low levels of precipitants (*e.g.*, dry microburst and gust fronts)
- A requirement for lower cost systems to support wind sensing in the terminal area; this is intended to increase the number of airports having this capability

Wake vortex detection and tracking is needed in the terminal area to support a safe environment while increasing airport capacity by reducing the time between landings. As noted previously, wake vortices are induced by aircraft on take-off and landing and pose a threat to smaller aircraft. To support increased capacity and flight safety, a wake vortex detection system must be able to operate under all weather conditions. Based on current wake vortex sensor development programs and known hazards associated with wake vortices, GTRI proposes the following requirement:

- A requirement for wake vortex detection and tracking in the terminal area under all weather conditions

For both VMC and IMC, some level of visibility is required to support an attempted landing. For the VFR pilot, visibility minimums are approximately 3 statute miles with 500 foot separation below clouds. For the IFR pilot, a decision height is defined at which the pilot must see the runway environment based on visual cues. In general, a pilot may be provided with ceilings and RVR conditions prior to entering the terminal area. The information is provided by sensors which take point or very localized measurements or by human observation. The pilot must use this information to extrapolate conditions which may exist along the intended glide slope. Through discussions with pilots and NASA, GTRI has identified a desire for a sensor system to provide real-time slant range visibility conditions along the glide slope. This would permit a pilot to make strategic decisions concerning the conditions at an airport thereby allowing him to divert to an alternate airport at an early point in the flight phase. The concept of a slant range visibility sensor is shown in Figure 3-8. Based on initial discussions and analysis, GTRI proposes the following requirements:

- A requirement for a sensor system to provide real-time slant range visibility conditions along the glide slope
- A requirement for improvements in ceiling and visibility forecast

As noted in the preflight analysis, the pilot (and/or dispatcher and ATC) may need to review large quantities of data from a number of sources to obtain an accurate picture of the current and forecasted conditions along the intended route. The need exists for an automated system that would permit a pilot to query a database using flight specific information. The weather products supplied to the pilot would then be tailored to his route, to the type of aircraft, and to the intent of the pilot as indicated by the flight plan. Based on a review of the current weather products, GTRI proposes the following requirement:

- A requirement for an automated system allowing a user to enter route and aircraft specific information that would then provide the pilot with tailored weather products to aid in preflight planning

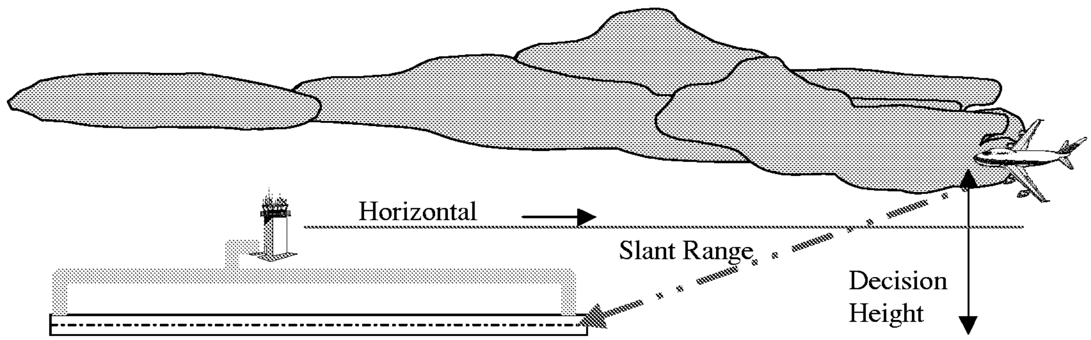


Figure 3-8. The concept of a slant range visibility sensor to alert the pilot of conditions along the glide slope

A need exists for a system to alert pilots (and/or dispatcher and ATC) in real-time of changing conditions that would result in a VMC to IMC transition with sufficient time for the pilot to take necessary measures to perform replanning in-flight. Such a system would need to provide real time updates of cloud ceilings and coverage on a finer spatial grid that currently exists. Area forecasts, which provide visual meteorological conditions, are forecasted over large areas (several states). Based on a review of the current weather products, GTRI proposes the following requirement:

- A requirement for a real-time system providing current information on VMC and IMC (*e.g.*, cloud ceilings and coverage) on a finer time and spatial scale than currently exists

Weather products are required which support finer spatial and temporal grids than currently exist if improvements in aviation safety are to be achieved. From a temporal perspective, a number of weather products used in pre-flight planning and strategic analysis are updated at intervals of hours (anywhere from 1 to 12 hours). The first four weather products in Table 3-18 are derived from radiosonde measurements that are taken at 0000Z and 1200Z each day. The spatial and temporal spacings of these measurements limit the accuracy of the weather prediction models and the update rates of the corresponding weather products. A requirement exists for updates to the radiosonde measurements on a finer temporal and spatial scale. Other weather products could also be updated on a finer time scale (*e.g.*, a METAR, a weather depiction chart, a radar weather report, and a radar summary chart) in order to better monitor changing conditions that impact aviation. However, the infrastructure must exists to support the increased amount of data. Based on a review of the current weather products, GTRI proposes the following requirements:

- A requirement for an increase in the update rate associated with a number of weather products used in pre-flight planning
- A requirement for a finer time and spatial spacing between radiosonde measurements

Weather products are also needed which report conditions that were not forecasted. The current system of delivering weather products to the pilot, based upon requests, needs to be converted to an automated system that provides continuous updates to changing conditions, especially those that were in not in the original forecast. Based on a review of the current weather products and delivery systems, GTRI proposes the following requirement:

- A requirement for an automated system, requiring little pilot interaction, to deliver updates to the pilot as weather conditions change

In terms of spatial requirements, weather products need to be designed to provide a more accurate localized description of forecasted and current conditions. Atmospheric conditions should be quantified in terms of a three dimensional coordinate system (*e.g.*, GPS coordinates) describing position, extent, and movement. A number of the in-flight weather advisories reference hazardous weather locations by VORs, airports, and geographic features. Systems should be developed that can interpret three dimensional coordinates and relate them to the aircraft's position and intended route in real-time. Based on a review of the current weather products, GTRI proposes the following requirements:

- A requirement for a standardized three dimensional coordinate system (*e.g.*, GPS coordinates) in which to describe a hazard's position, extent, and movement
- A requirement for on-board equipment to interpret position and movement of hazardous conditions (based on a three dimensional coordinate system) in relation to the aircraft's current position and intended route

Expert systems are required to support the large amounts of weather information that will be needed to increase flight safety. Both the air traffic control system (*e.g.*, tower, TRACON, ARTCC, AWC, FSS, *etc.*), support operations (*e.g.*, dispatchers and air line operation centers), and the pilot will need some level of artificial intelligence to handle the large amounts of data and to provide interpretation/analysis based on a particular flight plan. Some of the FAA/NWS systems already exhibit some level of artificial intelligence. However, pilots need to be supported by on-board weather data processors and displays that can receive, process, and display weather information in a format that is specific to their particular flight and is easily interpreted. The demands on the pilot are already high, and operating in adverse weather conditions dramatically increases the workload. The system needs to be as autonomous as possible, providing specific options for the pilot under duress. An autonomous, expert system would start to bridge the gap between Part 91 operators who rely solely on the FAA support system and Part 135/121 operators who are backed up by dispatchers and airline operations center personnel who provide automatic updates as conditions warrant. Based on a review of the current weather products and systems, GTRI proposes the following requirements:

- A requirement for an autonomous, on-board, expert system providing weather information in the cockpit in a graphical format; the expert system should be capable of handling and interpreting large amounts of data and should provide specific options for the pilot based on current and forecasted weather information

Two atmospheric phenomena/conditions that are not adequately detected or characterized by the current set of weather products and sensors are icing and turbulence. Currently, this information is provided either through forecast data or via PIREPS which pilots use to provide reports of adverse weather conditions they have experienced. On-board sensors are required to remotely detect and warn pilots of hazardous conditions with sufficient time for pilots to take evasive action. Based on a lack capability and the reality of the potential hazards, GTRI proposes the following requirements.

- A requirement for on-board sensors to address in-flight icing
- A requirement for on-board sensors to address turbulence

Cost is always a factor in the process of defining requirements and in some cases requirements are imposed or not imposed based on cost feasibility. Every effort should be made to provide the safest possible environment with the understanding that there exists a limit to the amount of funds which can be expended. The FAA, NASA, commercial airlines, and the aviation industry must work together to provide the safest environment possible. Some of the effort needs to focus on low-cost solutions that may permit certain weather products to be expanded in support of the user with limited funds. GTRI proposes the following requirements that will require a cooperative effort to obtain.

- A requirement for lower cost, on-board weather systems to support the smaller aircraft that fall under Part 91 operations
- A requirement for a reduction in the number of airports where the pilot is required to rely solely on personal observation or PIREPs to obtain local information

The current PIREP system is based on manual entry of information provided to flight service stations by pilots. This system is known to be stressed during times of adverse weather conditions. In addition, the reports are subjective based on pilot observations. To provide better reporting capabilities and more detailed information, an electronic pilot reporting system is desired. EPIREPs will provide a real-time method of receiving and entering reports into the system for dissemination without operator/pilot intervention. On-board sensors will provide inputs to EPIREPs for a more quantitative view of the current conditions. Based on stated objectives for EPIREPS and the obvious benefits in terms of both safety and further research, GTRI proposes the following requirement:

- A requirement for on-board sensors to provide inputs for EPIREPS

Precipitation and icing can have a significant impact on the runway coefficient of friction. This can impact an aircraft's ability to stop or main control during landing and takeoff. A sensor is need to report runway surface conditions. GTRI proposes the following requirement:

- A requirement for a system to sense and report runway surface conditions (*e.g.*, runway coefficient of friction) that relate to the pilot's ability to stop or maintain control of the aircraft while the aircraft is on the runway

With the future loss of the GOES split channel, satellite detection of volcanic ash will be significantly impaired. GTRI sees a need for a requirement to identify a replacement sensor to detect and track volcanic ash. Therefore, GTRI proposes the following requirement:

- A requirement for a replacement sensor (loss of GOES split channel) to detect volcanic ash

A summary of the weather information requirements developed during this study are captured in Table 3-23. These recommended requirements are intended as steps toward improving flight safety and efficiency.

Table 3-23. A Listing of the Requirements Developed Under this Study to Improve Flight Safety

• A requirement for aviation weather products to address the eight categories of weather phenomena defined in the report (reference Tables 3-2, 3-3, 3-4, 3-5, 3-6, and 3-7)
• A requirement for aviation weather products to address hazards in terms of forecasted conditions, current conditions (observations/measurements), intensity, location, extent, movement, and life cycle
• A requirement for aviation weather products to provide both strategic and tactical (for forecasted and current conditions) information as a function of the phase of flight (reference Tables 3-13, 3-14, 3-15, and 3-16)
• A requirement for more accurate, localized descriptions of forecasted and current conditions tailored to the needs of the aviation community
• A requirement for integration/fusion of weather sensors to develop an improved composite view of the weather conditions in the terminal area
• A requirement to support three-dimensional wind sensing in the terminal area
• A requirement to support detection of wind phenomena that contain low levels of precipitants (*e.g.*, dry microburst and gust fronts)
• A requirement for lower cost systems to support wind sensing in the terminal area; this is intended to increase the number of airports having this capability
• A requirement for wake vortex detection and tracking in the terminal area under all weather conditions
• A requirement for a sensor system to provide real-time slant range visibility conditions along the glide slope
• A requirement for improvements in ceiling and visibility forecast
• A requirement for an automated system allowing a user to enter route and aircraft specific information that would then provide the pilot with tailored weather products to aid in preflight planning
• A requirement for a real-time system providing current information on VMC and IMC (*e.g.*, cloud ceilings and coverage) on a finer time and spatial scale than currently exists
• A requirement for an increase in the update rate associated with a number of weather products used in pre-flight planning
• A requirement for a finer time and spatial spacing between radiosonde measurements
• A requirement for an automated system, requiring little pilot interaction, to deliver updates to the pilot as weather conditions change
• A requirement for a standardized three dimensional coordinate system (*e.g.*, GPS coordinates) in which to describe a hazard's position, extent, and movement
• A requirement for on-board equipment to interpret position and movement of hazardous conditions (based on a three dimensional coordinate system) in relation to the aircraft's current position and intended route
• A requirement for an autonomous, on-board, expert system providing weather information in the cockpit in a graphical format; the expert system should be capable of handling and interpreting large amounts of data and should provide specific options for the pilot based on current and forecasted weather information
• A requirement for on-board sensors to address in-flight icing
• A requirement for on-board sensors to address turbulence
• A requirement for lower cost, on-board weather systems to support the smaller aircraft that fall under Part 91 operations
• A requirement for a reduction in the number of airports where the pilot is required to rely solely on personal observation or PIREPs to obtain local information
• A requirement for on-board sensors to provide inputs for EPIREPS
• A requirement for a system to sense and report runway surface conditions (*e.g.*, runway coefficient of friction) that relate to the pilot's ability to stop or maintain control of the aircraft while the aircraft is on the runway
• A requirement for a replacement sensor (loss of GOES split channel) to detect volcanic ash

References

3-1. Mahapatra, Pravas, *Aviation Weather Surveillance Systems*, The Institution of Electrical Engineers, Micheal Faraday House, United Kingdom, 1999.

3-2. Gleim, I. N., *Aviation Weather and Weather Services*, Gleim Publications, Inc., Gainesville, Florida, 1998.

3-3. Doviak, R. J., and D. S. Zrnic, *Doppler Radar and Weather Observations*, 2nd Edition, Academic Press, San Diego, 1993.

3-4. Mahapatra, P. R., and D. S. Zrnic, "Sensors and Systems to Enhance Aviation Safety Against Weather Hazards," *Proceedings of the IEEE*, Vol. 79, No. 9, pp. 1234-1267, September 1991.

3-5. Fujita, T. T., and J. McCarthy, "The Application of Weather Radar to Aviation Meteorology," *Radar in Meteorology*, American Meteorological Society, Boston, MA, Chapter 31a, pp. 657-681.

3-6. Sherertz, F., et al., National Aviation Weather Initiatives, FCM-P34-1999, Washington, D.C., February, 1999, available at http://www.ofcm.gov/homepage/text/pubs_linx.htm

3-7. Ball, J. W., *et al.,* "Aviation Weather Communication Requirements," Lockheed Martin Aeronautical Systems, Phase I Report for Glenn Research Center, June 1999.

3-8. Crabill, N. L., and E. R. Dash, "Pilot's Weather Information Requirements and Implications for Weather Data Systems Design," DTFA-01-90-4-01019, NAS1-18585, available via NTIS, April, 1991.

3-9. "Two-Way Data Link versus Broadcast Communications for Flight Information Services," RTCA SC – 169, Working Group 3, Cockpit Requirements Issues Subgroup, DRAFT, August, 1993.

3-10. "Air Traffic Weather Requirements Report," prepared by the Air Traffic Weather Requirements Team (ATWRT), February, 1993.

3-11. FAA Office of System Safety, Weather Study, available at Internet World Wide Web Site www.asy.faa.gov/safety_analysis/weather_study

4 An Investigation of Sensor System Uses, Needs, and Requirements for Aviation Weather Information Collection

4.1 Task Summary

This section of the report contains an overview of sensors applied in obtaining aviation weather information. This phase of the study has focused on identifying new or existing sensors that may provide possible solutions in addressing weather product deficiencies identified in Sections 2 and 3. Possible sensors include radiometers, coherent lidar, polarization diverse radars, bistatic multiple-Doppler radars, and low-cost microburst detection radars.

This study has also identified possible sensor suites for inclusion in an electronic pilot report. Electronic pilot reports are designed to support both flight safety, research, and forecasting. The approach taken in this study is to identify low cost sensors or existing on-board sensors. Table 4-1 contains a list of the sensors identified under this study.

Table 4-1. A List of Possible Sensors to Include in an EPIREP Sensor Suite

EPIREP Reporting Options
An Outside Temperature Sensor
Wind Speed and Direction Sensors
A Relative Humidity Sensor
Location (GPS coordinates) and Time Stamp
Degree of Turbulence (Accelerometers)
Airborne Weather Radar Summaries
Icing Sensors on the Surface of the Aircraft

4.2 Introduction

Weather has a direct impact on aviation in three areas: economics, efficiency, and safety. The ability to sense measurable properties associated with atmospheric events provides the aviation community with information on which to base both strategic and tactical decisions in all three areas. Modern sensor systems provide a means of measuring the physical properties of the atmosphere either remotely or *in situ* and of processing the measured quantities to arrive at aviation specific products. This part of the study contains an investigation of the current set of sensors applied either directly or indirectly in support of aviation. This section of the report contains recommendations for existing, modified, or new sensor systems which may be applied in overcoming the deficiencies as noted in Sections 2 and 3. Special attention is given to candidate sensor packages that could be incorporated in an electronic pilot reporting system.

This section of the report is broken into six major sub-sections. The third sub-section gives an overview of the sensor systems currently applied either directly or indirectly in aviation weather applications. A section that expands upon each of the identified sensors follows this section. The fifth sub-section identifies sensor systems as potential solutions for detecting and characterizing a number of hazards identified in the second phase of the study . The final section discusses potential sensor suites that could provide input to an electronic pilot reporting system.

4.3 Overview of Sensors in Support of Aviation Related Weather Information

The aviation community depends on both direct sensor observation and forecast of meteorological conditions for safe and efficient flight. The forecasts, in turn, are generally derived from inputs from a number of different sensors. The current FAA and NOAA/NWS support system provides weather products that are tailored specifically for aviation or provides weather products that may be applied to aviation with some additional interpretation. The resulting weather products, derived from sensor measurements, may be applied in both strategic and tactical decision making. This section provides an overview of the current set of sensor systems supporting the aviation community. A more detailed description of the individual sensors and their operating parameters is given in Section 4.4.

The Federal Aviation Administration (FAA) is the governing agency that oversees or approves weather information sources for aviation. In a number of cases, the FAA has directly funded the development of aviation weather sensor systems and governs the operation and maintenance of these systems once they are fielded. Sensing, analysis, interpretation, prediction, and reporting of weather information on a national scale falls under the jurisdiction of the National Weather Service (NWS). The NWS owns and operates a number of assets that are used by the aviation community. In addition to FAA and NWS operational assets, a number of aviation weather sensing systems (including commercial, academic, and NWS/FAA funded) are under development. Sensors often provide weather information that may be applied in support of tactical aviation decisions. Sensors may also collect information that will used to derive forecast of weather conditions over the next several hours or days supporting both near-term strategic and long-term strategic decisions. For example, the National Centers for Environmental Prediction's Rapid Update Cycle (RUC) II model generates 3 hour forecasts using inputs from a number of different sensors positioned across the country. The following sections describe both tactical and strategic sensors which provide weather information to the aviation community either directly or indirectly (*e.g.,* as input to a forecast model).

Weather sensing systems perform measurements either remotely or *in situ* (in direct contact with). In the case of aviation, these sensors may be located on the ground, or they may be positioned on an aircraft, balloon, or satellite. A number of the weather sensors use electromagnetic (EM) energy as a means of either actively or passively measuring some property of the atmosphere. Radars are active EM sensors that operate in the 3 MHz to 300 GHz range [4-1]. Radars are a unique remote weather sensing device due to their ability to characterize the internal structure of a storm and to see through one storm and into the next. Attenuation is a factor, but long range systems have been designed to operate in all weather conditions in the frequency range from 3 MHz to 12 GHz (HF-band to X-band). The aviation weather support structure includes radars which support both en route and terminal area weather surveillance. On board the aircraft, FAA-approved and commercially available airborne weather radars (AWR) provide precipitation intensity, turbulence detection (when associated with precipitation), and wind shear detection (on approach and landing). Manufactures include Honeywell, Rockwell Collins, and Allied Signal (now merged with Honeywell). Parameters for several of the AWRs are given in Section 4.4. The wind shear mode is only found on versions supporting the commercial aircraft industry.

In the terminal area, the terminal Doppler weather radars (TDWR) and airport surveillance radars (ASR-9) retrofitted with a weather systems processor (WSP) provide wind shear detection, wind shift prediction, precipitation intensity, and storm tracking. The TDWRs are located at 45 major airports in the U.S., and the ASR-9s with a WSP are located at some 34 major airports in the U.S. The ASR-9's primary function is air traffic surveillance in the terminal area. The WSP retrofit is intended to provide the functionality of the TDWR without the additional cost. The air route surveillance radar (ARSR) is associated with an air route traffic control center (ARTCC). The ARSR provides en route air traffic surveillance. The ARSR also provides coarse precipitation information in the area assigned to the ARTCC. Each of these radars is under the jurisdiction of the FAA.

The National Weather Service also oversees a number of radar assets. NWS radar products, in general, find their way back into the aviation community either directly or indirectly. The NWS's most popular, and in some sense vital, asset is the weather surveillance radar – 88 D (WSR-88D). The network of 158 operational radars provides almost complete coverage of the 48 contiguous states, Hawaii, and Alaska. Weather products generated by the WSR-88D are supplied directly to the aviation weather center (AWC) and other air traffic control centers. The NWS falls under the jurisdiction of the National Oceanic and Atmospheric Administration (NOAA). NOAA also houses the Forecast Systems Laboratory (FSL) under the office of Oceanic and Atmospheric Research. The FSL maintains the NOAA wind profiler network (NWPN). Wind profilers are vertically oriented UHF radars that provide horizontal wind speed and direction information as a function of elevation. This information may be used as an input to the RUC II forecast model providing forecasted winds over the contiguous 48 states. A number of the NWPN sites are also equipped with a radar-acoustic sounding system (RASS) which provides temperature estimates as a function of altitude. The RASS uses a radar to estimate the speed at which an acoustic pulse travels through the atmosphere. The speed of propagation can be directly related to the temperature of the atmosphere. NOAA has also developed a more loosely bound network of boundary layer wind profilers. The boundary layer profilers are owned by some 34 different agencies. The boundary layer network provides an additional source of horizontal wind information for the RUC II forecast model. Wind profilers have been used at a limited number of airports to map horizontal winds but are not currently a part of the FAA radar support system. Table 4-2 and Table 4-3 contain a list of FAA and NOAA/NWS radar assets described in the preceding paragraphs.

Table 4-2. List of FAA and NOAA/NWS Radars

Operational Radar Systems	Governing Agency	Operational Area
Airborne Weather Radars	Pilot/FAA Approved	On-board Aircraft
Terminal Doppler Weather Radar	FAA	Terminal Area
Airport Surveillance Radar – 9	FAA	Terminal Area
Air Route Surveillance Radar	FAA	En route
Weather Surveillance Radar – 88D	NOAA/NWS	Continental U.S.
NOAA Wind Profiler Network	NOAA/NWS	Localized
Radio Acoustic Sounding System	NOAA/NWS	Localized
Boundary Layer Profiler Network	NOAA/NWS	Localized

Section 4.4 of this report contains a description of a number of experimental radars and some proposed operational radars that are in the concept or demonstration phase. A very brief description of each radar is given here as an overview. Table 4-4 contains a list of a number of these radars. The FAA has in its plans the development of a next generation terminal area surveillance system (TASS) that will incorporate the functions of the TDWR and ASR-9 into one radar system. The focus has been on a phased array radar providing electronic scan capabilities. However, the program seems to have stalled.

Table 4-3. A Functional Description of FAA and NOAA/NWS Radars

Radar	Frequency Band	Application
Airborne Weather Radars	X or C	Airborne radars used for the detection of severe weather en route and the detection of windshear on approach and take-off
TDWR	C	Ground based radars used to characterize weather conditions in the terminal area (*e.g.*, microburst, gust fronts, storms tracks)
ASR-9 w/ WSP	S	Ground based airport surveillance radars retrofitted with a weather processor to duplicate the functionality of a TDWR
WSR-88D	S	The National Weather Service's ground based radar which provides products to a number of different organizations including aviation
ARSR	L	The ground based air route surveillance radar which offers limited precipitation rate information
Wind Profiler Network	UHF	A network of ground based wind profilers providing horizontal wind speed and direction as a function of altitude
RASS	UHF/VHF	A system composed of a wind profiler radar and an acoustic sounder used to measure temperature
Boundary Layer Profiler Network	UHF	A loose network of low cost, low power wind profilers used to measure wind profiles within the boundary layer

Table 4-4. A List of Some of the Experimental Radars or Those Under Development

Experimental or Developmental Radar Systems
Terminal Area Surveillance System
Unisys Microburst Prediction Radar
SPY-1 Radar with a Weather Processor
Bistatic Multiple-Doppler Networks
Dual Doppler Radars
Dual Frequency Radars
Polarization Diverse Radars

This report also contains a description of a low cost, low power X-band phased array radar developed by Unisys for microburst detection in the terminal area. In addition, Lockheed Martin has been involved in the addition of a weather processor to the Aegis SPY-1 radar. This has potential application in gathering weather information over the oceans. There are plans in the works to field a SPY-1 Radar at NSSL in Norman, Oklahoma over the next 2 years. This system would include the Lockheed Martin weather processor.

Bistatic Doppler radars have also been applied in experimental systems as low cost alternatives to a dual Doppler radar system for obtaining wind field vector estimates. Research radars have also been designed with dual frequency capability or polarization diversity. A dual frequency radar is able to estimate liquid water content by exploiting Rayleigh scattering and frequency dependent attenuation. A polarization diverse radar offers the potential for discrimination between precipitant types. The application of polarization diversity is currently being addressed in the FAA sponsored NEXRAD Enhancements Product Development Team. These enhancements will be examined in Section 4.5 as possible solutions to fill the gaps identified in Sections 2 and 3.

Table 4-5 contains a list of some of the electro-optical/infrared (EO/IR) and millimeter wave sensors used in aviation weather sensing. Radiometers are passive devices operating in the tens of GHz range. These passive sensors have been applied in measuring the temperature of the atmosphere and measuring the integrated liquid water and water vapor content of the atmosphere. Radiometers are sensitive to water vapor content at specific frequencies where water vapor is strongly emitting. Weather satellites are equipped with radiometers, infrared sensors, and electro-optic sensors (visible light sensors). The infrared sensors are used to measure temperature, and the electro-optic sensors are used to observe cloud formations. The runway visual range sensors are derived from optical measurements of light scattering by hydrometers such as fog droplets. A ceilometer is a type of laser range finder. The altitude of a cloud is determined from the round-trip time for a pulse of light to travel from the ground to the cloud and back. A coherent lidar operates on the same basic principles as a coherent radar: a pulse of laser light is transmitted, and the received light is mixed with light from another laser that serves as a reference local oscillator. The local oscillator is usually offset in frequency by about 10 MHz to create an intermediate frequency (IF). Coherent lidars can estimate radial velocities by measuring scatterer induced Doppler shifts.

Table 4-5. A List of EO/IR and Passive Millimeter Wave Sensors

Sensors
Radiometers
Electro-optic Sensors (Visible Range)
Infrared Sensors
Runway Visual Range Sensors
Ceilometers
Coherent Lidar

In situ sensors also play an integral role in the aviation weather information support system. Table 4-6 contains a list of the *in situ* sensor systems. Automated surface observation systems (ASOS) located at airports provide wind, temperature, dew point, visibility, clouds/ceiling, and precipitation information. The ASOS sensor package includes a ceilometer, a visibility sensor, a precipitation identification sensor, a freezing rain sensor, pressure sensors, an ambient temperature sensor, a dew point sensor, and an anemometer. The automated weather observing system (AWOS) is a predecessor to the ASOS and may be fielded in a number of different configurations, some consisting of a subset of the sensors listed above. The low level wind shear alert system (LLWAS) is a network of anemometers placed in the terminal area to detect the presence of a wind shear condition. *In situ* sensors are also available on board aircraft. The basic aircraft is outfitted with sensors to measure wind speed and direction along the route and with sensors to measure the outside temperature. The meteorological data collection and reporting system (MDCRS) provides a telemetry capability for ACARS-equipped aircraft to report temperature and wind information as a function of altitude. Some aircraft have also been outfitted with a relative humidity sensor. This type of system provides data for input to forecast models. The NWS also maintains a national radiosonde network. Radiosondes are balloons instrumented with sensors to measure temperature, wind speed and direction, and relative humidity.

Table 4-6. A List of *In Situ* Based Sensors

***In Situ* Sensor Systems**
Automated Surface Observation System/Automated Weather Observing System
Low Level Wind Shear Alert System
Meteorological Data Collection and Reporting System
Radiosonde

Table 4-7 contains a list of sensors that did not fit neatly under the previously defined categories but are also an integral part of the aviation weather information support system. Lightning is a real threat to aviation since it is a source of electrical energy that may damage sensitive aircraft components. In addition, the presence of lightning is an indicator of severe weather. The National Lightning Detection Network (NLDN) is operated by Global Atmospherics, Inc. The NLDN is responsible for providing information on cloud-to-ground lightning strikes through a network of EM sensors. This information is made available to the aviation weather support system. Some aircraft are also outfitted with on-board lightning detection systems.

Table 4-7. List of Additional Sensors Used in Support of Aviation

Sensor Systems
National Lightning Detection Network
Airborne Lightning Detection Sensors
Global Positioning System - Integrated Precipitable Water Measurement System
Integrated Terminal Weather Support System

NOAA's Forecast Systems Laboratory (FSL) operates a network of global positioning system receivers that are used to estimate the integrated precipitable water along the signal path. Again, this information is used to support forecasting and modeling. Finally, the Massachusetts Institute of Technology (MIT)/Lincoln Laboratories (LL) has developed a system to integrate the outputs of a number of sensors (*e.g.*, TDWRS, WSR-88D, LLWAS, ASOS, etc.) in the terminal area. The goal is to provide a more complete characterization of weather in the terminal area.

4.4 Sensor Descriptions

The following sub-sections provide an overview of sensors currently in use or under development for aviation weather information collection. Each sensor is described in terms of its operating parameters, application, and output.

4.4.1 Airborne Weather Radars

Airborne weather radars are used by pilots to identify areas containing significant precipitation, turbulence (associated with precipitation), and wind shear on take-off and landing. These radars are commercially available through a number of companies. During this study, literature was obtained for radars manufactured by Rockwell Collins, Honeywell, and Allied Signal. These radars are described in the next two sections.

4.4.1.1 *Rockwell Collins Airborne Weather Radar System*

Airborne weather radars are designed to provide relative precipitation rate information, precipitation-related turbulence detection, and windshear detection. Rockwell Collins markets two radar systems, the WXR-700 and the TWR-850. The WXR-700 weather radar is flown on major airlines worldwide. The WXR-700 has captured more than 50% of the major airline market share. The TWR-850 weather radar is targeted for the business and regional airline aircraft. Both radars are solid state radars. The TWR-850 supports three antenna sizes: 12, 14, and 18 inches. The TWR-850 detects precipitation at ranges up to 300 miles and detects precipitation-related turbulence up to 50 nautical miles. Advertised turbulence detection is possible for rainfall rates below 0.8 mm/hr. Based on available literature, the TWR-850 does not possess a wind shear detection mode for application in the terminal area, whereas, the WXR-700 contains both a weather/turbulence detection mode and a wind shear detection mode. Table 4-8 contains a list of system parameters associated with the WXR-700.

Table 4-8. Rockwell Collin's WXR-700

Rockwell Collins WXR-700	
Maximum Weather Detection Range	320 nautical miles (592.6 kilometers)
Windshear Detection	
Coverage Area	±30°
Detection Range	5 nautical miles
Automatic Operation	Below 2,300 feet (above ground level)
Transmitter/Receiver	
Transmit Frequency	9.33 GHz (X-Band)
Transmit Frequency	5.44 GHz (C-Band)
Pulse Repetition Frequency	180 Hz (up to 9,000 Hz)
Pulse Widths	1 to 20 microseconds
Peak Power, X-band	150 watts (nominal)
Peak Power, C-band	200 watts (nominal)
Antenna	
Type	Flat Plate
Beam Width	3.5°
Gain	34 dB (nominal)
First Side Lobe	-31 dB
Scan Angle	
Weather/Turbulence Mode	±90°
Windshear	±60°
Scan Rate	
Weather/Turbulence Mode	4 seconds
Windshear	3 seconds
Scan Increment	0.25° (nominal)
Elevation Range	±40°
Elevation Rate	45°/second (minimum)
Elevation Increment	0.25°

4.4.1.2 Honeywell

Honeywell also produces a line of turbulence detection and weather avoidance radars for the non-commercial transport aircraft. This line of weather radars does not include a wind shear detection mode. The Honeywell radar parameters are given in Table 4-9. Note that the P-880 is the only one of the three radars with a precipitation-related turbulence detection mode. These radars are not solid state radars. Honeywell also produces a line of multi-function SAR radars for helicopters that incorporates a weather mode. This line of radars is termed the Primus 700 or 701 series.

Table 4-9. Honeywell Family of AWARs

	Honeywell		
	Primus-880	**Primus-660**	**Primus-440**
Transmitter Power	10 kW	10 kW	10 kW
Pulse Width	1 or 2 μsec	1 or 2 μsec	1 or 2 μsec
Available Antenna Size	12", 18", and 24"	12" and 18"	12"
Sector Scan Angle	60°	60°	60°
Maximum Scan Angle	120°	120°	120°
Tilt Range	+15° to –15°	+15° to –15°	+15° to –15°
Maximum Displayable Range	320 nm	320 nm	320 nm
Modes	Weather and Turbulence	Weather	Weather

4.4.1.3 Allied Signal's RDR Weather Radar

Allied Signal has recently merged with Honeywell and taken on the Honeywell company name. Allied Signal manufactures the RDR-4B Weather Radar with forward-looking windshear detection. This radar was the first to receive FAA/NASA approval for windshear detection. The approval was obtained on September 1, 1994. Table 4-10 contains a list of system parameters associated with the BDR-4B.

4.4.2 Terminal Doppler Weather Radar (TDWR)

The Federal Aviation Administration (FAA) funded, C-band terminal Doppler weather radar (TDWR) [4-2, 4-3, 4-4, 4-5, 4-6] provides windshear detection (microburst and gust fronts), wind shift prediction, precipitation intensity, and storm motion in the terminal area. These products are used by air traffic controllers to provide warnings of hazardous wind shear conditions and as flight planning products by air traffic supervisors. Table 4-11 contains a list of the parameters associated with the TDWR. TDWRs are located at approximately 45 airports within the U.S.

4.4.3 ASR-9 with a Wind Shear Processor

The FAA's Airport Surveillance Radar (ASR-9) [4-2, 4-3, 4-6, 4-7, 4-8] provides air traffic surveillance in the terminal area. With the success of the TDWR, a number of the ASR-9s have been equipped with a weather channel and a signal processor to provide similar functionality as that observed in the TDWR. Table 4-12 contains a list of the ASR-9 parameter set. The beam shape and block staggered pulse repetition frequencies of the ASR-9 impose some formidable processing requirements to meet the performance of the TDWR. These are discussed in [4-8]. There are some 34 ASR-9s located throughout the U.S. that are equipped with a WSP.

Table 4-10. Allied Signal's RDR-4B

Allied Signal RDR-4B	
Maximum Weather Detection Range	320 nautical miles (592.6 kilometers)
Windshear Detection	
Coverage Area	±40°
Detection Range	5 nautical miles
Automatic Operation	Below 2,300 feet (altimeter)
Transmitter/Receiver	
Transmit Frequency	9.4 GHz (X-band)
Pulse Repetition Frequency	190 Hz (up to 6,000 Hz)
Pulse Widths	1.5 to 18 microseconds
Peak Power, X-band	125 watts (nominal)
Antenna	
Type	Flat Plate
Beam Width	3.3°
Gain	35 dB (nominal)
First Side Lobe	-30 dB
Scan Angle	
Weather/Turbulence Mode	±90°
Windshear	±60°
Scan Rate	
Weather/Turbulence Mode	48 degrees/second
Windshear	48 degrees/second
Elevation Range	±43°
Elevation Rate	45°/second (minimum)

4.4.4 Air Route Surveillance Radar

The air route surveillance radars (ARSR) [4-9, 4-10] under the jurisdiction of the air route traffic control centers (ARTCC) provide both en route traffic surveillance in the airspace under the ARTCC's control and coarse precipitation intensity level estimates. Table 4-13 contains a list of operating parameters for the ARSR-2 [4-10]. The ARSR provides two levels of intensity. Moderate rainfall is defined for dBZ values between 30-41 dBZ and heavy rainfall is defined by dBZ values above 41 dBZ. The ARSR integrates 12 scans in estimating the dBZ values, which equates to an update rate of 144 seconds.

Table 4-11. Terminal Doppler Weather Radar Parameters

Terminal Doppler Weather Radar		
Antenna		
Beamwidth	< 0.55°	Pencil beam
Gain	50 dB	
Sidelobes	Near-in	- 27 dB
	Far-out	- 40 dB
Transmitter		
Frequency	5.60 - 5.65 GHz	
Power	Peak	250 kW
	Average	550 watts
Pulsewidth	1.1 μsec	165 m range equivalent
PRF	2000 Hz	Maximum
Receiver		
Linearity	61 dB	
Noise Figure	2.3 dB	
Dynamic Range	129 dB	
STC	26 dB	
AGC	42 dB	
Clutter Suppression	55 dB	
Range of Observation		
Radial Velocity	89 km	±1m/sec (accuracy)
Reflectivity	460 km	±1 dB (accuracy)

Table 4-12. Parameters for an ASR-9

ASR-9 with a Wind Shear Processor	
Frequency	2.884 GHz (S-band)
Transmitter Type	Klystron
Antenna Pattern	Cosecant-squared elevation
Peak Power	1.10 MW
Pulse Width	1.0 μsec
Range Sample Spacing	120 meters
Block Staggered Mode	8 pulses @ 940 Hz 10 pulses @ 1200 Hz
Maximum Range	60 nmi
Reflectivity	Six levels
Clutter Rejection	45 dB
Sensitivity	-108 dBm
Beam Width	6.0° elevation 1.3° azimuth
Polarization	Vertical/circular
Antenna Gain	34 dB
Scan Rate	12.5 RPM

Table 4-13. Air Route Surveillance Radar Parameters

ARSR-2	
Beamwidth (az)	1.2°
Beamwidth (el)	3.75°
Frequency (L-band)	1.3 GHz
Peak Transmitted Power	5000 kW
Antenna	Fan beam
Scan Rate	5 revs/min
Nominal Range	280 km
Pulse Duration	2 μsec
Pulse Repetition Frequency	360 Hz

4.4.5 Weather Surveillance Radar – 1988 – Doppler

The National Weather Service's (NWS) weather surveillance radar (WSR) [4-10,4-11,4-12,4-13,4-14, 4-15,4-16] was developed under the Next Generation Radar Program (NEXRAD). The development phase was completed in 1988 and represented a major milestone in NWS radars. This radar incorporates a Doppler capability not present in earlier versions (*e.g.*, WSR-74 radar). The new radar's official acronym is WSR-88D denoting the type of radar, the year its development phase ended, and the fact that is possesses a Doppler capability; however, the acronym NEXRAD is also often used to denote this radar. The S-band radar is located at some 158 operational [4-11] sites around the U.S. The WSR-88D provides weather information to a number of different governmental agencies and private companies meeting a broad spectrum of meteorological and hydrological needs. The FAA and air traffic control (ATC) support system are major users of this information. However, because the WSR-88D must supply information to meet the needs of a broad spectrum of users, the products are not necessarily tailored to aviation. Table 4-14 contains parameter values for the WSR-88D, and Table 4-15 contains a list of some of the higher level WSR-88D products.

Table 4-14. WSR-88D System Parameters

WRS-88D	
System Parameters	
Frequency	2.7 to 3.0 GHz (S-band)
Antenna Type	Center-fed parabolic dish
Circular Reflector Diameter	8.5 m
Polarization	Circular: RH transmit LH receive
Beamwidth (one-way)	0.89° at 2.7 GHz 0.95° at 3.0 GHz
Gain	45.5 dB @ 2.8 GHz
First Sidelobe Level	-29 dB
Steerability	360° (Az), -1° to +45° (El)
Rotation Rate (max)	36°/sec
Peak Power Output	750 kW
Pulse Widths	1.57 μsec and 4.5 μsec

Table 4-14. WSR-88D System Parameters

WRS-88D	
Pulse Repetition Frequency	318-452 Hz (long pulse) 318-1304 Hz (short pulse)
Signal Processing	
Basic Products	Reflectivity, mean radial velocity, Doppler spectral width
Algorithm	Pulse-pair
Accuracy	Reflectivity – 1 dB Velocity and width – 1m/sec
Number of Pulses Averaged	6 to 64 (reflectivity) 40 to 200 (velocity and width)
Range Resolution	1 km (reflectivity) 0.25 km (velocity and width)
Azimuth Resolution	1°

Table 4-15. WSR-88D Weather Products

WSR-88D Products
Precipitation
1 and 3 hour accumulation
Storm total accumulation
Storms
Storm tracks
Storm structure
Hail
Echo Tops
Vertically integrated liquid
Severe weather probability
Mesocyclone
Tornado
Velocity azimuth display
Velocity azimuth display (VCO) wind profile
Combined shear
Turbulence

4.4.6 NOAA Profiler Network

The National Oceanic and Atmospheric Administration currently oversees a network of wind profilers. Wind profilers [4-17, 4-18] provide clear air horizontal wind speed and direction information as a function of height. The reflective properties of clear air are due to fluctuations in the refractive index associated with relatively large eddies which dissipate slowly [4-10, page 292]. The network consists of thirty-four wind profilers located at the sites noted in Figure 4-1. The profilers are phased array radars operating at 404.37 MHz. The radars are capable of generating five beams: one vertically oriented, and four beams that are positioned 15° from vertical in the north, south, east, and west directions. The beams are positioned to derive horizontal wind speed information from radial wind speed components along each beam. The profilers measure wind speeds at heights up to 16.25 kilometers (53,300 feet). This includes the majority of the troposphere, and for this reason, the profilers are often denoted as "tropospheric wind profilers." The winds are measured every six minutes. Average wind profiles are generated every hour at 500 meter increments in elevation and with an accuracy of 1 m/s. Table 4-16 contains specifications for the Lockheed Martin Wind and Temperature Profiler used in the NOAA profiler network. The wind profiles are used to improve the accuracy of forecasts and to improve flight safety and fuel economy when applied to aviation.

Table 4-16. NOAA Wind Profiler

NOAA Profiler Network Lockheed Martin Wind and Temperature Profiler	
Maximum data height	16.25 km (53,300 feet)
Minimum data height	0.5 km (1640 feet)
Pulse width (compressed)	1.67 or 6.67 microseconds
Vertical resolution cell	250 or 1000 meters
Pulse repetition interval	100 or 153 microseconds
Frequency range	400 – 500 MHz (404.37 MHz) (UHF)
Peak power	16 kilowatts
Average power	2200 watts
Antenna type	Coaxial collinear array
Antenna gain	> 32 dB
Antenna sidelobes	- 30 to – 40 dB
Beamwidth	6 degrees
Number of beams	5 beams
Beam orientation	1 vertical, 4 in the N, S, E, and W directions at 15° from vertical
Maximum horizontal wind	200 mph
Maximum vertical wind	50 mph

In general, clear air reflectivity is higher at the lower altitudes. Systems designed for lower altitude measurements, (*e.g.*, lower tropospheric and boundary layer measurements), therefore, require less power and can in general operate at higher frequencies. Strauch [4-17] describes a 915 MHz wind profiler that was installed at the Denver Stapleton Airport to monitor wind conditions in the terminal area. Wind profilers, however, have not made their way into the aviation sensor suite supporting the terminal area.

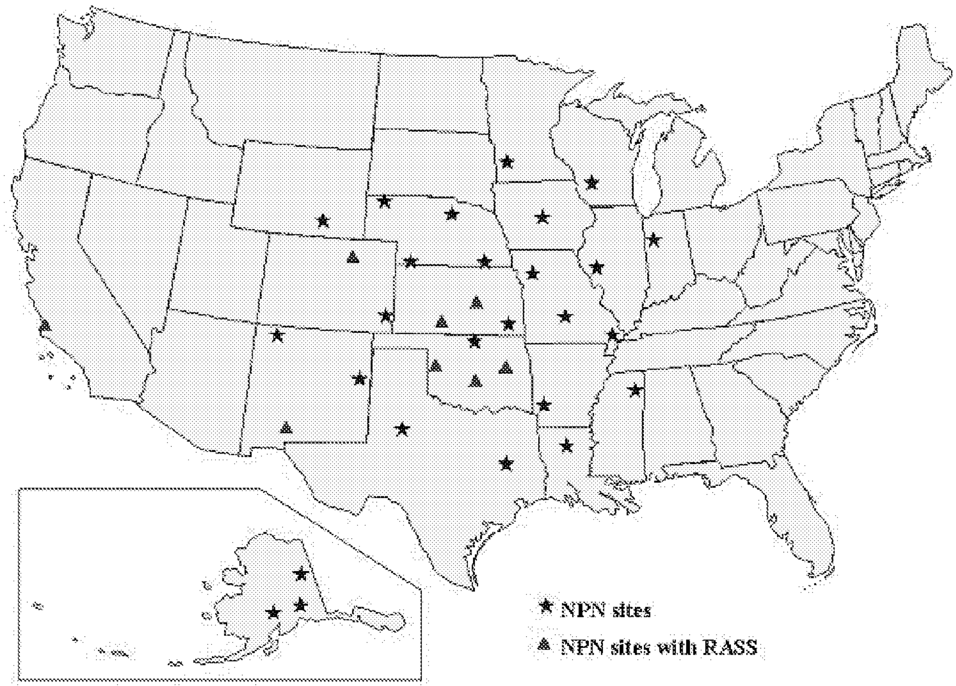


Figure 4-1. Locations of NWPN and RASS Sites

4.4.7 Radio Acoustic Sounding System

The speed of sound is related to virtual temperature through the following equation

$$T_v = \left(\frac{c_a}{20.047} \right)^2$$

where c_a is the speed of sound and T_v is the virtual temperature. Radio Acoustic Sounding Systems (RASS) use coherent radar to determine the speed of acoustic wavefronts and thereby estimate the temperature of the atmosphere as function of altitude. The reflective properties of clear air are enhanced by the irregularities in the index of refraction induced by the acoustic wave. The scattering due to irregularities in the index of refraction is termed the Bragg effect. Reflectivity is maximized for the case where the acoustic wavelength is matched to half of the radar wavelength. May [4-19] describes a number of RASS systems that were tested during 1988. The system parameters are given in Table 4-17. The 404.37 MHz system is similar to that employed in the profiler network. As shown in Figure 4-1, a number of the profile network sites are also instrumented with a RASS. Note that in Table 4-17, the maximum altitude increases with decreasing frequency, but the minimum altitude also increases.

4.4.8 Boundary Layer Profiler Network

The boundary layer profiler network [4-20,4-21] is a network of some 65 boundary layer profilers operated by some 30 different agencies. The profilers are small, low-cost UHF Doppler radars providing horizontal wind profiles up to 3 kilometers above ground level. The profilers update wind estimates on an hourly basis or in some cases every 10 minutes. Figure 4-2 shows the location of the 65 profilers. The red (or dark colored) circles indicate profilers that are routinely providing updates while the blue (or light colored) circles denote profilers that have a more intermittent update rate.

Table 4-17. Example Wind Profilers

Site	Platteville	Erie	Denver	Boulder
Radar				
Frequency	49.8 MHz	404.37 MHz	915 MHz	915 MHz
Wavelength	6.0 m	0.74714 m	0.3 m	0.3 m
Antenna Size	10,000 m^2	25 m^2	100 m^2	4m^2
Beamwidth (one way)	3°	7.8°	2°	9°
Range Resolution	300 m	150 m	150 m	150 m
Mean Power	200 W	30 W	100 W	3 W
Update Rate	1 min.	1 min.	1 min.	1 min.
Acoustic				
Frequency	110 Hz	900 Hz	2000 Hz	2000 Hz
Beamwidth (one way)	60°	18°	8°	9°
Acoustic Power	50 W	5 W	5 W	5 W
RASS Coverage				
Minimum Altitude	2.1 km	400 m	200 m	120 m
Maximum Altitude	5-9 km	1.5 – 2.5 km	0.7 – 1.5 km	0.6 – 1.0 km

4.4.9 Terminal Area Surveillance System

The terminal area surveillance system (TASS) program [4-22,4-23,4-24,4-25,4-26] has as its mission the development of the next generation terminal area surveillance radar which will incorporate the functions currently performed by the ASR-9 and TDWR radars. The single radar will incorporate both aircraft surveillance and weather prediction and detection functions. The TASS program has focused on an electronically scanned system with multiple faces. Table 4-18 contains a list of the proposed TASS weather mode capabilities.

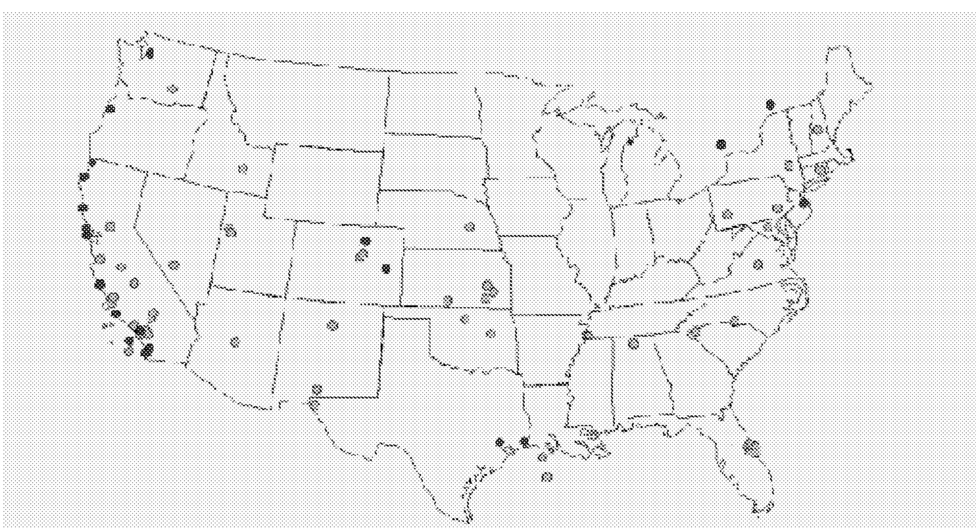


Figure 4-2. Sites containing boundary layer profilers

Table 4-18. A List of the Proposed TASS Weather Mode Capabilities

Proposed TASS Weather Capabilities
Microburst detection
Microburst with intensity returns above –10 dBZ
Detection within 12 km of the airport
Microburst predictive products (ITWS derived)
Microburst alert trend – microburst projection
Microburst strength
Microburst duration
Microburst onset prediction (10 minutes)
Weather impacted airspace detection
Six level intensity map
Individual storm identification
Hail and icing (freezing level) detection
Tornado detection
Snow detection
Freezing rain aloft
Gridded reflectivity
Gust front detection and prediction
Above –10 dBZ and 20 minute lead time
Wind shift line detection
Wind detection
Approach/departure corridor winds
Terminal winds
Vertical wind shear
Gridded winds
Weather impacted airspace prediction (ITWS derived)
Storm motion
Storm duration
Storm strength

4.4.10 Unisys Microburst Prediction Radar

In 1995, Unisys reported [4-27] that they had developed a low cost X-band weather surveillance radar. The system was advertised to provide warnings of hazardous microburst conditions 2 to 4 minutes in advance. The radar was to be sited at airports providing a coverage area out to a 10 km radius. The advertised price was $500K to $700K including installation. Based on a survey of the current literature, these radars have not made their way into the official U.S. air traffic control weather support system; however, they may have been used internationally. The parameters associated with the microburst prediction radar (MPR) are given in Table 4-19 and Table 4-20.

Table 4-19. Antenna Parameters for the UNISYS Microburst Prediction Radar

UNISYS Microburst Prediction Radar		
Parameter	***Prediction Beam***	***Surface Beam***
Antenna Type	Linear Phased Array	Flat Plate (slot dipole radiators)
Number of Beams	Six Pairs (12 Beams)	Single Beam
Steering: Elevation Azimuth	 Electrical, 10° – 70° Mechanical	 Fixed, 1.8° Mechanical
Beamwidth: Elevation Azimuth	 6.5° – 10.2° 7.0°	 3.2° 3.2°
Gain	28 – 23 dBi	37 dBi

Table 4-20. System Parameters for the UNISYS Microburst Prediction Radar

UNISYS MPR	
Frequency	9.345 GHz
Peak Power	60 Watts
PRF	7092 Hz
Pulse Width	1.25 μsec
Range Resolution	225 meters
Unambiguous Range	21 km
Unambiguous Velocity	±56 m/s

4.4.11 Weather Mode for the SPY-1 Radar

Lockheed Martin (LM) in Moorestown, New Jersey has developed a weather processor that provides a non-intrusive weather capability to the SPY-1 radar. Land-based experiments have been validated against data obtained from a WSR-88D. A coherent pulsed mode was added to the SPY-1 radar to provide Doppler information (mean radial velocity and spectrum width). A 3 pulse, pulse-pair approach is used in estimating mean radial velocity and spectral widths. The SPY-1 radar provides enhanced range and az/el resolution over a WSR-88D. A combination of enhanced resolution and multi-channel frequency agility permits an averaging in range, cross range, and frequency, over a single pulse, to reduce the measurement variance as compared to multiple pulses required in the WSR-88D. Field tests aboard an AEGIS cruiser were scheduled for 1999. SPY-1 radar parameters were not available for inclusion in this report.

4.4.12 Bistatic Multiple-Doppler Network

A single transmitter bistatic dual Doppler radar network has been proposed by Wurman [4-28,4-29] as a low-cost method for obtaining wind field vector information. A single transmitter and a low-cost bistatic receiver were deployed in Boulder, Colorado in 1993. Tests showed favorable results when compared to a Dual-Doppler system located in the area. Wurman notes that the bistatic receivers have an estimated cost of less than $40,000.

4.4.13 Dual Doppler Radars

Dual Doppler radars [4-30] provide the capability to estimate wind field vectors as opposed to estimating only the radial component of the wind. Research systems have been deployed such as the CHILL and Pawnee radars owned by Colorado State University [4-31,4-32]. However, dual Doppler radar technology is currently not applied in aviation weather applications, primarily due to cost.

4.4.14 Dual Frequency Radars

Under Rayleigh scattering conditions, (hydrometers with diameters much shorter than the radar wavelength), scattering and attenuation are a function of frequency. A single radar capable of operating over a wide frequency range or two radars with different center frequencies can be applied under Rayleigh conditions to estimate liquid water content [4-33,4-34]. Vivekanandan [4-33] shows some promising results using data taken with X-band and Ka-band radars, but further investigation is required since regions of non-Rayleigh scattering introduce errors in the process.

4.4.15 Polarization Diverse Radars

The current set of FAA and NWS radars described in this report employ a uniform polarization. However, research has shown that polarization diversity (*e.g.*, the ability to alternate pulses with orthogonal polarizations) [4-10,4-30] has the potential benefit of increasing the accuracy of rain rate estimates and provides the additional capability to discriminate between hail, heavy rain, and mixed phase hydrometers.

4.4.16 Satellite Sensors

Weather sensors located on satellites provide global coverage, which is important for aviation, because airline companies and regulation entities have geographical scales of operation that span much of the globe. Weather data from satellites come in two basic forms: multispectral imagery and sounding data. Visible-light imagery is confined to local daylight hours, while infrared sensing can be performed anytime. Infrared imagery is used to find cloud top temperatures, while soundings are used to develop vertical profiles of atmospheric temperature and water vapor concentration. Satellite data products are used as inputs for monitoring, modeling, and forecasting weather on a global scale [4-10].

Satellites are especially useful for tracking large-scale weather phenomena such as tropical cyclones and movements of fronts. They are less applicable for tracking terminal-area hazards because of limitations in their resolution. For example, the GOES have nominal resolutions of 1 km in the visible band, 8 km in the infrared band, and 14 km for soundings. In addition, the update rate of satellite data is usually 30 - 90 minutes, which is too slow to monitor evolving hazards in the terminal areas.

In spite of these limitations, a great deal of progress has been made in the satellite data reduction processes used to identify hazards, and this work is ongoing. For example, the National Oceanic and Atmospheric Administration (NOAA) routinely monitors hazards and disasters worldwide by analyzing image data from GOES, GMS, METEOSAT, and NOAA 12, 14, and 15. Daily reports are available by e-mail as a subscription, or at their web site [4-35]. The following hazard categories are available:

- dust
- fires
- floods
- ice
- severe weather
- snow
- storms
- unique
- volcanic

As an example of aviation-related weather information obtained from satellites, the NOAA website contains an image showing fog in the San Francisco Bay area on December 28, 1998. According to the caption, this fog persisted for days, causing delays and cancellations of many flights. The update rate of the NOAA information is probably too slow for aviation purposes, but it does serve to illustrate the kinds of satellite-based hazard warning data that might be available in future operational systems.

Volcanoes erupt at unpredictable times and locations around the globe. Many volcanoes are in remote regions. For these regions, satellites are probably the only technology that can monitor the entire global volcanic hazard. There are monitoring programs in place in NASA [4-36,4-37], and there are also on-going research efforts to improve the forecasting of eruptions.

One NASA program is known as the Interdisciplinary Science (IDS) Volcanology Team, which is a project activity of the Earth Observing System (EOS). The team, centered at the University of Hawaii, is primarily concerned with the environmental effects of volcanoes. They are developing new methods, models, and algorithms to monitor volcanoes with satellite sensors. This work may find future applications in monitoring potential aviation hazards associated with volcanic eruptions.

The GOES Project Volcano Watch is a collection of satellite images, including animations, of interesting volcanic events captured by the GOES weather satellites. As such, it does not currently provide useful warnings to the aviation community, but it does serve as a way to explore the utility of this type of technology.

The use of GOES imagery specifically for monitoring volcanic ash as an aviation hazard is an active research area. F. R. Mosher [4-38], of the Aviation Weather Center in Kansas City, Missouri, recently presented a new ash detection algorithm that produces an image product from the GOES visible channel and three of its infrared channels. Mosher demonstrated the ability of his approach to track ash clouds with data from the recent Montserrat eruption as well as a small eruption of Popocatepetl, near Mexico City. Mosher's algorithm provides clear pictures of ash clouds.

Erupting volcanoes emit a great deal of sulfur dioxide in addition to dust and small pieces of rock. The dust and rock settle out of the atmosphere quickly and so, in general, do not present a hazard to aviation. At aircraft altitudes, the phenomenon known as "ash" is actually hydrated droplets of sulfur dioxide. Sulfur dioxide has spectral characteristics somewhat like ozone, so the Total Ozone Mapping Spectrometer (TOMS) is capable of detecting it. Krueger and others [4-39,4-40] have investigated this technique.

Future capabilities for monitoring volcanic eruptions using next-generation satellites have also been addressed by Krueger [4-41]. Future multispectral imaging satellites may provide a capability to predict eruptions in advance by detecting a plume of sulfur dioxide that is emitted just before the eruption.

In summary, satellite sensors already provide some capability to monitor the volcanic ash hazard and there are significant ongoing efforts to improve this capability. Great improvements are expected in the next few years. It will then become increasingly important to develop mechanisms for transmitting real-time volcanic ash hazard data to the aviation community.

4.4.17 Runway Visual Range Sensors

4.4.17.1 Introduction

"Adequate" visibility is crucial to landing operations. The level of visibility must be measured and quantified for pilots and air traffic controllers. The measure of visibility relevant to airport operations is runway visual range (RVR), which is defined as the distance a pilot can see along a runway from the approach end. The earliest method of estimating RVR was human observation. Control tower personnel would simply look for fixed structures at known distances in the airport clearing. This method provides a rough idea of visibility, but in general airport structures are not ideal visibility targets, and their distances from the tower are arbitrary, so this approach does not lead to a good quantitative estimate over the full range of relevant RVR values.

4.4.17.2 Transmissometers

The first instruments developed for measuring RVR were transmissometers [4-10]. The weather phenomena that reduce runway visibility, such as fog and precipitation, are sometimes highly variable in both time and space. For this reason, each runway at major airports may be equipped with an RVR instrument near its midpoint, and time averaging is used to remove short-term time variations in the measured values.

A transmissometer has two ends: a projector, which transmits a collimated beam of light, and a detector, which measures the intensity of the light at some distance, generally in the range of 75 to 150 m. The measured transmittance τ is defined as

$$\tau = I / I_0, \tag{4-1}$$

where I is the light intensity in obscured conditions and I_0 is the light intensity in clear conditions. The range of values of τ is from 0 to 1. The value of τ only characterizes the optical path of the transmissometer, so it is necessary to derive a more general quantity from the transmissometer data. This quantity is the atmospheric extinction coefficient, which accounts for reductions in the intensity of the detected light by both absorption and scattering. The extinction coefficient is related to the measured transmittance through the Beer-Lambert law,

$$\tau = e^{-\alpha x} \tag{4-2}$$

where τ is the transmittance, e is the base of the natural logarithms, α is the extinction coefficient, and x is the distance between the projector and the detector. By taking the logarithm of both sides of equation (2), we can derive the relation

$$\alpha = -\ln(\tau)/x . \quad (4\text{-}3)$$

The extinction coefficient α is related to human visual range. The earliest, and simplest, relationship was developed by Koschmieder [4-42] who studied the ability of observers to detect black objects against the horizon sky in a sea coast environment. Koschmieder noted that, as the range was increased, the contrast between the black objects and the sky decreased, until finally the objects were no longer perceptible. Koschmieder found that the smallest contrast that could be perceived by the observers was two percent of the contrast at zero range. The natural logarithm of 0.02 is -3.91, so putting this value into the equation above and solving for x we have Koschmieder's Relation

$$x = 3.91/\alpha . \quad (4\text{-}4)$$

This is the basic relation between the atmospheric extinction coefficient and human visual range. For example, if the measured value of α is 1/km, equation (3-4) predicts that the visual range will be 3.91 km. In practice, several corrections are applied when calculating RVR to allow for different types of targets and the particular lighting conditions, including the brightness of runway lights at night [4-10].

Transmissometers have found widespread application, and they are in operation at many airports. However, they have several disadvantages as instruments for measuring the atmospheric extinction coefficient α.

The detector's maximum signal occurs in clear conditions. As α increases (worsening visibility), the detector signal becomes smaller. At some point it becomes equal to the system's electronic noise level. As α increases beyond this point, no further change in the transmissometer's output is possible. This causes a dynamic range problem.

Several phenomena unrelated to α can cause the detector signal to decrease. Among these are dirt on the optical windows of the projector and detector, changes in the optical alignment of the projector and detector, changes in the output of the projector bulb, and changes in the detector sensitivity. For these reasons, transmissometers require frequent maintenance and calibration.

Installation of a transmissometer requires the construction of two steel platforms and the installation of power and signal cables to both.

4.4.17.3 Forward Scatterometers

A different type of RVR sensor known as a forward scatterometer was developed to overcome these problems. The forward scatterometer has a transmitter and a receiver, but they are both mounted on two arms of the same instrument. The intersection of the transmitted light beam and the receiver field of view defines a region in space known as the sample volume. The receiver is off-axis relative to the transmitted beam, so when the air is clear, no light is received. When particles, such as fog droplets, enter the sample volume, light is scattered into the receiver. An electronic signal is generated, and the strength of the electronic signal is related to the density of the particles in the scattering volume, which is in turn related to the atmospheric extinction coefficient.

The amount of light scattered by a particle depends on its size. This could, in principle, be a problem for scatterometer calibration, because obscuring particles at airports range in size from 1 μm or less for fog droplets to several mm for large raindrops. However, choosing a scattering angle where the scattering by various sizes of droplets is nearly the same minimizes this problem. All scatterometers are designed in this way.

A scatterometer has a much greater dynamic range than a transmissometer because its receiver signal is zero in clear conditions and increases as visibility worsens. Dirt on the optical windows will cause a calibration error, but it will not cause an erroneous reading during clear conditions. Installation and calibration of a scatterometer are both facilitated by the fact that it is a single instrument, mounted on one pole. For these reasons, forward scatterometers have become the airport visibility instrument of choice. They are used in the AWOS and ASOS systems.

4.4.17.4 New Generation RVR

As a part of the FAA's Aviation System Capital Investment Plan, a new generation RVR system is being acquired and deployed, and a pre-planned product improvement will be conducted. The purpose is partly to replace obsolete fielded systems that are becoming difficult to maintain, but the larger purpose is to introduce improved technology.

The new generation sensor determines RVR in the same way as the previous sensors (*i.e.*, from measured visibility, background luminance, and runway light intensity), but it has been designed and proven to perform over the full range of instrument meteorological weather conditions, including fog, rain, freezing rain and snow. It measures RVR from 6,500 feet to 0 feet.

4.4.18 Wake Vortex Detection

4.4.18.1 Introduction

Every airplane generates a pair of vortices, which may be visualized as counter-rotating "horizontal tornadoes." The vortices are generally invisible and can possess sufficient air motion to seriously affect the trajectories of aircraft flying into them. This is especially hazardous during landings when aircraft are operating at low speeds close to the ground. Small airplanes encountering vortices in the wake of large airplanes have been flipped upside down, causing fatal accidents. Therefore, wake vortices are a potential aviation hazard.

The diameter of a typical wake vortex is tens of meters, and they have been observed to persist at airfields for up to 3 minutes after the landing of a large aircraft. The velocity fields in the vortices extend beyond their separation, so they affect each other. Each vortex pushes its neighbor down, so the pair descends toward the ground. Descent rates are in the range 1-2 m/s. Interaction with the ground pushes the vortices apart, but then secondary vortices can be generated that cause the original ones to rise. Generation of secondary vortices is a nonlinear effect, so it is sensitive to details of the local meteorology and even terrain conditions.

When vortices rise after an encounter with the ground, they may drift to an adjacent runway if a crosswind is present. This is a concern at airports with parallel runways. In the U.S., runways must be 3,400 feet apart for independent operation. If parallel runways are closer than 3400 feet, arrivals and departures must be synchronized. These rules are due, in part, to the fact that vortices generated at one runway may drift to an adjacent one.

The phenomenon of wake vortices is well known to pilots, and the precautions that are used to avoid them depend on flight conditions. Under VFR conditions, pilots have the primary responsibility for maintaining a safe spacing during landings. Because wake vortices move downward, pilots are trained to avoid them by not flying under the glide path of a leading aircraft.

During instrument landing conditions, the controller determines the aircraft spacing. The FAA mandates separations based on size according to three categories: heavy aircraft, such as DC-10s and 747s, large aircraft, in a range from 757s to Lear jets, and small aircraft, such as Cessnas. The mandated separation is six nautical miles for a small airplane behind a heavy airplane. At typical landing speeds, this corresponds to about three minutes, which is the longest time that vortices have been observed to persist near the ground. Current procedures are therefore based on a worst-case scenario, because real-time information on the wake vortex hazard is not available to controllers.

If the actual behavior of wake vortices were known in real time, controllers could reduce aircraft spacing during some periods of operation without compromising safety. This would increase airport capacity. This is the primary purpose of research on wake vortex detection: to increase airport landing capacity during instrument landing conditions.

4.4.18.2 Aircraft Vortex Spacing System

Work on wake vortex detection is the U.S. is under the umbrella of the NASA Aircraft Vortex Spacing System (AVOSS) program. Information on the program is available on the World Wide Web at http://avsp.larc.nasa.gov/avoss/avoss.html. AVOSS is an element of NASA's Terminal Area Productivity Reduced Spacing Operation Research Program, and it involves both the Langley and the Ames Research Centers. The goal of AVOSS is to provide Air Traffic Control (ATC) with a means to reduce spacing during instrument operations when the current weather conditions are such that wake vortices have dissipated or moved outside the terminal area and are no longer a threat. The full benefit of AVOSS is expected when it is interfaced to advanced ATC automation such as the Center-TRACON Automation System (CTAS).

AVOSS has three subsystems: Weather, Predictor, and Wake Sensor. The Weather subsystem is unusual in that atmospheric conditions from the surface to the top of the instrument approach path are used, rather than only surface wind. The predictor subsystem uses the weather information to predict the time required for the vortices of approaching aircraft to move out of the approach corridor or to decay. The wake sensor provides an independent measure of actual vortex behavior. The information from the three subsystems is integrated and provided to ATC as a separation matrix. The values are conservative. Human factors research is being conducted to optimize the presentation of AVOSS information to controllers.

AVOSS is being coordinated closely with CTAS and with the FAA's Integrated Terminal Weather System (ITWS). Current activities are focused on development of a prototype AVOSS for the Dallas-Fort Worth (DFW) International Airport. The goal is to do a demonstration at DFW in the year 2000 with all subsystems operating live. AVOSS will not actually change the separation of aircraft during the demonstration; airport capacity gains will be evaluated post-experiment using simulation tools at NASA Ames Research Center.

The development of AVOSS requires a large team comprising numerous disciplines. The current team includes the following participants:

- Boeing Commercial Airplane Company
- Dallas-Fort Worth International Airport

- FAA R&D Field Office at Langley, VA
- MIT Lincoln Laboratory
- Memphis International Airport
- NASA Ames Research Center
- NASA Langley Research Center
- North Carolina State University
- NorthWest Research Associates
- Transport Canada
- Volpe National Transportation Systems Center

Three major types of sensors have been used in the AVOSS program: MIT Lincoln Laboratory's continuous wave (CW) laser radar, coherent Doppler lidars built by Coherent Technologies, Inc. (CTI), and the Volpe Center's Ground Wind Vortex Sensing System (GWVSS). Although these sensors have been successfully used in demonstrations, it should be noted that laser-based sensors (laser radar and lidar) will have a limited range in weather conditions with reduced visibility.

The MIT laser radar, described by Su [4-43], is an infrared Doppler system, but it is not a conventional lidar. It is based on a CW laser operating at 10.6 μm with an output power of 20 Watts. The system is not range gated, so the scattering volume must be defined geometrically. The laser beam is focused in a region of interest, at any range from 12 to 300 m, and a typical scattering volume length is about 6 meters at a range of 100 m. The infrared laser light does not scatter significantly from air molecules; it is scattered by aerosols entrained in the moving air. MIT researchers have found that airport environments have sufficient aerosol concentrations to make this approach reliable. The local oscillator is offset in frequency by 10 MHz, and a Doppler shift of 1 MHz corresponds to a wind velocity of 5 m/s.

The MIT system was used in a demonstration at Memphis International Airport (among others). The main objective of this work was to determine how wake vortex behavior is affected by local meteorology. The system has a scanning capability, and it is operated under computer control to recognize vortices and track them. MIT researchers have used the system to investigate vortices in three different scenarios, which they refer to as "vortex regimes":

- Out-of-ground (under the approach path, looking up)
- Near-ground (off to the side, closer to touchdown)
- Touch-down (off to the side)

The MIT system is currently being used as a research tool. Because it uses a CW laser, it is simpler than a pulsed, range-gated lidar.

CTI has built a series of coherent, wind-sensing Doppler lidars operating at wavelengths near 2 μm. Information on CTI can be obtained at www.ctilidar.com. Performance predictions for coherent 2 μm lidars were summarized by Hannon [4-44,4-45]. CTI lidars have been used for a variety of applications, and CTI recently completed development of a transceiver specifically for wake vortex detection and tracking under Phase II SBIR funding. The laser pulse energy and duration are nominally 7 mJ and 400 nsec, respectively, at a pulse repetition frequency of 100 Hz. The transceiver features a temperature-stabilized optical bench in an environmental enclosure.

CTI also markets a 3-D wind sensing lidar known as the WindTracer MAG-1. The specifications for the WindTracer MAG-1 are given in Table 4-21.

Table 4-21. Specifications for the CTI Wind Tracer MAG-1

Laser type	diode-pumped solid state
Operating wavelength	2 μm
Pulse energy	10 mJ
Pulse repetition frequency	100 Hz
Receiver Aperture	10 cm
Detection	Coherent Doppler
Scanner	Full hemispherical
Minimum range	100 m
Maximum range	8-15 km
Range resolution	50-100 m
Velocity accuracy	0.1 - 0.5 m/s
Size	3.3 cubic feet
Weight	110 lbs.
Electric power required	less than 1 kW

The Wind Tracer MAG-1 includes a real-time data acquisition and display system. The entire sky dome can be scanned every 3-5 minutes, depending on the resolution desired. The lidar is said to be ruggedized for fixed, ground-mobile, or airborne operation. The manufacturer's suggested applications for this lidar include wind shear detection at airports, detection of clear air turbulence, and wake vortex detection and tracking.

The NASA Langley Research Center is also developing a special-purpose lidar for detecting and tracking wake vortices. This lidar will be based on a novel laser developed by Lite Cycles, Inc. that operates at a wavelength of 1.56 μm. This laser is a relatively new development that uses intra-cavity Raman shifting to produce 1.56 μm radiation in a Nd:YAG laser cavity operating at 1.06 μm. Lite Cycles claims that it produces a high repetition frequency, high average power, and excellent beam quality.

The Volpe Center's program on wake vortex sensing is described on the World Wide Web at http://www.volpe.dot.gov/wv//wvabout.html. The Volpe Center has participated in the AVOSS program by investigating or developing the following sensors:

- Laser Doppler Velocimeter (LDV)
- Monostatic Acoustic Vortex Sensing System (MAVSS)
- Ground Wind Vortex Sensing System (GWVSS)

In addition, the Volpe Center has conducted extensive test programs at airports, including measurement and classification of vortices generated by rotorcraft. During AVOSS work at Memphis International airport, GWVSS was set up for unattended data collection.

The Surveillance and Sensors Division of the Volpe Center maintains the most complete existing source of information on wake vortices, in the form of a web-based annotated bibliography. This is available at http://www.volpe.dot.gov/ssd/. The bibliography is searchable by keywords.

4.4.19 ASOS/AWOS

Automated Weather Observing Systems (AWOS) [4-10] support measurements of meteorological conditions in the terminal area. The AWOS system consists of a set of ground based sensors that provide both *in situ* and remote sensing. The AWOS system is available in several versions each with its own configuration of sensors. Table 4-22 provides a list of the measurements provided under each configuration. Qualimetrics, Inc. (www.qualimetrics.com) is an FAA approved supplier of AWOS systems. The Automated Surface Observation System (ASOS) is an upgrade to the AWOS system. ASOS sensors provide similar information including cloud height, visibility, precipitation identification, freezing rain, pressure, ambient temperature, dew point, wind speed and direction, and rainfall accumulation.

Table 4-22. A List of Measurements Derived from an AWOS System

	AWOS I	AWOS II	AWOS III	AWOS III-P	AWOS III-T	AWOS-P-T
Wind Speed	√	√	√	√	√	√
Wind Gust	√	√	√	√	√	√
Wind Direction	√	√	√	√	√	√
Variable Wind Direction	√	√	√	√	√	√
Temperature	√	√	√	√	√	√
Dew Point	√	√	√	√	√	√
Altimeter Setting	√	√	√	√	√	√
Density Altitude	√	√	√	√	√	√
Visibility		√	√	√	√	√
Variable Visibility		√	√	√	√	√
Precipitation		√	√	√	√	√
Day/Night		√	√	√	√	√
Sky Condition			√	√	√	√
Cloud Height			√	√	√	√
Cloud Type			√	√	√	√
Present Weather				√		√
Precipitation Discrimination				√		
Lightning Detection					√	√

4.4.20 Low Level Wind Shear Alert System

The low level wind shear alert system (LLWAS) consists of anemometers placed on poles (as high as 150 feet above the surface) which are located around the runway environment [4-10]. The sensors provide input to a processor that is used to detect wind shear conditions. The LLWAS was originally located at 110 airports. These systems are being phased out and are being replaced by an upgraded system termed the LLWAS-NE (network expansion) which will be located at 39 airports.

4.4.21 Meteorological Data Collection and Reporting System

The aircraft addressing and reporting system (ACARS) provides a digital data link on which appropriately equipped aircraft can provide meteorological reports. These reports are used as inputs to weather prediction models. This subsystem within ACARS is termed the meteorological data collection and reporting system (MDCRS) [4-20]. The current system reports the time of observation, latitude/longitude, flight level, temperature, and wind speed/direction. The reports are issued every 7.5 minutes during cruise and every 2,000 feet during ascent and descent. The number of participating aircraft ranges from 500 to 600. The accuracy of the measurements is: $< 0.5^{\circ}$ C RMS temperature error and < 3 m/s RMS wind vector error. An effort is currently under way to include a water vapor sensing system as a part of the MDCRS report. The sensors provide relative humidity measurements. Both United Parcel Services (UPS) and American Airlines have participated in this pilot program. Efforts are under way to equip additional aircraft with relative humidity sensors.

4.4.22 Radiosonde

Radiosondes are instrumented balloons that are released by the NWS at 0000Z and 1200Z each day. The radiosondes provide temperature and relative humidity information as a function of pressure altitude [4-46]. The temperature and humidity sensors are electrical devices whose resistive properties change as a function of temperature and humidity, respectively. Winds aloft information is also made available by tracking the radiosonde using a radar or a radio direction finder. The instrument packages currently used by the NWS are available from Vaisala (RS-80-57H), Sippican (VIZ-B2), and Sippican Loran-Microsondes. Radiosondes transmit data to ground-based telemetry stations for collection and further processing. Table 4-23 contains specifications for the Vaisala RS80 [4-47]. The NWS is in the process of implementing a program to upgrade the current radiosonde system to include GPS for tracking and the capability to support high resolution data collection [4-48].

4.4.23 Lightning Detection Systems

Lightning detectors have been developed both for ground based and airborne sensor applications. The next two sub-sections describe two such systems.

4.4.23.1 National Lightning Detection Network

The National Lightning Detection Network (NLDN) is operated by Global Atmospherics, Inc., in Tucson, Arizona. The NLDN [4-49,4-50] supplies cloud-to-ground lightning strike information including time, location, polarity, and amplitude. This information is provided to the electric utility industry, the National Weather Service, commercial users, and researchers. The network consists of approximately 105 ground based sensors located throughout the continental United States. Lightning strike information is collected by the individual sensors and linked via a satellite to the Network Control Center in Tucson. The information is then processed and distributed to the user community in near real time. Global Atmospherics advertises an IMPACT (Improved Accuracy from Combined Technology) enhanced sensitivity (ES) sensor with nominal operating ranges out to 540 kilometers. The IMPACT ES combines direction finding and time-of-arrival technology for improved location accuracy and detection performance. Global Atmospherics also markets a number of products for cloud to ground lightning detection in a more localized area (detection ranges out to 30 nautical miles).

Table 4-23. Sub-System Parameters for the VAISALA RS80 Radiosonde

VAISALA RS80 Technical Specifications	
Pressure Sensor	**BAROCAP® Capacitive aneroid**
Measurement range	1060 hPa to 3 hPa (mb)
Resolution	0.1 hPa
Reproducibility	0.5 hPa
Repeatability of Calibration	0.5 hPa
Temperature Sensor	**THERMOCAP® Capacitive bead**
Measurement range	+60°C to –90°C
Resolution	0.1°C
Reproducibility	0.2°C up to 50 hPa, 0.3°C for 50 - 15 hPa, 0.4°C above 15 hPa level
Repeatability of Calibration	0.2°C
Humidity Sensor	**HUMICAP® Thin film capacitor**
Measurement range	0 to 100% RH
Resolution	1 % RH
Reproducibility	< 3% RH
Repeatability of Calibration	2% RH

4.4.23.2 Honeywell Lightning Sensors

Honeywell markets an on-board lightning sensor system for aircraft. The LSZ-860 provides strike detection out to 200 nautical miles while providing 360° coverage. The presence of lightning is a good indicator of areas containing strong turbulence, hail, and heavy amounts of rain.

4.4.24 Global Positioning System Integrated Precipitable Water Measurement

The global positioning system (GPS) provides a means of estimating the integrated water vapor in the atmosphere. Water vapor delays radio signals transmitted from GPS satellites. The amount of delay can be related to the total water vapor content along the signal path. As of February 1999, the Forecast Systems Lab's Demonstration Division [4-51] had instrumented 40 sites with dual frequency GPS receivers with plans for 65 sites by the end of 1999 and 200 sites by 2002. The signal delays are typically estimated from 6 or more satellites. Figure 4-3 shows the current or scheduled GPS-IPW sites.

4.4.25 Integrated Terminal Weather Support System

The Massachusetts Institute of Technology/Lincoln Labs (MIT/LL) has developed the integrated terminal weather support system (ITWS) [4-52,4-53,4-54] which permits fusion of data from a number of sensors in the terminal area. The system is intended to support improvements in safety, efficiency, and capacity. The system accepts inputs from WSR-88D, TDWR, ASR-9 with WSP, LLWAS, ASOS/AWOS, NLDN, MDCRS, and NWS numerical forecasts (*e.g.*, RUC-II). The ITWS generates some 30 products that are made available to air traffic personnel, air traffic management (*e.g.*, TRACON), pilots, airlines, and air route traffic control centers (ARTCC). Over the past several years, MIT/LL has tested prototype systems at the Memphis, Orlando, and Dallas/Fort Worth airports. The FAA has awarded a contract to Raytheon Systems Co., Sudbury, Massachusetts, to build a full-scale system with four pre-production systems scheduled for 2000 with full scale deployment to commence in 2001. The ITWS is scheduled for deployment at some 45 major airports in the U.S.

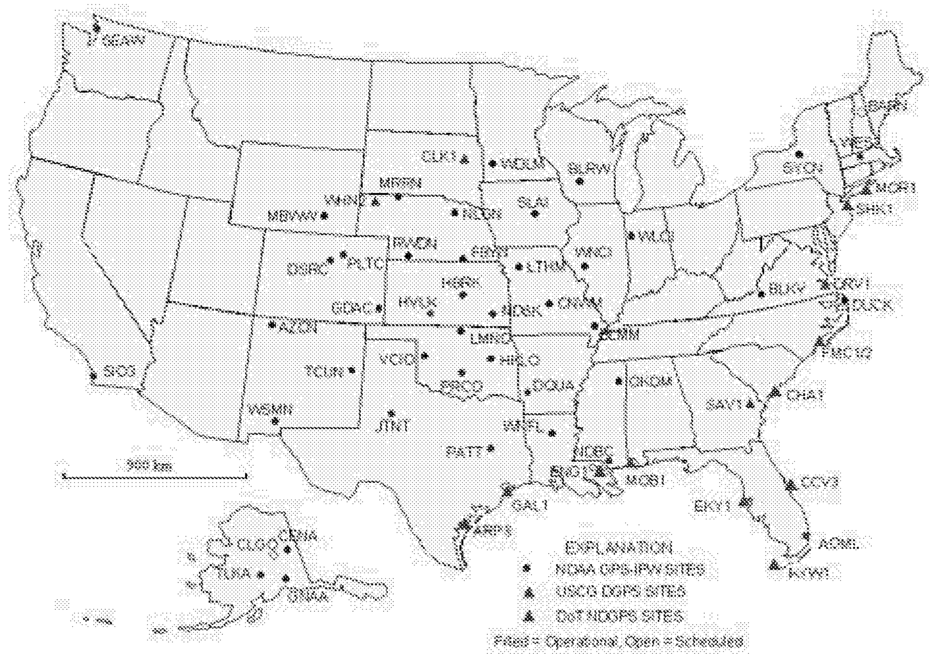


Figure 4-3. Locations of GPR-IPW sites

4.4.26 Rapid Update Cycle II Model

The Rapid Update Cycle II Model [4-55,4-57] located at the National Center for Environmental Prediction (NCEP) provides three dimensional analysis and short range forecasts. The RUC-II provides a 12 hour forecast that is updated every 3 hours and a 3 hour forecast that is updated hourly. The analysis is based on inputs from rawinsonde (temperature, height, moisture, wind), aircraft (MDCRS providing wind and temperature), wind profiler networks, surface observations (wind, temperature, dewpoint, and altimeter setting), ship reports, GOES integrated precipitable water retrievals, GOES high-density cloud drift winds, and tropical storm dropwindsonde data. The RUC-II provides information on a 40 km horizontal resolution grid for some 40 elevations.

4.5 Potential Sensor Solutions to Previously Identified Hazards

Section 3 of this report identified areas where improvements were needed in the current set of weather products. A number of these areas dealt with specific weather related hazards that could be addressed using existing or improved sensor technology. The first column in Table 4-24 contains a list of some of the identified hazards or phenomena. The second column contains a list of potential sensors that might be applied in the detection and characterization of these phenomena. Each potential sensor solution will be addressed in the following subsections.

Table 4-24. Hazards and Potential Sensor Options

Hazard/Phenomena	Potential Sensor
Hail	Polarization Diverse Radars
Icing	Temperature – Radiometry Water and Water Vapor – Dual Frequency Radar and Radiometry
Clear Air Turbulence	Lidar
Slant Range Visibility	Lidar
Vector Wind Sensing (Terminal Area) and Wind Shear Detection	Bistatic Doppler Radar Unisys Microburst Prediction Radar

4.5.1 Detection of Hail

The discrimination of precipitant type based solely on single a polarization reflectivity measurement is not possible since different precipitant types can exhibit equivalent reflectivity values (*e.g.*, hail and heavy rain). However, polarization diverse radars offer the potential capability to support precipitant discrimination. For example, Aydin [4-58] proposes the use of a differential reflectivity measure to distinguish between hail and rain. Differential reflectivity is defined as the logarithm of the ratio of the reflectivity measured using a horizontal polarization to that measured using a vertical polarization. Other polarimetric approaches [4-30] have been proposed for discriminating between mixed phases and estimating the percentage of each phase within a volume. Both airborne and ground based weather radars could benefit from polarization diversity. For example, the CHILL research radar at Colorado State University has a dual polarization capability. Polarization diversity does add significant cost to a radar system, but additional research is warranted in order to assess the cost versus benefit trades.

4.5.2 Icing Sensors

4.5.2.1 Introduction

At altitudes up to the tropopause, the atmosphere generally becomes colder with height. The height at which the air temperature equals the freezing point of water is known as the *freezing altitude* [4-10]. This altitude varies with latitude and season of the year, but it is common for aircraft to encounter freezing temperatures during some part of their operations. Under certain atmospheric conditions, the freezing temperatures lead to accretion of ice on the aircraft. This generally causes a decrease in lift and an increase in drag.

Icing is a major aviation hazard. Table 3-21 in this study shows that icing is a cause or factor in 3 percent (for Part 121) to 8 percent (for Part 91) of weather related accidents.

The rate of ice accretion depends on many atmospheric parameters, such as temperature, liquid water content, and cloud droplet size distribution. The effect of icing depends on the aircraft flight conditions, including speed, altitude, climb/descent rate, angle of attack, and wing loading [4-10]. Icing is a very complex phenomenon, but the atmospheric conditions that are particularly conducive to ice accretion have been identified.

The atmospheric conditions, most conducive to icing are the presence of supercooled liquid drops. Although water normally freezes at 0^{0} C, under certain conditions it may exists as liquid drops at temperatures below zero. Such drops freeze immediately on contact with an aircraft. The temperature range from -10^{o} to 0^{o} C is particularly conducive to ice accretion [4-59].

In addition to temperature, drop size is a key factor. Supercooled large drops (SLDs) have been identified as the primary aircraft icing hazard [4-60]. These drops, with diameters in the range from 30-400 μ m, are larger than typical cloud droplets but smaller than raindrops. In everyday experience they correspond to freezing drizzle. Studies have shown that "... freezing drizzle results in maximum rates of performance degradation, while cloud drops, freezing rain drops, and mixed phase environments result in minor rates of performance degradation (Ashenden and Marwitz, 1997). Ice particles grow at the expense of water droplets, so if ice is present, it will consume the droplets and diminish the icing hazard.

Because the atmosphere's temperature changes with altitude, icing conditions only exist in a fairly thin layer. This means that by a simple evasive maneuver (i.e., changing altitude), a pilot can avoid an icing condition if provided with a warning with sufficient lead-time to take evasive action. A practical sensor for detecting icing conditions would therefore be a valuable resource. Three types of sensors might be imagined: an *in situ* sensor, a remote sensor, or a satellite sensor. *In situ* sensors have the disadvantage of not giving advance warnings. Satellite sensors are considered in a different section of this report. Here, the current status of research and development efforts using airborne remote sensors for the detection of icing conditions is summarized.

Icing occurs in clouds, which are opaque at optical wavelengths, so remote sensing techniques must necessarily employ microwaves. There are two basic approaches: radiometry and radar. The history and current status of these techniques is discussed below, along with recommendations for further work.

4.5.2.2 Radiometry

Microwave techniques for detecting icing conditions have been investigated during the past few years in a series of experiments and analytical work known as the Winter Icing and Storms Program (WISP). The main objective of the WISP experiments was to investigate remote sensing of inflight icing conditions. However, a limited range of environmental conditions was experienced during these experiments, and in particular, no extensive testing occurred in freezing drizzle.

In April 1999, an extension of this program, known as the Mount Washington Icing Sensors Project (MWISP) took place on Mount Washington in New Hampshire [4-61]. Mount Washington frequently has cloudy and supercooled conditions at the summit, and it typically experiences freezing drizzle on several days during April. Based on weather records, the investigators expected 2 to 3 freezing drizzle events, each lasting 3 to 6 hours. The use of a mountaintop site rather than an aircraft made it possible for a large team of investigators to assemble a suite of instruments, so that comprehensive truth data could be collected along with the radar and radiometry data.

Passive microwave radiometry has been proposed as a means to provide advance warning of icing conditions to pilots. The radiometer would be aimed forward (in the direction of flight) and scanned up and down, above and below the horizon. Characteristic signals are expected from clouds of super-cooled water droplets, so signal processing techniques should be able to provide an advance warning when an aircraft is approaching such a cloud. The algorithms would determine the temperature and phase of the water in the cloud (i.e., whether it is liquid water or ice). If the water is in the liquid phase and its temperature is in the super-cooled range, then an alarm would sound.

A microwave radiometer aimed horizontally at flight altitudes in clear conditions observes the cold sky. Clouds generally appear warmer than the cold background sky, but the radiometric signal will depend on the phase of the water in the cloud and on the radiometer's polarization. A dual polarization radiometer might be able to determine water phase. For SLDs, the radiometric temperatures are expected to be the same for horizontal and vertical polarization, whereas for ice crystals they will be different by about 10^0 C. In addition, the ice will appear to be cooler than liquid water. In order to invert the data, the ambient air temperature will also be required. The current concept is to obtain this parameter from aircraft skin temperature sensors.

At MWISP, NOAA-ETL investigated passive radiometry by using a unique instrument, the Polarimetric Scanning Radiometer (PSR). A detailed description of this instrument is available on the World Wide Web at http://www.etl.noaa.gov/radiom/psr.html.

The PSR consists of a set of five polarimetric radiometers housed within a gimbal-mounted scanhead drum. The scanhead can aim the radiometers through a wide range of angles and also at external hot and ambient temperature calibration sources. The measurements taken at MWISP, using the PSR, are described in Table 4-25.

Table 4-25. Measurements defined for the PSR at MWISP

Frequency	Polarizations
10.7 GHz	v, h, U, V (full Stokes vector)
18.7 GHz	v, h, U, V (full Stokes vector)
21.5 GHz	v, h
37.0 GHz	v, h, U (first three Stokes parameters)
89.0 GHz	v, h, U (first three Stokes parameters)

The sensitivity (ability to discriminate temperature differences) is about 0.5° C with a 50 msec integration time, and much higher sensitivity can be obtained by time averaging. The absolute accuracy of the radiometers is about 1° C after calibration with external sources.

The data recorded by NOAA-ETL at MWISP are the only data ever recorded to support the radiometric icing sensor concept described above [4-62]. The data are currently being analyzed, and the results are not yet available.

4.5.2.3 Radar

A single-frequency, single polarization radar can detect clouds, but it cannot discriminate SLDs from other particles, such as ice crystals. For this reason, all proposed radar icing sensors require either dual polarization or dual frequency (or both).

Dual polarization radars seek to classify hydrometeors by their shapes. SLDs are spherical, whereas raindrops, which fall faster, are somewhat flattened by air resistance, and ice crystals occur as plates, needles, and other non-spherical shapes. A scattering difference between H and V polarizations can therefore be interpreted as an indicator that the particles are not SLDs. This technique is described in more detail by Kropfli et al. [4-63].

Under certain conditions, dual wavelength radars can be used to measure the liquid water content of clouds because the attenuation of microwaves by clouds depends on wavelength [4-59]. In addition, using two wavelengths provides some information on the size of hydrometeors. The radar cross sections of spherical particles are dependent on both particle size and frequency, so a radar with two appropriately chosen frequencies might be capable of size discrimination.

Simulations have shown that a radar operating at Ka band (8.66 mm) and X band (3 cm) can discriminate between drizzle, ice, graupel, and rain. However, the inversion scheme would break down if snow crystals were present because they are non-spherical.

Radar data were also acquired during the MWISP experiment, using several different radars and several different scan patterns. These data are currently being analyzed.

4.5.2.4 Recommendations

Task 3 of the FAA Inflight Aircraft Icing Plan (1997) calls for accelerating the development of airborne technologies that remotely assess icing conditions. As mentioned before, such technologies will necessarily have operating wavelengths in the microwave region in order to penetrate clouds. Research in this area (both radar and radiometry) is basically in its infancy, but it has the potential to provide remote sensing techniques for icing conditions. For these reasons, GTRI recommends continued development in the microwave techniques.

Dual-frequency and dual-polarization radars are complex systems incurring a higher price tag. This will limit their range of application. On the other hand, radiometry has the potential for widespread and inexpensive deployment on aircraft, using low-cost Monolithic Microwave Integrated Circuit (MMIC) technology. For this reason, GTRI recommends continued development of techniques based on microwave radiometry as a first priority.

4.5.3 Optical Detection of CAT

The term Clear Air Turbulence (CAT) generally refers to air turbulence at altitudes above 15,000 feet that is not associated with thunderstorms or cumulus clouds [4-10]. There are several mechanisms responsible for CAT: shear instabilities, breaking gravity waves, and turbulence generated near strong convective regions. In general, CAT occurs in regions of vertical shear and low stability [4-56].

It is important for aircraft to avoid CAT. In May 1998, six people were injured when a U.S. Airways flight hit CAT south of Wichita, Kansas. In December 1998, a United Airlines flight encountered CAT on a flight from Japan to Hawaii, causing one death and injuries to over 100 passengers. The annual cost to airlines for turbulence damage and injury is estimated as $100 M. These factors provide a strong motivation to provide advance warnings so that aircraft can avoid regions of CAT.

CAT regions are elusive. Although they are more likely over mountainous regions, they can occur anywhere on the earth at altitudes from the surface to the upper troposphere. Currently there is no effective means of detecting CAT. Several different approaches have been tried, but they were all too expensive or too cumbersome. For this reason, the FAA currently relies mainly on pilot reports (PIREPs) to reroute aircraft around CAT regions, even though the PIREPs are subjective and tend to be unreliable.

NOAA's Forecast Systems Laboratory is attempting to improve forecasting by using data from a variety of sources in a fine-resolution numerical weather model [4-56]. NOAA's Environmental

Technology Laboratory has also conducted several experiments to evaluate Doppler lidar as an airborne CAT sensor. NASA has also conducted airborne measurements of the ability of Doppler lidar to detect CAT, under the ACLAIM (Airborne Coherent Lidar Advanced In-flight Measurement) program. These tests included flights over the Rocky Mountain region, in conjunction with the National Center for Atmospheric Research (NCAR).

Coherent Doppler lidars operate at infrared wavelengths, where light scattering by air molecules is insignificant. The infrared lidar's signal is provided by light scattering from atmospheric aerosols, which are entrained in the air, so they act as tracers for air motion. The lidar is aimed in the direction of flight to probe the air ahead of the aircraft. A scattering volume is defined at some distance ahead of the aircraft by range gating. If the air is not turbulent, the lidar signal will contain one Doppler shift that corresponds to the velocity of the aircraft relative to the scattering volume. If the air is turbulent, the signal will exhibit different Doppler shifts for parcels of air moving at different velocities. This spreading of the Doppler spectrum is taken as the signature of turbulent air. Some current lidar research efforts are aimed at correlating lidar turbulence signatures with the level of turbulence actually encountered, as measured with on-board accelerometers.

The fundamental problem with all turbulence lidar sensors to date is that their range is limited to a few kilometers. For a 747 flying at 600 mph, a lidar range of 2 km would provide an advance warning of only a few seconds, far too short to take evasive action or even to get all seat belts fastened. Today's research on airborne optical remote sensing of turbulence may be laying the foundation for future technology, but a practical system should not be expected in the immediate future.

4.5.4 Slant Range Visibility

4.5.4.1 Introduction

As noted in Section 3.5 of this report, during IFR landings a pilot must see the runway environment, based on visual cues, by the time he reaches the decision altitude. The FAA has defined a set of decision altitudes for various types of aircraft and levels of pilot training. If a pilot cannot see the runway when he reaches his decision altitude, he must abort the landing. This is undesirable from both airport capacity and safety points of view. Knowing in advance which aircraft can land safely in IFR conditions would be of great benefit.

At the time a pilot reaches his decision altitude, his aircraft is on the glide slope and is at some specified distance from the end of the runway. His line of sight to the runway is along or slightly above the glide slope. The relevant parameter is the line of sight distance at which the pilot will be able to see the runway. The term coined for this distance is the Slant Visual Range (SVR).

A present, there are no instruments to measure SVR, and neither the pilot nor the air traffic controllers have a reliable means of estimating it. RVR instruments measure surface visibility, but only at one height (ten feet above the surface). Ceilometers measure cloud base height, and when a cloud ceiling is the only limitation to visibility, this may be sufficient. But in the general case, where fog, haze, or precipitation may be present at any altitude between the surface and the decision altitude, there is currently no way to measure or infer SVR.

4.5.4.2 Technology

The SVR problem requires a single-ended remote sensor that can be pointed from the ground toward the approaching aircraft. The sensor should be optically based since visibility is an optical quantity. These requirements suggest the use of lidar.

Lidar systems operate by transmitting a short pulse of laser light and measuring the return signal from aerosols or cloud droplets as a function of time, which can be interpreted in terms of range. The lidar signal is due to light, which is backscattered by the particles, but the atmosphere between the scattering volume and the lidar system also attenuates the light. Lidar signals therefore depend on both backscatter and attenuation, so a mathematical inversion technique must be used to infer the extinction coefficient α as a function of range. The SVR can then be determined from the range profile of α.

Attempts to measure SVR with lidar date back 30 years [4-64]. This early work did not result in useful systems because eye safe lasers were not available at that time, and mathematical inversion techniques with sufficient accuracy had not yet been developed. Recent progress on both lasers and inversion techniques has made the development of an SVR system possible.

In practice, the eye safety requirement means that the laser wavelength must be greater than 1.4 μm. Patterson [4-65] reported a lidar for clouds and aerosols that operated in this wavelength range by using Stimulated Raman Scattering in a high-pressure gas cell to shift the light from an Nd:YAG laser from 1.06 μm to 1.54 μm. Since this time, reliable solid state lasers have been developed that shift Nd:YAG radiation to 1.57 μm by use of Optical Parametric Oscillator OPO) technology. These lasers are commercially available from Big Sky Laser Technologies in Bozeman, Montana, in a range of models with different specifications.

Using modern laser technology, it would be fairly straightforward to develop a reliable, eye safe lidar with sufficient sensitivity for the SVR problem. The other requirement is a sufficiently accurate inversion technique.

As noted above, lidar signals depend on both backscatter and attenuation, so the inversion problem is not simple. The beginning of practical lidar inversion schemes is generally traced to the work of Klett [4-66], and much work has been done since.

Bissonnette [4-67] has recently reported a side-by-side comparison of a lidar with a transmissometer. This unusual experiment took place in the Alps, on a slant path 2,325 m long, inclined at 30 degrees. The lidar and the transmissometer were operated on parallel optical paths. The main measurement event lasted 1.5 hours, and it included transmittances in a range from less than 5 percent to more than 90 percent. The measurements showed a good correlation between the lidar data and the transmissometer data. This result, along with many others over the past two decades, indicates that lidar techniques can give sufficiently accurate measurements to be useful in the SVR scenario.

4.5.4.3 Recommendations

Lidar technology is sufficiently advanced so that a prototype SVR system could be developed and fielded. GTRI recommends that this technology be pursued. The payoff in having SVR available to air traffic controllers would probably be much like the payoff of wake vortex detection: it would increase airport capacity and also enhance safety, by providing controllers with real-time information about a specific aviation hazard.

4.5.5 Vector Wind Sensing and Wind Shear Detection

As noted in Section 3.5 of this report, wind field vector sensing in the terminal area would improve both safety and efficiency. A dual Doppler radar system provides such a capability, but at the cost of two Doppler radars. Wurman [4-28] has proposed the use of a single transmitter bistatic system as a low-cost system for estimating wind field vectors. In the terminal area, a TDWR could serve as the transmitter with multiple receiving sites located throughout the terminal area. GTRI recommends investigation of this technique as a possible low cost solution for obtaining additional wind vector information in the terminal area.

In terms of a low-cost wind shear prediction system, a system similar to the Unisys Microburst Prediction Radar might be proposed. This system would not have the range and functionality of a TDWR but would provide some additional level of wind shear detection at a lower cost. This type of system might be used in a conjunction with an existing LLWAS for better detection at those airports or as a stand-alone system for those airports not currently supported by a wind shear detection system. GTRI would recommend an initial review of tests performed by Unisys to further access the capabilities of the MPR.

4.6 EPIREPS

The FAA's Aeronautical Information Manual (AIM) [4-68] states that FAA air traffic facilities (*e.g.*, flight service stations (FSS) and ARTCC) are to solicit pilot reports (PIREPS) when the following conditions are reported or forecast:

- Ceilings at or below 5000 feet
- Visibility at or below 5 miles (surface or aloft)
- Thunderstorms and related phenomena
- Icing of light degree or greater
- Turbulence of moderate or greater degree
- Wind shear
- Volcanic ash clouds

Pilots are urged to provide requested information and volunteer information as conditions warrant. The main objective of the PIREP system is to warn other pilots and air traffic facilities of adverse weather conditions experienced en route. The current system requires FSSs and ARTCCs to verbally solicit PIREPs and manually enter the reports into the National Weather Service's (NWS) communication gateway. However, a number of problems exist with the current system [4-69]. FSSs can only receive PIREPs on selected frequencies. However, as is often the case, the pilot is using a different set of frequencies to communicate with air traffic control or is monitoring other frequencies [4-69]. In addition, during FSS peak workloads PIREPS may not get entered into the system [4-69]. In addition to the warning aspect of a PIREP, there is also a desire to use PIREP data in weather research and forecasting. For example, PIREPs could possibly be used to aid researchers in the development of turbulence and icing forecasts.

With the need for more consistency in reporting and with the desire for additional information to support flight safety and research/forecasting, an automated approach to PIREPs has been proposed. This automated approach is termed an electronic pilot report (EPIREP). An example of such a system is

MDCRS, which reports temperature, wind speed and direction, and relative humidity via ACARS. This information is only available from specially equipped commercial aircraft participating in the MDCRS program. As a part of this task, GTRI examined possible suites of sensors that one might want to include as a part of an EPIREP system both to directly impact aviation safety and to impact safety indirectly through support of research and forecasting.

In an ideal world, an EPIREP sensor suite would support measurements associated with each of the hazards listed above, for both flight safety reasons (alerting pilots and air traffic facilities of hazardous in-flight conditions) and research and forecasting initiatives. However, due to costs and limits on sensor capabilities, such a sensor suite is not feasible. The approach then is to identify low cost or existing sensors that could be used to collect information about specific hazards.

The easiest sensor to include in such a suite is the outside temperature probe. All aircraft are required to be equipped with such a device. Outside temperature information aids the pilot in identifying areas of potential supercooled liquids (-20°C to 0°C) and provides research and forecast models with *in situ* measurements. Aircraft are also required to be equipped with a Pitot tube for measuring flight speed. Wind speed and direction are available on aircraft equipped with GPS or an inertial navigation system. Wind speed and direction should be a part of any EPIREP sensor suite. Both temperature and water vapor/liquid water content are important in predicting icing conditions and are needed to support atmospheric models. As described in the section on MDCRS, a relative humidity sensor is being used to provide moisture information at different altitudes.

To aid in registering the data, EPIREPs should include positional information as well as a time stamp. PIREPs have traditionally included pressure altitude and location referenced to a fixed navigation aid (NAVAID) identifier, a distance from a NAVAID, or a route segment [4-69]. EPIREPs should include pressure altitude information and when available GPS coordinates.

To aid in the reporting of turbulence, accelerometers (which are a part of the inertial navigation systems found in many aircraft [4-10, p. 310]) can be used to measure the severity of turbulence experienced by an aircraft. Modifications to these systems may aid in the reporting of turbulence. For the researcher, associating turbulence with precipitation, clouds, or the lack of both is key in categorizing the source of the turbulence (*e.g.*, clear air turbulence). Aircraft equipped with weather radars provide an existing source of data that could be summarized or compressed for down linking as a part of an EPIREP. The airborne weather radar provides information on precipitation amounts and precipitation related turbulence. Radial wind information as a function of range is also available. A summary of the information averaged of time or spatially may be needed to reduce the amount of data to downlink.

Commercial aircraft are often equipped with acoustic or electrical sensors for the detection of icing while in-flight. These sensors are applied in-flight to activate de-icing systems. A sensor that automatically reports icing, via EPIREPs, on the surface of the aircraft would greatly enhance the present reporting system requiring pilot intervention. Sensors could also be designed to report the amount of icing accumulating on the wings. Allied Signal markets an ice detection sensor called the C/FIMS [4-70] for in-flight detection of icing on the wings of the aircraft.

In the future, if aircraft are retrofitted with additional sensors (*e.g.*, lidar or radiometers) to detect or predict other hazards such as hail, icing, or clear air turbulence, these sensors can be incorporated into the EPIREP's data link. For example, radiometers could provide information on atmospheric temperatures and integrated liquid water and water vapor content in the atmosphere. However, these systems represent a larger capital investment. However, equipping a limited number of aircraft with additional sensors, that are accessible via EPIREPs, would support a number of research efforts.

Table 4-26 contains a list of the proposed sensors to include in an EPIREP sensor suite. A number of the sensors are already present on some aircraft, but interfacing issues may limit access. However, except for the AWR, these sensors are relatively low cost. A second set of the sensors could be added to the aircraft in support of EPIREPs. An equivalently important question that needs to be addressed is "what infrastructure will be in place to receive and process the EPIREP data." This question is not addressed under this task, but users of the data should be identified and benefits defined as a part of the EPIREP effort.

Table 4-26. A List of Possible Sensors to Include in an EPIREP Sensor Suite

EPIREP Reporting Options
Outside Temperature Sensor
Wind Speed and Direction Sensors
Relative Humidity Sensors
Location (GPS Coordinates) and Time Stamp
Degree of Turbulence (Accelerometers)
Airborne Weather Radar Summaries
Icing Sensors on the Surface of the Aircraft

References

4-1. Skolnik, M., *Radar Handbook*, 2nd Edition, McGraw-Hill Publishing, New York, 1990.

4-2. Mahapatra, P. R., and D. S. Zrnic', "Modern Aviation Weather Systems for Efficient Flight Management," *1990 IEEE National Radar Conference*, pp. 457-463.

4-3. Turnbull, D. H., "Aviation Weather Radar," *IEEE International Radar Conference*, pp. 748-751.

4-4. Evans, J. E., et al., "Terminal Doppler Weather Radar Clutter Control," *1990 IEEE International Radar Conference*, pp. 12-16.

4-5. Evans, J., and D. Turnbull, "Development of an Automated Windshear Detection System Using Doppler Weather Radar," *Proceedings of the IEEE*, Vol. 77, No. 11, November 1989, pp. 1661-1673.

4-6. Mahapatra, P. R., and D. S. Zrnic', "Sensors and Systems to Enhance Aviation Safety Against Weather Hazards," *Proceedings of the IEEE*, Vol. 79, No. 9, September 1991, pp. 1234-1267.

4-7. Weber, M. E., and M. L. Stone, "Low Altitude Wind Shear Detection Using Airport Surveillance Radars", *IEEE AES Systems Magazine*, June 1995, pp. 3-9.

4-8. Weber, M. E., et al., "Data Processing Techniques for Airport Surveillance Radar Weather Sensing," *1995 IEEE International Radar Conference*, pp. 521-528.

4-9. Whiton, R. C., and P. L. Smith, "History of Operational Use of Weather Radar by U.S. Weather Services, Part I: The Pre-NEXRAD Era," *American Meteorological Society, NEXRAD Special Issue*, June 1998, Vol. 13, No. 2, pp. 219-243.

4-10. Mahapatra, P., *Aviation Weather Surveillance Systems*, The Institution of Electrical Engineers, Michael Faraday House, United Kingdom, 1999.

4-11. Crum, T. D., et al., "An Update on the NEXRAD Program and Future WSR-88D Support to Operations," *American Meteorological Society, NEXRAD Special Issue*, June 1998, Vol. 13, No. 2, pp. 253-262.

4-12. Alberty, R. L., and T. D. Crum "NEXRAD and the Operational Doppler Weather Radar for the 1990s and Beyond," *Dig. Int. Geosci. Remote Sensing Symposium*, 1990, pp. 725-728.

4-13. *Federal Meteorological Handbook No. 11*, Doppler Radar Meteorological Observations, Part B, Doppler Radar Theory and Meteorology, FCM-H11B-1990, June 1990.

4-14. *Federal Meteorological Handbook No. 11*, Doppler Radar Meteorological Observations, Part D, WSR-88D Unit Description and Operational Applications, FCM-H11D-1992, April 1992.

4-15. *Federal Meteorological Handbook No. 11*, Doppler Radar Meteorological Observations, Part C, WSR-88D Products and Algorithms, FCM-H11C-1991, February 1991.

4-16. *Federal Meteorological Handbook No. 11*, Doppler Radar Meteorological Observations, Part A, System Concepts, Responsibilities, and Procedures, FCM-H11A-1991, June 1991.

4-17. Strauch, R. G., and et al., "Wind Profilers for Support of Flight Operations," *Journal of Aircraft*, Vol. 26, No. 11, pp. 1009-1015, November 1989.

4-18. Martner, B. E., and et al., "An evaluation of Wind Profiler, RASS, and Microwave Radiometer Performance," *Bulletin of the American Meteorological Society*, Vol. 74 No. 4, pp. 599-613, April 1993.

4-19. May, P. T., and et al., "Temperature Sounding by RASS with Profiler Radars: A Preliminary Study, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 28, No. 1, pp. 19-28, January 1990.

4-20. Ramamurthy, M., "Modern Observing Systems Used in National Weather Prediction," Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, COMET Faculty Course on NWP, June 7, 1999, available at www.comet.ucar.edu/class/faculty/Jun071999/html/OSSE2/ sld001.htm.

4-21. Forecast Systems Lab Boundary Layer Profilers available at http://www.fsl.noaa.gov/~vondaust/fir96/www.fir96deo.html.

4-22. Rogers, J. W., C. J. Tidwell, "Terminal Area Surveillance System," *1995 IEEE International Radar Conference*, pp. 501-504.

4-23. Buckler, L. M., "The Use of Phased Array Radars at Civilian Airports," *1996 IEEE Internal Symposium on Phased Array Systems*, pp. 334-339.

4-24. "Terminal Area Surveillance System (TASS) Phased Array Radar Study," Final Technical Report, prepared by Raytheon, submitted to FAA, DTFA01-94-C-00049, June 1995.

4-25. "Phased Array Technology Status and Assessment," prepared by Horizons Technology, Inc., prepared for Technology Planning Incorporated, October 29, 1993.

4-26. "TASS Four Faced Electronically Scanned Array Radar Point Design," prepared by Massachusetts Institute of Technology, Lincoln Laboratory, prepared for James Rogers, Federal Aviation Administration, June 1994.

4-27. Leyh, C., et al., "A Low Cost Microburst Early Warning and Detection Radar," *IEEE International Radar Conference*, 1995, pp. 496-500.

4-28. Wurman, J., "Vector Winds from a Single-Transmitter Bistatic Dual-Doppler Radar Network," *Bulletin of the American Meteorological Society*, Vol. 75, No. 6, June 1994, pp. 983-994.

4-29. Wurman, J., "A Bistatic Multiple-Doppler Radar Network: Part I, Theory," available at www.atd.ucar.edu/rsf/bistatic/network/bistatic.network.2.html.

4-30. Doviak, R. J., and D. S., Zrnic, *Doppler Radar and Weather Observations,* 2nd Edition, Academic Press, New York, 1993.

4-31. The CSU CHILL Radar System available at http://olympic.atmos-colostate.edu/CHILL/Radar.html.

4-32. Pawnee Doppler Radar available at http://olympic.atmos-colostate.edu/CHILL/chill_pawnee.html

4-33. Vivekanandan, J., et al., "Aircraft Icing Detection Using Dual-wavelength and Polarization Radar Observations", *IEEE 1998.*

4-34. Adams, W. M. and J. Vivekanandan, "Snowfall Rate and Supercooled Liquid Water Content Retrieval Using the Dual-Frequency Radar Technique," *Dig. Int. Geoscience Remote Sensing Symposium*, 1993, pp. 1922-1924.

4-35. NOAA satellite images are available from the Satellite Services Division web site at http://www.ssd.noaa.gov, and from the Operational Significant Event Imagery database at http://www.osei.noaa.gov.

4-36. Information on the NASA EOS satellite volcanology program may be found at http://volvano2.pgd.hawaii.edu/eos/.

4-37. Information on the NASA GOES Project Volcano Watch may be found at http://rsd.gsfc.nasa.gov/goesb/chesters/web/text/goes.volcanoes.html.

4-38. Mosher, F. R., "Four channel volcanic ash detection algorithm," available at http://www.awc-kc.noaa.gov/publications/mosher/paper3.html.

4-39. Krueger, A. J., Walter, L. S., Bhartia, P. K., Schnetzler, C. C., Krotkov, N. A., Sprod, I., Bluth, G. J. S., "Volcanic sulfur dioxide measurements from the total ozone mapping spectrometer instruments", *Journal of Geophysical Research*, 100 (D7), pp. 14057-14076, 1995.

4-40. Krueger, A. J, Doiron, S. R., Bluth, G. J. S., Walter, L. S. Schnetzler, C. C. "Volcanic hazard detection with the total ozone mapping spectrometer (TOMS)," *U.S. Geological Survey Bulletin v.* 2047, pp.367-372, 1994.

4-41. Krueger, A. J., "The earth System Science Pathfinder VOLCAM Volcanic Hazard Mission," paper C08_11:30, *IEEE International Geoscience and Remote Sensing Symposium*, Hamburg, Germany, 28 June-2 July 1999.

4-42. Koschmieder, H., "Measurements of visibility at Danzig," *Monthly Weather Review 58*, No. 11, pp. 439-444, 1930.

4-43. Su, F., "CW laser radar detects wake vortices", OE Reports No. 148, April 1996.

4-44. Hannon, S. M., and T. L Clark, "Lidar measurement of windshear and turbulence and comparison with a predictive fine-mesh mesocale model," *Proc. SPIE, 2464*, 1996.

4-45. Hannon, S. M., S. W. Henderson, J. A. Thomson, and P. GATT, "Autonomous lidar wind field sensor: performance predictions", *Proc. SPIE, 2832*, pp. 76- 90, 1996.

4-46. Gleim, I. N., *Aviation Weather and Weather Services*, Gleim Publications, Inc., Gainesville, Florida, 1998.

4-47. Vaisala RS80 available at www.vaisala.fi

4-48. NWS Radiosonde available at www.rrs.nws.noaa.gov

4-49. Global Atmospherics, Inc., available at www.glatmos.com/products/products.html

4-50. National Lightning Detection Network Platform Document, available at http://eosims.msfc.nasa.gov:5721/source_documents/nldn_platform.html.

4-51. NOAA/FSL Ground-Based GPS-IPW Demonstration Network available at http://www-dd. fsl. noaa.gov/gps/background.html.

4-52. Nierow, A., et al., "The Role of ITWS in the Modernization of the National Airspace System," *The 8th Conference on Aviation, Range, and Aerospace Meteorology*, abstract available at www.confex2.com/ams/99annual/abstracts/527.htm.

4-53. Wieler, J. G., et al., "Integrated Terminal Weather Surveillance – A System Perspective," *The 29th Conference on Radar Meteorology*, abstract available at www.confex2.com/ams/rm29/abstracts/304.htm.

4-54. MIT Lincoln Lab Aviation Weather available at www.ll.mit.edu/AviationWeather/index.html.

4-55. Implementation of the Rapid Update Cycle available at http://maps.fsl.noaa.gov/tpbruc.cgi.

4-56. "Clear Air Turbulence Primer," NOAA, available at http://www-frd.fsl.noaa.gov/mab/scatcat/cat.html, 1999.

4-57. Rapid Update Cycle available at www.comet.ucar.edu/nwplessons/RUClesson4/rucpp/sld001.htm.

4-58. Aydin, K., et al., "Remote Sensing of Hail with a Dual Linear Polarization Radar," J. Clim. Appl. Meteorol. Vol. 25, 1986, pp. 1475-1484.

4-59. Westwater, E. R., and R. A. Kropfli, "Remote Sensing Techniques of the Wave Propagation Laboratory for the measurement of supercooled water: Application to Aircraft Icing," NOAA Technical Memorandum ERL WPL-163, May 1989.

4-60. Politovich, M. K., "Aircraft icing caused by large supercooled droplets," *J. Appl. Meteorol. 28*, pp. 856-868, 1989.

4-61. Politovich, M. K., *Mount Washington Icing Sensors Project*, National Center for Atmospheric Research, 1999.

4-62. Gasiewski, A. J. , NOAA-ETL, private communication, 1999.

4-63. Kropfli, R. A. , et al., "Radar and radiometer measurements of the physical parameters of clouds and precipitation at the NOAA Environmental Technology Laboratory," *Conference on Battlespace Atmospheric and Cloud Impacts on Military Operations*, Hanscom AFB, Massachusetts December 1-3, 1998 (8 pp.).

4-64. Viezee, W., E. E. Uthe, and R. T. H. Collis, "Lidar observations of airfield approach conditions: an exploratory study," *J. Appl. Meteor*. 8, pp. 274-283, 1969.

4-65. Patterson, E. M., G. G. Gimmestad, and D. W. Roberts, "Initial measurements using a 1.54 μm eyesafe Raman-shifted lidar," *Appl. Opt*. 28, pp. 4978-4981,1989.

4-66. Klett, J. D. "Stable analytical inversion solution for processing lidar returns," *Appl. Opt*. 20, 211-220, 1981.

4-67. Bissonnette, L. R., G. Kunz, and K. Weiss-Wrana, "Comparison of lidar and transmissometer measurements," *Opt. Eng*, 36(1) pp.131-138, 1997.

4-68. Gleim, I. N., *Federal Aviation Regulations and Aeronautical Information Manual*, 1999 Edition, Gleim Publications, Inc., Gainesville, Florida, 1998.

4-69. Schwartz, B., "The Quantitative Use of PIREPS in Developing Aviation Weather Guidance Products," *Weather and Forecasting*, Vol. 11, September 1996, pp. 372-384.

4-70. Allied Signal Ice Detector (C/FIMS) available at http://aerospace.alliedsignal.com/aerosp…raft/ products/products/ice_detector.html

Acronyms

A	arrival
AATT	Advanced Air Transportation Technologies
ACARS	Aircraft Communications Addressing and Reporting System
AFSS	Automated Flight Service Stations
AGL	above ground level
AIM	Aeronautical Information Manual
AIRMET	Airman's Meteorological Advisory
ARC	AMES Research Center
ARL	Air Resources Laboratory
ARSR	air route surveillance radar
ARTCC	air route traffic control centers
ASOS	Automated Surface Observation System
ATC	Air Traffic Control
ATCT	airport traffic control tower
ATIS	automatic terminal information service
AVOSS	Aircraft Vortex Spacing system
AvSP	Aviation Safety Program
AWC	aviation weather center
AWIN	Aviation Weather Information
AWOS	Automated Weather Observing System
AWR	airborne weather radar
AWRP	Aviation Weather Research program
Az	azimuth
C	current
C&V	ceiling and visibility
CAT	clear air turbulence
Convective SIGMET	Convective Significant Meteorological Information
CTAS	Center-TRACON Automation System
CTI	Coherent Technologies, Inc.
CW	continuous wave
CWA	Center Weather Advisory
CWSU	center weather service unit
D	departure
D-ATIS	Digital Automated Terminal Information Service
DCL	data communication link

Acronyms (Continued)

DFRC	Dryden Flight Research Center
DFW	Dallas-Fort Worth International Airport
DH	decision height
DIAL	Differential Absorption Lidar
Domestic SIGMET	Domestic Significant Meteorological Information
DUAT	direct user access terminal
E	en route
EFAS	En Route Flight Advisory Service
El	elevation
EM	electromagnetic
EO	electro-optical
EOS	Earth Observing System
EPIREP	electronic pilot report
ES	enhanced sensitivity
ETA	estimated time of arrival
ETD	estimated time of departure
EWINS	Enhanced Weather Information Systems
ExWP	Enhanced Weather products
F	forecasted
FA	area forecasts
FA	aviation forecast
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FBR	visual flight rules
FIS	Flight Information Systems
FMF	flight movement forecast
FSL	Forecast Systems Laboratory
FSS	Flight Service Stations
GOES	Geostationary Operational Environmental Satellites
GPS	Global Positioning System
GRC	Goddard Research Center
GTRI	Georgia Tech Research Institute
GWVSS	Ground Wind Vortex Sensing System
H	horizontal
HIWAS	Hazardous In-Flight Weather Advisory Service
HLSWC	High Significant Weather Charts

Acronyms (Continued)

HO	human observer
IDS	Inter-disciplinary Science
IF	intermediate frequency
IFR	instrumented flight rules
IMC	instrument meteorological conditions
IMPACT	Improved Accuracy from Combined Technology
International SIGMET	International Significant Meteorological Information
IR	infrared
ITWS	integrated terminal weather support
LaRC	Langely Research Center
LDV	Laser Doppler Velocimeter
LH	left hand
LL	Lincoln Laboratories
LLSWC	Low Level Significant Weather Charts
LLWAS	Low Level Wind Shear Alert System
LLWAS-NE	LLWAS-Network Expansion
LM	Lockheed Martin
MAVSS	Monostatic Acoustic Vortex Sensing System
MDA	minimum descent altitude
MDCRS	meteorological data collection and reporting system
METAR	Aviation Routine Weather Report
MIS	Meteorological Impact Statement
MIT	Massachusetts Institute of Technology
MMIC	Monolithic Microwave Integrated Circuit
MPR	microburst prediction radar
MSL	mean seal level
MWISP	Mount Washington Icing Sensors Project
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVAID	navigational aid
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Weather Surveillance Radar
NLDN	National Lightening Detection Network

Acronyms (Continued)

nmi	nautical miles
NOAA	National Oceanic and Atmospheric Administration
NTSB	National Transportation Safety Board
NWPN	NOAA wind profiler network
NWS	National Weather Service
O/S	Operator/Support
OAR	Oceanic and Atmospheric Research
OPD	Optical parametric Oscillator
PIREPS	pilot reports
PRF	pulse repetition frequency
PSR	Polarimetric Scanning Radiometer
R&D	research and development
RAD	Radiosonde Additional data
RASS	radio-acoustic sounding system
RF	route forecast
RH	right hand
RPM	revolutions per minute
RUC	rapid update cycle
RVR	runway visual range
SE	Systems Engineering
SEPCI	Aviation Selected Special Weather Report
SI	satellite imagery
SIGMET	significant meteorological information
SLD	supercooled large drops
SVR	slant visual range
TA	temperatures aloft
TAF	Terminal Area Forecast
TASS	terminal area surveillance system
TOMS	Total Ozone mapping Spectrometer
TOWR	Terminal Doppler Weather Radar
TRACON	Terminal Radar Approach Control
TS	thunderstorms
TWEB	Transcribed Weather Broadcast
TWIP	Terminal Weather Information for Pilots
UHF	ultra-high frequency

Acronyms (Concluded)

UPS	United Parcel Service
V	vertical
VAD	velocity azimuth display
VHF	very high frequency
VMC	visual meteorological conditions
VOR	VHF omnidirectional range
WA	winds aloft
WARP	Weather and Radar Processing
WFO	Weather Forecast Offices
WISP	Winter Icing and Storms Program
WMO	meteorological watch offices
WRF	Weather Research and Forecast
WSI	Weather Services International
WSP	Weather Systems Processor
WW	Severe Weather Watch

Appendix A Enhanced Weather Information Systems

1453. GENERAL. Enhanced weather information systems (EWINSs) incorporate advanced technical capabilities, are FAA approved, and provide certificate holders with aviation weather data which permits quick, flexible, and operationally efficient responses to changing meteorology conditions. These systems detect, track, report, and forecast ordinary weather conditions as accurately as they do adverse weather phenomena. An EWINS uses *reported and forecast weather conditions not only to aid* in controlling daily flight movements, but also to permit short and long-term operational planning for enhancing an operator's capability to protect schedules and to use equipment and personnel with maximum efficiency.

1455. CONCEPT OF AN EWINS. The basic concept of an EWINS is to use a weather information system for maximum effectiveness in tracking, evaluating, reporting and forecasting the presence or absence of adverse weather phenomena. The basic requirement of an EWINS is it must always incorporate a subsystem capable of obtaining, evaluating, and disseminating reports and forecasts of adverse weather phenomena. Adverse weather phenomena, by definition, can directly diminish flight operation safety. Consequently, an Adverse Weather Phenomena Report and Forecasting subsystem must effectively, rapidly, and reliably process weather information from the time the information is obtained from approved sources until it is used by flightcrews and other operational control personnel in making decisions concerning the control of flight movements.

1457. CHARACTERISTIC FUNCTIONS OF AN EWINS. There are three basic functions of an EWINS. These functions are an inward flow of weather information, analysis and evaluation of the information, and an outward flow of the information in an operationally appropriate format. Additional components include a *policies and procedures manual, training programs, qual*ity assurance procedures, work facilities, and equipment.

A. An EWINS must include sufficient procedures, personnel, and communication and data processing equipment, to effectively obtain the aeronautical weather data described in section 2 from approved sources. The communication and data processing equipment and procedures must include back-up capabilities to provide uninterrupted operation should any single component of the system fail.

B. An EWINS must have the necessary qualified personnel, procedures, and equipment for effective analysis and evaluation of aeronautical weather data and of the affect of changing weather conditions on current and future operations. Based on conclusions derived from EWINS data, authorized personnel may prepare and issue flight movement forecasts, forecasts of adverse weather phenomena, and other meteorological advisories to control *flight operations. Personnel authorized to analyze and* evaluate weather data for the purpose of making and issuing forecasts must be trained and qualified in accordance with paragraphs 1463 and 1465.

C. An EWINS must have the necessary communication systems, data processing equipment, procedures, and personnel to provide rapid, timely, and reliable dissemination of weather information used to make operational decisions. Flight movement forecasts, adverse weather phenomena forecasts, and any other meteorological advisories must be appropriately disseminated to flightcrews during preflight planning and while they are en route. The same information must be provided to other operational control elements within the operator's organization.

1459. FAA POLICIES CONCERNING EWINSs. The following are FAA policy statements concerning EWINSs used by Parts 121 and 135 operators.

A. Each EWINS must be FAA approved. FAA approval of an EWINS includes approval of an Adverse Weather Phenomena Reporting and Forecasting subsystem and requires certificate holders to use that subsystem.

B. An EWINS must provide rapid and reliable dissemination of weather data through communication channels independent of any air traffic control system.

C. Each EWINS includes capabilities for continuous quality assurance and authoritative procedures for correcting discovered deficiencies.

D. Except for provisions for quality assurance, any other appropriate part of an EWINS may be owned and/or operated by a private weather company, private communication company, or by another U.S. Parts 121 or 135 operator.

E. An aviation meteorologist or a dispatcher with IMF authority must continuously be on duty when any flight operations are in progress.

F. Properly trained and qualified aviation meteorologists and dispatchers with IMF authority who operate an EWINS may be authorized to prepare and issue flight movement forecasts.

G. Flight movement forecasts are official weather forecasts which control specific flight operations for a particular operator.

H. Aeronautical weather data provided by an EWINS satisfies all regulatory requirements for each Part 121 and/or Part 135 certificate holder specifically authorized to use a particular EWINS.

1461. EWINS POLICIES AND PROCEDURES MANUAL

A. *Responsibility for Preparing an EWINS Manual.* A certificate holder or a combination of certificate holders and noncertified organizations may jointly operate an EWINS. The operator or operators of an EWINS must develop, prepare, and keep current an EWINS policies and procedures manual.

(1) If an EWINS is operated by a single certificate holder, that certificate holder shall be responsible for preparation and currency of an EWINS policies and procedures manual. This manual shall be incorporated as part of the manual requirements of FAR 121.133 or FAR 135.21.

(2) If an EWINS is cooperatively or contractually operated by more than one organization (at least one of which must be a certificate holder authorized to operate under Part 121 or Part 135), the EWINS policies and procedures manual must establish who is responsible for preparing and keeping the manual current. Each cooperating certificate holder must incorporate appropriate provisions of the EWINS manual in its manual.

(3) A certificate holder who does not operate an EWINS and does not participate with others in a cooperative EWINS arrangement may, through contractual arrangements, acquire aeronautical meteorological data from an approved EWINS. In this case the certificate holder must use all the weather products provided by the approved EWINS for control of its flight operations. The contracting certificate holder must incorporate in its manual appropriate provisions of the approved EWINS policies and procedures manual. Additionally, the contracting certificate holder's manual must contain specific restrictions on use of forecasts from sources other than the approved EWINS.

B. *Contents of an EWINS Manual.* An EWINS policies and procedures manual must include descriptions of the structure of the EWINS and how the EWINS operates. This manual must provide information concerning the following areas:

(1) Facilities:

(a) The location of the primary meteorological office

(b) Descriptions of, and instructions for, using communications and data processing equipment

(2) Weather Sources:

(a) A list of sources for weather reports

(b) A list of sources for weather forecasts

(c) Normal, abnormal, and emergency procedures

(d) Conditions and limitations for use of private weather services as sources for reports and forecasts

(3) Personnel:

(a) Qualification standards for dispatchers with FMF authority and aviation meteorologists

(b) Training requirements for dispatchers with FMF authority and aviation meteorologists

(c) Staffing requirements for the EWINS

(4) Operating Policies and Procedures:

(a) Detailed procedures for obtaining, evaluating, and disseminating aviation weather

(b) Procedures for obtaining PIREPS/AIREPS

(c) Procedures for operating in areas affected by adverse weather

(d) A description of the EWINS interface with dispatch/operational control elements

(e) The identification, authorization, and responsibility of persons permitted to make flight movement forecasts

(5) Quality Assurance Procedures:

(a) Procedures to assure accuracy of the EWINS weather reports and forecasts

(b) Procedures to measure effectiveness of the EWINS communication capabilities

(c) Policies and procedures for correcting deficiencies detected within an EWINS

1463. PERSONNEL QUALIFICATIONS. Aviation meteorologists and dispatchers with FMF authority who are part of an EWINS must meet the following special qualifications:

A. *Aviation Meteorologist.* An aviation meteorologist must have a degree in *meteorology (or* its equivalent) awarded by an accredited university or college and be certified by his employer as competent to perform aviation forecasting duties. Each EWINS operator must have a program which ensures that aviation meteorologists understand that their professional actions influence aviation safety, and the required operational and regulatory responsibilities for persons using the meteorologists' forecasts. In addition, aviation meteorologists must receive briefings, as *necessary, to obtain current* information on changes to the operations controlled by their forecasts. A briefing and training scheme for aviation *meteorologists must* be included in the EWINS policies and procedures manual. Training can be self-directed study, briefings, and/or formal training. It must include information on weather requirements of the FARs which regulate certificate holders who use the EWINS. Traditional types of professional meteorological training are encouraged.

B. Dispatcher with FMF Authority. A dispatcher who has satisfactorily completed an approved training program which includes the training specified in paragraph 1465, may be authorized by his employer to make and issue flight movement forecasts.

1465. TRAINING FOR DISPATCHERS WITH FMF AUTHORITY

A. Dispatchers shall not be authorized to make and issue flight movement forecasts unless they have satisfactorily completed an FAA-approved initial training course in meteorology. In addition, dispatchers with FMF authority must satisfactorily complete an FAA-approved recurrent training course *in meteorology* at least once every 24 months. Recurrent training modules may be scheduled at periodic intervals that provide for a complete cycle of recurrent meteorological training every 24 months. Any dispatcher with FMF authority who is also assigned duties in domestic or flag operations under Part 121 must satisfactorily complete the training and qualification requirements specified in Subparts N and P of Part 121 in addition to the meteorological training specified in this paragraph. Any meteorological training required by Subpart N, however, is satisfied by the meteorological training specified in this paragraph.

B. Approved initial and recurrent meteorological training curriculum segments must include training in at least the following subjects:

(1) Basic properties of the atmosphere:
Composition
Density
Measurement
General circulation
Solar heating

(2) Clouds:
Formation
Condensation
Precipitation
Use of cloud knowledge in forecasting
Stability and instability

(3) Air mass analysis:
Classification
Flying conditions
Use of air mass knowledge in forecasting

(4) Analysis of fronts:
Structure and characteristics
Cloud sequences in fronts
Establishing positions of fronts by cloud types
Fronts and seasonal variation
Flying weather in fronts
Cyclones and anticyclones

(5) Fog: Reading a weather map
Type
Cause and formation

(6) Ice:
Types
Cause and formation

(7) Thunderstorms, hurricanes, tornadoes:
Causes
Methods of forecasting
Structure and complexity of internal winds
Hail (cause and formation)

(8) Windshear: Detection
Reporting
Cause
Avoidance technique

(9) Turbulence
Determining the smooth level of flights
Cause

(10) Interpreting weather data:
Weather sequences and symbols
Weather map symbols
Drawing a weather map
Reading a weather map
Upper-level charts
Adiabatic charts
Winds-aloft charts
Instruments used to gather and record weather data
Radar products and images
Satellite products and images

(11) Weather forecasting:
Extrapolation
Movement of fronts and air masses
Isobars
Barometric tendency
Use of advanced technology in weather forecasting techniques

(12) Application of weather knowledge
Planning
Domestic
Oceanic (if applicable)
International

1467. APPROVAL OF AN EWINS

A *Requests for Approval.* Part 121 and Part 135 operators are not required to use an EWINS. These operators, however, may elect to establish and use an EWINS. All EWINS must be FAA approved. An operator or group of operators choosing to establish an EWINS must make a written request for approval. The letter must describe the planned EWINS in sufficient detail to allow the POI (or POI'S) to evaluate the proposal. The letter must be accompanied by the proposed EWINS policy and procedures manual, details of any contractual arrangements, and resumes of the key personnel employed by any commercial weather service to be involved in the proposed EWINS.

B. *Evaluations and Inspections of an EWINS.* Before approving an EWINS, POIs must evaluate the material submitted with the request for approval and conduct inspections of the facilities, equipment, and other components. POIs must also verify the professional qualifications and training of aviation meteorologists and dispatchers with FMF authority who will be used in the EWINS. When the POI has determined the proposed EWINS has the characteristic functions described in paragraph 1457, and complies with the FAA policy statements in paragraph 1459, and meets the criteria specified in paragraphs 1461, 1463 and 1465, the EWINS may be approved.

C. *Approval or Denial of an EWINS*

(1) Approval for a certificate holder to use an EWINS shall be accomplished by issuing operations specifications paragraph AIO with reference to the EWINS policy and procedures manual to be used by the operator. The original date of the EW INS manual, and the last revision date, shall also be referenced in paragraph A IO of the operations specifications. Any revisions to the EWINS and/or the EWINS manual should be evaluated and inspected by the FAA as soon as possible, but not later than 15 days after the revision is made.

(2) If after evaluation and inspection, the POI determines a proposed EWINS does not meet the requirements of this handbook, all submitted materials shall be returned to the operator with an explanatory letter.

This letter must state the proposed EWINS is not approved and clearly explain why. If an EWINS has been approved, and a POI determines later that the EWINS does not continue to meet the requirements of this handbook, the POI shall immediately inform the certificate holder. If the certificate holder does not take immediate and appropriate corrective action the POI must take action to amend paragraph AIO of the operations specifications and rescind approval of the EWINS.

Appendix B Parts 121/135 Weather Information Systems

SECTION 2. PARTS 121/135 WEATHER INFORMATION SYSTEMS

1417. REGULATORY REQUIREMENTS FOR WEATHER INFORMATION. There are many FAR's and ICAO Standards and Recommended Practices which directly establish specific weather information requirements. For example FAR's 121.613 and 135.219 both specify that weather reports or forecasts must indicate the destination airport (at time of arrival) will be at or above the authorized minimums before an IFR flight can begin. Other FAR's specify weather information requirements indirectly, even though the requirements are not specificaly referenced in the FAR titles or text. In such cases an operating requirement is established which cannot be complied with unless specific weather data is available during preflight planning and while the aircraft is aloft. For example, Subpart I of both Parts 121 and 135 establish airplane performance standards. These regulations indirectly require appropriate means for determining the probable temperature, pressure altitude, and other weather factors (which will exist inflight) necessary for calculating the aircraft's performance capabilities.

1419. GENERAL CHARACTERISTICS OF A WEATHER INFORMATION SYSTEM. Each certificate holder operating under Part 121 or Part 135 must have methods for gathering and disseminating aeronautical meteorological data. Weather information systems must rapidly disseminate accurate and complete weather information in formats that are operationally suitable for use by flightcrews, dispatchers, and other flight control personnel. All aeronautical weather systems include equipment and personnel to collect, process, and disseminate reports of weather observations and forecasts. These systems must include reliable methods for communicating weather information between appropriate ground facilities and between ground facilities and aircraft during ground and flight operations. Systems which include an approved Adverse Weather Phenomena Reporting and Forecasting subsystem must provide ground to air communications (independent of ATC) capable of keeping flightcrews informed of potentially hazardous conditions when they are identified, reported, or forecasted.

1421. WEATHER INFORMATION SYSTEMS - OPERATIONAL REQUIREMENTS. A weather information system must provide at least that meteorological information needed to conduct all phases of flight operations in consideration of operational and regulatory requirements. Weather products (aviation weather information) which must be provided by a weather information system are discussed in the following paragraphs. These weather products are common to weather information systems used by both Part 121 and Part 135 operators.

1423. OPERATIONAL REQUIREMENTS - FLIGHTCREWS. Flightcrews need accurate weather information to determine the present and forecast weather conditions on any planned operation. For example, for adequate flight planning, flightcrews should know existing and expected weather conditions at the departure airport, along the planned route of flight, and at destination, alternate, and diversionary airports. While inflight, flightcrews should be able to obtain current surface weather observations and updated forecasts. When a significant change in observed weather data occurs, the location, intensity, and movement of the phenomena affecting flight operations should be updated and made available to en route aircraft.

A. *Preflight Planning.* Operational flight-planning decisions require consideration of the following weather information:

- Terminal forecasts for departure, destination, alternate, and diversionary airports (FT)
- Winds and temperatures aloft for various route segments at planned cruising altitudes (FD)
- Surface observations for departure, destination, alternate, and diversionary airports (SA)
- NOTAM's for departure/destination/alternate/diversionary airports and navigation NOTAM's (if not provided by other means)
- Area forecasts (FA)
- Information to determine the density altitude at points of takeoff and landing
- AIRMET's, SIGMET's, and Convective SIGMET's
- Thunderstorms (location, intensity, movement, direction, and speed)
- Squall lines located or forecast to occur along the route of flight

- Areas of heavy precipitation
- Freezing levels
- Icing (location, type, and severity)
- Turbulence (intensity, type, areas, and altitudes of occurrence)
- Hail (areas of occurrence)
- En Route PIREP's
- Mountain waves (standing lenticular clouds, rotor clouds)
- Tornadoes (waterspouts, funnel clouds)
- Low level windshear

B. *Inflight Weather Advisories.* Inflight weather advisory requirements available from a weather information system include the following:

- Updated areas of adverse weather (such as thunderstorms, turbulence, and heavy precipitation)
- Updated reports and forecasts of winds and temperatures aloft
- Updated reports and forecasts of destination and alternate airport weather
- Reports or forecasts of unanticipated weather conditions below landing minimums at airports specified in a dispatch, flight release, or flight plan

1425. OPERATIONAL REQUIREMENTS - DISPATCH AND/OR FLIGHT CONTROL PERSONNEL. Dispatchers and other flight control personnel need current and forecast weather information to plan, control, direct, or terminate flight operations. These personnel require updated information for long-term planning and for assisting crews inflight who are required to amend their flight plans due to changing weather, changing airport conditions, mechanical difficulties, or any other reason. Flight control personnel must be able to keep crews informed of reported or forecast adverse weather phenomena.

A. All weather information systems must provide flight control personnel with access to at least the meteorological information associated with the following kinds of weather products:

- Surface weather analysis and prognosis charts
- Radar summary charts
- Severe weather outlook charts
- Upper winds and temperature information
- Weather depiction charts
- Freezing level charts
- Terminal and area forecasts
- Aviation weather observations (surface reports)
- Pilot weather reports
- Hazardous weather reports and depiction charts
- Weather advisories (such as convective SIGMET's, SIGMET's, AIRMET's, and CWA's)

B. Weather information systems which support flight operations above 18,000 feet must provide the following additional information:

- High level severe weather information (clear air turbulence)
- Tropopause height information
- Vertical windshear information
- Constant pressure charts
- Constant pressure analysis charts (5 levels)
- High level (400 - 70 millibar) significant weather prognosis

1427. ADVERSE WEATHER PHENOMENA REPORTING AND FORECASTING REQUIREMENTS. Any weather information system used in domestic or flag operations under Part 121 must include an Adverse Weather Phenomena Reporting and Forecasting subsystem. FAR 121.101(d) requires only those operators which conduct domestic and/or flag operations to have FAA-approved

Adverse Weather Phenomena Reporting and Forecasting subsystems. These subsystems allow certificate holders to monitor weather reports from various sources in their operating areas to quickly and accurately identify adverse weather phenomena, and to predict their effects on safety of flight and ground operations. These subsystems must include forecasting abilities which are at least equal in capability to government weather system forecasting abilities and which are specifically oriented to the certificate holder's operational needs with respect to adverse weather phenomena.

A. *Adverse Weather Phenomena.* Adverse weather phenomena are meteorological conditions which, if encountered in flight or during ground operations, could directly diminish safety of an operation. The following meteorological conditions are considered by the FAA to be adverse weather phenomena:

- Strong surface winds (exceeding 30 knots)
- Widespread low ceilings and/or visibilities which affect selection of destination and alternate airports
- Active thunderstorms (particularly those with increasing VIP levels)
- Moderate or severe inflight icing
- Icing which affects ground operations (including snow, freezing rain or drizzle, ice fog, or sleet)
- Severe or extreme turbulence (including clear air and mountain wave)
- Low altitude windshear (below 2000 feet AGL)
- Occurrence of unforecast weather conditions below landing or takeoff minimums
- Volcanic ash
- Sandstorms and duststorms
- Meteorological conditions which contaminate a runway surface and adversely affect aircraft performance or prohibit use of a runway

B. *Capabilities of Adverse Weather Phenomena Reporting and Forecasting Subsystems.* Adverse Weather Phenomena Reporting and Forecasting subsystems must meet all the following criteria:

- Provide direct access to sources of weather information capable of identifying, reporting, and forecasting adverse weather phenomena which could directly diminish the safety of a scheduled flight or ground operation
- Incorporate methods to modify forecasts of adverse weather phenomena when reports indicate adverse weather of different severity than originally forecast
- Contain methods and procedures to collect and evaluate adverse weather information
- Use effective and timely methods to disseminate the potential effects of adverse weather to flightcrews and other company personnel responsible for operational control functions
- Incorporate methods for describing the location of adverse weather phenomena with reference to navigational fixes or locations (the fixes or locations should be displayed on navigation charts, weather plotting charts, other inflight operational charts or displays normally used during the certificate holder's en route operations)
- Incorporate methods for suspending, restricting, or modifying (as necessary) flight operations affected by adverse weather
- Provide continuous and direct on-duty participation of a certificated dispatcher or aviation meteorologist
- Use pilot/dispatcher communications which meet at least the regulatory requirements applicable to Part 121 domestic and flag operations

1429. APPROVAL OF ADVERSE WEATHER PHENOMENA REPORTING AND FORECASTING SUBSYSTEMS.

A. *Requests for Approval.* All Adverse Weather Phenomena Reporting and Forecasting subsystems must be FAA approved. An operator required to use an approved Adverse Weather Phenomena Reporting and Forecasting subsystem must make a written request for approval. The initial request must describe the planned subsystem in sufficient detail for the POI to evaluate the proposal. This request must be accompanied by proposed manual materials, details of any contractual arrangements, and resumes of key personnel used in the subsystem or employed by any commercial weather service involved.

B. *Evaluations and Inspections of Adverse Weather Phenomena Reporting and Forecasting Subsystems.* Before approving a subsystem, a POI must evaluate the submitted material with the request for approval and conduct inspections of the facilities, equipment, and other components. The POI must also verify the professional qualifications and training of meteorologists and dispatchers who will be used in the Adverse Weather Phenomena Reporting and Forecasting subsystem. When a POI has determined the proposed subsystem complies with the criteria specified in paragraph 1427, the subsystem may be approved.

C. *Approval or Denial of Adverse Weather Phenomena Reporting and Forecasting Subsystems.*

(1) Approval for a certificate holder to use an Adverse Weather Phenomena Reporting and Forecasting subsystem shall be accomplished by issuing operations specifications paragraph A10 with a description of the subsystem or reference to the certificate holder's manual. Any proposed revisions to the subsystem, including manual material, should be evaluated and inspected by the FAA as soon as possible.

(2) If after evaluation and inspection, a POI determines a proposed Adverse Weather Phenomena Reporting and Forecasting subsystem does not meet the requirements of this handbook, all submitted materials shall be returned to the operator with an explanatory letter. This letter must clearly state why the proposed subsystem was not approved. If at anytime after a subsystem has been approved, a POI determines it does not continue to meet the requirements of this handbook, the POI shall immediately inform the certificate holder. If the certificate holder does not take immediate and appropriate corrective action, the POI must take action to amend paragraph A10 of the operations specifications and rescind approval of the Adverse Weather Phenomena Reporting and Forecasting Subsystem.

1431. SPECIAL OPERATIONAL REQUIREMENTS. Weather information systems must accommodate any special operational needs a certificate holder may have because of the type of operations, the aircraft used in operations, or environmental conditions in the operating area.

A. *International Flight.* Transoceanic flight planning and other long-range operations require precise navigational capabilities. The precision of the navigational capabilities is a direct result of careful preparation using the most current weather information available. Forecasts used for long-range flight planning should include forecasts of winds and temperatures aloft for 500mb, 300mb, 250mb, 200mb, and 150mb (as applicable), tropopause height information, and significant en route weather phenomena. This information should cover the intended flight operations with regard to time, altitude, and geography. SIGMET information should be provided regarding active or expected thunderstorms, widespread lines of cumulonimbus (Cb) clouds, and Cb embedded in cloud layers or concealed by haze. In addition to the weather information required for domestic flight, the following weather information is specifically required by ICAO procedures for international flight:

(1) At cruising levels below FL450:

- Active thunderstorms
- Tropical cyclones
- Severe squall lines
- Hail
- Severe turbulence
- Severe icing
- Mountain waves
- Standing lenticular clouds

(2) At cruising levels above FL450:

- Moderate or severe turbulence
- Cumulonimbus clouds
- Hail

B. *Helicopter Remote Site Operations.* Helicopter operations at remote sites may require special meteorological information. The extent of special weather information needed for a particular operation depends on the type of operation and the operating environment. High density altitudes, high winds, and icing conditions can be critical factors in helicopter operations, particularly when helicopters are required to hover out-of-ground-effect or to make downwind or crosswind takeoffs or landings. In addition to weather information ordinarily required for helicopter operations, the following weather information is required for remote site operations:

(1) High elevation operating site:

- Mountain waves
- Low level windshear
- Strong surface winds (20 knots or greater)
- Moderate turbulence
- Surface temperatures (for density altitude computations)

(2) Offshore operations.

- Wave height (for single-engine operations or IFR helicopter operations using airborne radar approach (ARA) procedures or offshore standard approach procedures (OSAP)
- Strong surface winds (20 knots or greater)
- Fog conditions

1432. - 1434. RESERVED.

[PAGES 3-671 THROUGH 3-676 RESERVED]

Appendix C Aviation Weather Products

4.7 C.1 International Aviation Products

4.7.1 C.1.1 Aviation Routine Weather Reports (METAR)

The aviation routine weather report (METAR), provided by the National Weather Service, contains information on surface conditions at the airport. The METAR is derived from human observations of the weather conditions and/or instruments located at the airport or from Automated Weather Observing Systems (AWOS) or Automated Surface Observation Systems (ASOS). It represents weather information that is associated with only the terminal area. The METAR provides information on winds, visibility, runway visual range (RVR), weather phenomena, sky conditions, dewpoint, temperature, and altimeter settings. The reports are updated on an hourly basis. In the case of degrading weather conditions that may impact aviation in the terminal area, an Aviation Selected Special Weather Report (SPECI) may be issued. The SPECI contains the same information contained in the METAR, but with additional remarks pertaining to the information contained in the report. The SPECI is issued as soon as possible after the criteria has been met. The SPECI provides real-time updates to support both tactical and near-term strategic decisions in the terminal area. The current delivery systems for METAR to the cockpit are FSS/AFSS/EFAS, AWOS/ASOS, ATIS, D-ATIS, and TWIP. Each of these systems are described in this appendix. [C-1, C-2, C-3, C-4, C-5]

4.7.2 C.1.2 Terminal Aerodrome Forecasts (TAF)

Terminal area forecasts or aerodrome forecasts (TAF) are prepared by the NWS weather forecast offices and are issued four times a day. The schedule times are 000 UTC, 0600 UTC, 1200 UTC, and 1800 UTC. The forecasts are valid for 24 hours. The forecasts contain specific information affecting aviation within five statute miles of the center of a runway complex. Weather information includes: wind, visibility, weather phenomena, sky conditions, optional data (*e.g.,* windshear). Amended forecasts are made when significant changes in flight category and atmospheric conditions, which impact aviation are noted. The significant conditions are given in Reference [7.] The amended forecast may be issued at non-scheduled times to alert pilots of changing conditions. TAFs are provided to the cockpit via FSS/AFSS/EFAS. [C-1, C-2, C-6, C-7, C-8, C-9, C-10]

4.8 C.2 USA Aviation Products

4.8.1 C.2.1 In-Flight Advisories

In-Flight Advisories notify en-route pilots of the possibility of encountering hazardous flying conditions.

4.8.1.1 C.2.1.1 Airman's Meteorological Information (AIRMET)

Airman's Meteorological Information is provided by the Aviation Weather Center. They advise of weather that may be hazardous to single engine, light aircraft, or aircraft flying under VFR. The AIRMET does not contain information on convective activity which is covered in a SIGMET. They are issued for weather conditions affecting or forecast to affect an area of at least 3000 square miles at one time. AIRMETs are issued for six hour periods. There are three Types of AIRMET Bulletins: AIRMET Sierra, AIRMET Tango and AIRMET Zulu. AIRMET Sierra items include ceilings less than 1000 feet and/or visibility less than three miles affecting over 50% at one time and Instrument Flight Rules (IFR) and Extensive mountain obscuration. AIRMET Tango bulletins are issued for moderate turbulence and sustained surface winds exceeding 30 knots. AIRMET Zulu bulletins are issued for moderate icing and freezing levels. Amendments may be made to AIRMETs as conditions warrant. [C-1, C-2, C-11]

4.8.1.2 C.2.1.2 Significant Meteorological Information (SIGMET)

Significant Meteorological Information is provided by the Aviation Weather Center. SIGMETs cover weather that is potentially hazardous to all aircraft. Items covered are severe and extreme turbulence, severe icing, volcanic ash and widespread dust or sandstorms that reduce visibility to less than three miles. SIGMETs must be affecting or be forecast to affect an area of at least 3000 square miles at any one time. There are three types of SIGMETs: Domestic, Convective and International. Domestic SIGMETs are issued for potential hazardous conditions other than convective. Weather items include severe icing, severe or extreme turbulence, duststorms/sandstorms lowering visibility to less than three miles and volcanic ash. SIGMETs issued for Alaska and Hawaii also include tornadoes, lines of thunderstorms, embedded thunderstorms and hail less than or equal to 3/4 inch diameter. Convective SIGMETs are used for any convective situation which the forecaster feels is hazardous to all aircraft types. They are issued for the Eastern (E), Central (C) and Western (W) United States for regions affecting 40% or more of an area at least 3000 square miles. Bulletins issued hourly and are valid for two hours. Weather items reported include: severe thunderstorms, embedded thunderstorms, lines of thunderstorms and thunderstorms affecting 40% or more of a 3000 square mile area. International SIGMETs are used for oceanic areas adjacent to the United States and routes over United States coastal waters. They are issued by the Meteorological Watch Office (MWO). International SIGMET bulletins are issued hourly and are valid for four hours for the following phenomena: thunderstorms, lines of thunderstorms, embedded thunderstorms, large areas of thunderstorms, tornadoes, large hail, severe icing, severe or extreme turbulence and duststorms/sandstorms lowering visibility to less than three miles. Tropical cyclones are issued for six hours and volcanic ash is issued for twelve hours. [C-1, C-2, C-12, C-13]

4.8.1.3 C.2.1.3 Severe Weather Forecast Alerts/Severe Weather Watch (AWW/WW)

Severe Weather Forecast Alerts are a service provided by the National Severe Storm Forecast Center. Severe Weather Watches (WW), are issued by the Storms Prediction Center in Norman, Oklahoma. An Alert Serve Weather Watch precedes a WW to notify users (*e.g.,* WFOs, CWSUs, and FSSs) that a WW is to follow. AWW/WWs define areas of possible severe thunderstorms or tornado activity. Severe thunderstorms are defined as those containing ¾ inch hail or greater and/or wind gust in excess of 50 knots. AWW/WW messages are unscheduled and issued as required. [C-1, C-2]

4.8.1.4 C.2.1.4 Center Weather Advisories (CWA)

The Center Weather Service Unit of the National Weather Service at the Air Route Traffic Control Center (ARTCC) issues Center Weather Advisories. They are an unscheduled in-flight, flow control, air traffic, and air crew weather. CWA are nowcast that aid flight crews in avoiding hazardous conditions en route and in the terminal area. CWAs contain information about conditions that will exist within a two hour time period starting at the issuance of advisory. CWAs may modify or redefine a SIGMET, Convective SIGMET or AIRMET. [C-1, C-2]

4.8.2 C.2.2 Area Forecasts (FA)

Area forecasts (FA) are issued by the Aviation Weather Center for the 48 contiguous states, by the Alaska Aviation Weather Unit for Alaska, and by the NWS Weather Forecast Office in Honolulu for that area in the pacific. The area forecast contains VFR cloud information and weather conditions over an area the size of several states. Information regarding IFR conditions are contained in the AIRMET Sierra weather product. The area forecasts contain twelve hour forecast with a six hour outlook. These forecasts are issued three times a day. Amendments to the FA are issued as needed. The AWC help page notes that AIRMET Sierra and FA may used in conjunction to provide en-route weather forecast and to estimate weather conditions at airports not supported by TAF. The FA provides en-route information to aid in both near and far-term strategic decisions. [C-1, C-2, C-14, C-15]

4.8.3 C.2.3 Route Forecast

Route Forecasts are issued by the NWS forecast offices for some 300 selected routes over the continental U.S. The forecasts provide information about atmospheric conditions along the route in a corridor 25 miles wide on either side. The forecasts include information on: Sky cover (height and amount of cloud base), Cloud tops, Visibility, Weather and Obstructions to vision. The information is similar to that given in a TAF. Route forecasts are issued three times a day and are valid for 15 hours.

4.8.4 C.2.4 Meteorological Impact Statement (MIS)

The Center Weather Service Unit at the ARTCC issues a Meteorological Impact Statement. MISs provide unscheduled weather information to aid in flow control, flight operations and planning. The forecasts are targeted at events that will initiate to begin beyond two hours but within twelve hours after issuance. It enables the impact of expected weather conditions to be included in air traffic control decisions in the near future. MISs are issued for: Convective SIGMETs criteria, moderate or greater icing and/or turbulence, heavy or freezing precipitation, low IFR conditions, surface winds/gusts greater than or equal to thirty knots, low-level wind shear within 2,000 feet of the surface and volcanic ash, dust or sandstorms. [C-16]

4.8.5 C.2.5 Winds and Temperatures Aloft

Winds and Temperatures Aloft are computer prepared forecasts of wind direction and speed as well as forecast temperatures for different flight levels above specific navigation reference points. They are generated using models and inputs from a number of sensors including radiosonde and satellites. The reports are provided by the National Center for Environmental Prediction. Winds and Temperatures Aloft are provided for 176 locations in the United States and twenty-one locations in Alaska. They are updated twice a day and include a six hour, a twelve hour and twenty four hour forecast. Each forecast includes a valid time, the forecast location, forecast winds for 3000 feet and forecast winds (heading and speed) and temperature data at other flight levels. The forecast of winds and temperatures are provided for eight discrete elevations above mean sea level (6,000, 9,000, 12,000, 18,000, 24,000, 30,000, 34,000, and 39,000 feet). [C-2, C-17]

4.8.6 C.2.6 Pilot Reports (PIREPs)

Pilot reports (PIREPs) are direct observations of the atmosphere by either instruments on board the aircraft (*e.g.*, temperature probes and pilot tubes) or by the pilot. PIREPs are most often given in a specified format and contain information on: sky cover (cloud amount, height of cloud base and height of cloud tops), flight visibility, temperature, wind speed and direction, turbulence, icing, and remarks (which may contain information on wind shear if experienced by the pilot at low altitudes). PIREPs may be tagged as routine or urgent to alert other pilot of hazardous conditions. PIREPs may also be used to fill in the gaps between observations and to aid the NWS in verifying and refining a forecast. [C-1, C-2]

4.8.7 C.2.7 National Weather Service (NWS) Fax Products

The National Weather Service has several weather phenomena and products available to the aviation community. These include: standard barotropic levels, winds/streamlines, surface analysis, weather depiction/significant weather, radar summary, cloud thickness, multi-panel forecasts, hemispheric products and miscellaneous products including precipitation, thunderstorm probability, freezing levels, observed temperatures and relative humidity. [C-18]

4.8.8 C.2.8 World Area Forecast System (WAFS) Fax Products

The National Weather Service, through the World Area Forecast System has available the following weather information: winds, temperatures, significant weather and Volcanic Ash. [C-19]

4.8.9 C.2.9 High Level Significant Weather Charts

High Level Significant Weather Charts are issued by the Aviation Weather Center. They are provided for the en-route portion of international flights. These charts are issued four times a day to aid airline dispatchers and flight crews. The weather information is associated with flight levels between 25,000 feet and 60,000 feet. Items forecast include: thunderstorms and cumulonimbus clouds, tropical cyclones, severe squall lines, moderate or severe turbulence, moderate or severe icing, widespread sand storms and dust storms, well-defined surface convergence zones, surface fronts with speed and direction of movement, tropopause heights, jetstreams and volcanic eruptions. [C-20]

4.8.10 C.2.10 Low Level Significant Weather Charts

Low Level Significant Weather Charts are issued by the Aviation Weather Center. The low-level graphics product is a forecast of aviation weather hazards, providing graphical information to aid in briefing the VFR pilot. The low level significant weather chart is composed of four panels displaying information on freezing levels, turbulence, low cloud ceilings, fronts, and precipitation areas. The charts are issued four times a day at specified time periods. The ETA model is used to derive the charts, which are valid for twelve to twenty four hours. Some of this information is provided by the National Center for Environmental Prediction and the Hurricane Prediction Center. The charts cover the 48 contiguous states, southern Canada, and the coastal water for flights below 24,000 feet. [C-21]

4.8.11 C.2.11 Hurricane Advisory

The National Weather Service will issue a Hurricane Advisory if a hurricane threatens a coastline but is still located at least 300 NM offshore. The advisory gives the location of the storm center, its expected movement and the maximum winds in and near the storm center. Hurricane advisories do not contain details of associated weather, such as ceilings, visibility and hazards. [C-16]

4.8.12 C.2.12 Convective Outlook

Convective outlooks are issued by the Storm Prediction Center (SPC), in Norman, Oklahoma. Convective outlooks are a two-day forecast of severe and non-severe thunderstorms across the nation. They are used as a tool for planning flights later in the day to avoid thunderstorms. Convective Outlooks consist of a Day 1 (24 hour) and a Day 2 (next 24 hour) forecast. These forecasts describe where a high, moderate or slight risk of thunderstorms exists. The forecast for the first 24 hours is issued/updated five times a day (0600Z, 1100Z, 1500Z, 1930Z, and 0200Z) and the next 24 hours is issued/updated twice a day (0800Z and 1800Z). [C-16]

4.8.13 C.2.13 Stormscope

The Stormscope Series II Weather Mapping System from 3M is a real-time thunderstorm detection and mapping system. Stormscope is the first airborne instruments developed specifically to detect and map thunderstorms (with their potentially dangerous turbulence and convective wind shear). The BF Goodrich® WX-950 Stormscope® provides views of up to 200 NM with heading stabilization. It has a sophisticated processor which precisely maps lightning while filtering out electronic pulses from other sources. In cell mode, the WX-950 detects lightning up to 200 nautical miles out and displays storm cell areas of greatest intensity. In strike mode, the WX-950 detects and maps individual strikes, allowing you to monitor sporadic electrical activity which may indicate the beginnings of a storm. [C-22, C-23]

4.8.14 C.2.14 Additional Charts

A number of weather related charts are also available to the aviation community. These include: Surface Analysis Chart, Weather Depiction Chart, Radar Summary Chart, Constant Pressure Analysis Chart, Composite Moisture Stability Chart, Winds and Temperature Aloft Chart, Convective Outlook Chart and Volcanic Ash Forecast Transport and Dispersion Chart. For a complete description of these charts see [C-16].

4.9 C.3 Aviation Weather Radar and Satellite Products

4.9.1 C.3.1 Terminal Doppler Weather Radar (TDWR)

Terminal Doppler Weather Radar is a highly sensitive, high resolution radar are installed at 36 major airports through the country to aid in the detection of wind shear (microbust), gusts, and heavy precipitation in the terminal area. It is provided by the Federal Aviation Administration (FAA). TDWR is a C-band Doppler radar that automatically detects and displays a set of weather products from the radar base data. Base data consists of estimates of reflectivity, mean Doppler velocity, spectrum width, and signal-to-noise ratio. Data comes in a readily understood format that can be read directly to pilots. Radar and processor are typically located eight to twelve miles from the airport, because TDWR cannot look directly up to see the weather developing overhead. There are four types of weather products: Microburst detection, windshear detection, gust front detection and precipitation detection. The products are graphical, alphanumeric, and/or an alarm representation of detected weather phenomena. TDWR has four major functional divisions: Radar Data Acquisition (RDA), Radar Product Generation (RPG), Remote Monitoring Subsystem (RMS) and Display functions. These four functions provide timely detection and reporting of hazardous windshear phenomena in and near the terminal approach and departure zones of an airport. [C-1, C-24, C-25]

4.9.2 C.3.2 Next Generation Weather Radar (NEXRAD)

The National Weather Service provides some 18 products which are generated by the WSR-88D radars (or Next Generation Weather Service Radars (NEXRAD)) located thorough the country. These products are delivered to private companies, which then add value for resale. There are three private companies, WSI, Kavouras and UNISYS, that are permitted to receive NEXRAD products under the NEXRAD Information Dissemination System. These companies add value (*e.g.*, overlays) to the products and then resell them. The NWS also provides direct feeds to different agencies within the federal government, which are responsible for air traffic safety and management. NEXRAD is an "S" band Doppler weather radar capable of detecting the location, severity, and movement of both routine and hazardous weather phenomena in the en-route and oceanic environment. These capabilities allow for more efficient air traffic control since aircraft can be rerouted around bad weather systems detected in advance. The FAA is deploying NEXRAD systems at non-CONUS (offshore) locations such as Alaska, Hawaii and the Caribbean. [C-1, C-2, C-26]

4.9.3 C.3.3 Radar Weather Report

The WSR-88D radars located across the country provide weather reports that contain information on the type (limited to rain, rain shower, snow, snow shower, and thunderstorm), intensity, and location of the echo top of the precipitation. These reports are generated every hour by the NWS. The reports are given in a coded format. [C-16]

4.9.4 C.3.4 Radiosonde Additional Data (RADAT)

Radiosonde additional data is obtained from radiosonde observations, which are conducted every twelve hours. Radiosondes are instrumented balloons that are released at specified locations across the country. The balloons are released at 0000Z and 1200Z. RADAT is a report generated from these soundings. Data is measured and transmitted, via radio transmitter, to a ground station. RADAT information includes: the observed freezing level (height) and the relative humidity associated with the freezing level. [C-16]

4.9.5 C.3.5 Weather Radar (Airborne)

Airborne weather radars provide real-time information on precipitation and windshear events. The information may be displayed graphically or provided audibly as a warning (*e.g.*, in the case of a hazardous wind shear event).

4.9.6 C.3.6 Airport Surveillance Radar

An alternative solution to the more expensive TDWR, is to add a Weather System Processor (WSP) to the existing Airport Surveillance Radars (ASR-9) to extract weather information from the measured data in the terminal area. There are currently 34 airports that have this capability. Hazard information is reported directly to the ATC tower.

4.9.7 C.3.7 Satellite Imagery

The National Weather Service/FAA as well as private companies provide visible & infrared satellite imagery through weather satellites in orbit. There are two types of Satellites: Geostationary Operational Environment (GOES) Satellite and the National Oceanic and Atmospheric Administration (NOAA) satellite. The two GOES satellites cover North and South America and the surrounding waters. Each transmits an image of the earth, pole to pole every 15 minutes. If severe weather exists, the satellites can scan small areas rapidly and transmit images as often as every 7.5 minutes. The NOAA satellite orbits the earth on a track that nearly crosses the north and south poles. Two types of imagery are available: Visible, which is available only during the day and Infrared, which is available both day and night. The type of cloud (from shape & texture), temperature of cloud tops, height of cloud and the thickness of cloud layers can be determined through interpretation. [C-16]

4.10 C.4 Aviation Weather Sensors

4.10.1 C.4.1 Low-Level Windshear Alert System (LLWAS)

The Low-Level Windshear Alert System is provided by the Federal Aviation Administration. LLWAS provides air traffic controllers and pilots with information on microbursts and windshear in the terminal area. It uses a network of anemometers to determine the presence of dangerous windshear and microbursts on or near airports. There are two configurations for the 110 LLWASs currently in operation: LLWAS-2 and LLWAS Network Expansion (NE). *LLWAS-2* uses six anemometers located around the airport to measure and report sector-oriented wind direction, speed and gust. LLWAS-NE uses a much larger network of up to 32 anemometers to provide increased probability of detecting microbursts and windshear on the airport and along the runway corridors. The LLWAS-NE can be integrated with the TDWR and provide an interface to the maintenance processor system. The LLWAS is located at 39 airports through the country. The LLWAS system provides hazard information directly to the ATC tower. [C-1, C-2, C-27]

4.10.2 C.4.2 Automated Weather Observing Systems (AWOS)

The Automated Weather Observing Systems provided by the FAA, consist of various sensors, processors, computer-generated voice subsystems, and a transmitter to broadcast local weather data directly to pilots via a VHF discrete frequency or a navigational aid voice channel as a voice message. The basic AWOS sensors provide wind speed and direction, temperature, dew point, pressure (altimeter setting), visibility, and cloud height information. [C-1, C-2, C-28]

4.10.2.1 C.4.2.1 AWOS Data Acquisition System (ADAS)

The AWOS Data Acquisition System (ADAS) was developed to collect (from AWOS), process, and archive weather data and then disseminate this information to various National Airspace System (NAS) subsystems. [C-29]

4.10.2.2 C.4.2.2 Automated Lightning Detection & Reporting System (ALDARS)

The Automated Lightning Detection & Reporting System (ADAS/ALDARS) eliminates manual observation of lighting at airports by having the ADAS collect, process and disseminate the National Lightning Detection Network (NLDN) data. [C-2, C-30]

4.10.3 C.4.3 Automated Surface Observation Systems (ASOS)

The Federal Aviation Administration Automated Surface Observation Systems consist of various sensors, processors, computer-generated voice subsystems, and a transmitter to broadcast local weather data directly to pilots. ASOS provides surface weather observations in METAR format which is updated every sixty seconds, or when weather conditions cross preset thresholds for ceiling height and/or visibility. Data is transmitted over discrete VHF or voice portion of local NAVAID. Each ASOS contains: cloud height indicator, visibility sensor, precipitation identification, freezing rain sensor, pressure sensor, ambient temperature/dew point temperature sensor, anemometer (wind direction and speed sensor) and rainfall accumulation sensor. [C-1, C-2, C-31, C-32, C-33]

4.10.4 C.4.4 Runway Visual Range (RVR)

Runway Visual Range is an FAA product which measures visibility, background luminance, and runway light intensity to determine the distance a pilot should be able to see down the runway. It is used to define the precision landing category of operations. The forward scatter visibility sensor, which measures the amount of light scattered by fog or snow particles, is designed and proven to perform over the full range of instrument meteorological weather. The system measures RVR from 6500 feet to 0 feet in all conditions of fog, snow, and freezing rain. [C-1, C-34, C-35]

4.11 C.5 Aviation Weather Processors

4.11.1 C.5.1 Weather Systems Processor (WSP)

The Airport Surveillance Radar-9 (ASR-9) Weather Systems Processor is provided by the FAA to enhance the safety of air travel through the timely detection and reporting of hazardous windshear in and near the terminal approach and departure zones of an airport. Specific sources of the hazardous windshear that are to be detected are microbursts and gust fronts. The WSP detects, locates, quantifies, and displays low altitude terminal area windshear and microburst events. It Generates runway specific alerts in the event of hazardous windshear and microburst events. It detects, locates, quantifies, predicts and displays the current and future location of gust fronts. It detects, locates, quantifies and extrapolates the future position of, storm cells. The WSP generates National Weather Service six-level precipitation intensity maps and reduces false heavy precipitation errors caused during atmospheric conditions of Anomalous Propagation (AP). [C-1, C-36, C-37]

4.11.2 C.5.2 Meteorologist Weather Processor (MWP)

The FAA Meteorologist Weather Processor provides the processing tools to consolidate weather data from multiple sources into one database. Processed data is used to provide weather updates and forecasts for air traffic personnel. [C-38]

4.11.3 C.5.3 Integrated Terminal Weather System (ITWS)

The Integrated Terminal Weather System is an FAA automated weather system that provides near term (thirty minute) prediction of significant terminal area weather in the terminal domain. The ITWS acquires, processes, and disseminates weather products to other subsystems and users. It provides NEXRAD and TDWR weather radar data and enhanced terminal forecasts to the controller's traffic display at the Terminal Radar Approach Control (TRACON) and airport control tower facilities. It provides the air route traffic control center (ARTCC) with information to help track storm activity at major airports and to coordinate traffic flow with the TRACONs. It also generates products including windshear and predictions, storm cell and lightening information, and terminal area winds aloft. The ITWS can differentiate between real and false weather returns. [C-2, C-39]

4.11.4 C.5.4 Weather and Radar Processor (WARP)

The FAA Weather and Radar Processor receives and processes real time weather data from multiple sources, and produces displays of weather information for multiple users in the en route domain. WARP acquires, processes, and disseminates weather products to other subsystems and users. It provides a mosaic of NEXRAD data to the ARTCC controller's traffic display and improved weather data to ARTCC meteorologists, traffic managers, and flight service station specialists via the operational and supportability implementation system (OASIS). WARP will replace existing Meteorologist Weather Processor (MWP) systems. [C-2, C-40, C-41]

4.12 C.6 Aviation Weather Delivery Systems/Services

4.12.1 C.6.1 In-Flight Delivery Systems

4.12.1.1 C.6.1.1 Air Route Traffic Control Center (ARTCC)

Federal Aviation Administration Air Route Traffic Control Centers are capable of direct communications with IFR air traffic on certain frequencies. ARTCCs broadcast Severe weather forecast alerts (AWWs), Convective SIGMETs, SIGMETs, or Center Weather Advisories (CWAs). ARTCCs alert once on all frequencies, except emergency, when any part of the area described is within 150 miles of the airspace under their jurisdiction. [C-1, C-2]

4.12.1.2 C.6.1.2 Hazardous In-Flight Weather Advisory Service (HIWAS)

The Federal Aviation Administration Hazardous In-Flight Weather Advisory Service is a continuous broadcast of recorded in-flight weather advisories. HIWAS broadcasts: AWW, Convective SIGMETs, SIGMETs, CWAs, AIRMETs and Urgent PIREPs. Where HIWAS has been implemented, a HIWAS alert will be broadcast on all except emergency frequencies once upon receipt by ARTCC and terminal facilities, which will include an alert announcement, frequency instruction, number, and type of advisory updated. [C-1, C-2]

4.12.1.3 C.6.1.3 Transcribed Weather Broadcast (TWEB)

Transcribed Weather Broadcast are provided by the National Weather Service, World Forecast Office (WFO). TWEBs provide continuously updated recorded weather information and aeronautical data for short or local flights. TWEBs are based on a route-of-flight concept. Broadcasts are made from a series of individual tape recordings, and changes, as they occur, are transcribed onto the tapes. Information available includes: In-Flight Advisories, winds aloft, METAR/SPECI, Notice's to Airmen (NOTAMs) and any other special notices. TWEB products are valid for twelve hours and are issued four times a day. [C-1, C-2, C-16]

4.12.1.4 C.6.1.4 Automatic Terminal Information Service (ATIS)

The FAA's Automatic Terminal Information Service is a continuous broadcast of recorded non-control information. It is primarily used by airports for weather/runway conditions of importance to arriving and departing aircraft. ATIS is broadcast over discrete VHF radio or the voice portion of a local NAVAID. [C-1, C-2]

4.12.1.5 C.6.1.5 Aircraft Communications Addressing and Reporting System (ACARS)

The Aircraft Communications Addressing and Reporting System is a VHF air/ground datalink that relays Aircraft Operational Control (AOC), Airline Administrative Control (AAC), and Air Traffic Control (ATC) messages between ground-based organizations and the cockpit. Aeronautical Radio, Inc. (ARINC) was the first to design and implement a VHF data link using dedicated aeronautical frequencies to transmit ACARS information from aircraft to ground host processing facilities. Weather information is provided to the cockpit in digital format. In-Flight Weather Information currently available: Terminal Weather Information for Pilots (TWIP), Digital Automated Terminal Information Service (D-ATIS), airport weather, runway status, field conditions, and various products from resources within AOC. [C-2, C-42]

4.12.1.6 C.6.1.6 Terminal Weather Information for Pilots (TWIP)

Terminal Weather Information for Pilots provides ground-based terminal weather information to pilots via ACARS. It is generated using weather data from Terminal Doppler Weather Radar (TDWR) or the Integrated Terminal Weather System (ITWS) testbed. TWIP is updated every minute for text messages and every five minutes for character graphics messages. TWIP data includes microburst alerts, wind shear alerts, gust fronts, significant precipitation and convective activity within 30 NM of the terminal area. [C-1, C-2]

4.12.1.7 C.6.1.7 Operational and Supportability Implementation System (OASIS)

OASIS is a Federal Aviation Administration program designed to enhance the safety, security, and efficiency of the National Airspace System (NAS) and to reduce the supportability problems of the existing Flight Service Automation System. The capabilities provided by OASIS include: alphanumeric and graphic weather product acquisition and display, flight plan processing, search and rescue services, administrative and supervisory capabilities, flight planning and regulatory information and system maintenance functions. The weather graphic capabilities include: capability to acquire, display, and store near real-time weather radar images and products, weather satellite imagery and lightning detection data. [C-43]

4.12.1.8 C.6.1.8 Flight Information Service (FIS)

Flight Information Service is an FAA generated data link program. FIS provides information for safe flight and flight planning in the air and on the ground. FIS provides weather products from the Weather and Radar Processor (WARP), the Integrated Terminal Weather System (ITWS) and aeronautical information to pilots by commercial service providers. [C-2]

4.12.1.9 C.6.1.9 Direct User Access Terminal System (DUATS)

DUATS is an FAA funded program which provides immediate online access to FAA approved information. DUATS can be accessed by pilots with a current medical certificate via personal computer. Information is current, continuously updated, and easy-to-understand. DUATS includes graphical weather maps, flight plan filing and closing, and automated flight planning. DUATS can receive alpha-numeric preflight weather data and file domestic VFR and IFR flight plans. Two commercial vendors provide Service: Data Transformation Corporation (DTC) and GTE Federal System Division. GTE DUATS only provides weather for the United States, including Alaska, Hawaii, and Puerto Rico. The flight planning databases contain only U.S. airports, navigational aids, and airways. Flight plan filing can only be done for plans that would be filed with U.S. FAA facilities (flight service stations for VFR flight plans and air traffic control facilities for IFR flight plans). [C-1, C-44, C-45]

4.12.2 C.6.2 Aviation Weather Call-Up Services

4.12.2.1 C.6.2.1 Flight Service Stations (FSS)

Flight Service Stations are FAA traffic facilities which provide pilot briefings, en route communications and VFR search and rescue services, assist lost aircraft in emergency situations, relay air traffic control clearances, originate NOTAMs, broadcast aviation weather and NAS information, receive and process IFR flight plans and monitor navigational aids (NAVAIDs). Most of the older FSSs have been consolidated and replaced with Automated Flight Service Stations (AFSSs). [C-1, C-2]

4.12.2.2 C.6.2.2 Automated Flight Service Stations (AFSS)

Federal Aviation Administration Automated Flight Service Stations are replacing FSSs. AFSSs provide preflight and in-flight briefings, transcribed weather briefings, scheduled and unscheduled weather broadcast and furnishes weather support to flights in its area. AFSSs also provide VFR search and rescue services, assist lost aircraft and aircraft in emergency situations, relay ATC clearances, originate NOTAMs, broadcast aviation weather and NAS information and receive and process IFR flight plans. [C-1, C-2]

4.12.2.3 C.6.2.3 En Route Flight Advisory Service (EFAS), (Flight Watch)

En Route Flight Advisory Service (Flight Watch) is a Federal Aviation Administration program which provides en-route aircraft weather advisories pertinent to the type of flight intended, route of flight, and altitude. It is intended for weather updates only. EFAS is available 6am to 10pm. EFAS is provided by specially trained aviation weather specialists in selected AFSSs. [C-1, C-2, C-46]

4.12.2.4 C.6.2.4 Pilot's Automatic Telephone Weather Answering System (PATWAS)

PATWAS is a continuous telephone recording of meteorological and/or aeronautical information provided by FSS briefing offices. PATWAS messages are recorded and updated at a minimum of every five hours. [C-16]

4.12.2.5 C.6.2.5 Telephone Information Briefing Service (TIBS)

The Telephone Information Briefing Service is provided by Automatic Flight Service Stations (AFSSs). TIBS is a continuous recording of meteorological and aeronautical information. It provides area and/or route briefings, airspace procedures, and special announcements. TIBS also provides surface observations, METARs, TAFs, and winds/temperature aloft forecasts. [C-1]

4.13 C.7 Aviation Weather Data Sources

4.13.1 C.7.1 National Weather Service Telecommunications Gateway (NWSTG)

The National Weather Service Telecommunications Gateway is provided by the National Weather Service. It provides unaltered weather information services to Government, Commercial and International customers. Weather information service is known as the NWS FOS (Family of Services).

There are six data streams of weather information: Public Product Service, Domestic Data Service (DDS), International Data Service, High Resolution Data Service, Digital Facsimile Service, AFOS Graphics Service. [C-2]

4.13.1.1 C.7.1.1 Domestic Data Service (DDS)

The NWS Domestic Data Service provides users with coded observations, reports, forecasts and analyses. Aviation Weather Products available on the Domestic Data Service include: METAR/SPECI, TAF, FA, AIRMETs, SIGMETs, Convective SIGMETs, CWA (Center Weather Advisories), Winds Aloft, PIREPs/Urgent PIREPs, Meteorological Impact Statements, Offshore Aviation Area Forecasts, PIBAL Observations, Hourly Observations, Transcribed Weather Broadcasts and Wind and Temperature Forecasts. [C-2]

4.13.2 C.7.2 Aviation Digital Data Service (ADDS)

The Aviation Digital Data Service is developed as the data distribution component of the FAA Aviation Gridded Forecast System (AGFS). It is a Web-based aviation Weather products/information tool. ADDS makes available digital and graphical analyses, forecasts, and observations of meteorological variables. Aviation weather products available on ADDS include: PIREPs, AIRMETs, METARs, TAFs, IFR, WINDS, ICING, TURBULENCE, CONVECTIVE, SATELLITE and RADAR. [C-2, C-47]

4.13.3 C.7.3 Weather Concepts

Weather Concepts is a Web-based aviation weather products/information tool. It is provided by Weather Concepts Online Services. Available weather products include: TAFs, AIRMETs, FAs, Winds and Temperatures Aloft, NOTAMs, PIREPs, SIGMETs, Convective SIGMETs, TWEBs, Satellite, National Radar and Local NEXRAD. Weather Concepts updates every eight minutes for Local NEXRAD, thirty to sixty minutes for Live Weather and every twelve to twenty four hours for Forecasted Weather Depictions Charts. [C-48]

4.13.4 C.7.4 International Flight Folder Documentation Program (IFFDP)

The United States provides standardized meteorological information to all countries under the International Civil Aviation Organization (ICAO). The International Flight Folder Documentation Program is a standardized meteorological service provided to ensure safety of flight and a consistent level of service worldwide. Weather data is obtained from the World Area Forecast System (WAFS) out of the Office of System Operations and the AWC, utilizing a high-speed data line. The AWC provides meteorological information to flight crews and operators for (1) dispatch planning, (2) flight crew pre-flight, and (3) en-route decisions. Information is provided for specific airports within the U.S. The information is packaged as a folder contains the following weather products: wind and temperature aloft forecast charts, significant weather charts, Terminal Aerodrome Forecasts (TAFs) for departure, destination and alternate, SIGMET charts of tropical cyclones and/or volcanic ash as appropriate, METAR/SPECI, SIGMETs and appropriate special air reports (aireps). This information is available as FAX products or on the internet. The information is tailored to the specific route and altitude and for the departure, destination, and alternate airport. [C-49]

4.14 C.8 Experimental Forecast Products

4.14.1 C.8.1 Aircraft Vortex Spacing System (AVOSS)

NASA's Langley Research Center is currently developing the Aircraft Vortex Spacing System. AVOSS will provide the means to allow Air Traffic Control to safely reduce spacing in instrument operations when the appropriate weather conditions exist. The full benefit of AVOSS will be realized when interfaced to advanced Air Traffic Control (ATC) automation, such as the Center-TRACON (Terminal Radar Approach Control) Automation System (CTAS). The AVOSS differs substantially from previous efforts to deploy wake vortex systems in that the atmospheric conditions from the surface to the top of the instrument approach path are measured and used, rather than only surface wind. AVOSS Performs the integration of several subsystems: The Weather Subsystem is responsible for providing measurements of wind, temperature, and turbulence levels aloft as well as making short term predictions of likely weather changes in the next hour. The Predictor Subsystem predicts the time required for the wake vortices of approaching aircraft to move out of the approach corridor or to decay. The Wake Sensor Subsystem provides an independent measurement of actual wake vortex behavior. This measurement provides a safety monitoring function to prevent reduced separation from being applied if the Weather Subsystem or Prediction Subsystem fails to predict long lived wakes. [C-50]

4.14.2 C.8.2 Convective Forecasts

4.14.2.1 C.8.2.1 Vertical Velocity Storm (VVSTORM)

Vertical Velocity Storm is provided by the Aviation Weather Center (AWC). The AWC computes grids of VVSTORM every hour. Forecasts are out from two or three to twelve hours. VVSTORM uses numerical model outputs from toady's numerical models to find the most unstable air parcel at a model grid point. It then lifts that parcel with a vertical velocity determined by the maximum of one of three methods: frontogenesis, Eckman pumping, or model-based omega. If that parcel reaches its Level of Free Convection (LFC) still with an upward vertical velocity, then buoyancy takes over and accelerates the parcel upward through the troposphere until it reaches the Equilibrium Level (EL). At the EL the parcel begins deceleration. The vertical velocity at the EL is a measure of a thunderstorm's intensity. [C-51]

4.14.2.2 C.8.2.2 Probabilistic Outlook

The Aviation Weather Center/Storm Prediction Center (SPC) provides a tool called Probabilistic Outlook. Probabilistic Outlook includes forecasts of Tornado Probabilities, Severe Hail Probabilities and Severe Thunderstorm/Wind Event Probabilities. As part of this effort, a scheme has been developed to convey the expected likelihood of large hail, damaging winds, and tornadoes in terms of probabilities. Probability forecasts will allow forecasters more flexibility in producing forecasts, plus the graphics will provide more explicit information regarding the severe weather threat. [C-52]

4.14.3 C.8.3 Turbulence Forecasts

4.14.3.1 C.8.3.1 Mountain Wave (MWAVE)

Mountain Wave (which can also be called gravity waves) is defined as turbulence caused by mountain waves. MWAVE is a mountain wave diagnostic developed by the Experimental Forecast Facility (EFF) at the Aviation Weather Center. Mountain waves develop as air flows over a mountain in a stable stratified atmosphere. Mountain Waves can propagate both horizontally and vertically because there is no sharp density boundary in the atmosphere. MWAVE computes two diagnostics: the strength of the wave, which MWAVE estimates as the drag the mountain wave exerts on the atmosphere and the breaking potential, which MWAVE estimates as a non-dimensional wave amplitude. [C-53]

4.14.4 C.8.4 Icing Forecasts

4.14.4.1 C.8.4.1 Neural Network Icing (NNICE)

Neural Network Icing is an icing intensity predictive forecast tool being developed by the Aviation Weather Center. Neural networks are an artificial intelligence tool that does very well at pattern recognition. The maps of icing intensity are composites of the output of two neural networks taught to predict icing intensity from input data of temperature, relative humidity, and convective potential from the Rapid Update Cycle model. The output values range from zero to six with zero representing no icing and six severe icing. A two is light icing and a four is moderate icing. [C-54]

4.14.4.2 C.8.4.2 Vertical Velocity Icing (VVICE)

Vertical Velocity Icing is a physically-based aircraft icing diagnostic/forecast tool developed by the Aviation Weather Center. VVICE bases aircraft icing forecasts on ice accumulation potential and the subsequent degradation of aircraft performance. The pilot that encounters icing will increase power to maintain altitude and airspeed. VVICE shows forecast icing contours as a Percent Power Increase (PPI) required to overcome the additional drag so the aircraft can continue at a steady speed and altitude. VVICE attempts to: improve aircraft icing forecasts, improve communication of the icing threat to pilots, and improve pilot reporting of the icing threat back to forecasters. VVICE not only forecasts meteorological factors but also makes an initial interpretation of the possible aerodynamic consequences of these forecasts. [C-55]

4.15 C.9 Commercial Aviation Weather Providers

Several private weather companies provide pre-flight briefing services and aviation weather information for pilots. The most common are: [C-2]

Company	Weather Tools	Web Site
Kavouras	Weatherlink Vistas	http://kavouras.com/
WSI	PILOTbrief VECTOR	http://www.wsicorp.com/
UNISYS	Weather Processor	http://www.weather.unisys.com/
Alden	Weather Works	http://www.alden.com/
Universal	Windstar Plus	http://www.univ-wea.com/
Accu-Wx	AMPS/AccuData	http://www.accuweather.com/
GTE	Skycentral DUATS	http://www.skycentral.com/
Harris	WeatherTAP - Aviation Weather	http://www.hisd.harris.com/
WINGS – OASIS Workstation equiv. to DUATS		
WINDS – Part of WARP System		

4.16 References

3-1. Irvin N. Gleim, FAR/AIM Reprint, Federal Aviation Regulations and Aeronautical Information Manual, 1998, Gleim Publications, Inc.

3-2. Lockheed Martin Aeronautical Systems, NASA John H. Glenn Research Center at Lewis Field, Data Communications Requirements, Technology and Solutions for Aviation Weather Information Systems, Phase I Report, Aviation Weather Communication Requirements, June 1999.

3-3. National Weather Service METAR/TAF information, http://www.nws.noaa.gov/oso/oso1/oso12/metar.htm

3-4. METAR/TAF, http://www.faa.gov/avr/news/Metar.htm

3-5. METAR Data Access, http://weather.noaa.gov/weather/metar.shtml

3-6. National Weather Service Operations Manual, Part D, Chapter 31, Part 1, June 6, 1997.

3-7. National Weather Service Operations Manual, Part D, Chapter 31, Part 2, June 6, 1997.

3-8. National Weather Service METAR/TAF information, http://www.nws.noaa.gov/oso/oso1/oso12/metar.htm

3-9. METAR Data Access, http://www.faa.gov/avr/news/Metar.htm

3-10. TAF Data Access, http://weather.noaa.gov/weather/taf.shtml

3-11. Aviation Weather Center, "What is are AIRMETs?", http://www.awc-kc.noaa.gov/awc/help/what_are_airmets.html

3-12. Aviation Weather Center, "What is are SIGMETs?", http://www.awc-kc.noaa.gov/awc/help/what_are_sigmets.html

3-13. Aviation Weather Center "What are Convective SIGMETs?", http://www.awc-kc.noaa.gov/awc/help/what_are_convective_sigmets.html

3-14. Aviation Weather Center "What are Aviation Area Forecasts?", http://www.awc-kc.noaa.gov/awc/help/what_is_the_fa.html

3-15. Aviation Weather Center, "What is an Aviation Area Forecast?", http://204.185.136.10/awc/help/what_is_the_fa.html.

3-16. Irvin N. Gleim, Aviation Weather and Weather Services, 1998, Gleim Publications, Inc.

3-17. Aviation Weather Center "What are Winds and Temperatures Aloft?", http://www.awc-kc.noaa.gov/awc/help/what_are_fd.html

3-18. NWS Fax Charts, http://weather.noaa.gov/fax/nwsfax.shtml

3-19. WAFS Facsimile (T4) Charts, http://weather.noaa.gov/fax/wafsfax.shtml

3-20. About High Level SIGWX Charts (FL250-FL600), http://www.awc-kc.noaa.gov/awc/help/sgwxinfo.html

3-21. About Aviation Low Level SIGWX Charts, http://www.awc-kc.noaa.gov/awc/help/lolvlinfo.html

3-22. American Flying Adventures, Stormscope, http://www.amfly.com/wx950.html

3-23. Georgia Avionics, Stormscope, http://www.gaavionics.com/wx1000.htm

3-24. Terminal Doppler Weather Radar, http://www.af.jccbi.gov/aboutaf/org/440/tdwr/tdwr.htm

3-25. FAA, Terminal Doppler Weather Radar, http://wx.aw.tc.faa.gov/tdwr.htm

3-26. FAA, Next Generation Radar, http://wx.aw.tc.faa.gov/nexrad.htm

3-27. FAA, Low-Level Windshear Alert System, http://wx.aw.tc.faa.gov/llwas.htm

3-28. FAA, AWOS Information, http://www.faa.gov/asos/awosinfo.htm

3-29. FAA, AWOS Data Acquisition System (ADAS), http://wx.aw.tc.faa.gov/aldars.htm

3-30. FAA, Automated Lightning Detection & Reporting System, http://wx.aw.tc.faa.gov/aldars.htm

3-31. AWOS Data Acquisition System (ADAS), http://wx.aw.tc.faa.gov/ace.htm

3-32. ASOS: Automated Surface Observing System, http://www.nws.noaa.gov/asos/index.html

3-33. ASOS Information, http://www.faa.gov/asos/asosinfo.htm

3-34. Federal Meteorological Handbook No. 1 Chapter 7 RUNWAY VISUAL RANGE, http://www.nws.noaa.gov/oso/oso1/oso12/fmh1/fmh1ch7.htm

3-35. FAA, New Generation Runway Visual Range (RVR), http://wx.aw.tc.faa.gov/rvr.htm

3-36. FAA Weather Systems Processor (WSP), http://wx.aw.tc.faa.gov/wsp.htm

3-37. http://wx.aw.tc.faa.gov/WeatherRadarGrp/Wsp/Wsp.htm

3-38. Weather Systems Processor, www.faa.gov/and/and400/and460.htm

3-39. FAA, Integrated Terminal Weather System (ITWS), http://wx.aw.tc.faa.gov/itws.htm

3-40. FAA, Weather and Radar Processor (WARP), http://wx.aw.tc.faa.gov/warp.htm

3-41. WARP, http://www.faa.gov/aua/ipt_prod/weather/warp1.htm

3-42. ARINC, ACARS, http://www.arinc.com/Products_Services/acars.html

3-43. Welcome to the OASIS Homepage, http://www.faa.gov/aua/ipt_prod/oasisweb/

3-44. GTE Federal Systems, http://www.duats.com/

3-45. Data Transformation Corporation, http://www.duat.com/,

3-46. Enroute Flight Advisory Service http://www.faa.gov/ats/afss/gnvafss/EFAS.HTM

3-47. Aviation Digital Data Service, http://adds.awc-kc.noaa.gov/

3-48. Weather Concepts, http://weatherconcepts.com/

3-49. AWC, International Flight Folder Documentation Program, http://www.awc-kc.noaa.gov/awc/iff/iffdp.html

3-50. The Aircraft Vortex Spacing System (AVOSS), http://avsp.larc.nasa.gov/avoss/

3-51. AWC, Vertical Velocity Storm, http://www.awc-kc.noaa.gov/awc/vvstorm.html

3-52. AWC, Experimental Forecast Products, http://www.awc-kc.noaa.gov/awc/experimental.html

3-53. AWC, Mountain Wave, http://www.awc-kc.noaa.gov/awc/mwave.html

3-54. AWC, Neural Network Icing, http://www.awc-kc.noaa.gov/awc/nnice.html

3-55. AWC, Vertical Velocity Icing, http://www.awc-kc.noaa.gov/awc/vvice.html

Appendix D Example Survey Form

July 29, 1999

RE: NASA Survey

Tom:

Attached is the NASA /GTRI survey for which you have kindly agreed to participate. If you have any questions please don't hesitate to call or e-mail with your questions.

This survey is in Word 97 format. If you have any difficulty opening the document please let us know. Once you have opened the document please print the document and enter your responses on the printed survey. DO NOT ENTER YOUR RESPONSES DIRECTLY TO THE WORD DOCUMENT. If you can have 2 or 3 pilots complete the survey it will help to get more diverse opinions on weather products.
We would appreciate your returning the completed survey to us by mail or fax not later August 6, 1999. Please send or fax the survey to:

Cliff Eckert
Aerospace and Transportation Laboratory
Georgia Tech Research Institute
7220 Richardson Road
Smyrna, GA 30080
Fax 770 528-3271

NASA and GTRI greatly appreciate your time and effort.

AVIATION WEATHER INFORMATION REQUIREMENTS STUDY

NASA Langley Research Center has tasked Georgia Tech Research Institute to conduct a survey of aviation weather users as part of the Aviation Weather Information (AWIN) Requirements Study. AWIN is a level III project under the NASA Aviation Safety Program's (AvSP), Weather Accident Prevention element. The goal of the Weather Accident Prevention element is to "develop and support the implementation of technologies to reduce aviation weather-related accidents and focus its work in three areas: synthetic vision displays, turbulence detection and mitigation, and aviation weather information distribution and presentation."

The purpose of this survey is to gather information from the various weather information stakeholders on weather information functional utility and availability for aeronautical decision making. The information gathered in this survey will be combined in a database with weather product characteristics, flight phase characteristics, aircraft characteristics and weather element characteristics. The database will be used to develop correlations between "users", flight phases, hazards, and weather products. It will assist in determining weather information shortfalls and will aid in developing requirements that represent the most effective path to improving weather information.

What follows is a questionnaire seeking responses from various aviation weather user perspectives. Individual responses will not be divulged or made public. Once the responses have been reviewed by GTRI, further dialogue may be necessary to clarify your responses or to ask additional information.

Please contact Cliff Eckert (770 528-7933), Chuck Stancil (770 528-3224) or Susan Brown (770 528-7889) if you have any questions.

We appreciate the time and effort you put into responding to this survey. Ultimately, your time and effort will lead toward better weather information and a reduction in weather related accidents.

AVIATION WEATHER INFORMATION REQUIREMENTS STUDY

Please complete the following information:

Name ______________________	Title ______________________
Employer ______________________	

Address 1 ______________________________________

Address 2 ______________________________________

City ______________	State ______________	Zip Code ______________
Telephone Number ______________	Fax Number ______________	E-Mail Address ______________

Indicate the FAR category in which you operate under. If you operate under more than one category, indicate each type.

FAR Category:

Part 91 VFR	☐	Part 121	☐
Part 91 IFR	☐	ATC	☐
Part 135 non-sched.	☐	Technology Developer	☐
Part 135 scheduled	☐		

What is your role in using the weather product, e.g. pilot, dispatcher, controller: ___________

Note: If certain sections are not pertinent to your functional activity please enter n/a for non applicable.

How long have you been in this position? __________ years.

Indicate the type of aircraft used (on average) for the given FAR category. If you operate more than one type of aircraft, indicate the most complex.

Aircraft Type:

Single engine	☐	Light Jet	☐
Light Twin	☐	Medium Jet	☐
Turboprop	☐	Commercial Jet	☐
Commuter Turboprop	☐	Rotorcraft	☐

4.17 MATRIX A – OPERATIONAL DATA

Matrix A provides operational information related to selected flight phases identified by the FAA. Please complete this matrix for each type of aircraft you identified on the first page (if you have indicated more than one aircraft type, please make a copy of the matrix and complete for each aircraft type.)

The speeds and times asked for in this matrix should be for your typical or average flight. The lower and upper altitudes requested are the approximate altitude ranges you would fly during the cruise, climb and decent flight phases.

(6) Enter the aircraft type

(7) Enter the appropriate information in each of the white boxes.

Matrix A

Aircraft Type: ____________	Preflight Planning; Flight Plan Filing	Taxi Out & Takeoff Operations	Initial Climb Segment	Initial Cruise Operations	Cruise Operations	Approach Operations	Landing Operations
Time for Preflight Planning (min)		(shaded)	(shaded)	(shaded)	(shaded)	(shaded)	(shaded)
Average Taxi Time (min)	(shaded)		(shaded)	(shaded)	(shaded)	(shaded)	(shaded)
Average Cruise Speed (kts)	(shaded)	(shaded)	(shaded)			(shaded)	(shaded)
Average Cruise Range (statute miles)	(shaded)	(shaded)	(shaded)	(shaded)		(shaded)	(shaded)
Cruise: Lower Altitude (MSL)	(shaded)	(shaded)	(shaded)			(shaded)	(shaded)
Cruise: Upper Altitude (MSL)	(shaded)	(shaded)	(shaded)			(shaded)	(shaded)
Rate of Climb (ft/min)	(shaded)	(shaded)		(shaded)	(shaded)	(shaded)	(shaded)
Climb Speed (Vy) (kts)	(shaded)	(shaded)		(shaded)	(shaded)	(shaded)	(shaded)
Climb: Lower Altitude (MSL)	(shaded)	(shaded)		(shaded)	(shaded)	(shaded)	(shaded)
Climb: Upper Altitude (MSL)	(shaded)	(shaded)		(shaded)	(shaded)	(shaded)	(shaded)
Rate of Descent (ft/min)	(shaded)	(shaded)	(shaded)	(shaded)	(shaded)		
Descent Speed (kts)	(shaded)	(shaded)	(shaded)	(shaded)	(shaded)		
Descent: Lower Altitude (MSL)	(shaded)	(shaded)	(shaded)	(shaded)	(shaded)		
Descent: Upper Altitude (MSL)	(shaded)	(shaded)	(shaded)	(shaded)	(shaded)		

4.18 MATRIX B – WEATHER INFORMATION -FLIGHT PHASE DATA

Matrix B on the next page provides data on the weather information you receive during the listed flight phases. Place a number rating in the box associated with each flight phase and weather information source for which you receive and apply weather information. Use the following number rating:

(1) = Used for every flight

(2) = Used occasionally

(3) = Used infrequently

Please complete this matrix for each type of aircraft you identified on the first page (if you have indicated more than one aircraft type, please make a copy of the matrix and complete for each aircraft type.)

1. Enter the aircraft type

2. Enter the appropriate number rating for each of the products that you receive during each of the flight phases. If you do not receive weather information during a particular flight phase then no entry is required.

Matrix B

Aircraft Type: ______ Weather Information Source	Preflight Planning; Flight Plan Filing	Preflight Operations	Taxi Out & Takeoff Operations	Departure Operations	Initial Climb Segment	Initial Cruise Operations	Cruise Operations	Approach Operations	Landing Operations	Taxi In & Parking Operations	Post Flight Operations	Alternate Airport Operations
METAR												
TAF												
FA												
AIRMET Sierra												
AIRMET Tango												
AIRMET Zulu												
SIGMET Domestic												
SIGMET Convective												
SIGMET International												
AWW/WW												
CWA												
Winds Aloft												
PIREPs												
NWS Fax Products												
WAFS Fax Products												
AVOSS												
Low Level Sig Wx Forecasts												
High Level Sig Wx Forecasts												
TDWR												
NEXRAD												
Weather Radar (Airborne)												
Stormscope												
LLWAS												
AWOS												
ASOS												
RVR												
WSP (ASR-9)												
MWP												
ITWS												
WARP												
ARTCC												
HIWAS												
TWEB												
ATIS												
ACARS												
OASIS												
FIS												
DUATS												
FSS												
AFSS												
EFAS												
PATWAS												
NWSTG												
ADDS												
IFFDP												
Kavouras												
WSI												
UNISYS												
Alden												
Universal												
Accu-Weather												
GTE												
Harris												
Other ______												
Other ______												
Other ______												

[1] = Used for every flight [2] = Used occasionally [3] = Used infrequently

MATRIX C – WEATHER INFORMATION DATA

Matrix C provides data on weather information you currently use or have used in the past. For each weather information source listed please apply the appropriate code keeping in mind the flight phases for which you use(d) the weather information. Feel free to add any comments in the comment section below. (For an explanation of "Utilization" please see the definition paragraph below.)

Matrix C

Weather Information Source	* **Utilization:** 1 - Tactical, 2 - Strategic Near Term, 3 - Strategic Far Term	**Accuracy:** 1 - Reliably Accurate, 2 - Somewhat Accurate, 3 - Marginally Accurate	**Constraints:** 1 - Availability, 2 - Equipment Requirements, 3 - Complexity, 4 - Other - Enter in Comments Below	**Utility:** 1 - Critical, 2 - Very Useful, 3 - Somewhat Useful	**Price:** 1 - Not an Issue, 2 - Moderately Expensive, 3 - Too Expensive
METAR					
TAF					
FA					
AIRMET Sierra					
AIRMET Tango					
AIRMET Zulu					
SIGMET Domestic					
SIGMET Convective					
SIGMET International					
AWW/WW					
CWA					
Winds Aloft					
PIREPs					
NWS Fax Products					
WAFS Fax Products					
AVOSS					
Low Level Sig Wx Forecasts					
High Level Sig Wx Forecasts					
TDWR					
NEXRAD					
Weather Radar (Airborne)					
Stormscope					
LLWAS					
AWOS					
ASOS					
RVR					
WSP (ASR-9)					
MWP					
ITWS					
WARP					
ARTCC					
HIWAS					
TWEB					
ATIS					
ACARS					
OASIS					
FIS					
DUATS					
FSS					
AFSS					
EFAS					
PATWAS					
NWSTG					
ADDS					
IFFDP					
Kavouras					
WSI					
UNISYS					
Alden					
Universal					
Accu-Weather					
GTE					
Harris					
Other ________________					
Other ________________					
Other ________________					

***Utilization defined:**

The FAA often refers to airborne weather-related decisions as “tactical” and “strategic”. Tactical decisions refer to reactive penetration decisions which need to be made quickly and are often safety related and time-critical. For this survey, tactical decisions have a time frame of 0 to 15 minutes ahead of the aircraft. Strategic decisions are more pro-active, planning for avoidance rather than penetration. Strategic decisions can be further categorized as “near-term strategic” and “far-term strategic”. For this survey near-term strategic decisions have a time frame of 15 to 60 minutes ahead of the aircraft, far-term strategic decisions have a time frame of 60 minutes or greater.

Utilization Comments: ______________________________

Accuracy Comments: ______________________________

Constraints Comments: ______________________________

Utility Comments: ______________________________

Price Comments: ______________________________

Other Comments: ______________________________

Comment on what areas you feel weather products could be improved (please address in relation to the various flight phases):

Appendix E Weather Product Database

4.19 E.1 Database Structure

The Weather Product Database is organized into various tables. The primary tables include (the name in parentheses indicate the table name used by Access):

Weather Element Table (WXELEMENT_TABLE)

Weather Product Table (WXPRODUCT_TABLE)

Delivery System Table (DELIVERYSYSTEM_TABLE)

Survey Tables (SURVEY_QUALITY_TABLE) (SURVEY_USAGE_TABLE) (OPERATIONS_TABLE)

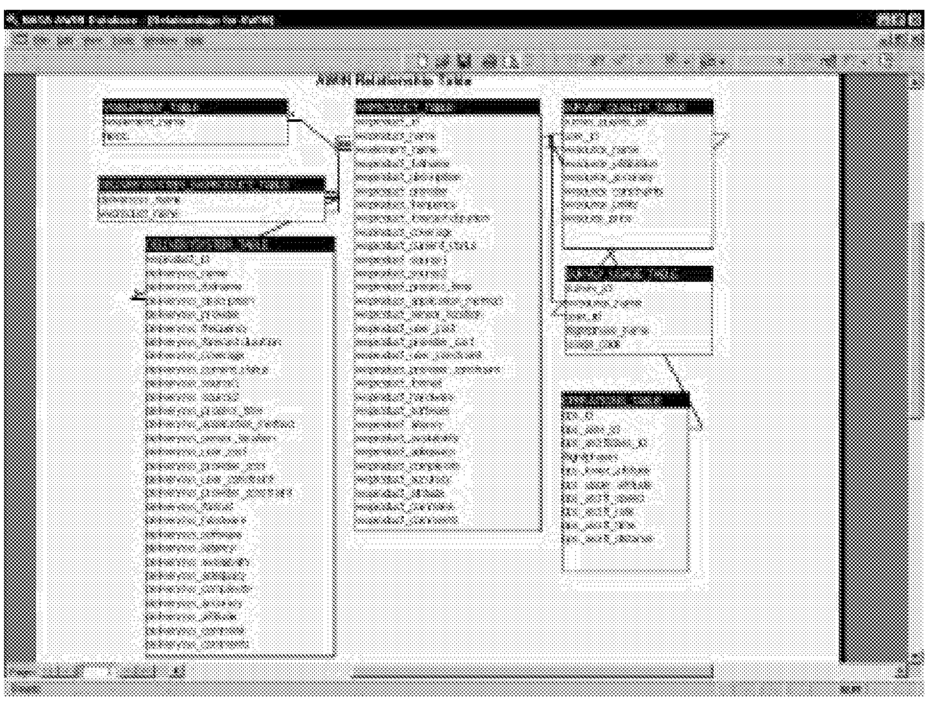
Weather Product Table & Delivery System Table DELIVERYSYTEM_WXPRODUCT_TABLE)

Reference Tables

Each of the above tables are linked by common attributes as shown in relationship figure below:

Weather Element Table (WXELEMENT_TABLE)

The weather element table currently has a single attribute of name (wxelement_name). Examples of weather elements include visibility, thunderstorm, icing, hail, fog, precipitation, and lightening. One or more weather elements are linked to each weather product by the weather element attribute in the weather product table.



Weather Product Table

As mentioned previously, each weather product is linked to one or more weather elements via the weather element attribute in this table. For example, AIRMET Tango is linked with three different weather elements: surface winds, turbulence and windshear. AIRMET Zulu is linked to two different weather elements: icing and temperature. This method of linking weather elements to weather products allows a more granular breakdown of the weather product's characteristics and capabilities. The weather product table has thirty attributes identified for each weather product. In some cases, the product attributes have not been assigned due to a lack of information. Several of the product's attributes have not been assigned values due to the lack of information on the weather product.

Delivery System Table

A number of different delivery systems exist which may used to disseminate weather products to the user community. Each delivery system is linked to one or more weather products and is linked to a weather element by way of the weather product table. Attributes in this table are the same as the attributes in the weather product table with the exception of the weather element attribute.

Survey Tables

The survey data has been organized into three separate tables. Each table corresponds to a matrix in the survey. Matrix A data was entered into OPERATIONS_TABLE, Matrix B data was entered into SURVEY_USAGE_TABLE and Matrix C data was entered into SURVEY_QUALITY_TABLE. A user identification number (user_id) links the three survey tables.

There are ten attributes in OPERATIONS_TABLE that deal with operational information about the surveyed user. The attributes consist of altitude ranges and speeds for each flight phase as well as aircraft range and taxi times.

There are five attributes in the SURVEY_USAGE_TABLE. Four of the attributes uniquely identify the user to a given flight phase and weather product /delivery system. The fifth attribute (usage_code) indicates the frequency of weather product use by flight phase.

There are eight attributes in the SURVEY_QUALITY_TABLE that describe, from the survey respondent's point of view, the use and quality of the weather product. "Use" refers to a pilot's tactical or strategic application of the weather product. Quality refers to the weather product accuracy, constraints, criticality, and price.

Weather Product Table and Delivery System Table

This table links delivery systems to one or more weather products. For example, TIBS is linked to the weather products METAR, TAF, and Winds Aloft. When additional delivery systems are added to DELIVERYSYSTEM_TABLE, the DELIVERYSYSTEM_WXPRODUCT_TABLE must be updated to establish the appropriate link to one or more weather products in WXPRODUCT_TABLE.

Reference Tables

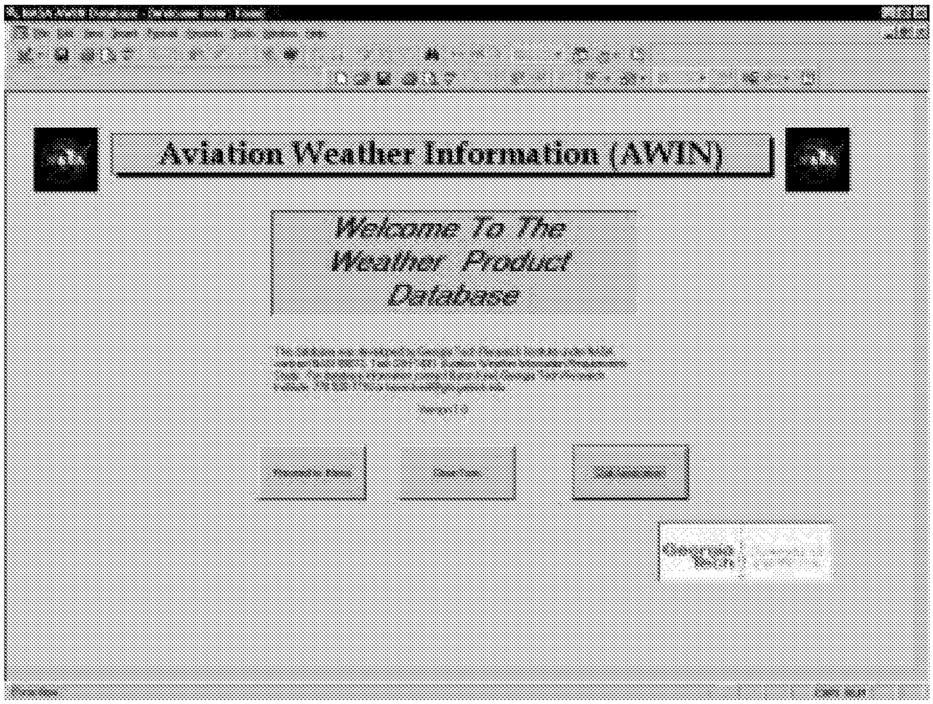
Reference tables are used primarily for converting coded values (*e.g.,* 1,2,3) to textual values. For example, for the usage_code attribute in the SURVEY_USAGE_TABLE, data is entered as a 1, 2 or 3. The >usage_code table converts the values 1, 2 or 3 to "used for every flight," "used occasionally", and "used infrequently" respectively. Reference tables are preceded with the symbol ">"

List Table

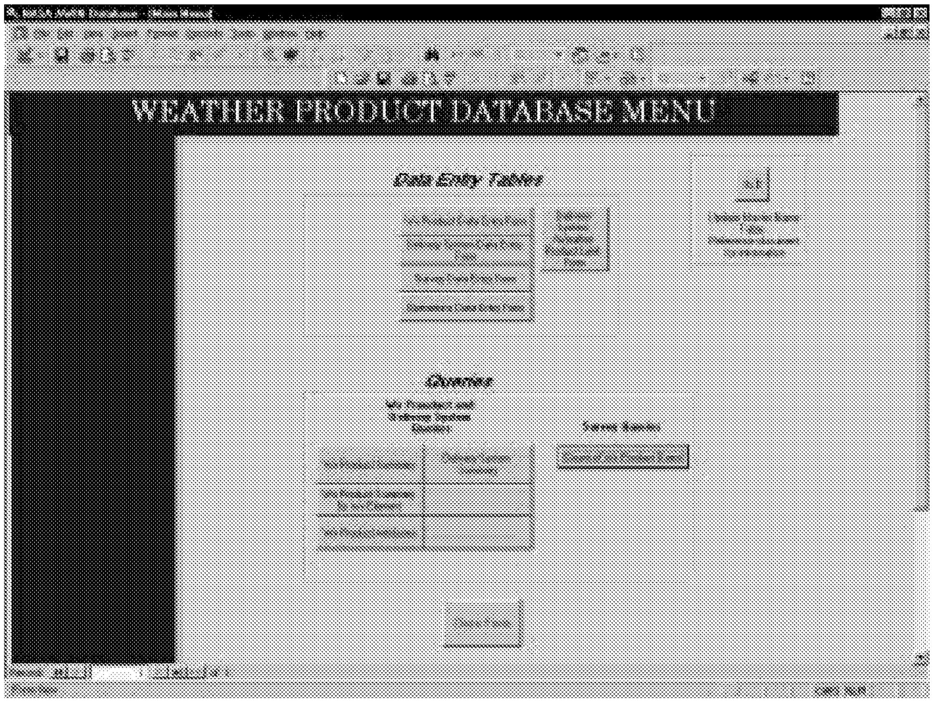
List tables are used for drop down menus that are incorporated in various table, queries, and forms.

4.20 E.2 Database User Instructions

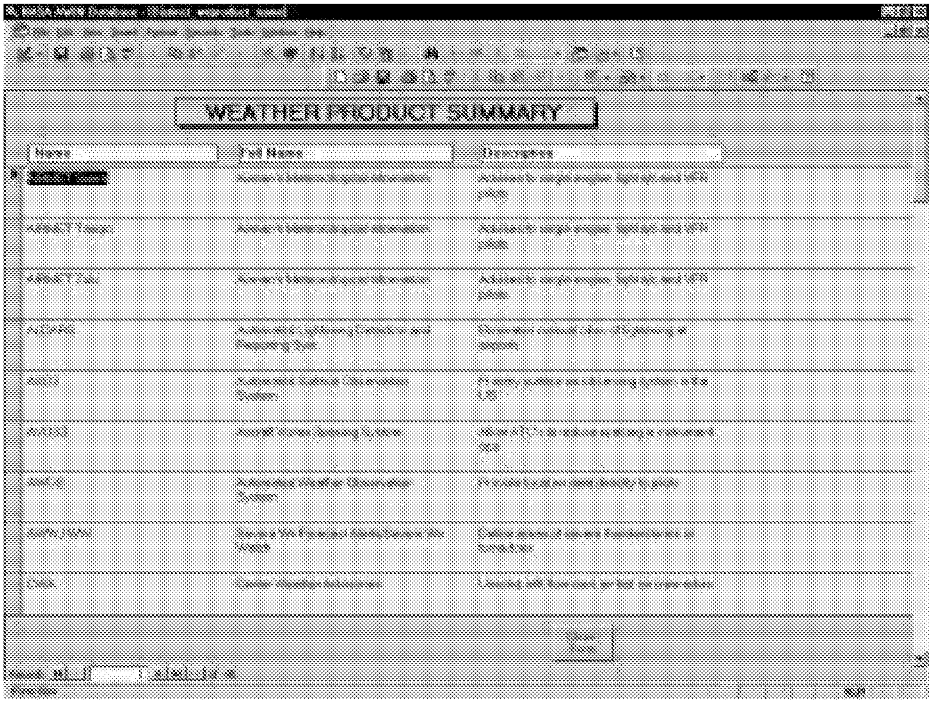
Microsoft Access is required to use the Weather Product Database. Once the database file (AWIN_v1.0.mdb) has been loaded on the computer, start MS Access and open AWIN_v1.0. When the file is opened a welcome screen will appear (see figure below).



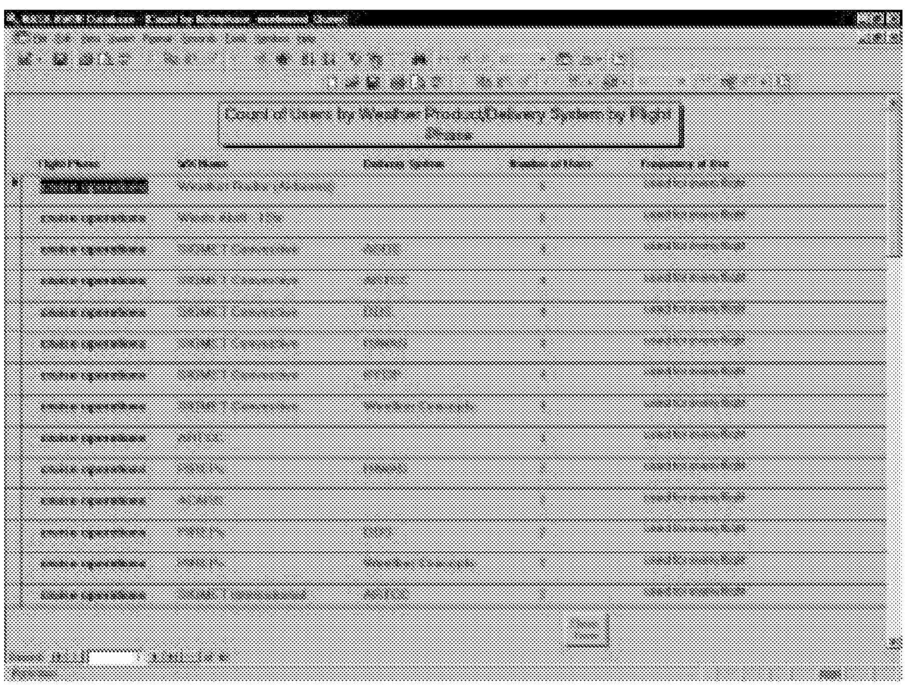
From the Welcome screen the user can quit the application, close the form or proceed to the Main Menu by clicking on the appropriate button. If "Proceed to Menu" is selected a new menu screen appears (see figure below).



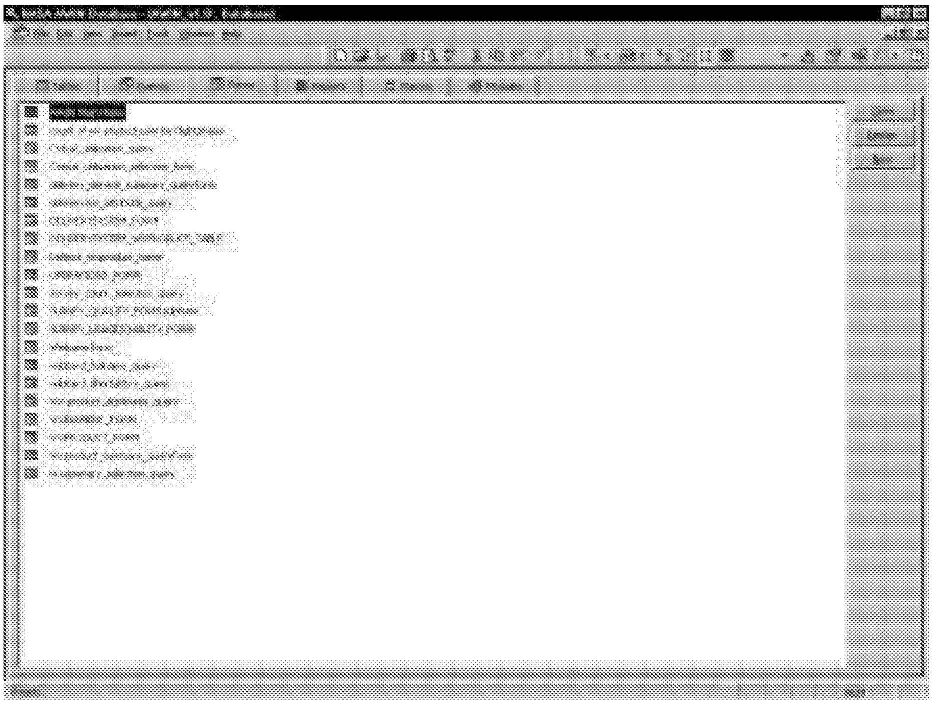
The Main Menu screen provides direct access to the Weather Product Table, the Delivery System Table, the Survey Data tables and the Operations Table. This Menu screen also provides a few sample queries that show the types of queries that can be performed on the database. “Wx Product Summary” is a simple query that goes to the Weather Product Table and selects and displays certain weather product attributes. The figure below shows the result of this query. There is also the query “Count of Wx Product Users” that allows the user to input “user frequency” and “flight phase” parameters then queries five linked tables. The result is a list which ranks the weather products and delivery systems used by survey respondents by flight phase and frequency of use. The figure below shows the result of this query. There are an unlimited number of queries that can be derived from the various tables in the database. With a working knowledge of Access and familiarity with the tables in the database the user can develop many useful queries thus making the Weather Product Database an extremely useful tool.



Master Table Update On the Menu screen there is a button for updating the "master table". This button will run a macro that updates the master table after any weather product or delivery system product is added, deleted or edited to the Weather Product Table or Delivery System Table. It is advised that this macro be run periodically even if the user is unsure of any changes to the tables. Running the macro will not do any harm to the database even if no changes are made to the Weather Product Table or Delivery System Table.



Because query information and parameters will depend on user needs, the user will need to develop his/her own queries using Access query functions. Database functions can be found on the AWIN_v1.0 database menu. The user can either close or minimize the Welcome screen and Main Menu screen to access the AWIN_v1.0 database menu (see figure below).



For questions, problems or assistance using the Weather Products Database, contact Byron Keel at Georgia Tech Research Institute, 770 528-7710 or byron.keel@gtri.gatech.edu.

Appendix F Delta Dispatcher Requirements

The following is a job description for a Delta Airlines dispatcher:

(a) Job Description of the Aircraft Dispatcher

The Aircraft Dispatcher is licensed airman certificated by the Federal Aviation Administration.

He/She has joint responsibility with the captain for the safety and operational control of flights under his/her guidance.

He/She authorizes, regulates and controls commercial airline flights according to government and company regulations to expedite and ensure safety of flight.

He/She is also responsible for economics, passenger service and operational control of day to day flight operations.

He/She analyzes and evaluates meteorological information to determine potential hazards to safety of flight and to select the most desirable and economic route of flight.

He/She computes the amount of fuel required for the safe completion of flight according to type of aircraft, distance of flight, maintenance limitations, weather conditions and minimum fuel requirements prescribed by federal aviation regulations.

He/She prepares flight plans containing information such as maximum allowable takeoff and landing weights, weather reports, field conditions, NOTAMS and many other informational components required for the safe completion of flight.

He/She prepares and signs the dispatch release which is the legal document providing authorization for a flight to depart.

He/She delays or cancels flights if unsafe conditions threaten the safety of his/her aircraft or passengers.

He/She monitors weather conditions, aircraft position reports, and aeronautical navigation charts to evaluate the progress of flight.

He/She updates the pilot in command of significant changes to weather or flight plan and recommends flight plan alternates, such as changing course, altitude and, if required, enroute landings in the interest of safety and economy.

He/She originates and disseminates flight information to others in his/her company including stations and reservations. This is the source of information provided to the traveling public.

He/She has undergone extensive training to have earned the coveted Aircraft Dispatcher's certificate having taken and passed both an extensive oral examination and the comprehensive Dispatch ADX test, administered by the Federal Aviation Administration. These tests are equivalent to the same Air Transport Pilot (ATP) written and oral examinations that an airline captain must successfully complete.

He/She participates in frequent and detailed recurrent training courses covering Regulations as required by the FAA.

Appendix G Weather Products Summary

The following tables contain summary information on existing weather products.

Weather Product Name:	**Route Forecast**
Issued by:	NWS WFO
Type:	Forecast
Application Area:	Air Traffic Routes
Coverage Area:	A 25 mile corridor on either side of some 300 routes in the 48 contiguous states
Update Rate:	Issued 3 times per day
Product Life:	Valid for 15 hours
Contains information on:	1. Sustained surface winds 2. Visibility 3. Weather and obscuration to vision 4. Thunderstorms 5. Volcanic ash 6. Sky conditions (coverage and ceiling/cloud heights) 7. Mountain obscurements 8. Non-convective low-level windshear
Comments:	A synopsis may also be issued with the route forecast which describes weather systems affecting the route (pressure systems, fronts, upper air disturbances, and air flow). A route forecast does not address icing or turbulence. A route forecast will not be issued if a TAF has not been issued for that airport.

Weather Product Name:	Terminal Aerodrome Forecast (TAF)
Issued by:	NWS WFO
Type:	Forecast
Application Area:	Terminal Area
Coverage Area:	A forecast of conditions within 5 miles of the terminal area
Update Rate:	Issued 4 times per day, amended as conditions warrant
Product Life:	Forecast are valid for 24 hours
Contains information on:	1. Wind 2. Visibility 3. Weather 4. Sky condition 5. Wind shear (non-convective low-level windshear)
Comments:	Has the same report format as a METAR. The issuance of a TAF is dependent upon the availability of two (either a manual or automated) METARs spaced no less than 30 minutes apart and no more than 1 hour apart. If the METARs are not available, a TAF will not be issued.

Weather Product Name:	Aviation Routine Weather Report (METAR)
Issued by:	Weather observer (FAA, NWS, or contract personnel) at the airport or by automated systems. The weather data are collected through manual or automated observation.
Type:	Current Conditions
Application Area:	Terminal Area
Coverage Area:	Terminal area, measurement site
Update Rate:	Hourly
Product Life:	1 hour
Contains information on:	1. Wind 2. Visibility 3. Run way visual range 4. Weather phenomena 5. Sky condition 6. Temperature/dew point 7. Altimeter 8. Remarks
Comments:	A **SPECI** (a non-routine aviation weather report) may be issued as conditions warrant on less than an hourly basis.

Weather Product Name:	**Convective SIGMET**
Issued by:	Aviation Weather Center (AWC)
Type:	In-flight Advisory – current and forecast conditions
Application Area:	En route and terminal area
Coverage Area:	The bulletins are divided into three regions of the U.S. 48: eastern, central, and western. These regions are separated at 87°W and 107°W. The convective activity is referenced to specific location identifiers (either VORs, airports, or well-known geographic areas).
Update Rate:	Hourly; special bulletins may be issued as conditions warrant
Product Life:	2 hours
Contains information on:	Issued if the following conditions exists: 1. Severe thunderstorm with a. Surface winds greater than or equal to 50 knots b. Hail at the surface greater than or equal to 0.75 inches in diameter c. Tornadoes 2. Embedded thunderstorms 3. A line of thunderstorms 4. Thunderstorms producing heavy precipitation affecting 40% or more of an area of least 3000 square miles
Comments:	A convective SIGMET implies the presence of severe or extreme turbulence, severe icing, and low-level wind shear. In Alaska, the Alaska Aviation Weather Unit issues in-flight advisories, and in Honolulu, the WFO issues the advisories.

Weather Product Name:	Domestic SIGMET
Issued by:	Aviation Weather Center (AWC)
Type:	In-flight Advisory – current and forecast conditions
Application Area:	En route and terminal area
Coverage Area:	Are issued for six regions in the continental U.S., for 23 regions in Alaska, and for Hawaii. These are considered as "widespread" forecast because the conditions must be affecting or forecast to affect an area of at least 3,000 square miles. The forecasted area may be considerably larger even though conditions are only affecting a small portion (3,000 square miles) of the area.
Update Rate:	As conditions warrant
Product Life:	4 hours, unless associated with a hurricane then the product life is 6 hours
Contains information on:	Issued if the following conditions exists or expected to exists: 1. Severe icing not associated with a thunderstorm 2. Severe or extreme turbulence or CAT not associated with a thunderstorm 3. Dust storms, sandstorms, or volcanic ash lowering surface or in-flight visibilities to below 3 miles. 4. Volcanic eruption In Alaska and Hawaii, SIGMETs also include: 1. Tornadoes 2. Lines of thunderstorms 3. Embedded thunderstorms 4. Hail greater than or equal to ¾ inches in diameter

Weather Product Name:	**International SIGMET**
Issued by:	International Civil Aviation Organization designated Meteorological Watch Offices (in the U.S., the Meteorological Watch Office (MWOs) are the NWS offices in Anchorage, AK, Honolulu, HI, Kansas City, MO, and Gaum Island. The tropical prediction center in Miami, FL is also an MWO.
Type:	In-flight advisory – current and forecast conditions
Application Area:	En route
Coverage Area:	Alaska, Hawaii, portions of the Atlantic and Pacific Oceans, and the Gulf of Mexico
Update Rate:	As conditions warrant
Product Life:	12 hours for volcanic ash events, 6 hours for hurricanes and tropical storms, and 4 hours for all other events
Contains information on:	Issued if the following conditions exists or expected to exists: 1. Thunderstorms occurring in lines, embedded in clouds, or occurring in large areas that produce tornadoes or large hail 2. Tropical cyclones 3. Severe icing 4. Severe or extreme turbulence 5. Dust storms and sandstorms lowering visibility to less than 3 miles 6. Volcanic ash

Weather Product Name:	AIRMET
Issued by:	Aviation Weather Center (AWC)
Type:	In-flight Advisory – current and forecast conditions
Application Area:	En route and terminal area
Coverage Area:	Are issued for six regions in the continental U.S., for 23 regions in Alaska, and for Hawaii. These are considered as "widespread" forecasts because the conditions must be affecting or forecast to affect an area of at least 3,000 square miles. The forecasted area may be considerably larger even though conditions are only affecting a small portion (3,000 square miles) of the area.
Update Rate:	Every six hours, updated as conditions warrant
Product Life:	6 hours, variable
Contains information on:	There are three types of AIRMET each advising of specific weather conditions: **AIRMET Sierra** – issued for 1. IFR weather conditions – ceilings less than 1000 ft. and/or visibility less than 3 miles affecting over 50% of the area at one time 2. Extensive mountain obscuration **AIRMET Tango** – issued for 1. Moderate turbulence 2. Sustained surface winds of 30 knots or greater 3. Low-level wind shear **AIRMET Zulu** – issued for 1. Moderate icing 2. Freezing-level heights

Weather Product Name:	**Aviation Area Forecast (FA)**
Issued by:	Aviation Weather Center (AWC)
Type:	In-flight advisory – current and forecast conditions
Application Area:	En route and terminal area
Coverage Area:	Are issued for six regions in the continental U.S., for 23 regions in Alaska, and for Hawaii. A specialized FA is issued for the Gulf of Mexico by the TPC in Miami, FL.
Update Rate:	3 times per day or as conditions warrant
Product Life:	8 hours
Contains information on:	An area forecast is a forecast of visual meteorological conditions (VMC), clouds, and general weather conditions over an area the size of several states. International area forecast also are prepared for the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. The international forecasts are prepared in text format for altitudes from the surface to 25,000 feet. Charts are prepared for forecast containing significant weather between 25,000 and 60,000 feet.

Weather Product Name:	**Winds and Temperature Aloft Forecast**
Issued by:	National Center for Environmental Prediction
Type:	Forecast
Application Area:	En route
Coverage Area:	Winds and temperature aloft forecast at specific locations through out the contiguous U.S.; most states contain several forecast locations
Update Rate:	2 times per day
Product Life:	12 hours
Contains information on:	Winds and temperature aloft forecast available for the following altitudes: True altitudes: 3,000, 6,000, 9,000, and 12,000 feet Pressure altitudes: 18,000, 24,000, 30,000, 39,000, 45,000, and 39,000 feet.

Weather Product Name:	Meteorological Impact Statement (MIS)
Issued by:	Center Weather Service Unit located at the ARTCC
Type:	Forecast
Application Area:	En route and terminal areas
Coverage Area:	Airspace assigned to the ARTCC
Update Rate:	As conditions warrant
Product Life:	2 to 12 hours
Contains information on:	Forecast of conditions that will impact air traffic flow in the ARTCC area. The conditions are forecast to begin beyond 2 hours of the issuance, but within 12 hours of the issuance. MISs are issued for the following conditions: 1. Convective SIGMET criteria 2. Moderate or greater icing and/or turbulence 3. Heavy or freezing rain 4. Low IFR conditions (ceilings less than 500 ft. and/or visibility less than 1 mile) 5. Surface winds/gusts 30 knots or greater 6. Low-level wind shear within 2000 feet of the surface 7. Volcanic ash, dust, or sand storm

Weather Product Name:	Center Weather Advisory (CWA)
Issued by:	Center Weather Service Unit located at the ARTCC
Type:	Forecast
Application Area:	En route and terminal areas
Coverage Area:	Airspace assigned to the ARTCC
Update Rate:	As conditions warrant
Product Life:	2 hours
Contains information on:	Forecast of conditions that will impact air traffic flow in the ARTCC area. The conditions are forecast to begin within 2 hours of the advisory. The CWA may refine/tailor the forecast for the ARTCC area of responsibility. CWA may also be issued in advance of an in-flight advisory as conditions warrant. A CWA may even be issued when conditions do not meet AWC in-flight advisory status but may impact the safe flow of traffic in the ARTCC area of responsibility.

Weather Product Name:	Severe Weather Watch Bulletin (WW)
Issued by:	Storms Prediction Center in Norman, Oklahoma
Type:	Watch (Forecast)
Application Area:	En route and terminal area
Coverage Area:	Regional
Update Rate:	As conditions warrant
Product Life:	Not available
Comments:	An alert severe weather watch (AWW) may be issued prior to the WW to notify WFOs, CWSUs, FSS, and other users of the pending WW. The AWW will contain a brief message contain a summary of the watch information.

Weather Product Name:	Hurricane Advisory
Issued by:	Not available
Type:	Advisory
Application Area:	En route and terminal area
Coverage Area:	Hurricanes location
Update Rate:	Once hurricane is 300 nm offshore
Product Life:	Not available
Contains information on:	Provides: 1. Location of storm center 2. Expected movement 3. Maximum winds near the center of the hurricane

Weather Product Name:	**U.S. Low-Level Significant Weather Program**
Issued by:	Not available
Type:	Forecast
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	4 times per day
Product Life:	12 | 24 hour forecast
Contains information on:	Some of the information provided on the charts: 1. Fronts 2. Pressure centers 3. Forecast precipitation and/or thunderstorms 4. IFR, MVFR, turbulence, and freezing levels 5. The significant weather is forecast from the surface to 24,000 feet referenced to MSL.

Weather Product Name:	**High-Level Significant Weather Program**
Issued by:	Not available
Type:	Forecast
Application Area:	En route and terminal area
Coverage Area:	U.S. and International
Update Rate:	4 times per day
Product Life:	6 hours
Contains information on:	These charts contain information on the airspace between (25,000 feet and 60,000 feet (in pressure altitude)). Some of the information provided in the charts includes: 1. Thunderstorms 2. Tropical cyclones 3. Moderate or severe turbulence 4. Convergence zones 5. Fronts 6. Tropopause heights 7. Jet stream 8. Volcanic activity

Weather Product Name:	Convective Outlook
Issued by:	Storms Prediction Center
Type:	Forecast
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	5 | 2 times per day
Product Life:	24 | 48 hours
Contains information on:	A convective outlook defines areas which are at risk of severe thunderstorms over the next 24 and 48 hours.

Weather Product Name:	Surface Analysis Charts
Issued by:	Not available
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	Every 3 hours
Product Life:	3 hours
Contains information on:	A chart showing the pressure systems and isobars across the 48 contiguous states and adjacent areas.

Weather Product Name:	Radar Summary Chart
Issued by:	NWS
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	Every hour
Product Life:	1 hour
Contains information on:	A graphical display of areas of precipitation. Includes information on type, intensity, location, coverage, echo top, and cell movement. These charts are generated from data collected by the WSR-88D network.
Comments:	The charts are to be used for pre-flight planning purposes only.

Weather Product Name:	**Weather Depiction Chart**
Issued by:	NWS
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	Every 3 hours starting at 0100Z
Product Life:	3 hours
Contains information on:	A summary of METARs across the U.S. in a chart format. The chart provides, a broad overview of sky conditions based on the METARs. Include are sky cover, cloud height, weather and obstructions to vision, and visibility.
Comments:	The charts are to be used for pre-flight planning purposes only since weather conditions can change considerable in a 3 hour period. Specific, up-to-date METARs should be consulted along the planned route.

Weather Product Name:	**Weather Depiction Chart**
Issued by:	NWS
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	Every 3 hours starting at 0100Z
Product Life:	3 hours
Contains information on:	A summary of METARs across the U.S. in a chart format. The chart provides a broad overview of sky conditions based on the METARs. Included are sky cover, cloud height, weather and obstructions to vision, and visibility.
Comments:	The charts are to be used for pre-flight planning purposes only since weather conditions can change considerable in a 3 hour period. Specific, up-to-date METARs should be consulted along the planned route.

Weather Product Name:	Radar Weather Report
Issued by:	NWS WFO
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	Every hour
Product Life:	1 hour
Contains information on:	This report describes general areas of precipitation. The reports include type (limited to rain, rain shower, snow, snow shower, thunderstorm), intensity, and location of echo top.
Comments:	Should be used for planning purposes only. Does not provide information on clouds and fog that impact ceilings and visibility.

Weather Product Name:	Satellite Weather Pictures
Issued by:	NWS and private companies
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	15 minutes to 1 hour
Product Life:	Not available
Contains information on:	Visible Imagery: 1. Presence of clouds 2. Type of cloud infrared imagery 3. Cloud height based on cloud temperature

Weather Product Name:	Radiosonde Additional Data
Issued by:	NWS
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	Every 12 hours
Product Life:	12 hours
Contains information on:	Observed freezing level and relative humidity at the freezing level obtained from radiosonde data.

Weather Product Name:	Constant Pressure Analysis Charts

Weather Product Name:	Constant Pressure Analysis Charts
Issued by:	NWS
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	Every 12 hours
Product Life:	12 hours
Contains information on:	Contains the following information 1. Temperature 2. Temperature – dew point spread 3. Wind (direction and speed) 4. Height about sea level 5. Height change of the pressure surface over the past 12 hours. This information is obtained from radiosonde, aircraft, and satellite date. The charts are produced for the following pressures in millibars/hectoPascal: 850, 700, 500, 300, 250, and 200. These pressures correspond to a pressure altitude of 1,500, 3,000, 18,000, 30,000, 34,000, and 39,000 feet. The charts provide contours of constant height, isotherms of equal temperature, and isotachs of equal wind speed.

Weather Product Name:	Composite Moisture Stability Chart
Issued by:	NWS
Type:	Current conditions
Application Area:	En route and terminal area
Coverage Area:	U.S.
Update Rate:	Every 12 hours
Product Life:	12 hours
Contains information on:	Consists of four charts containing information on stability, freezing levels, precipitation water, and average relative humidity. Reporting levels include the surface, 1,000 mb/hPa, 850 mb/hPa, 700 mb/hPa, and 500 mb/hPa.

Weather Product Name:	**Volcanic Ash Forecast Transport and Dispersion Chart**
Issued by:	NOAA Air Resources Laboratory (ARL)
Type:	Forecast
Application Area:	En route and terminal area
Coverage Area:	International
Update Rate:	6, 12, 24, and 36 hours after a volcanic eruption
Product Life:	6 and 12 hour forecast
Contains information on:	A model is used to forecast ash concentrations for three layers of the atmosphere: 1. surface to 20,000 ft (MSL) 2. 20,000 to 35,000 ft (MSL) 3. 35,000 to 55,000 ft (MSL)

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 2000	Contractor Report (6/2/99-11/18/99)

4. TITLE AND SUBTITLE
Aviation Weather Information Requirements Study

5. FUNDING NUMBERS
C NAS1-99073
TA 1002
WU 577-40-10-01

6. AUTHOR(S)
Byron M. Keel, Charles E. Stancil, Clifford A. Eckert, Susan M. Brown, Gary G. Gimmestad, and Mark A. Richards

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, GA 30332-0800

8. PERFORMING ORGANIZATION REPORT NUMBER
GTRI Contractor Report A-5990

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-2199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/CR-2000-210288

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: Philip R. Schaffner

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 03 Distribution: Standard
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
The Aviation Safety Program (AvSP) has as its goal an improvement in aviation safety by a factor of 5 over the next 10 years and a factor of 10 over the next 20 years. Since weather has a big impact on aviation safety and is associated with 30% of all aviation accidents, Weather Accident Prevention (WxAP) is a major element under this program. The Aviation Weather Information (AWIN) Distribution and Presentation project is one of three projects under this element. This report contains the findings of a study conducted by the Georgia Tech Research Institute (GTRI) under the Enhanced Weather Products effort, which is a task under AWIN. The study examines current aviation weather products and there application. The study goes on to identify deficiencies in the current system and to define requirements for aviation weather products that would lead to an increase in safety. The study also provides an overview the current set of sensors applied to the collection of aviation weather information. New, modified, or fused sensor systems are identified which could be applied in improving the current set of weather products and in addressing the deficiencies defined in the report. In addition, the study addresses and recommends possible sensors for inclusion in an electronic pilot reporting (EPIREP) system.

14. SUBJECT TERMS
Safety, Aviation, Weather, Sensors, Weather Products, Requirements

15. NUMBER OF PAGES
178

16. PRICE CODE
A09

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL