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National Plan to Improve Aircraft Icing Forecasts

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FOREWORD

This National Plan to Improve Aircraft Icing Forecasts has been developed in response to a National Transportation Safety Board recommendation to improve aircraft icing forecasts (NTSB, 1981). The initial reply to NTSB, "A Report on Improving Forecasts for Icing Conditions for Aviation" (OFCM, 1982), indicated a lack of programmatic activities in this area at that time.

Development of a detailed program plan is practicable, now, as opportunities for forecast improvement are becoming possible with the development of new remote-sensing and automated weather information processing capabilities. This plan is a more comprehensive treatment of the program outlined in Section 3-3 of the National Aircraft Icing Technology Plan (OFCM, 1986), prepared for the National Aircraft Icing Program Council.

This forecast plan has been prepared by an ad hoc group under the guidance of the Committee for Aviation Services of the Interdepartmental Committee for Meteorological Services and Supporting Research. The ad hoc group had technical assistance from Mr. Cleon J. Biter and Mr. W. A. Cooper at the National Center for Atmospheric Research, Dr. Ingrid A. Popa Fotino at the Cooperative Institute for Research in the Environmental Sciences, Mr. Leon F. Osborne and Mr. Michael R. Poellot at the University of North Dakota, and Dr. Wayne R. Sand of the University of Wyoming. We thank them all for their participation.

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EXECUTIVE SUMMARY

Background

Icing remains one of the primary causes of accidents among general aviation aircraft. Approximately 210,000 general aviation, air taxi, and small commuter aircraft, including 7,100 helicopters, are not equipped with deicing or anti-icing devices and must theoretically avoid all areas of potential aircraft icing. Protection systems on the 12,000 civil aircraft certified to fly into icing conditions are generally not adequate to handle prolonged exposure to moderate icing or short exposures to severe icing. With little ice protection equipment, most military aircraft generally avoid icing encounters. Timely and accurate forecasts of icing are thus of critical importance to flight safety. However, as indicated in a National Transportation Safety Board (NTSB) Report (NTSB, 1981) and elsewhere, icing forecasts are imprecise and widely considered in need of improvement. Improved forecasts of icing conditions will not only provide substantial benefits to aviation safety, there will also be gains through increased aircraft utility resulting from more precise flight planning and more optimal use of the national airspace.

Goals and Benefits

This program will gather a reliable data base to better understand the characteristics of aircraft icing, for evaluation of icing forecast techniques, for development of improved methods for detecting and forecasting icing, and to provide the technology transfer of these needed observations and improved forecasting techniques to the aviation weather services. This plan features data collection by modern remote sensors and by instrumented aircraft, and use of new technology--the Program for Regional Observing and Forecasting Services (PROFS) Exploratory Development Facility (EDF) and research workstations for acquisition, display, and analysis of these data in the context provided by a comprehensive set of meteorological observations. The goal is to improve flight safety through exploitation of modern observational tools and recent improvements in our understanding of wintertime storm structure. The data collected will also be a valuable resource for use in improving aircraft design and certification standards, icing protection systems, and pilot training.

Opportunity

The prospects for success in this program are high due to recent advances in two areas. First, there has been substantial progress in the development of new sensors able to observe meteorological phenomena related to aircraft icing. Foremost among these are the new remote sensors, including radiometers and profilers, which yield new information on finer scales with a continuity that was previously unavailable. Second, the research community has made substantial progress toward understanding the structure of wintertime storms, and the atmospheric conditions that can lead to icing in those storms are understood fairly well. Because of their experimental nature, neither of these two major developments has yet had much influence on operational forecasting. This program provides an ideal opportunity that should facilitate the needed technology transfer.

Program Tasks

This national program for detecting, monitoring, and forecasting aircraft icing is a cooperative effort of the National Oceanic and Atmospheric Administration (NOAA), Federal Aviation Administration (FAA), Department of Defense (DOD), National Science Foundation (NSF), and the university community, with NOAA/Environmental Research Laboratories (ERL) the lead agency. The Program Tasks are as follows:

- In-situ detection of icing conditions. Instrumented aircraft will be used to document the presence or absence of icing conditions during various weather events. These observations will provide the basic data sets that will be used to determine whether such icing conditions can be detected remotely and whether forecasting methods can be verified or improved.

- Remote detection and monitoring of icing conditions. New facilities now in place in eastern Colorado will be used to collect observations during icing episodes. The facilities to be used include profilers, a mesoscale surface observing network, Doppler radars, radiometers, and satellite sensors. Data from these instruments will be collected by the PROFS EDF and used to determine whether icing conditions can be detected and monitored remotely, and the data collected by research aircraft will be used to validate this ability.

- Acquisition and analysis of meteorological and microphysical data. To support the development of forecasting techniques, data sets on both the conventional synoptic scale and the higher-resolution mesoscale, data from the new remote sensors, and aircraft data will be collected and analyzed during winter storm conditions to describe the conditions under which icing occurs. The PROFS EDF workstation display and analysis capabilities will also be used to examine and correlate these data sets.

- Development and evaluation of forecasting techniques. The analysis facilities and the above data sets will be used to develop and evaluate methods for forecasting icing, and additional observations will be collected as needed to test these forecasting techniques.

- Study of the physics of airframe icing. The data from this and other research and operational programs will be used to study the links between aircraft icing and characteristics of the icing clouds.

Program Schedule Overview

Phase I of the program began in Fiscal Year (FY) 1986 and will continue through FY 1988. The FAA, National Center for Atmospheric Research (NCAR), and existing NOAA/ERL mesoscale facilities in Eastern Colorado will be the focus for an interagency program where research aircraft will be used to 1) study the ability of remote sensors to detect icing conditions, 2) evaluate current icing forecast techniques, 3) test promising new forecasting techniques, and 4) provide essential data for studies of airframe icing and for general characterization of the clouds associated with aircraft icing. The emphasis during this phase will be on improvements in the detection of icing conditions and in short-term (0-4 hour) forecasting.

Phase II will take place during FY 1989 and FY 1990. During this phase, expanded instrumentation, new data sources, experimental forecast techniques, and environmental data describing icing encounters will be evaluated. During selected observational periods, research aircraft will provide data for the validation of forecast techniques, for cloud microphysics research, and for studies of aircraft performance in icing conditions (though these studies are not part of this program area). The emphasis will be on improvements in both short and longer term (0-12 hour) forecasting.

Phase III will start in FY 1991. A broader range of forecast settings coinciding with the expansion of the Stormscale Operational and Research Methodology (STORM) project will be used to determine the operational applicability of icing forecast techniques in other regions.

Costs

The program costs for both forecasting technique research and development and validation and verification are $1,100,000 for FY 1986, $1,400,000 for FY 1987, $1,700,000 for FY 1988, and $1,000,000 for both FY 1989 and 1990, totaling $6,200,000 for the five-year period. Costs in later years will depend on further program definition.

Program research and development costs include the costs of developing capabilities to detect, monitor, and forecast icing events, and the costs of studies of the relationship between airframe icing and the characteristics of icing clouds. Validation and verification costs include field and aircraft operations. These costs represent additional increments to the national investment in other major ongoing and planned research and development programs. Thus, any cutback in those programs would limit opportunities for the success of this icing program unless funds for the icing program are augmented.

1. INTRODUCTION

Almost 95 percent of the 210,000 general aviation aircraft, including 7100 helicopters, are not certified for flight into known icing conditions, and even on aircraft so certified, the ice protection equipment often will not handle prolonged exposure to moderate icing encounters or limited exposure to severe icing. Most military aircraft have little ice protection equipment and generally need to avoid icing encounters. In a recent study of icing conditions near Denver, Colorado, Decker et al., (1986) found pilot reports of icing conditions in about 8% of all 3-hr blocks spanning 9 months. Since the majority of all aircraft can operate safely in icing conditions for only a limited time, icing is a serious concern in many locations.

The hazards associated with icing are most serious for smaller fixed-wing aircraft and for helicopters. These hazards are, therefore, of greatest concern to the general aviation community, military training programs, helicopter operators, and to some air taxi and commuter airlines. The aircraft used by these groups frequently operate in instrument meteorological conditions (IMC) at altitudes where icing is possible, and often do not have sufficient reserve power or ice protection to permit operation in icing environments. For these aircraft, the principal means of preventing icing accidents must be the avoidance of reported and forecast hazardous icing conditions. The improved air traffic control system, the high quality of aircraft and avionics, and the resultant increased utility of general aviation aircraft have all increased the exposure of these aircraft to IMC, while icing forecasting has remained virtually unchanged.

Icing forecasts usually cover large volumes, and meteorologists working with coarse-resolution data forecast on the side of safety by predicting icing over unduly large areas or expanded times. Although this practice is not in itself unsafe, it leads to unnecessarily long flights and cancellations with related expense and inconvenience. In addition, a pilot who has frequently encountered little or no icing in areas where icing was forecast may be tempted to disregard future icing forecasts. The aviation community has frequently emphasized the urgent need to improve icing forecasts.

The Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) published "The National Aircraft Icing Technology Plan" (OFCM, 1986) prepared by the National Aircraft Icing Program Council. One section of the plan proposes a national program under the leadership of the National Oceanic and Atmospheric Administration (NOAA) to develop the capability for accurate and timely delineation and forecasting of icing areas. This is in consonance with NTSB recommendations (NTSB, 1981). The plan advocates improvement in detecting, monitoring, and forecasting of aircraft icing conditions through the use of research, aircraft, and new remote sensing technology, including vertical profilers, Doppler radars, satellite soundings, and automated surface observations.

The following program provides the details that were requested in that plan. This program will provide appropriate data for the study of aircraft icing and the evaluation of existing techniques and will develop improved methods for detecting and forecasting icing conditions. The plan provides for the research needed to determine how the icing hazard depends on microphysical characteristics of the clouds, and to relate those characteristics to mesoscale or synoptic-scale characteristics that are readily observable. The approach features the application of modern technology, uses the recent advances in meteorology, and focuses on meeting the operational needs of the aviation community.

2. PROGRAM OVERVIEW

2.1 SCOPE

This national program to improve the detecting, monitoring, and forecasting of aircraft icing is an initiative that uses the latest technology:

- For real-time measurement of atmospheric conditions conducive to icing;
- For rapid data assimilation, and for monitoring, analyzing, and forecasting;
- For operational evaluation of product validity and utility; and
- For research applications in both ongoing and planned programs.

The program is based upon the cooperative participation of key Federal organizations which have the technological capabilities essential to a solution of the aircraft icing problem or will sponsor other organizations with these capabilities. These Federal organizations include the National Oceanic and Atmospheric Administration/Environmental Research Laboratories (NOAA/ERL), the Department of Defense/United States Air Force (USAF) and United States Army (USA), the National Science Foundation (NSF), and the Federal Aviation Administration (FAA). They plan to use NCAR and university (e.g., the Universities of North Dakota and Wyoming) support for the program. It is anticipated that the program can serve as a framework for the participation of other groups who may find it attractive to pursue related research topics in conjunction with this program. In addition, data sets available from this program may be useful to others concerned with aircraft icing (particularly aircraft designers and certification/qualification authorities).

2.2 OBJECTIVES

The basic program objective is the timely, accurate delineation of actual and expected icing areas by location, altitude, duration, and potential severity. The research and development necessary to accomplish this primary objective must involve definitive descriptions of the icing environment by all available means, especially through the use of instrumented research aircraft. This will also provide data which may improve aircraft certification criteria. Ultimately, the data base developed through this program should be useful in providing critical engineering data for design and certification of future aircraft and for improving pilot training.

2.3 POTENTIAL BENEFITS

The potential benefits of this program are:

- More accurate and timely delineation of current and forecast icing areas to help reduce accidents and provide for more efficient use of the airspace, with attendant economic benefits.

° Additional data for characterization of the icing environment and development of better icing protection systems.

° Better understanding of cloud microphysics and the related physical processes that can lead to improved:

  ° Aircraft design and certification

  ° Guidance for pilots

2.4 PROGRAM SCHEDULE

The essential sensing, assimilation, and analysis facilities for the three-phase development program, depicted in Fig. 1, are already in place or programmed for eastern Colorado and the Central United States. Another essential ingredient for this program is the availability of specially instrumented research aircraft such as those available at the University of North Dakota, University of Wyoming, and NCAR. NOAA/ ERL will be the lead agency working jointly with other key agencies, including NSF (NCAR), DOD (the Air Force and Army), FAA, and universities, in implementing the program. An Aircraft Icing Project Office has been established within ERL.

2.4.1 Phase I (1986-88)

Program activities to date have included:

° ERL/WPL analysis and correlation of hourly Denver Stapleton profiler Temperature and Vapor/Liquid observations and aircraft icing PIREPs within a 50-mile radius of Denver.

° FAA/University of North Dakota research aircraft flights conducted in February and March 1986 into icing situations in the Grand Forks, North Dakota area.

° Preliminary planning for Eastern Colorado operational test program in FY 1987.

During FY 1987, research aircraft flights will be conducted and PROFS facilities will be used to access and collect data from eastern Colorado remote sensors, to ingest PIREPs, and to integrate and provide automated, coordinated display of all data sets. The capabilities and limitations of currently available analysis and forecast algorithms and routines will be evaluated, and cloud microphysics research analyses will be conducted. The addition of the remote sensing data currently available in eastern Colorado and the automatic plotting of PIREPs will assist in providing a more precise evaluation of actual icing conditions. Approximately one hundred flight hours per aircraft per annum will be required. At least one of the research aircraft will be equipped with remote-sensing lidar and possibly with microwave radiometer systems.

Program Phases

Phase I 1986-1988	Phase II 1989-1990	Phase III 1991 →
• Initiation • Use of In-Place Capabilities for Detection (Eastern Colorado) NOAA/ERL Facilities • Research Aircraft Operations • Evaluation of Present Forecast Techniques, Models, etc. • Potential Forecast Technique Analysis	• Operational Evaluation of Detection and Monitoring Capabilities in Eastern Colorado, Central U.S. • Experimental Test and Eval. of Forecast Techniques in Eastern Colorado, Central U.S. • Cloud Microphysics Research Data Analysis	• Operational Evaluation of Forecast Capabilities in Eastern Colorado, Central U.S., Other Areas (1990-1993) • Research and Operational Test Data Inputs to Certification and New Aircraft Development

Figure 1. Program Schedule Overview

2.4.2 Phase II (1989-90)

The NOAA expanded 30-station network of ground based Profilers operating in the central United States, along with other new sensors including Next Generation Weather Radars (NEXRAD), VISSR Atmospheric Sounder (VAS), etc., new data assimilation and data handling capabilities such as the PROFS Mesoscale Analysis and Prediction System (MAPS), and instrumented research aircraft from NCAR, NOAA, and the university community will be utilized to provide even more detailed measurements of actual icing conditions. This phase will involve intensive mesoscale observation periods during early spring and late autumn when icing is most prevalent. Experimental testing and evaluation of all available forecast techniques and cloud microphysics research data analysis will be conducted during this period.

2.4.3 Phase III (1991)

Evaluation of icing prediction techniques in broader operational forecast settings will coincide with an expanded mesoscale STORM research program. Techniques developed will be tested in other regions to determine operational applicability. An improved icing severity index evaluation based on criteria provided by the FAA will be conducted. The detailed evolution of Phase III activities is highly dependent upon Phase II program results.

3. DETAILED PROGRAM PLAN

3.1 FACILITIES AND INSTRUMENTATION

Facilities suitable for this program already exist in eastern Colorado, and additional experimental facilities are planned to be added in the near future. These facilities will support the program outlined in this plan. Figure 2 indicates the location of the available PROFS mesonet and remote sensing instrumentation in eastern Colorado which will be the basic aircraft icing test and demonstration area for Phase I. A brief description of this instrumentation and the research aircraft necessary to conduct this program follows.

° Profiler Network The four existing stations in north-east Colorado (Denver, which measures wind, temperature, and vapor/liquid water; and Flagler, Fleming, and Platteville, which measure wind, vapor/liquid water) will be used initially. These stations report every hour. Thirty additional wind profilers will be installed in FY 1988 in Colorado and the plains to the east. Temperature and vapor/liquid water will be added at 10 of the additional 30 sites. Figure 3 depicts the expanded profiler network to be used in Phase II. It is anticipated that this 30-station profiler network will be further expanded in the 1990s.

° Mesoscale Surface Network The existing PROFS 22-station automated surface observation mesonet provides surface winds, peak gusts, temperature, humidity, pressure, and solar insolation data every five minutes.

° Radars The WSR-57 at Limon, Colorado, the WSR-74C at Cheyenne, Wyoming, at least one NEXRAD-type 10-cm Doppler Radar NCAR (CP-2 or MIT Lincoln Laboratory radar) and the 5-cm University of North Dakota Doppler radar will be available subject to continued Federal support of these non-Federal facilities and availability of the radars.

° Satellite Data Visible, Infrared (IR), and Visible and Infrared Spin-Scan Radiometer Atmospheric Sounder (VAS) wind, temperature, and water vapor data will be available through PROFS EDF.

° The Boulder Atmospheric Observatory (BAO) Tower A meteorologically instrumented 300-meter tower located 25 km east of Boulder will make available detailed boundary layer winds, temperature, humidity and pressure measurements.

° Other Remote Sensors Cloud observations from a variety of ground-based sensors including K-band/X-band radars, lidar, and radiometers will be available.

° PROFS Exploratory Development Facility (EDF) and Experimental Workstation. The EDF assimilates satellite, radar, pilot reports (PIREPs), Profiler, mesonet and AFOS data in real time. The workstation integrates and provides automated/graphic display of the various data sets.

° Profiler Hub Data from each Profiler site will be collected at the Profiler Hub facility and made available to the PROFS EDF and workstation.

° Denver ARTCC Center Weather Service Unit (CWSU) The PROFS CWSU workstation in the FAA's Denver Air Route Traffic Control Center (ARTCC) in Longmont,

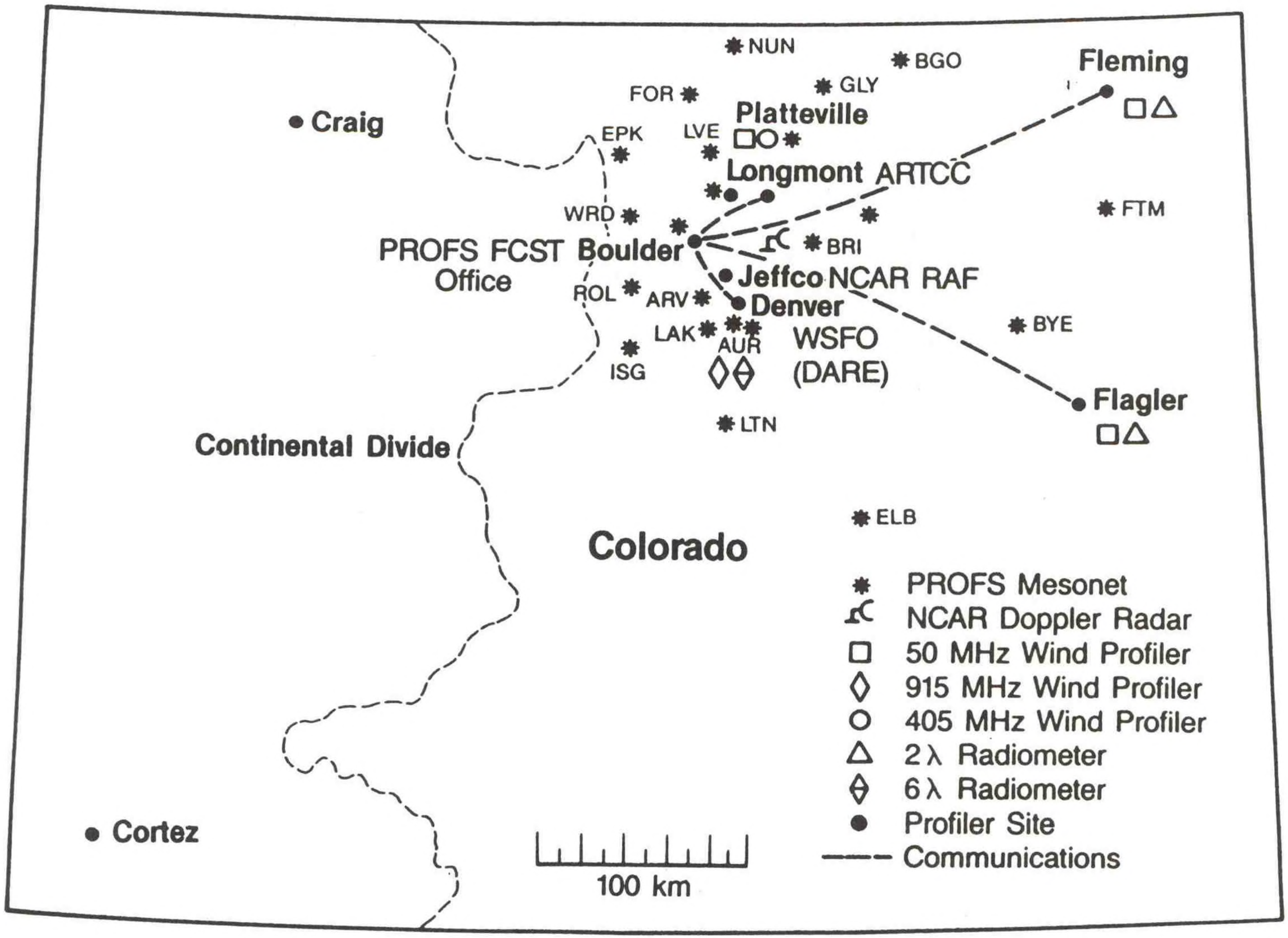

Figure 2. Aircraft Icing Program Test and Demonstration Area

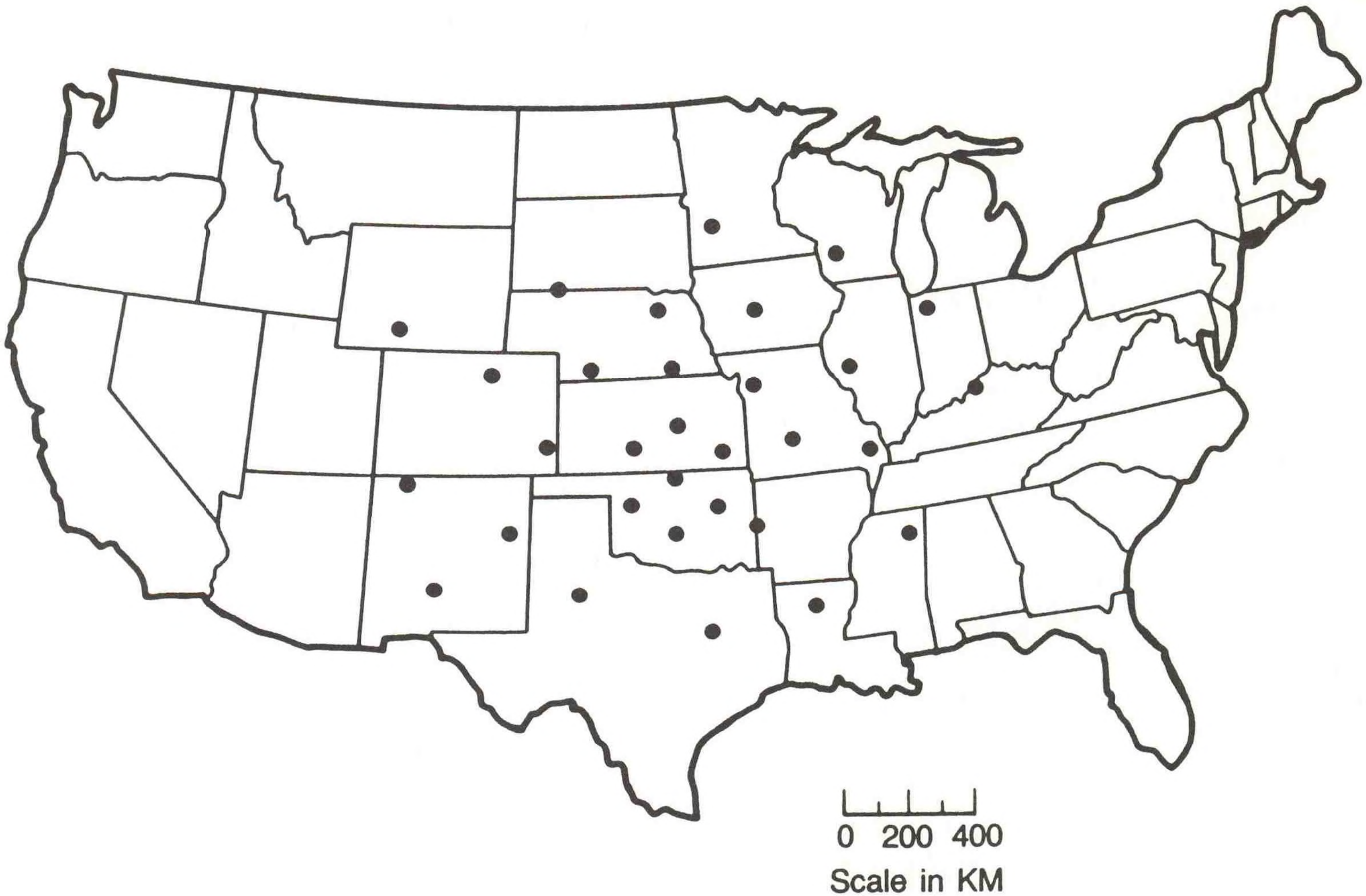

Figure 3. Aircraft Icing Program—Expanded Profiler Network Test Area

Colorado, receives both conventional and advanced data from the PROFS EDF. This facility provides an operational aviation test and evaluation capability.

° Denver WSFO/Denver AWIPS-90 Risk Reduction and Requirements Evaluation (DAR^{3}E A PROFS workstation will be implemented at the Denver Weather Service Forecast Office (WSFO) in October 1986. This workstation, with the capability to provide access to both conventional and new advanced sensor data, will become an NWS operational test and evaluation facility.

° Research Aircraft Research aircraft, such as those operated by the University of North Dakota, University of Wyoming, and NCAR, are to be used to measure wind, temperature, liquid water content, and drop size distribution. The University of North Dakota aircraft is currently supporting FAA aircraft icing studies. These aircraft are also equipped to make all the necessary measurements to determine performance degradation as a result of aircraft icing, making the data sets useful for other aspects of the National Aircraft Icing Technology Program. In-situ measurements will be used for verification of cloud properties as measured by ground remote sensors and for research purposes. Remote sensing equipment, including a lidar and a microwave radiometer (probably available), will be used to improve the spatial coverage possible from the NCAR aircraft. Details concerning aircraft specifications, instrumentation, and performance are contained in Appendix A.

3.2 PROGRAM TASKS

This program plan establishes the framework within which five tasks that lead to the program objectives will be accomplished. These tasks are described in detail in the following sections.

3.2.1 In-situ Detection of Icing Environment

At present, the only operational indication that icing conditions are present comes from PIREPs, which are inconsistent and unreliable indicators of icing severity. Aircraft are not always flown into icing areas, pilots do not always report icing encountered, and icing PIREPs are always subjectively based on the aircraft type and the pilot's experience and perception of severity. A central program goal is therefore the acquisition of an unbiased, comprehensive, quantitative description of the icing conditions in eastern Colorado. This will require the extensive use of instrumented research aircraft, in two modes: to monitor icing conditions in a wide variety of potential icing situations, and to examine serious icing episodes. Ground-based remote sensing equipment will be used to direct the aircraft to regions where icing is likely and to indicate when flights are needed. The data collected during these flights will provide the basic data set for development and verification of forecasting schemes.

The data set to be collected should be continuous or unbiased in coverage, comprehensive (in temporal and spatial coverage) so as to define the extent and duration of icing conditions, and quantitative in regard to severity and physical character of the icing and other environmental parameters. The observations from aircraft will be collected in four ways:

° Instrumented research aircraft will fly predetermined tracks during periods when there is the potential for airframe icing. Monitoring of conditions will be designed to avoid bias that might arise from preconceived ideas regarding where icing conditions should be found.

° Instrumented research aircraft equipped with remote sensing instruments will be able to detect icing environment conditions several thousand feet below the aircraft, or to detect integrated supercooled water above the aircraft flight level. These flights will be particularly effective in cases where no icing is present at flight level, since icing above and below flight level can be verified by flight at a single level; if icing conditions are found, the aircraft can return to the appropriate level for more detailed study of the icing clouds.

° Commercial carriers, under a cooperative arrangement, will report on the icing conditions encountered during regularly scheduled flights in the test area.

° Special aircraft research missions will investigate icing conditions either on the basis of a forecast or following detection of supercooled liquid water (SLW) by remote sensors or PIREPs. Later in the program, these flights will be used to test the forecasting methods developed in the program. They will also support evaluation of the profiler/radiometer observations for icing detection, and will provide the primary data set for study of the microphysical characteristics of the icing clouds, the physics of airframe icing, and the effects of airframe icing on performance.

In addition, conventional PIREPs of icing encountered will continue to be included in the data base.

3.2.2 Remote Detection and Monitoring of Icing Conditions

The development and deployment of new remote-sensing devices, such as profilers, VAS, and NEXRAD, are expected to provide great improvements in icing detection and monitoring (Cf. Smith, 1985) and provide valuable inputs for forecasting aircraft icing. These sensors not only offer measurements useful for estimating the icing potential, but also provide better temporal and spatial resolution than is presently available. The profilers (which include radiometric measurements) provide a potential means of detecting icing conditions from ground-based sensors, especially if used in combination with other remote detection devices. The radiometers detect the total amount of liquid in a column above the radiometer, without distinguishing different liquid water contents or whether the water is supercooled. A method to infer and predict icing conditions from these profilers would have to incorporate other remote-sounding parameters, e.g., radar cloud altitudes and satellite-sensed cloud tops, and incorporate other meteorological data. Development of such a method will provide a much more complete and useful data set than is obtainable from research aircraft alone.

Remote detection of icing conditions will be valuable, not only during this program, but also as an operational tool which can warn of icing without the need for an aircraft to encounter those conditions. Operational use of such techniques would be feasible in the 1990s when the new remote sensors are expected to be deployed.

Some evaluations of the ability of microwave radiometers to detect icing conditions have already been conducted (Decker et al., 1986), and show that there is high correlation between the radiometric observations of liquid water content (LWC) and pilot reports of icing. However, such studies can only be as good as the basic data set used for evaluation, and current PIREPs are inconsistent and unreliable as quantitative indicators of icing. Improvements in the methods used to detect icing conditions need to be based on a reliable set of observations such as will be gathered in Task 2.2.1 using research aircraft.

In eastern Colorado, the wind profilers aid in detecting upslope conditions, and so provide a means of detecting one weather condition conducive to icing. There should be many other applications of the wind profiler to the icing problem, since icing is closely associated with ascent and subsequent cooling of air masses, and such conditions should be detectable from the structure of the wind fields.

The data being obtained from VAS have not yet been studied in relation to the icing problem, but the wide coverage available (including ocean areas) and the fact that it can detect moisture will make it very useful in the development of good icing detection and monitoring algorithms. Since the profiler is known to be more accurate in measuring temperature and moisture near the surface, and VAS is more accurate measuring the same variables higher up, the ERL Profiler/VAS (PROVAS) project was formed to combine the best from each system. PROVAS outputs will greatly aid in using these data.

NEXRAD-type radars make it possible to detect smaller particles in the atmosphere and Doppler radar also allows us to determine movement, an advantage not only in detection but also in forecasting. Although ways of using weather radar to detect icing have not yet been explored adequately, vertical profiles of reflectivity, low-level radial convergence, areal convergence, and bright band level offer considerable promise and need to be evaluated. Experimental radars, utilizing dual polarization, have demonstrated the capability of providing hydrometeor type and drop-size information.

Mesoscale surface networks such as the PROFS network that measure temperature, moisture, winds, sky cover, precipitation, etc. will provide additional input for developing icing algorithms.

It is critical that cloud physics "truth," i.e., actual icing environment conditions--SLW drop size, temperature, ice accretion, altitude, and aircraft flight parameters measured quantitatively by research aircraft--correlate with inferences of icing potential derived fro the above-mentioned data sets. These data and inferences must in turn be systematically verified against the cloud physics "truth." The assimilation of all these measurements will then provide a three-dimensional grid of temperature, LWC, and drop size distribution. Knowing these three things, an icing value can be assigned to each grid point and an analysis performed. The forecaster will be able to view a clear, uncluttered display of areas of icing potential in both the vertical and horizontal planes.

If SLW and drop size are not available at each grid point, cloud type and amount at each grid point from satellite cloud analyses--such as the real-time nephanalyses (RT-Neph) presently in use by the U.S. Air Force--may enable the forecaster to infer icing type and intensity. The greatest difficulty is in determining cloud layers. An area which appears overcast from the satellite view and from surface observations may in fact have several clear areas in between. It is important to know about these layers both for the credibility of the icing analysis and for the safety of aircraft which may need to enter these clear areas to avoid icing.

3.2.3 Acquisition and Analysis of Meteorological and Microphysical Data

The PROFS EDF has access to conventional meteorological data, radar and satellite data, PIREPS, data from the PROFS mesoscale surface observing network, and data from the NOAA network of remote sensors in eastern Colorado listed in Section 2.1. The research aircraft data sets and these other data sets will provide the primary data base for use in this program and in subsequent studies of aircraft icing.

In addition, a high resolution "event" data base will be developed incorporating all available mesoscale data available for "displaced" real-time analysis (playing back past situations in real time on the PROFS workstation). This data base and the access to it that will be provided by the PROFS system will be most useful in research and training and provide technology transfer to operational forecasters.

In order to add to meteorological and climatic descriptions of the icing environment, the program will utilize data from ongoing and planned national and international cloud physics, mesoscale, and subsynoptic-scale research and development programs which use appropriately instrumented aircraft. Examples of programs which have acquired or are acquiring relevant data are the Bureau of Reclamation Sierra Cooperative Pilot Project (SCPP), the NOAA Federal-State Cooperative Weather Modification Programs in Utah, Nevada, Illinois, and North Dakota, and the World Meteorological Organization (WMO) Precipitation Enhancement Program (PEP) in Spain. Direct participation in experimental development and operational evaluation programs such as the Wave Propagation Laboratory (WPL) Ice Detection Project, the FAA PROFS Central Weather Processor (CWP) Display Product Project, the PROFS Denver ARTCC CWSU Program, and the PROFS Denver WSFO DAR^{3}E Program will also add to descriptions of the icing environment, and major new programs such as STORM should provide additional opportunities for experiments and observations related to icing.

These data would be made available on a continuing basis to supplement and enhance the existing FAA icing environment data base. Data from these research projects will be utilized to continue to build icing microphysics climatologies and to provide better measures and descriptors of the microphysical and dynamical aspects of clouds that cause icing conditions. The relationship of these aspects to operationally measurable and potentially forecastable mesoscale cloud and meteorological parameters will be explored.

3.2.4 Forecast Technique Development and Evaluation

Background

It is likely that in the long term there will be improvements in aircraft capabilities to fly in icing conditions, but this would have little impact on the present fleet of aircraft. In the near term, any reduction in icing-related accidents and improvement in the efficient use of the airspace when there is an icing potential most likely will occur by developing improved procedures for avoidance of icing conditions. Severe icing conditions are rare in stratiform clouds. In cumuliform clouds or clouds with embedded convection, icing conditions are rather common but represent a significant hazard to flying only when the cells occupy a critical part of the airspace. Although severe icing is a rare occurrence, when it does occur it represents a major hazard to many aircraft operators.

Existing forecast procedures typically overforecast the occurrence of icing. The overforecast often results in much longer flights or cancellation of flights by aircraft not certified for flight in known icing conditions and alerts pilots flying aircraft which are "certified for flight in known icing conditions" to the possibility of icing so that they closely monitor PIREPs for reports of actual icing and closely monitor possible ice accretion on their own aircraft. A number of recent weather modification research projects have attempted to develop reliable techniques for forecasting the time and location of super-cooled liquid water (SLW), and these efforts are closely related to the needs of the icing program. Examples of some recent weather modification projects in the mountainous West include the Colorado River Pilot Project (Marwitz et al., 1980), the Colorado State University experiment (Rauber et al., 1986), the Utah programs (Sassen et al., 1986); and the Sierra Cooperative Pilot Project (Heggli and Reynolds, 1985; Reynolds and Dennis, 1986). Other research programs including CYCLonic Extratropical Storms (CYCLES) project (Hobbs, 1978), and Genesis of Atlantic Lows Experiment (GALE) have added to our knowledge regarding the distribution of SLW in wintertime storms.

The forecasters for weather modification projects have identified SLW in various stages of a storm, in certain storm types, in preferred locations with respect to topography, and following passage of certain clouds and echo structures observed by satellite and radar. These projects have been instrumental in developing techniques for confirming the presence of SLW using ground based radiometers and instrumented research aircraft.

Outside of these research programs, pilot reports of icing have been the primary mechanism for confirming the presence of SLW in clouds. These reports are limited to times and locations of flights and are subject to considerable error and subjectivity. Microwave radiometers are a recent instrumentation development for continuously sensing the amount of liquid water along the path of the beam. All of the major domestic weather modification projects since 1980 have used radiometers to sense the presence of SLW.

Generally, SLW is produced by cooling which is most often associated with ascent of air masses, and is depleted by ice (especially in widespread systems) or by entrainment (in cumulus clouds). The balance between the source and these sinks determines the amount of SLW in the cloud, and so SLW amounts tend to increase with higher vertical velocities and decrease with higher ice concentrations or in smaller cells where mixing with the environment is rapid. These factors lead to the following common features of clouds which contain SLW:

° Generally, the cloud top temperatures are warmer than -20°C. The cloud top temperature is important because the probability of natural ice formation in the clouds rather than SLW, increases dramatically with decreasing temperature.

° Severe icing in clouds near coast lines is less likely than in equivalent clouds which are inland because of the prevalence of ice nucleii in such clouds which produce high ice concentrations that deplete the SLW. However, a recent observation (Cooper et al., 1984; Sand et al., 1984) indicates that when maritime clouds do not have sufficient nucleation, they sometimes develop extremely large supercooled drops. These drops in turn can produce a substantial increase in drag if they impact and freeze on unprotected portions of an aircraft.

° Cumuliform clouds have a higher probability of containing SLW than do stratiform clouds because they contain higher vertical velocities and condensation rates.

° The visual characteristics of both cumuliform and stratiform clouds which contain SLW are the distinctness or sharpness of their boundaries. In the case of cumuliform clouds most of the boundaries are visible, while in stratiform clouds one can only observe the top and bottom. If the top boundary of a cloud is distinct and at a temperature warmer than -20°C, and temperatures in the cloud are less than 0°C the probability is high that the cloud contains SLW. If a cloud base is distinct and sharp, there is also a good probability that SLW exists above the 0° C level in that cloud.

° The radar echo structure of clouds containing SLW is characterized by either no echo or, if large supercooled drops are present, a weak (<10 dBZ) echo. Without significant quantities of ice, there can be no bright band, so a bright band is a good indicator that icing is unlikely. In the case of vigorous convection, the region of strong updrafts and hence SLW is often bordered by a strong reflectivity gradient, which is an indicator that high icing rates are likely.

Objective and Tasks

The objective of the forecast element is to improve operational forecasts of aircraft icing intensity, type, and extent. To meet this objective, a series of interactive task efforts will be required. These are as follows:

° Develop a current operational forecast accuracy baseline. A test plan has been prepared to accomplish this task.

° Develop an understanding of the common characteristics of clouds containing SLW. This can be done by analyzing and synthesizing a number of case studies of clouds known to contain SLW and which were documented by a number of sensors such as satellite, radar, rawinsondes, radiometers, profilers, and aircraft. The initial case studies will be only crudely documented, but with time the quantity and quality of the documentation will improve. So, too, will the understanding. The existing understanding developed in weather modification projects and icing studies using radiometers (Sand et al., 1984) is the starting point for this effort.

° Develop procedures for near real-time identification or nowcasting of clouds containing SLW. In addition to developing procedures for incorporating direct measurements of SLW from PIREPs and radiometers, a procedure is needed which makes a number of other observations available to the nowcaster. The other observations may be either surrogate parameters which are indirectly associated with the presence of SLW or observations of cloud characteristics which are directly related to SLW. Display routines developed by PROFS for the FAA Central Weather Processor (CWP) are the starting point for this effort.

° Develop procedures for short range (0 to 4 hour) forecasting of clouds with SLW. Initially, the short range forecast will be made subjectively based on the understanding and skill of the individual forecaster. To produce a reliable short-range forecast will require the merging of a mesoscale model with the improved understanding described above. The mesoscale model will need to be initialized or updated with the real-time data also described above. Examples of possible mesoscale models include the NMC Nested Grid Model and the Penn State/NCAR mesoscale model. The starting point for this objective will be to test such models as the USAF Air Weather Service Smith-Feddes Model (Feddes, 1974), (Smith, 1974), the USAF Automated Icing Forecast (AUTICE), (Mansur, 1984), and PROFS' Mesoscale Analysis and Prediction System (MAPS). The development of procedures for improved longer term (0-12 hour) forecasting will be based on use of the procedures for improved short range forecasting developed herein incorporated into longer term mesoscale models.

° Participate with university, Federal, and other groups exploring expert system technology to assess possible applications in the icing forecast problem.

Test and Evaluation

As soon as the combination of increased understanding, facilities, and models results in reliable nowcasting and forecasting of aircraft icing, the procedures will be field tested by operational aviation forecasters. The initial region for these field tests will be eastern Colorado because of the presence of profilers, radiometers, and PROFS-type data assimilation systems. As the observing facilities expand and the validity of the forecasts improve, the procedures can be implemented in operational forecast facilities such as the National Aviation Weather Advisory Unit (NAWAU), WSFOs, DOD base weather stations, and FAA ARTCC CWSUs. Ongoing procedures for verifying the forecasts, upgrading the understanding, and improving the facilities and models will be implemented.

3.2.5 Studies of the Physics of Airframe Icing

The objective of these studies is to assist in improving the understanding of how characteristics of the icing clouds affect aircraft operating in that environment. It is desirable to place these efforts to improve icing forecasting into proper perspective by considering what icing conditions present particular hazards to aviation. For example, it has been demonstrated (Cooper et al., 1984) that the effects of icing on performance are not simply a result of supercooled liquid water content, but can depend on the mass present in large droplets. The National Aircraft Icing Technology Plan encompasses such studies of the hazardous effects of icing on aircraft performance.

3.3 PROGRAM MILESTONES

Figure 4 shows the key milestones for the various program elements and tasks. Analysis of the acquired data sets and improved understanding of the physical processes involved will pace all the schedules during the program.

In summary:

During Phase I (FY 1986 through FY 1988)

1. The National Aircraft Icing Project Coordination Office, established in ERL in Boulder, will plan and coordinate detailed program activities including the research aircraft flight program. Preliminary planning for the Eastern Colorado operational test program in FY 1987 has already been completed.

2. Data from all remote sensing systems--profilers, satellites, radars, etc.--will be assimilated in real time in the PROFS EDF and made available for field operational display and research data analysis on the PROFS Aircraft Icing Workstation. The research aircraft data, including remotely sensed data, will be integrated into the EDF data sets.

3. Analysis of currently available operational data sets will be completed to establish a forecast capability baseline. An initial analysis of Denver Stapleton profiler and icing PIREP data by WPL has been completed, and this type of analysis will be continued.

4. Various available icing analysis and forecast routines and algorithms--including current forecast routines, CWP products, AWS developed Smith-Feddes Forecast Model and AUTICE--will be tested to assess operational utility. Planning for additional forecast techniques evaluation--MAPS, etc.--will be initiated and potential forecast techniques will be selected for Phase II evaluation.

5. Research aircraft are required during the spring, fall, and winter periods of 1987 and 1988 to provide inflight validation and performance data and to initiate research data collection. Approximately 100 flight hours per aircraft will be required per year. Some flights have already been conducted into icing situations in North Dakota.

During Phase II (FY 1989 through FY 1990)

1. The expanded NOAA 30-station profiler network (including 10 temperature and vapor/liquid water sensing systems), operating continuously in the Central United States, and other new remote sensors (NEXRAD-type radars, VAS, etc.) will be incorporated into the data base through the PROFS EDF.

2. Increased research aircraft use will be required for research and validation purposes. At least 100 hours per aircraft per year will be required.

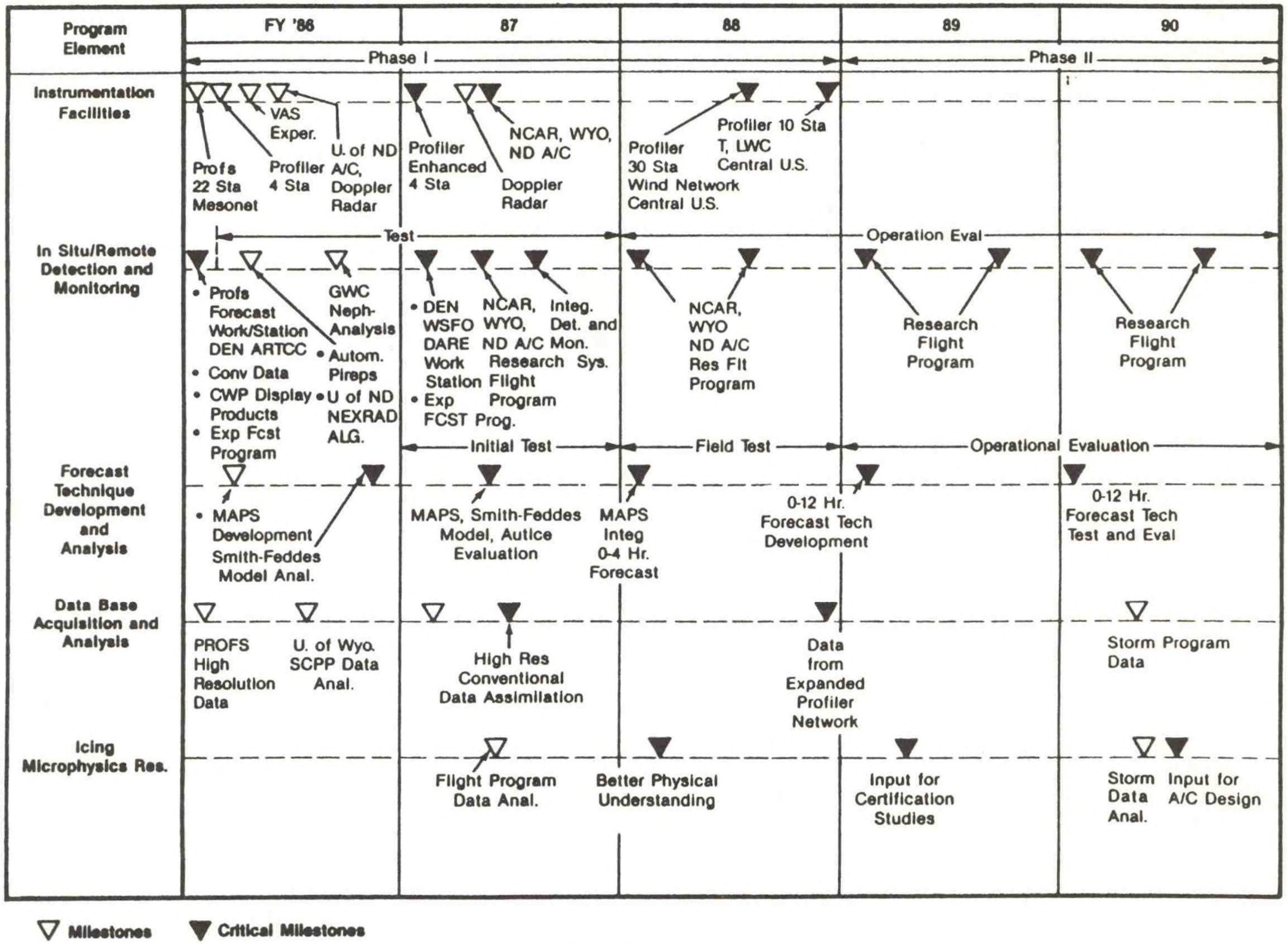

Figure 4. Program Milestones

3. Those icing analysis and forecast techniques successfully evaluated during Phase I will be tested in operational environments. Evaluation of new forecast techniques and models--MAPS, etc.--will be conducted using the expanded observation network.

4. Studies of the physics of airframe icing will involve those icing conditions presenting particular hazards and the specific forecasts required.

During Phase III

1. Forecast evaluation will be conducted in expanded operational forecast areas as new technology is implemented in these areas. Detailed evolution of evaluation activities depends on Phase II results.

2. An improved icing severity index developed by FAA will be evaluated.

Initial improvements in short-period forecasting (nowcasting) can be expected in the 1987-1989 time period. Improved longer period forecasting will occur in 1988-1991 with the expansion of the profiler network, implementation of NEXRAD and VAS, and improved techniques and algorithms.

4. RESOURCE REQUIREMENTS

In order to effectively meet the task schedule outlined in the previous sections, the specific research, development, and evaluation resources required --personnel, field operational activities, and related costs--are listed by fiscal year in Table 1 for the Fiscal Years 1986 through 1990. Estimates have not been made for activities in later years. Table 2 summarizes costs by research, development, and operational validation and verification activities. Project office resource requirements are included in these costs. Costs of operational personnel participation--forecasters, etc.--in test, validation, and verification activities, are not included. Therefore, the annual costs of this program represent the incremental cost added to the national investment in other major research, development, and operational programs that will be available to support the icing program.

Funding and manpower shown in this plan represent estimates of what is needed to perform the stated activities, and do not represent Federal commitments to perform the work or to fund at the stated levels. Regardless of the stated needs and objectives, individual agencies have to qualify and endorse their own programs to obtain funding approval. Non-Federal facilities are mentioned with the assumption that they will continue to receive Federal support.

	Costs
FY86	
• Detection/Monitoring Capability Development	50k
• Forecast Technique Analysis	25k
• Research Aircraft Operation (includes personnel costs)	1.0M
• Cloud Physics Data Analysis	25k
	1.1M
FY87	
• Detection/Monitoring Experimental Operation	250k
• Forecast Technique Development and Test	100k
• Research Aircraft Operations	1.0M
• Cloud Physics Data Analysis	50K
	1.4M
FY88	
• Detection/Monitoring/Forecasting Experimental and Test Evaluation	400k
• Research Aircraft Operations	1.1M
• Cloud Physics Research	200k
	1.7M
FY89	
• Forecast Technique Evaluation-Test Area	100k
• Research Aircraft Operations	700k
• Cloud Physics Research	200k
	1.0M
FY90	
• Forecast Technique Evaluation	200k
• Expanded Area	600k
Research Aircraft Operations	
• Cloud Physics Research	200K
	1.0M

Table 1. Program Resource Requirements for Each Program Activity

Research and Development	FY86	FY87	FY88	FY89	FY90
Detection and Monitoring	50k	100k	100k		
Forecast Technique Development	25k	100k	100k	50k	100k
Cloud Microphysics Research	25k	50k	200k	200k	200k
	100k	250k	400k	250k	300k
Validation and Verification					
Field Operations		150k	200k	50k	100k
Aircraft Operations (includes personnel)	1.0M	1.0M	1.1M	700k	600k
	1.0M	1.15	1.3M	750k	700k
TOTALS	1.1M	1.4M	1.7M	1.0M	1.0M

Table 2. Aircraft Icing Program
Resource Requirements Summary

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APPENDIX A

RESEARCH AIRCRAFT SPECIFICATIONS, PERFORMANCE, AND INSTRUMENTATION

This appendix contains specifications, performance, instrumentation, and operating cost data for three research aircraft which are capable of providing support to the Aircraft Icing, Detection, Monitoring, and Forecasting Program--The University of North Dakota Citation II, and the University of Wyoming and NCAR Beechcraft Super King Air 200's.

Aircraft Specification, Performance, and Instrumentation Data

Aircraft specifications and performance data for the University of North Dakota Citation II are contained in Table A-1, and instrumentation capabilities are contained in Table A-2.

Aircraft specification and performance data for the University of Wyoming Super King Air 200 are contained in Table A-3 and instrumentation capabilities are contained in Table A-4. NCAR Super King Air 200 specifications, performance, and instrumentation data are nearly identical to the University of Wyoming Super King Air.

TABLE A-1

UNIVERSITY OF NORTH DAKOTA

CESSNA CITATION II

AIRCRAFT SPECIFICATIONS AND PERFORMANCE

Specifications

Load factors	
Max. T.O. wt. - lbs.	13,300
Max. ramp wt. - lbs.	13,500
Max. landing wt. - lbs.	12,700
Empty wt. with equip - lbs.	8,500
Fuel capacity - gals.	5,000
Dimensions - exterior	
Wing span - ft.	47.3
Length - ft.	51.0
Height - ft.	14.5
Dimensions - cabin	
Length - excl. cockpit - ft.	16.8
Height - ft.	4.7
Width - ft.	4.9
Environmental	
Cabin pressurization - 8000 ft.	43,000
Pressure diff.	8.5

Performance

Take off distance	
Two engine - ft.	2,430
Accelerate stop - ft.	2,500
Rate of climb	
Two engine - ft/min.	3,370
Single engine - ft/min.	1,055
Service ceiling	
Two engine - ft.	43,000
Single engine - ft.	19,500
Airspeed limits	
Max. oper. spd. - kts.	370
Cruise spd. - kts.	347
Stall speed - kts	83
Range - miles	1,750

TABLE A-2

UNIVERSITY OF NORTH DAKOTA

CITATION II

RESEARCH INSTRUMENTATION

Measurement	Instrument	Manufacturer	Response	Accuracy	Resolution
Temperature	Platinum Resistance	Rosemount Model 102 Probe	1 sec Nominal	±0.5°C	0.03°C
Reverse Flow Temperature	Platinum Resistance	Minco element Rosemount 510BF	1 sec nominal	±0.5°C	0.03°C
Dew Point	Cooled Mirror	EG&G Model 137	2°C/sec max heating or cooling	±0.5°C 0° to 70°C ±0.6°C -30° to 0°C ±1.1°C -50° to -30°C	0.03°C
Static Pressure	Absolute Pressure	Rosemount 1201F1	15 msec	300 nt/m^2	2.5 nt/m^2
Altitude	INS and Static Pressure	Litton LTN-76 858AJ	---	Uncertain due to lack of standard	2m
Attach Angle and Sideslip	Differential Pressure	Rosemount 1221F1,858AJ	10 msec	±1.3 nt/m^2	1.7 nt/m^2
Indicated Airspeed	Differential Pressure	Rosemount 1221F	0.3 msec	55 nt/m^2	2.1 nt/m^2
Heading	Inertial Nav System (with dual speed resolvers)	Litton LTN-76	42 msec update	±12 arc min	6 arc min
Pitch, Roll	INS	Litton LTN-76	42 msec	±2 arc min	0.25 arc min
Vertical Acceleration	INS	Litton LTN-76	42 msec	0.1 m/s^2	.05 m/s

TABLE A-2 (continued)

Measurement	Instrument	Manufacturer	Response	Accuracy	Resolution
Ground Speed	INS	Litton LTN-76	42 msec update	±0.5 m/s	.05 m/s
Position	INS and VOR DME	Litton LTN-76 2 Collins VIR30A and DME 40	42 msec update 1 sec 0 to 554 km	1.8 km per hour of Nav time (without update) ±2 deg (VOR) ±0.4 km (DME)	18 m 1 deg 0.2 km
Cloud Photographs	16 mm cameras	L-W International (Automax)	---	---	---
Liquid Water Content	Johnson-Williams Liquid Water Detector	Cloud Technology Inc.	1 sec	20%	0.05 g/m^3
Cloud Droplet Spectrum	Forward Scattering Spectrometer Probe	Particle Measurement Systems	0.1 sec (counting interval)	±1 count	1 count
Ice crystals and water drops	Optical Array Probe 2D-C	Particle Measurement Systems	0.1 sec (counting interval)	±1 count	1 count
Large Particles	Optical Array Probe 200Y	Particle Measurement Systems	0.1 sec (counting interval)	±1 count	1 count
Icing Rate	Vibrating Cylinder	Rosemount Model 671FA	7 sec	±.013 cm	0.003 cm
Time	Quartz Crystal	Perkin-Elmer	---	±1 sec/day	0.001 sec
Engine Fan Speed	Tach Generator	TRW GEU-7/A	1 sec	±1.0%	0.025%

TABLE A-3

UNIVERSITY OF WYOMING

BEECHCRAFT SUPER KING AIR MODEL 200T

AIRCRAFT SPECIFICATIONS AND PERFORMANCE

Specifications		Performance	
Load factors		Take off distance	
Max. T.O. wt. - lbs.	14,000	Two engine - ft.	3,345
Max. ramp wt. - lbs.	14,000	Accelerate stop - ft.	3,364
Max. landing wt. - lbs.	13,500		
Empty wt. with equip - lbs.	8,882	Rate of climb	
Fuel capacity - gals.	3,645	Two engine - ft/min.	2,450
		Single engine - ft/min.	810
Dimensions - exterior			
Wing span - ft.	55.5	Service ceiling	
Length - ft.	43.7	Two engine - ft.	32,800
Height - ft.	15.0	Single engine - ft.	810
Dimensions - cabin		Airspeed limits	
Length - excl. cockpit - ft.	16.7	Max. oper. spd. - kts.	245
Height - ft.	4.9	Cruise spd. - kts.	215
Width - ft.	4.5	Stall speed - kts	77
Environmental		Range - miles	1,400
Cabin pressurization - 8000 ft.	27,360		
Pressure diff.	6.0		

TABLE A-4

UNIVERSITY OF WYOMING

BEECHCRAFT SUPER KING AIR MODEL 200T

RESEARCH INSTRUMENTATION

Measurement	Instrument	Manufacturer	Response	Accuracy	Resolution
Temperature #1	Platinum resistance	Rosemount	<1 s	±0.5°C	<0.1°C
Temperature #2 (reverse flow)	Platinum	NCAR design Minco element	<0.5s	±0.5°C	<0.1°C
Dew point	Cooled mirror	Cambridge Model 137C3	3°C/s (slew rate)	±0.5°C(>0°C)	0.3°C
Heading	Magnetic INS	King KP1 553 Litton LTN-51	1 s	±1 deg	0.1 deg
Altitude	Pressure	Rosemount 1201FA1B1A	15 ms	±4 mb	0.3 mb
Altitude	Radar altimeter	Stewart-Warner APN 159	152 m/s (slew rate)	2.4 or 1%	0.07 m
IAS	Differential pressure	Rosemount 831 CPX	25 ms	±1 mb	0.1 mb
Rate of climb	Differential altitude INS	Rosemount 1241-A-4BCDE Litton LTN-51	50 ms	1% to 4.5 km 2% to 8 km	0.25 m/s
Position	VOR DME INS	King KNR 615 King KDM 705A Litton LTN51	1 s 1 s	1.5 deg 0.4 km	 0.2 km

TABLE A-4 (continued)

Measurement	Instrument	Manufacturer	Response	Accuracy	Resolution
Vertical acceleration	Stabilized accelerometer	Humphrey 10 s SA-09-0502-1	10 s	0.002 g	
	INS	Litton LTN-51			
Pitch, roll	Stabilized accelerometer	Humphrey SA-09-0502-1	10 s	0.2 deg	
Ground speed	Doppler radar	Singer	1 s	0.17% $\pm$.2 m/s	0.5 knot
	INS	Litton LTN-51			
Drift angle	Doppler radar	Singer	2 s	0.2 deg	0.2 deg
	INS	Litton LTN-51			
Yaw, attack angles	Differential pressure	Rosemount 858AJ28	0.1 s	0.2 deg	<0.1 deg
Turbulence	Pressure	M.R.I.	3 s	10%	1%
Liquid water content	Hot wire (JW)	Bacharack Instruments Model LWH	<1 s	0.2 g/m^3	0.1 g/m^3
	FSSP	PMS			
Liquid water content	CSIRO hot-wire	University of Wyoming	-10 ms	0.1 g/m^3	0.05 g/m^3
Liquid water content	Icing probe	Rosemount	<5 s		
Droplet size	FSSP	PMS	0.1 s	2 m	2 m
Hydrometeor size and shape	IDC	PMS	0.1 s	12.5 m	12.5 m
	2 DC	PMS	s	25 m	
	2 DP	PMS	s	200 m	

APPENDIX B

ABBREVIATIONS AND ACRONYMS

AFGWC - Air Force Global Weather Central
AFOS - Automation of Field Observations and Services
ARTCC - Air Route Traffic Control Center
AUTICE - Automated Aircraft Icing Forecast Technique
AWIPS-90 - Advanced Weather Interactive Processing System of 1990's
AWS - Air Weather Service
CWP - Central Weather Processor
CWSU - Center Weather Service Unit
CYCLES - CYCLonic Extratropical Storm project
DAR^{3}E - Denver AWIPS Risk Reduction and Requirements Evaluation
DOD - Department of Defense
EDF- Exploratory Development Facility
ERL - Environmental Research Laboratories
FAA - Federal Aviation Administration
FY - Fiscal Year
GALE - Genesis of Atlantic Lows Experiment
GOES - Geostationary Operational Environmental Satellite
IFR - Instrument Flight Rules
IMC - Instrument Meteorological Conditions
IR - Infrared
LWC - Liquid Water Content
MAPS - Mesoscale Analysis and Prediction System
MDR - Manually Digitized Radar
MIST - Microburst and Severe thunderstorm Experiment
NAWAU - National Aviation Weather Advisory Unit
NCAR - National Center for Atmospheric Research
NEXRAD - Next Generation Weather Radar
NGM - Nested Grid Model
NMC - National Meteorological Center
NOAA - National Oceanic and Atmospheric Administration
NSF - National Science Foundation
NTSB - National Transportation Safety Board
OFCM - Office of Federal Coordinator for Meteorological Services and Supporting Research
PEP - Precipitation Enhancement Program
PIREPs - Pilot Reports
PROFS - Program for Regional Observing and Forecasting Services
PROVAS - Profiler/VAS Program
SAO - Surface Aviation Observations
SCPP - Sierra Cooperative Pilot Project
SLW - Supercooled Liquid Water
STORM - Stormscale Operational and Research Methodology
USA - United States Army
USAF - United States Air Force
VAS - VISSR Atmospheric Sounder
VISSR - Visible and Infrared Spin-Scan Radiometer
VFR - Visual Flight Rules
WPL - Wave Propogation Laboratory
WSFO - Weather Service Forecast Office
WSO - Weather Service Office
WSR - Weather Service Radar

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