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# **Prospects for the Acquisition of Icing Data From Operational Aircraft**

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Final Report

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16. Abstract Task 13I of the FAA In-Flight Aircraft Icing Plan addresses the possibility of acquiring icing data from operational aircraft. The FAA Working Group 13I investigated two possible approaches for this task.  The "icing sensor/downlink approach," which would downlink icing data from existing or enhanced icing sensors on operational aircraft, would benefit from similar successful efforts in downlinking and utilizing other kinds of meteorological data (temperature, winds) from commercial carriers. More recent programs are working toward the downlinking of humidity and in situ turbulence measurements. The downlinked icing data would have multiple uses. It potentially could be uplinked in near real time to other aircraft, enhancing safety by providing frequent and objective icing information as well as accurate location of the icing conditions to pilots of other aircraft. The data could be ingested into operational numerical weather forecast models, ingested into icing diagnosis and forecasting algorithms, and archived for improved, objective assessment of forecast tools and for characterization of the atmospheric icing environment.  The "compact integrated icing instrumentation package approach" would entail the installation of a processor and size-reduced liquid water content (LWC) and droplet sizing probes on at least one operational aircraft. The compact integrated icing instrumentation package approach seems more likely to be tried first with a government operational aircraft, either in the U.S. or Canada whose mission requires frequent operation in icing conditions. If instrumented with a compact integrated version of instrumentation currently carried by icing research aircraft, such an aircraft could provide a valuable and voluminous data set for forecast assessment and atmospheric characterization.					
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## EXECUTIVE SUMMARY

The FAA In-Flight Aircraft Icing Plan addresses the possibility of acquiring icing data from operational aircraft. This report discusses two different approaches. One approach, the “icing sensor/downlink approach,” would downlink icing data from existing or enhanced icing sensors on operational aircraft. A second approach, the “compact integrated icing instrumentation package approach,” would entail the installation of a processor and size-reduced liquid water content (LWC) and droplet sizing probes on at least one operational aircraft.

Both approaches have the potential to provide valuable data. The pursuit of the icing sensor/downlink approach would benefit from similar successful efforts in downlinking and utilizing other kinds of meteorological data from commercial carriers. The compact integrated icing instrumentation package approach seems more likely to be tried first with a government operational aircraft, either in the U.S. or Canada.

Commercial airlines have downlinked temperature and wind data for nearly two decades, and this information is routinely ingested into numerical weather forecasting models run by the National Weather Service. More recent programs are working toward the downlinking of humidity and in-situ turbulence measurements. Thus there is ample precedent for the downlinking of icing sensor data, and a program aimed at this goal will greatly benefit from the methods that have been developed and the lessons learned from the earlier efforts. Commercial carriers have demonstrated their willingness to join as partners in these programs, so long as the programs are carefully structured not to have any adverse impact on their operations. The downlinked icing data would have multiple uses. It potentially could be uplinked in near real time to other aircraft, enhancing safety by providing frequent, objective, and precisely-located information about icing conditions to pilots of other aircraft. The data could be ingested into operational numerical weather forecast models, ingested into icing diagnosis and forecasting algorithms, and archived for improved, objective assessment of forecast tools and for characterization of the atmospheric icing environment.

The mission of some government aircraft, both in the U.S. and Canada, requires them to frequently operate in icing conditions. If instrumented with a compact integrated version of instrumentation currently carried by icing research aircraft, such an aircraft could provide a valuable and voluminous data set for forecast assessment and atmospheric characterization.

## INTRODUCTION

The FAA In-Flight Aircraft Icing Plan [1] includes a task (13I) to determine whether the FAA should pursue programs to acquire icing data from operational aircraft. This effort would require the FAA to solicit the cooperation of aircraft operators. The plan notes that a variety of simple to complex measurement devices are available for installation on aircraft to provide measurements that would be available in real-time and/or recorded for later use. Appropriate aircraft, instruments, data collection, data format, and applications would need to be assessed. Some instruments, such as ice detection equipment used for pilot warning/deicing equipment activation, already exist and are installed on many operational aircraft. Data recorders, including written or voice pilot notes, digital recording, or ground telemetry, may be needed for documentation.

A working group formed to consider this task includes representation from the FAA Aviation Weather Research Program, the FAA Certification Service, FAA Flight Standards, the FAA Technical Center, the National Center for Atmospheric Research (NCAR), the NASA Glenn Research Center, and the Atmospheric Environment Service of Canada. This report represents the result of the investigations conducted thus far.

## ICING SENSOR/DOWNLINK APPROACH

This approach would utilize existing or enhanced icing sensors on operational aircraft. Data would be transferred from the sensor to a data stream downlinked to ground stations. The data would then be available for a variety of uses, including uplink to other aircraft, ingestion by numerical weather forecasting models and icing diagnosis and forecasting algorithms, and archiving for later use in assessment of icing forecasts and characterization of atmospheric icing conditions.

## TYPE OF DATA.

BINARY ICE DETECTION SIGNAL. Many commercial carriers currently carry ice detectors that indicate whether ice is accreting on the aircraft. These carriers also regularly downlink information to the ground. A binary ice detection signal (yes/no) could be downlinked from such aircraft provided the signal is transferred to the downlinked data stream. This may require the addition of a wire connection between the ice detector and the Digital Flight Data Acquisition Unit (DFDAU) in some cases. Total temperature would need to be available in the data stream in order to correctly interpret the yes/no signal. For example, a jet with a speed of 200 meters per second (m/s) true airspeed has a total temperature rise of 15-20°C and thus would have an unpredictable ice detector response for clouds warmer than -15°C.

LIQUID WATER CONTENT (LWC) ESTIMATE. It may be possible to modify the design of some ice detectors currently in use so as to estimate LWC. Specifically, a microprocessor could run an algorithm inputting icing rate, velocity, and temperature and outputting an estimate of LWC. It has been estimated that such an estimate could be accurate to within 30%.

SUPERCOOLED LARGE DROPLET (SLD) DETECTION SIGNAL. Research is underway to develop a sensor which would provide a signal indicating when an aircraft had entered SLD conditions, which are generally defined to be outside the icing certification envelope. If available, such a device could find wide use by operational aircraft. Note that the Ice Protection Harmonization Working Group (IPHWG) of the Aviation Rulemaking Advisory Committee (ARAC) is currently tasked to consider the need for a regulation that requires installation of a means to discriminate between conditions within and outside the certification envelope.

#### UTILIZATION OF DATA.

ELECTRONIC PILOT REPORTS. The data could be uplinked in near real time to other aircraft, providing an objective indication of the presence of icing conditions in a given location. As noted above, in the future it may be possible to provide an objective estimate of LWC and indication of SLD conditions. Currently computer maps are available displaying pilot reports (PIREPs); electronic PIREPs could be displayed in the same way. These electronic PIREPs also could be used by meteorologists at the Aviation Weather Center (AWC) of the National Weather Service (NWS) for creating weather advisories such as airman's meteorological information (AIRMET) and significant meteorological information (SIGMET), and by airline meteorology offices for formulating their in-house icing forecasts.

IMPROVEMENT OF WEATHER SERVICE NUMERICAL WEATHER FORECASTS MODELS. Winds and temperatures are currently downlinked by commercial aircraft and ingested by the Rapid Update Cycle (RUC) numerical weather forecast model and other models run by the National Centers for Environmental Prediction (NCEP) of the NWS. Since it is anticipated that the icing data would be downlinked in the same way, it too could be ingested by such models.

IMPROVEMENT OF ICING ALGORITHMS FOR DIAGNOSES AND FORECASTS. The National Center for Atmospheric Research (NCAR) has developed the Integrated Icing Diagnosis Algorithm (IIDA) which utilizes information from a variety of sources to diagnose icing conditions. The Integrated Icing Forecast Algorithm (IIFA) is in an advanced state of development. Both of these algorithms utilize input from multiple sources, including numerical forecast models and satellites. They are designed to be able to readily incorporate data from other sources as it becomes available, and they could utilize icing data downlinked from operational aircraft.

The potential benefit in this area is illustrated by recent development of the Integrated Turbulence Forecasting Algorithm (ITFA) at NCAR. Vertical acceleration (g) is currently downlinked by some commercial aircraft and ingested into the IFTA, enabling the algorithm to provide a good indication of where turbulence does not exist. A new algorithm will make possible the down linking of eddy dissipation rate (edr) instead of acceleration in gravitational units (g) on some aircraft. [2]

IMPROVEMENT OF ASSESSMENT/EVALUATION OF PERFORMANCE OF DIAGNOSTIC AND FORECAST TOOLS. Currently there is rather heavy reliance on PIREPs for this purpose. However, PIREPs are affected by pilot interpretation, experience, attention

span and, of course, whether or not the reports ever get into the system. Moreover, they are haphazard and thus not systematic in either time or space. Uncertainties associated with PIREPs, as well as their limited spatial coverage, lead to less-than-optimal verification capabilities, including the inability to compute some standard verification measures. Downlinked icing data could provide regular and objective measurements of icing that would allow computation of a complete set of verification statistics that would lead to more reliable results from verification analyses and consequently to improvements in forecasting algorithms.

The potential benefit in this area is also illustrated by experience in the assessment and verification of forecasting of clear-air turbulence. These data provide a much broader view of turbulence conditions than can be obtained from PIREPs; and they represent a much better data set because they are objective and thus do not suffer from the biases and subjectivity of PIREPs. The vertical acceleration data currently are used by the Forecast Systems Laboratory (FSL) in near real time in their Real-Time Verification System (RTVS) as well as in post-analysis verification studies at Research Applications Program (RAP) of NCAR. [2]

ATMOSPHERIC CHARACTERIZATION AND CLIMATOLOGY. Atmospheric characterization by the National Advisory Committee for Aeronautics (NACA) provided the data for the icing envelopes in Appendix C to Part 25 of the Federal Aviation Regulations (FAR). Task 9 of the FAA In-Flight Aircraft Icing Plan calls for consideration of a comprehensive redefinition of certification envelopes for the global atmospheric icing environment.

Nearly all data collected for atmospheric characterization, both by NACA in the 1940s and 1950s and by many organizations in recent years, have been from icing research aircraft. Although absolutely essential to atmospheric characterization, this data has certain inherent limitations. First, it is biased in that icing research flights are usually conducted so as to find particular kinds of icing conditions, usually heavy icing conditions or conditions of special interest, such as SLD. Although such bias is generally recognized, there is no accepted way to take it into account in analysis and interpretation of the data. Additionally, the data can provide little information on the frequency with which commercial or other aircraft will encounter icing conditions in the course of normal operations. It can only be used to make inferences as to the nature of the icing conditions once they are encountered. For example, how likely is it that the liquid water content (LWC) will exceed some threshold? (Note that such inferences require the assumption that icing encounters by operational aircraft will be similar in nature to those of icing research aircraft.)

Archived data that had been downlinked from icing sensors on operational aircraft would be valuable in complementing icing data from research aircraft in characterizing the atmospheric icing environment. First, the downlinked data would be representative of actual conditions experienced by operational aircraft in the normal course of operations. Second, the data would provide objective information that is now lacking regarding the frequency with which operational aircraft encounter icing conditions. Although even a downlinked indicator of ice/no ice would be valuable for characterization purposes, the value would be greatly enhanced if an estimated LWC and/or an SLD indicator were also available. Third, broad participation by commercial carriers would provide aircraft icing data from geographic areas where little or none

are currently available which would lead to improvement of icing climatologies for North America.

### PARTICIPATION OF OPERATIONAL AIRCRAFT.

All commercial carriers currently downlink a large number of variables, including some meteorological variables. (See appendix A.) If icing variables can be added to the data stream without additional costs to the airlines, it can be anticipated that they will participate.

NCAR participates in working groups concerned with the downlinking of icing data from commercial carriers. Participating airlines have reacted positively to the idea of downlinking icing data. However, it is clear that they would want to keep any additional communications costs absolutely minimal and any hardware or software changes to their aircraft minimal as well.

Once an airline is identified to participate in a demonstration project, the first question will concern what has to be done on their airplanes in order to pick up the ice detection signal and transfer it to the downlinked datastream. It may require no more than running a wire from the detector to the digital flight data acquisition unit (DFDAU). The actual requirement will depend on the aircraft used in the demonstration project.

### ICING INSTRUMENTATION PACKAGE APPROACH

This approach would entail the installation a package of size-reduced icing instruments on an operational aircraft. Included in the package would be a microprocessor, an LWC probe, one or perhaps two droplet sizing probes (the second for SLD), and perhaps an ice detector. These probes would all be similar to instruments currently used by research aircraft but would be considerably smaller and packaged together. The probes would need to be miniaturized because standard icing probes, especially droplet-sizing probes, would be rather large to install on operational aircraft. The reason for attempting to combine the instruments in a single package is to minimize the installation requirements on the operational aircraft.

### TYPE OF DATA.

Data would be recorded much as it is on current research aircraft. Included would be droplet spectra, images of larger cloud particles, LWC measurements, and an ice/no ice signal. At regular intervals, the data would be sent to a research organization or contractor for processing. A procedure would need to be in place for maintenance of the instrumentation. (Icing instrumentation, especially droplet-sizing probes, requires regular check-out and not infrequent maintenance and adjustment.)

This approach of course requires the availability of a miniaturized icing instrumentation package. Research and development is underway in this area in the private sector. However, information is not readily available on how advanced such efforts are or on when they are likely to provide an operational product. It is not clear whether government investment in this area is needed or desirable.

## UTILIZATION OF DATA.

The near real time uses listed for the icing sensor/downlink approach are not applicable here. However, the data would be useful for processing of archived data. Data would be available from fewer aircraft than with the other approach, but the data from a participating aircraft would be much richer. Each flight in which the operational aircraft encountered icing conditions would provide much the same data as a research flight. Depending on which data fields were recorded, there would be the possibility of relating performance and handling characteristics directly to environmental icing conditions.

IMPROVE ASSESSMENT/EVALUATION OF PERFORMANCE OF DIAGNOSTIC AND FORECAST TOOLS. The reliance on and limitations of PIREPs for assessment/evaluation of diagnostic and forecast tools was discussed earlier. A single aircraft operating regularly in icing conditions and recording LWC and droplet spectra would provide a kind of data available only in very limited quantity from research aircraft today. Such data would permit careful algorithm assessment for a given geographic region, and the results would be applicable to other regions with similar climatic characteristics. It would be possible to evaluate the performance of algorithms in the diagnosis and forecasting of both LWC and droplet size.

ATMOSPHERIC CHARACTERIZATION AND CLIMATOLOGY. It was noted earlier that data from icing research aircraft has certain inherent limitations. One limitation is a bias relating to the way that research flights are planned and conducted. Another limitation is the little information the data can provide on the frequency of icing encounters of operational aircraft. An operational aircraft with an icing instrumentation package would not have the same limitations. It should be noted, however, that since at least initially only one or a few operational aircraft are likely to carry such an instrumentation package, the data would be applicable only to the regions and routes flown by the participating aircraft.

If aircraft participating in the project frequently encountered icing, the resulting data could significantly augment the less than 100 thousand miles of flight in icing conditions collected since World War II by research aircraft.

## PARTICIPATION OF OPERATIONAL AIRCRAFT.

There has been little investigation of the prospects for operational aircraft involvement in such an effort. Some of the ideas that have been discussed are listed below. It would be desirable to secure the participation of aircraft that are operated in a specified single location so that the data and equipment can be serviced by specialists in icing research who are already located in the area.

COMMERCIAL OPERATORS. Because of past experience in icing, some commercial operators may be interested in equipping one or more of their fleet (particularly aircraft operating on a route characterized by frequent encounters with icing conditions) with an icing instrumentation package.

GOVERNMENT OPERATORS. Various government agencies operate aircraft fairly often in icing conditions. One of these agencies might be willing to cooperate in such a project. One possible advantage of working with a government aircraft is that certification or qualification might be less of a hurdle than with a commercial operator.

In Canada, one possibility might be the Canadian Fisheries Patrol in St. John's, Newfoundland. This agency operates three King Air aircraft that routinely encounter icing conditions in the winter. An attractive feature of this possibility is that the Canadian Atlantic Storms Project and the Canadian Freezing Drizzle Experiment both conducted research flights in this area. This coincidence would enable comparison of the data from the operational aircraft to extremely rich and well documented research data sets.

Another possibility in Canada would be the Canadian National Defense aircraft operating off the east coast of Canada that routinely fly in all-weather conditions for Search and Rescue and submarine detection exercises.

In the U.S., aircraft operated by the Coast Guard or the Department of Defense have been suggested.

## CONCLUSIONS

Pursuant to Task 13I in the FAA In-Flight Aircraft Icing Plan, a working group has explored prospects for the acquisition of icing data from operational aircraft. Two approaches have been addressed, and both are viewed as potentially very valuable. Each approach has its own distinct set of positive attributes.

The icing sensor/downlink approach would downlink icing data from existing or enhanced icing sensors on operational aircraft. It would follow procedures and work through organizations already established for the downlinking of other kinds of meteorological data. The data acquired would be valuable both in near real time ("electronic PIREPS," ingestion of data by numerical weather models and icing algorithms, and formulation of operational icing forecasts) and for processing of archived data (forecast assessment, atmospheric characterization). Success requires the cooperation of airlines and the availability of sufficient funding. Efforts are underway to acquire the cooperation of an airline in a demonstration project. Initial funding is available and efforts have begun to assess longer-terms costs.

The compact integrated icing instrumentation package approach would entail the installation of a processor and miniaturized LWC and droplet sizing probes on operational aircraft. The data would be available for processing after each flight and would be valuable for forecast assessment, atmospheric characterization, and other uses. As a minimum, success requires availability of a reliable instrumentation package, cooperation of at least one operational aircraft which frequently encounters icing conditions, and sufficient expert support to maintain the equipment and process the data.

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## APPENDIX A—ACARS AND MDCRS

Reference 3 notes that the “resurgence of the use of commercial aircraft for weather information began with the availability of a real-time digital communications system, which was developed by Aeronautical Radio, Inc. (ARINC) for the aviation industry. This line-of-sight VHF telecommunication system is called Aircraft Communications Addressing and Recording System (ACARS).” Winds and temperatures were added to ACARS in the late 1970s, and the use of ACARS for winds and temperatures has continued to grow. The number of reports received daily now exceeds 20,000, and partly as a consequence “the United States now has the only operational 3-hour analysis/forecast cycle.” Most U.S. carriers now downlink data via ACARS.

In recent efforts there have been new programs to acquire and downlink meteorological data. Two very promising efforts are the Water Vapor Sensing System (WVSS) Program [3, 4] and the Clear Air Turbulence Program.[2]

The Meteorological Data Commercial Reporting System (MDCRS) is a subset of ACARS which consists of meteorological variables. The MDCRS Working Group is an informal advisory group which meets semiannually to assess progress in implementing MDCRS nationally and internationally and to deal with issues like reporting frequency, data link formats, and cost reimbursement. Membership includes the National Oceanic and Atmospheric Administration (NOAA), NWS, AWC, FAA, NCAR, ARINC MDCRS program manager, and participating airlines. The participating airlines include American, NWA, United, FedEx, Delta, and UPS. Participating airlines have given enthusiastic support to MDCRS, although they strive to keep additional communication costs minimal and to avoid, if at all possible, either certified hardware or software changes to their aircraft.

The costs associated with MDCRS integration of icing data would depend heavily on the bit size of any metric sent and whether it could be fit in a current ARINC block size rather than requiring use of a new block. It appears that the ice/no ice signal would not require use of a new block but an LWC estimate probably would.

The ACARS contract involves the FAA Aviation Weather Division, NOAA, and ARINC. It is a fixed-price contract, no matter what the volume of reports, so long as formats are not changed and airlines not added. Changes that can be accommodated by the current meteorological report format should result in little or no cost for the airlines currently under contract (including United, American, and Delta). A change in the software to enable the processor to pull out some data not in the current format would result in a one-time reprogramming cost for each airline avionics package

ACARS meteorological data is available through the Web site <http://acweb.fsl.noaa.gov/> maintained by the NOAA Forecast Systems Laboratory (FSL). Examples can be viewed in ACARS maps. NCAR currently acquires ACARS data (T, RH, g, and edr) from FSL.