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Development of Icing Condition Remote Sensing Systems and their Implications for Future Flight Operations

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ABSTRACT

NASA and the FAA are funding the development of ground-based remote sensing systems specifically designed to detect and quantify the icing environment aloft. The goal of the NASA activity is to develop a relatively low cost stand-alone system that can provide practical icing information to the flight community. The goal of the FAA activity is to develop more advanced systems that can identify supercooled large drop (SLD) as well as general icing conditions and be integrated into the existing weather information infrastructure. Both activities utilize combinations of sensing technologies including radar, radiometry, and lidar, along with Internet-available external information such as numerical weather model output where it is found to be useful. In all cases the measured data of environment parameters will need to be converted into a measure of icing hazard before it will be of value to the flying community. Before the technologies currently being developed are made widely available to users, the R&D to operations transition will be controlled by a weather product or hardware technology transfer process. This process assures that the final weather data products are accurate, timely, and robust enough to warrant their use by the aviation community. Once available, these new sources of icing information will have impacts on aviation operations. On the positive side, the overall safety and efficiency of the aviation system will be improved with automated 24/7/365 icing information. With icing data always available, flight crews, dispatchers, and traffic controllers can make better-informed strategic and tactical decisions. Always-available icing state data will benefit weather forecast models with improved initiation and verification data. On the downside, the definition of "known icing" will need to be addressed to handle the presence of knowledge of the icing environment without direct aircraft encounters. Also, the ever-expanding catalog of weather information will be increased with yet another parameter that must be ingested, processed, disseminated, and understood. All users -- from forecasters to flight crews -- will need to be trained to properly understand and use this new form of weather product.

INTRODUCTION

The US Government Inflight Icing Remote Sensing activity started with the findings of the 1997 White House Commission on Aviation Safety and Security, which directed the FAA and NASA to significantly increase the level of safety for aircraft, including all-weather operations. NASA then initiated the Aviation Safety Investment Strategy Team (ASIST), which prioritized aviation safety activities required to meet the White House goals. The ASIST Weather team identified Inflight Icing as one of its top three priorities to improve flight safety. Simultaneous to this activity, the NASA Advanced General Aviation Transport Experiment (AGATE) was defining technologies required to enhance General Aviation (GA) aircraft safety and operation. Within AGATE, the Ice Protection Systems Workpackage was defining the *Avoid and Exit* strategy as the key to improving flight safety in the icing environment. Key to success of the *Avoid and Exit* strategy was the ability to remotely measure the icing environment.

In 1997, NASA Glenn Research Center (then Lewis Research Center), the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), and the FAA sponsored the Inflight Remote Sensing Icing Avoidance Workshop. The outcome of this workshop was the formulation of the NASA Icing Remote Sensing activity.

The primary thrust of the NASA Icing Remote Sensing activity is to develop the required sensing technologies and test them in the real-world aviation environment. The technologies considered for the NASA activity were examined by Ryerson (2000) and Reehorst (2001).

The NASA development activity was designed with several assumptions in mind:

1. The information generated by an icing remote sensing system will be used not only by flight crews, but by the entire aviation community, including also air traffic controllers, airline dispatchers, and aviation weather forecasters.
2. The development of ground-based systems will likely be less costly and technically more achievable than for airborne systems due to relaxed size, power, and weight restrictions. Therefore, ground-based system development should occur before airborne system development.
3. It is likely that no one technology will be able to satisfy the requirements of the remote measurement of icing conditions.
4. To complement the FAA program, the NASA remote sensing activity should target low-cost, stand-alone instrumentation that can protect airport terminal areas that would not benefit from the more integrated FAA-planned systems.

To assist in the assessment of the candidate technologies, reviews of the various technologies were presented at the 2000 In-Flight Icing Remote Sensing Workshop hosted at the Ohio Aerospace Institute by NASA GRC in November, 2000.

DESCRIPTION OF RESEARCH REMOTE SENSING SYSTEMS

For several years, NOAA's Environmental Technology Laboratory (ETL) has worked with the FAA to develop radar- and radiometer-based icing diagnostic techniques. Having demonstrated that a dual-polarized K_a-band radar can detect SLD, ETL has begun to design and implement an operational prototype demonstration system, the Ground-based Remote Icing Detection System (GRIDS, see NOAA, 2001). GRIDS integrates a K_a-band dual-polarized radar, a microwave radiometer, local surface meteorological measurements, and information from a numerical weather forecast model (the U.S. National Center for Environmental Prediction's Rapid Update Cycle Model, or RUC) ingested via the Internet.

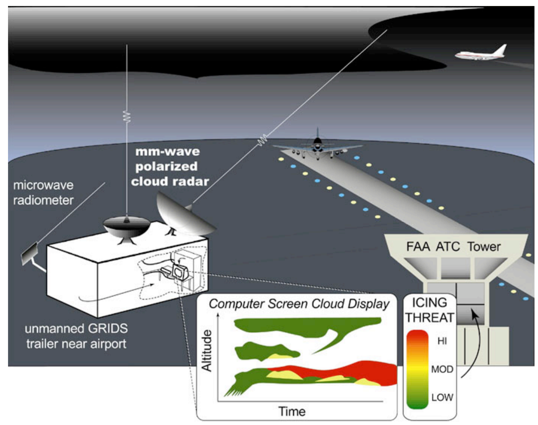

Fig. 1: GRIDS concept (courtesy NOAA ETL).

NCAR's SPolK_a radar system is based on their S-Band (10-cm) S-Pol radar. The radar is being supported jointly by the FAA and the National Science Foundation (NSF). SPolK_a is a K_a-band (0.86 mm) transmitter and receiver add-on to the S-band radar; the small 1-m antenna "rides along" at the edge of the larger 10-m S-band dish. Beam widths are carefully matched to avoid mismatch problems experienced in the past. This system is the product of years of research into dual-wave techniques for deriving liquid water content in clouds; the NOAA Environmental Technology

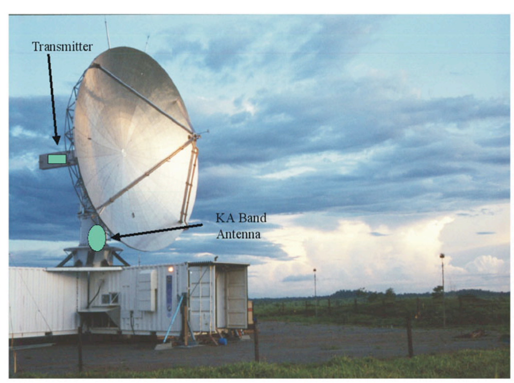

Fig. 2: FAA/NSF's SPolK_a Radar.

Laboratory pioneered this work (Martner et al., 1997) and it was further carried out in AIRS-I by Spec, Inc. (Lawson, 2000; Vivekanandan et al., 2000). The original S-Pol radar has full polarimetric capability and has been deployed in numerous field programs. A neural net-based Particle Identification System (Vivekanandan et al.1999), developed using this radar, could prove useful in further characterizing the icing environment.

NASA Glenn is developing the NASA Icing Remote Sensing System (NIRSS) that will combine a vertically-staring radar, a multifrequency microwave radiometer, and a ceilometer (Reehorst and Koenig, 2001). In the near term, the NASA system will consist of a Honeywell X-band radar (a modified Primus 880 airborne radar), a Radiometrics TP/WVP 3000 radiometer, and a Vaisala CT25K ceilometer. Data acquisition will be accomplished through the use of locally networked PCs. The goal of the development effort is to demonstrate a relatively low-cost, stand-alone icing condition detection system in the airport (terminal) environment. The component data will be fused to produce a single icing detection product. Another important part of the NASA remote sensing activity is to develop and evaluate methods for dissemination of the icing product to flight crews, dispatchers, traffic controllers, and meteorologists.

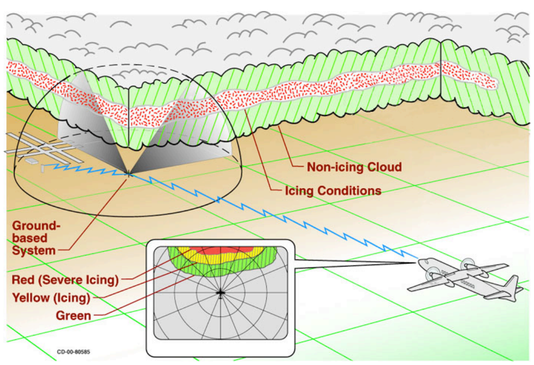

Fig. 3: NIRSS

ISSUES OF TRANSITION FROM R&D TO OPERATIONS

Even though the hardware for the three icing remote sensor systems has not yet been completed, it's time to consider paths from research and development to operations.

The FAA-sponsored systems are at this time considered research tools for measuring atmospheric characteristics related to icing and learning more about the environment. Yet, they are designed specifically for detecting icing conditions: low reflectivity, subtle signals in relatively noisy fields, and slight differences in hydrometeor shape and orientation.

The GRIDS system is waiting for NWS initiative approval for a FAA-NWS partnership to use the system to verify what the NEXRAD radars can detect regarding icing environments. The idea is to pair GRIDS with a NEXRAD and either use GRIDS to verify NEXRAD-detected icing algorithms (based on a planned polarization upgrade) or to consider possible augmentation of NEXRAD with GRIDS in icing-prone terminal areas. Alternatively, GRIDS could work as a stand-alone system in these terminals.

Since one of the SPolK$_a$ wavelengths is S-band, like NEXRAD, it may be possible to pair a K$_a$-band transmitter/receiver with a NEXRAD for dual-wavelength icing detection. Tests of the accuracy and reliability of the method will determine the feasibility of this approach. SPolK$_a$ is also looked upon by the NSF user community (primarily universities) as a powerful research facility for remotely quantifying liquid water content for basic storm studies.

Either system could also be used for local verification of high-resolution icing diagnosis or forecast algorithms such as CIP or FIP (McDonough and Bernstein, 1999). Currently, using research aircraft to penetrate such regions is the only means to obtain the kind of detailed icing information needed for verification; obviously aircraft have limited use in that their on-station time is limited to a fraction of the day and they cannot be everywhere in the model domain.

For full implementation into FAA and/or NWS operations, it may be desirable and possible to consider the Aviation Weather Technology Transfer (AWTT) process. This was set up in 2000 to consider research through implementation paths for algorithms being developed for detection and forecast of aviation weather hazards (as in Albersheim et al., 2003). AWTT to date has considered models or algorithms but icing remote sensor systems could be included in this process if it is demonstrated that they add significant value to a terminal-scale CIP or FIP.

The NASA system will also need to move through the FAA/NWS system for its eventual transition to operational use. NASA will be responsible for the technical development, assessment, and demonstration of the system. However, it is beyond the scope of NASA's charter to widely field an aviation product to the user community. The NASA program has initiated a dialog with the FAA AWR program, which would likely be the conduit into any future FAA/NWS transition.

IMPLICATIONS FOR FLIGHT OPERATIONS

Conditions for flying in icing conditions are covered under the Federal Aviation Regulations (FARs), in 14 CFR 135.85 (for air taxi operators and commercial operators for small aircraft, other sections cover other types of aircraft). Under these regulations, no pilot may fly under IFR into known or forecast light or moderate icing conditions; or under VFR into known light or moderate icing conditions; unless the aircraft has functioning deicing and anti-icing equipment. No pilot may fly an aircraft into known or forecast heavy icing conditions.

Currently, "known icing" is defined as "atmospheric conditions in which the formation of ice is observed or detected in flight". Forecast icing is defined as an environmental condition expected by the FAA-approved weather provider to be conducive to the formation of in-flight icing on aircraft. In order for icing remote sensor systems to be regarded as legal warnings of icing conditions, these definitions will need to be expanded from the current implied human-centered definitions to versions that accept remotely detected icing environments. This further establishes the need for reliability and accuracy of the described systems.

Additionally, newly-approved changes to icing severity definitions are as follows:

> *Light:* The rate of ice accumulation requires occasional cycling of ice protection systems to remove/prevent accumulation. A representative accretion rate for reference purposes is 1/4 inch in 15 minutes or more on the outer wing. The pilot should consider exiting the condition as soon as possible.
>
> *Moderate:* The rate of ice accumulation requires frequent *cycling* of ice protection systems to remove/prevent accumulation. A representative accretion rate for reference purposes is 1/4 inch in 5 to 15 minutes on the outer wing. The pilot should consider exiting the condition as soon as possible.
>
> *Heavy:* The rate of ice accumulation requires maximum use of the ice protection systems to remove/prevent accumulation. A representative accretion rate for reference purposes is 1/4 inch in less than 5 minutes on the outer wing. Continuous pilot vigilance is required and immediate exit from the conditions should be considered.
>
> *Severe:* The rate of ice accumulation is such that ice protection *systems* fail to remove the accumulation of ice and ice accumulates in locations not normally prone to icing, such as areas aft of protected surfaces and areas identified by the manufacturer. Immediate exit from the condition is necessary.

A conversion of these definitions to liquid water contents and drop sizes, at scales appropriate to those that can be detected and displayed by the remote systems, is needed. Politovich (2003) described a system that could be applied to a variety of aircraft types to define the expected intensity, or atmospheric condition, that the aircraft would encounter. In such a system, or any detection or forecast system, severe icing would not be defined since this is a condition that is defined explicitly by the aircraft response.

The National Research Council's report, *Weather for Those Who Fly* (NRC, 1994), put forward twelve recommendations for improvements in the U.S. aviation weather system. The report concludes that:

> *"Over the next decade, improvements will arise as a result of several factors: Information content; presentation format; and availability."*

The icing remote sensor systems described in this paper address these in the following manner:

Information content: The information from the systems will *reliably* detect icing conditions on highly-resolved scales in terminal areas. Additional information such as freezing level, precipitation rates, and hydrometeor type could be included. The information can be ingested into numerical weather prediction models or algorithms that combine model output with observations, such as CIP. Detailed information such as from NEXRAD or GOES has been found to be of great benefit to weather models. Subsequently, the model outputs can be translated or combined with additional information to provide aviation weather products tailored to specific weather hazards and to a variety of users.

Presentation format: These icing remote sensor systems lend themselves to graphical presentation formats, rather than the current text AIRMETs. Displays can be designed for specific users to convey information quickly and in appropriate formats. This graphical information will be of particular value to forecasters, dispatchers, and pilots developing pre-flight plans. However, means must be developed to allow for the dissemination of remote detected icing information to aircraft. MIT has proposed initially using verbal information transfer via terminal ATIS communications to provide *pre*-datalink era icing information dissemination to aircraft (Vigeant-Langlois and Hansman, 2002). Their concept for an ATIS based communication would stress altitudes that are free of icing and only include intensity if the conditions are deemed to result in severe icing (examples. “No icing conditions are detected over the [XXX] airport.” Or “Icing conditions measured of the [XXX] airport. Icing detected in a single layer, tops at [YY] thousand feet, no icing below [ZZ] thousand feet.”). The current reporting of sky condition is the closest analogy to the concept communication.

Availability: Within the Aviation Gridded Forecast System (Sherretz, 1991), a common format and display will be available either as a graphic product or GRIB-formatted files via the Aviation Digital Data System, or ADDS. As soon as the infrastructure is in place, the data can also be made available via datalinking to the cockpit for inflight updates of weather information. This will be done on a 24/7/365 basis to insure all-hours availability for the aviation user community.

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