P5.2 **CONCEPT AND DESIGN FOR A PILOT DEMONSTRATION GROUND-BASED REMOTE ICING DETECTION SYSTEM**

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I. Introduction

The FAA is supporting research to develop remote sensing technologies that will detect in-flight icing hazards. Recommendations from a FAA workshop (Riley and Horn 1996) emphasized the need for remote detection of supercooled large droplets (SLD). SLD are larger than cloud droplets, smaller than rain drops, and recognized as a cause of extremely dangerous icing, despite their very low reflectivities (Ashendon et al. 1996, Politovich 1996). Their detection identifies the main icing hazard. Also, identification of the types of ice implies much about cloud processes that determine whether supercooled droplets can form and how fast those present will be consumed or if they will be maintained at small, non-hazardous sizes by the ice particles competing for the water.

For more than a decade, the NOAA Environmental Technology laboratory (ETL) has participated in the FAA program to develop appropriate radar- and radiometer-based icing diagnostic techniques. ETL's most important on-going task has been to develop a dual-polarization K_a-band (8.66-mm) radar to detect clouds of hazardous SLD and to distinguish them from clouds with non-hazardous ice particles. It has succeeded. In tests including the 1999 Mt. Washington Icing Sensors Project (MWISP), ETL was able to demonstrate a radar capability for deterministic hydrometeor identification. By measuring one parameter, a depolarization ratio (DR) The technology was shown to be capable of distinguishing among the "regular" types of ice crystals and even the more spherical and irregular ice particles, and to differentiate all of these from clouds of SLD. The state of the transmitted polarization was key. Excellent agreement between measurements and scattering theory provided proof of concept (Matrosov et al. 1996, 2001; Reinking et al. 1997a,b, 2000, 2001). Integration of a microwave radiometer (MR) with the polarization radar to measure the column-integrated quantity of cloud liquid water (LW) will help to detect and quantify the icing hazard.

The technology is now ready to move to an operational demonstration. The engineering design phase of a robust Ground-based Remote Icing Detection System (GRIDS) as an initial part of the FAA Icing Remote Sensor Testbed (FIRST) is in progress. Hardware and software development and integration will follow.

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2. Concept for an Operational GRIDS/FIRST

Four existing ETL technologies establish the foundation and will be integrated to build the new system (Fig. 1): (1) the scanning K_a-band dual-polarization radar technology, (2) microwave radiometry, (3) the operational millimeter-cloud radar (MMCR), and (4) a state-of-the art Radar Data and Acquisition System (RADS).

Hydrometers depolarize a signal primarily according to their shape and the elevation angle χ of the antenna. The simplified concept is that (shaped) ice depolarizes the signal in accord with χ but (spherical) SLD do not. Actually, SLD cause the smallest (χ-independent) DR. A hybrid slant-linear or circular transmitted polarization state can provide excellent hydrometeor differentiation and will be far superior to the standard horizontal state (Reinking et al. 2001). Circular will be best by 2 or 3 dB (Matrosov et al. 2001), shows large SLD -ice particle differentiation (Fig. 2), and has been selected for GRIDS . A beam transmitted at a fixed χ of 30° to 45° will provide the necessary, optimal differentiating DR measurement. An optional capability to also measure both DR and hydrometeor velocity spectra (V_s) at χ = 90° will respectively enhance specific ice type identification and may sort liquid from ice in particle fallspeed differences (Zawadski et al. 2000). With either option, GRIDS will provide a time-height profile of DR (and optionally V_s) and the icing hazard.

A MR can be tilted to match the χ of the radar to provide continuous, independent verification of icing potential from the measured presence or absence of LW and the quantity, which can be allocated to the radar-

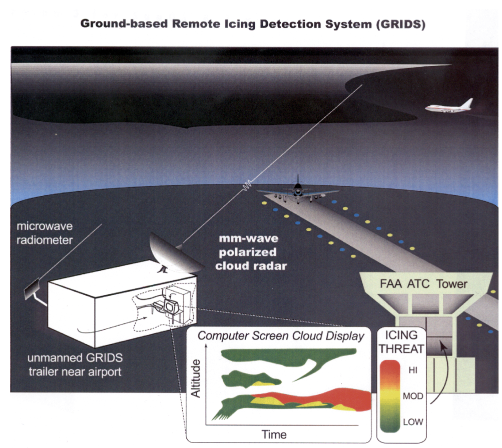

Fig 1. Artist's concept of GRIDS/FIRST (slant-fixed-beam version)

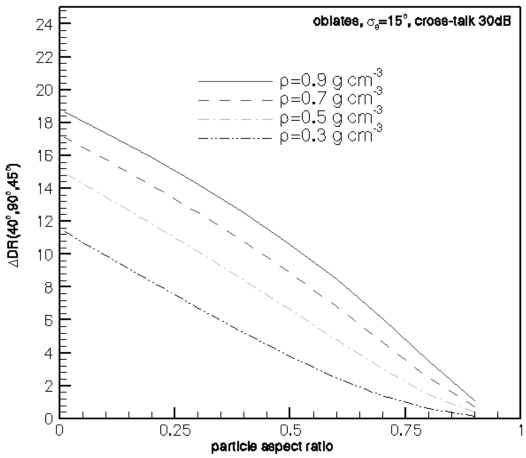

Fig. 2. Circular DR difference (dB) between ice particles (shape of aspect ratio < 1) of varied densities and SLD (ratio =1) at χ = 40°.

observed cloud layer(s). A system ingest of hourly temperature profile data from the operational RUC model, combined with the radar-indicated radial range of lowest-DR cloud echo, will indicate if all or part of the liquid is supercooled and thus locate a potential hazard.

The MMCR, which measures reflectivity (Z_e) and velocity, was developed to perform operationally in an unattended, continuous, vertically-pointing mode (Moran et al. 1998). This proven technology applied at K_a-band provides the basic transmitter and receiver electronics, up/down converter technology for 60 Mhz - 35 Ghz, and the robust design for automated operation, calibration, diagnosis, and control.

RADS was developed to modernize the software/hardware interface of ETLs scanning K_a-band radar (NOAA-K) and the Coast Guard's iceberg detection radars (Campbell and Gibson 1997). This adaptable system will integrate the control of the instruments, external data ingest, data processing, computation, and transmission of the determined potential icing hazard indicators to users.

3. GRIDS/FIRST Design

The GRIDS 8.6-mm radar will transmit 1000 w peak power and 14.1 w average power. PIREP statistics (Schultz and Politovich 1992) indicate that ~ 90% of icing events occur at temperatures between 0 and −20°C, below 6.0 km MSL, or within 9.3 km range at χ = 40°, the fixed-beam elevation selected for GRIDS. SLD generally cause reflectivities between about +5 and −15 dBZ and are undetectable with longer wavelength radars. Essentially all clouds that create an icing hazard will have $Z_e \geq -20$ dBZ. The corresponding *cross-polar* reflectivity, Z_{cr}, is ~ −50 dBZ, so we require the GRIDS radar to gain a main-channel sensitivity of ~ −60 dBZ at 10 km range to determine DR of these low reflectivity clouds. The sensitivities of NOAA/K, the MMCR, and GRIDS radar are compared in Fig. 3. The GRIDS sensitivity will be achieved with a large antenna (3 m), long dwell time (60 s) and long pulse width (1.0-1.5 μs). The design calls for 150 m vertical range resolution and 0.24 ms^{-1} vertical velocity resolution; these can be enhanced in adjusted modes. Some parameters for the 40°-slant and vertical operating modes, which optionally will be mechanically alternated in ~5 min periods, are listed in Table 1.

4. The GRIDS/FIRST Algorithm

The simplest, or core GRIDS algorithm uses four decision points based on the slant-path, fixed beam measurements of LW, Z_e, and DR plus the ingested temperature profile (Fig. 4) to determine icing potential as a function of altitude. Here a hazardous cloud is identified as one that exhibits measurable LW, T < 0°C, a Z_e large enough to warrant consideration (−20 dBZ, e.g.), and a DR that matches the minimum hydrometeor signature (± 2 dB), thus indicating droplets, not ice. This is a foundation for a more sophisticated algorithm.

The vertical boundaries of all cloud layers will be identified. The MR liquid *quantity* can be assigned to liquid (minimum-DR) layers to quantitatively assess icing severity. A scaled icing hazard warning will be added (red for probable, yellow for caution, green for no threat; Fig.1). Detection and use of the uniquely high DR of any bright band will confirm altitudes where the clouds are supercooled, and that precipitation is occurring. The vertical mode will detect droplet-generating embedded convection. Appropriate combinations of measured parameters will provide data quality control.

4. Conclusion

GRIDS/FIRST will integrate a wealth of existing hardware and software technologies into the most sensitive cloud radar ever built. The vertical profile of the in-flight icing threat will be derived from the depolarization ratio and the quantity of supercooled

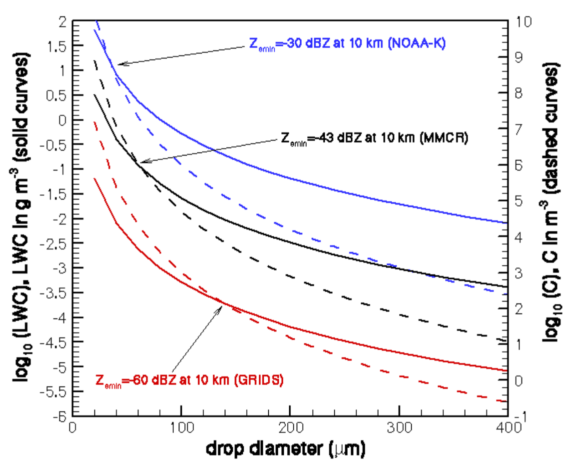

Fig. 3. Sensitivity in terms of drop size and concentration compared for the GRIDS radar (30 dB cross-talk), the MMCR, and NOAA/K.

liquid, supported by other radar parameters. Plans are that the pilot demonstration unit will be deployed to the holding pattern of a major icing-prone airport and operate in a unattended mode. Products of the continuous stream of microphysical and additional cloud and atmospheric information from GRIDS/FIRST will warn of icing hazards and also potentially provide a real-time data stream to anchor numerical icing and general prediction models.

Table 1. Typical GRIDS/FIRST operating modes.

Mode	40° Slant	Vertical
Pulse rep. pd.	110 µs	71 µs
Pulse width	1.55 µs	1 µs
No. FFT points	64	256
No. spectra averaged	8522	3301
No. range gates	69	67
Unambig. range	16.49 km	10.64 km
Max. unambig. radial velocity	19.55 m/s	30.28 m/s
Radial velocity resolution	0.61 m/s	0.24 m/s
Range resolution	232.3 m	149.9 m
Height resolution	150 m	150 m
Dwell time	60 s	60 s
Est. sensitivity at 10 km *AGL*	-57 dBZ_e	-57 dBZ_e

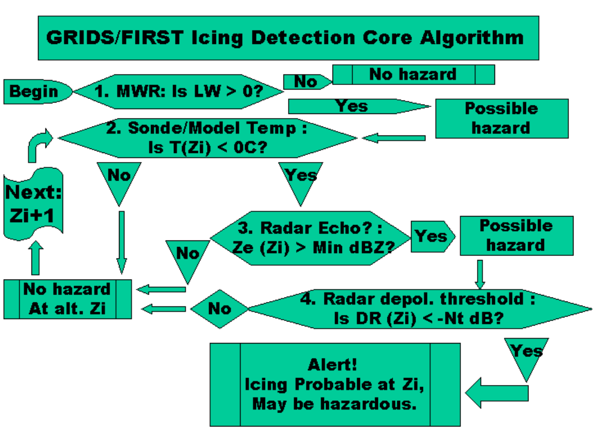

Fig. 4. Concept of the icing detection algorithm for GRIDS in its simplest form.

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