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A Report on Improving Forecasts of Icing Conditions for Aviation

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FOREWORD

The purpose of this paper is to review the current state-of-the-art in the forecasting of icing conditions for aviation operations and to suggest some areas that might be explored to improve icing forecasts. This paper briefly addresses the following:

1. Concerns of how icing forecasts impact aviation safety and efficiency;

2. Contribution of observational data to icing forecasts;

3. Current procedures used to develop forecasts of icing conditions;

4. Recent developments in technology that may contribute to more accurate icing forecasts;

5. Current research and development by agencies represented on the Subcommittee on Aviation Services that may contribute to improved icing forecasts; and,

6. Recommendations for consideration.

A REPORT ON

IMPROVING FORECASTS OF ICING CONDITIONS FOR AVIATION

1.0 BACKGROUND

In an earlier background paper by A. Hilsenrod and F. Coons, "Forecasts of Icing Conditions for Aviation," November 1980, it was established that, during the period 1973 through 1977, 525 accidents involving all classes of aircraft were identified as being icing related. Of the total accidents reviewed, they represented about three percent. To update those data, the following information was received from the National Transportation Safety Board's (NTSB) subcommittee member, Mr. James McLean. In the four years 1976 through 1979, a review of 17,372 general aviation accidents revealed 178 accidents in which icing was a probable cause. Of the 178 icing related accidents, the forecast of icing conditions encountered was deemed "substantially correct" in 62 percent of the cases.

In addition to the above, special concern was expressed in the December 1980 meeting by the Federal Aviation Administration (FAA) member that, while the total numbers of icing related accidents appeared comparatively small, evidence exists that the percentage of icing related accidents is on the increase. Also, previously established in the November background paper was the concern that by 1990, with a more than doubling of the number of helicopters in the mix of General Aviation aircraft types, the icing related accident rate could increase significantly. Nearly all general aviation aircraft, especially helicopters, are vulnerable to icing encounters.

1.1 The following article was extracted from the January 5, 1981, FAA Headquarters Intercom Newsletter. It is an example for which there is concern.

"ICE STILL KILLS

> "Ice is still a killer, and the National Transportation Safety Board doesn't want pilots to forget it. In issue No. 12 of its 1979 "briefs" of general aviation accidents, the Board warns, "While advanced in design ... have reduced the hazards of ice in general aviation flying, they have by no means been eliminated." To underscore the warning, NTSB cites the crash of a modern sophisticated Cessna Turbo Centurion in which six persons were killed. In this case, the pilot was over mountainous terrain and could not climb because of the ice. Her last transmission was, 'We're having problems with ice.' With this pathetic transmission remembered, the Board's last warning: 'Never take icing control for granted' carries real weight."

1.2 The economic penalties that aviation incurs due to inaccurate icing forecasts are not well documented. Certainly, "over-forecasting" of icing conditions either by volume or intensity would restrict many general aviation operations. The economic losses associated with "over-" or "under-" forecasting of icing conditions remain essentially unaddressed. Aside from inferences such as more ice requires more power which increases fuel consumption, little data are available for analysis.

1.3 The effects of icing on aircraft performance were previously reviewed and will not be repeated. It suffices to say that "nothing good can be said about icing in connection with aircraft performance or control." A review of these effects is available in AWS/TR-80/001(1). In addition, the FAA, in cooperation with NASA and the Department of Defense, is in the process of examining its Federal Air Regulation (FAR), Part 25, Appendix C, as those criteria apply to the certification of rotary wing and other general aviation aircraft to "fly in known icing conditions." When those criteria were established, they applied to supercooled clouds. Data on meteorological phenemona such as freezing rain, snow, and aggregates of snow and ice are now being added to the original data base to see if the existing criteria are still valid or require modification. More will be said about the above in Section 5. An excellent article about this facet of icing is contained in the February 1981 AOPA PILOT magazine (2). The application of this work on FAR 25 could ultimately lead to changes in the existing icing intensity definitions.

1.4 As introduced in Paragraph 1.1, the addition of icing accumulation rate equipment on general aviation aircraft is a consideration that has considerable potential for aircraft safety and to a lesser extent, reduced fuel consumption. The Rosemount Ice Detector (3) for large turbojet aircraft and a low-cost derivative of the Rosemount type probe for General Aviation and helicopters, if installed and operated on enough aircraft to give a nationwide distribution of airborne observations could provide a valuable icing data base to supplement existing atmospheric sampling techniques. This will be developed in more detail in Section 2.0.

2.0 OBSERVATIONS

The icing forecast data base consists almost exclusively of surface and radiosonde observations and pilot reports (PIREPS). The radiosondes consist of temperature pressure and humidity sensors designed to provide the accuracies presented in the following Table 1:

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(1) Anon: "Forecasters' Guide on Aircraft Icing," AWS/TR-80/001, March 1980, Air Weather Service (MAC) Scott AFB, IL.

(2) Horne, Thomas A., "Reflections on a Black Art," February 1981, Aircraft Owners and Pilots Association (AOPA) Pilot, Vol. 24/ Number 2, pps. 52-62.

(3) Rosemount, Inc., "The Rosemount Ice Detector," 1970, Minniapolis, Minnesota.

Table 1. RADIOSONDE SENSOR ELEMENT ACCURACY

Temperature (degree C)	± 1
Humidity (percentage)	± 5
Pressure (mb)	± 2

Radiosonde sites are scattered throughout the continental United States, many of them hundreds of miles from its nearest neighbor. For example, the Oakland, CA, site is about 400 miles south of the site at Medford, OR. Observations are routinely taken at 12-hour intervals. The courseness of this network coupled with the relative infrequency of new observational data does not lend itself to accurate and well-defined assessments of the atmosphere's potential for icing. The input "Forecasting Icing" from the National Weather Service (NWS) member identifies yet another area where the atmospheric sounding system and products derived thereof require improvement. In the discussion of "Significant Aviation Weather Prognosis," the height of the zero degree C isotherm to the nearest 500-foot movement would appear to identify a potential problem before any forecasting of icing begins.

2.1 If PIREPs serve as the primary filler for atmospheric icing potential between soundings and at off-sounding times, then other problems present themselves. Once significant icing airspace is identified, general aviation pilots avoid those areas and air carrier pilots that do transit the icing areas seldom report icing problems, because their aircraft are equipped to handle the accretion. In addition, the PIREP distribution system is random in airspace and time.

2.2 The key atmospheric elements needed to produce reasonably accurate icing forecasts are knowledge of:

- Cloud liquid water content
- Cloud drop-size distribution
- Cloud droplet temperature
- Ambient temperature

Note that of the four listed only one, ambient temperature, is routinely measured and reported. It is reasonably safe, therefore, to say that the data base for icing forecasts needs considerable improvement.

3.0 ICING FORECAST PROCEDURES

Both NWS and the Department of Defense (DoD) provided information on the techniques they use to produce icing forecasts. A review of each provided some similarities and some basic differences. Both use the same relative data base; i.e., Raobs and surface observations tempered with PIREPS. NWS icing forecasts are implied in their "Low-level Significant Aviation Weather Prognosis" and, specifically, in definitive areas and times by in-flight warnings known as SIGMETs or AIRMETs (designed to alert pilots to a variety of hazards). NWS uses a number of models that are machine calculated to provide the guidance which is then translated into icing forecasts. Both NWS and DOD use the rationale provided in AWS/TR-80/001, "Forecasters' Guide on Aircraft Icing" in educating their forecasters on the nuances of aircraft icing. However, DOD's icing forecast procedures would appear more diligent in their their guidance suggests an in-depth review of relevant Raob's. This is not specifically suggested by NWS procedures.

Dissemination of Icing forecasts once they are produced is a subject unto itself and, while critically important to the success of the forecast process, will not be discussed here. It suffices to say, efforts are underway by the NWS and FAA to improve the dissemination process.

4.0 TECHNOLOGY

A number of new technologies has evolved over the past decade which may have relevance to the icing forecast problem.

4.1 Icing Accretion Meters - initial studies on aircraft icing conducted in the early 1950's by NASA formed the basis for much of what we know about aircraft icing and the meteorological elements that cause it. The instruments used during those investigations were rotating cylinders and variations of oil slides designed to collect drop size distributions, ice particles and ice aggregates From these measurements, cloud liquid water content and rate of ice accretion were determined. Since those early measurements, the sampling apparatus has evolved through a variety of electrical devices that range from rotating disks of varying sizes to hot wire elements and the Rosemount-type device mentioned in Paragrph 1.4. An assessment of these devices is offered by William Olsen from NASA/Lewis Research Center (4) in the proceedings of the Fourth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems (Report FAA-RD-80-67). Additional information on aircraft icing instrumentation is also provided by Phyllis Kitchens of the U.S. Army Test and Evaluation Command in the very next article (5) of those proceedings. The results of the testing done thus far on ice accretion meters indicates that more development is required to meet accretion rate standards for research purposes. Very little is said about their use as practical warning devices for significant icing encounters. This, therefore, is an area that requires more investigation.

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(4) Olsen, W., "Icing Instrumentation," March 1980, Proceedings: Fourth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, Univ. of Tenn. Space Institute.

(5) Kitchens, D.F., "Aircraft Icing Instrumentation--Unfilled Needs," March 1980, Proceedings: Fourth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, Univ. of Tenn. Space Institute.

4.2 Liquid Water Content (LWC) and Drop-Size Distribution (DSD) determination - as with icing accretion meters, LWC and DWD measuring equipment have also evolved over the years. Originally, the rotating multicylinder collection techniques were used and, now, various electronic spectrometers and Johnson-Williams LWC probe, as well as hydrometer samplers, are in widespread use. Nearly all of the data collection is done from aircraft and requires rather large amounts of data processing to determine LWC and DSD. No participating subcommittee agency collects these data on a routine basis.

4.3 In 1979, it was proposed that an ice detection system be developed that could be flown as part of the standard radiosonde package. The instrument would be a light weight probe which would convert super cooled droplet and ice particles which impinge on it into LWC data that could be routinely microwaved back to radiosonde receiver sites. While such a proposal would appear to be a high risk undertaking, it is perhaps time to reexamine the concept to see if it will meet requirements for vitally needed LWC data. Some of the details of the proposal are included as Appendix A.

4.4 The use of satellite data to determine the vertical distribution of temperature and humidity or LWC is not specifically addressed by NWS or Dod as an viable source of data upon which icing forecasts could be influenced. Certainly, icing related information is contained in the visual and infra-red data, but application to the icing forecast areas is barely realized.

4.5 The use of microwave radar has been suggested as a possible source of icing related data (Para. 28 of AWS/TR-80/001), but the relationship between the radar "bright band" where the precipitation changes from snow and ice crystals to water droplets is not strong. One of the requested design functions of the Next Generation Weather Radar (NEXRAD) is the identification of icing zones. Whether this design goal can be met is still unknown at this time.

5.0 RESEARCH AND DEVELOPMENT

Research and Development (R&D) having relevance to improved icing forecasts is almost nonexistent. DOD, NASA and FAA all have active R&D programs which are related to icing, but only DOD is trying to improve its icing forecast techniques. The scope of the research being performed by the Air Force Geophysics Laboratory's (AFGL) Meteorological Division is contained in Appendix B (AFGL's "Aircraft Icing Program Summary). It is possible that the work currently related to other aspects of icing might have some payoff for forecasting downstream -- perhaps, a better understanding of the microphysics of the icing process, as well as indirect input to cloud physics modeling.

6.0 RECOMMENDATIONS

Further improvements in the forecasts of icing are warranted and potential solutions exist that are worthy of further investigation.

The following recommendations are submitted for consideration and action to members of the Subcommittee on Aviation Services, Interdepartment Committee on Meteorological Services and Supporting Research (ICMSSR):

6.1 DOC take the lead in developing procedures to improve icing forecasts exclusive of distributing the forecasts to users.

6.2 DOC be responsible for investigating the potential for satellite data and microwave radar in improving icing forecasts.

6.3 NASA be responsible for investigating the feasibility of developing ice accretion meters for carrier and general aviation aircraft, including rotary-wing.

6.4 NASA be responsible for investigating the feasibility of developing a low-cost liquid water content meter which can be flown on existing radiosonde balloons or be made a part of the radiosonde sensor elements.

6.5 FAA be responsible for reviewing, recommending changes of the existing definition of icing intensity as they apply to helicopter operations, air carrier, air taxi, and general aviation aircraft.

Appendix A

FEASIBILITY DESIGN OF INSTRUMENT FOR ATMOSPHERIC LIQUID WATER CONTENT MEASUREMENT

4.1 Conceptual Designs

Design Concepts

The basic principal of the proposed instrument is to measure the rate of ice buildup and to relate this through calibration to liquid water content. If the OAT is low, the ice accretion will occur naturally. When natural icing does not occur, the innovative concept is to force ice accretion by cooling the probe. Several types of ice detection devices have been proposed [7] which are directly applicable to the innovative concept simply by mechanically cooling the probe. Since the rate of ice accretion is the parameter to be measured, alternating cooling and heating of the probe may be required. Each type of ice detection system available will be explored along with other original concepts which may be determined during the course of the study. Typical methods of detecting ice which may have been proposed are listed in Table 4.1. A brief description of each type follows:

Table 4.1 CURRENT ICE DETECTOR TYPES

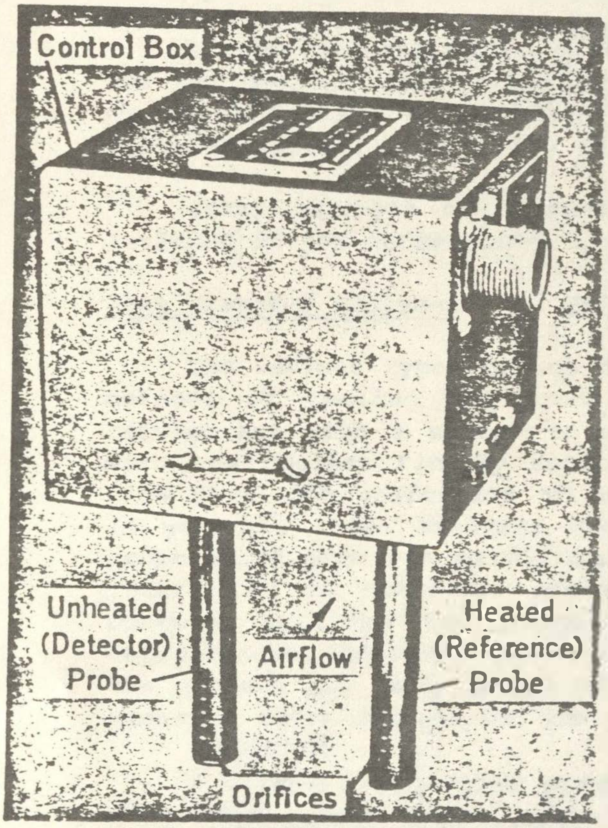
Differential Pressure	Beta Radiation Detector
Electrical Conductivity	Rotating or Reciprocating Cylinder
Vibrating Rod	
Mass Balance	

The differential pressure or pressure probe detects ice by sensing the difference in pressure between a heated reference probe and an unheated detector probe when the forward-facing holes in the unheated probe become blocked with ice or by sensing a change in pressure when holes in the forward face of a single probe become blocked with ice while the aft-facing holes remain free of ice. This concept can be immediately utilized by providing cooling for the unheated detector probe. An illustration of this type of probe is given in Figure 4.1a. Miniaturization and incorporating a cooling device along with a small pressure sensing crystal would make this system a viable design concept.

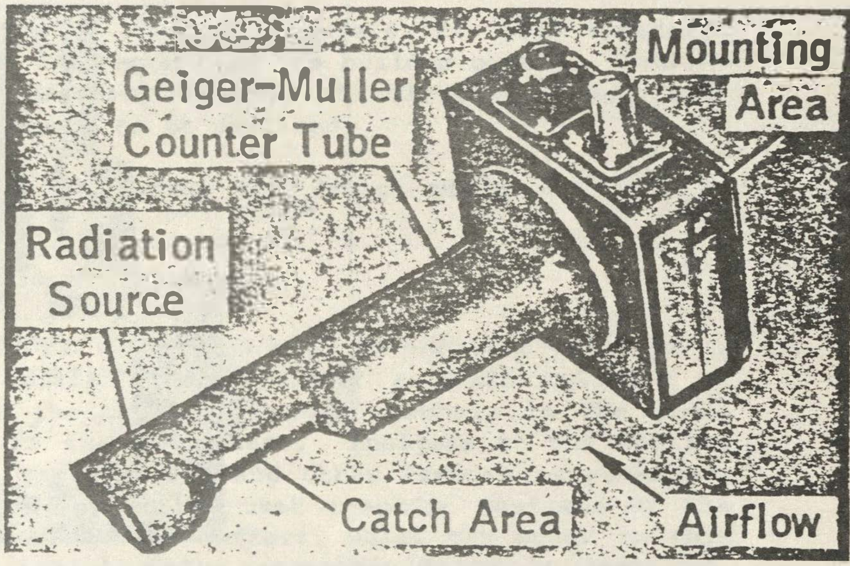
An electrical conductivity-type ice detector is illustrated in Figure 4.1b. This type of detector has two airfoil-shaped probes separated by an air gap. Icing is detected when the air gap is bridged with ice. Again, miniaturization plus a means of cooling the airfoil-shaped probes would provide a viable concept.

A radiation-type ice detector is shown in Figure 4.1c. The instrument is designed, so that accreted ice will block off or weaken the flow of beta particle radiation between two points. This device has the advantage that it operates at low airflow speeds, such as those associated with balloon-rate of rise velocities, but has other less attractive features from a safety point of view.

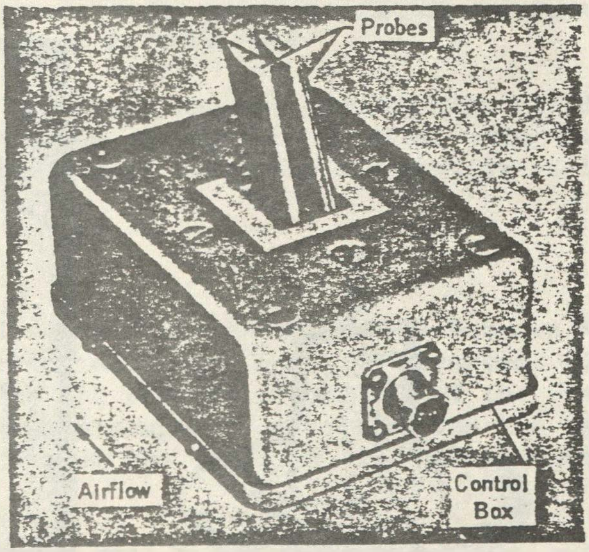
An example of a rotating cylinder-type of ice detector is illustrated in Figure 4.1d. In this detector, a cylinder exposed to the airstream rotates slowly passed a scraper. Ice accreting on the cylinder is shaved off by the scraper; the torque required to move the ice actuates a warning system. Cooling of the cylinder would make this a viable system, although miniaturization and transmission of the signal by radio from a balloon-borne platform promises difficulty.


Control Box
Unheated
(Detector)
Probe
Airflow
Heated
(Reference)
Probe
Orifices

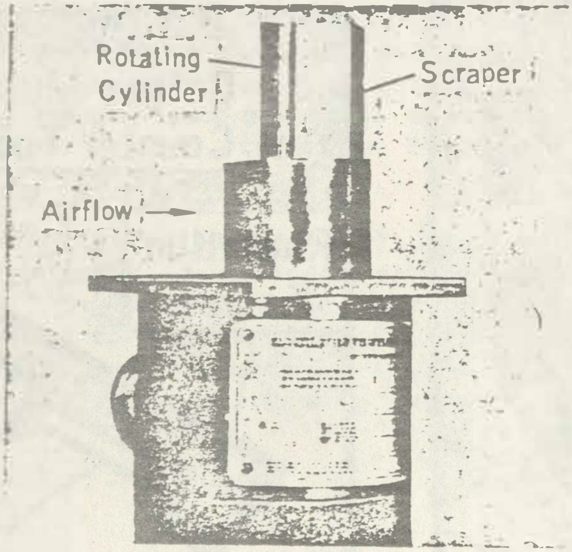
4.1a


Geiger-Muller
Counter Tube
Mounting
Area
Radiation
Source
Catch Area
Airflow

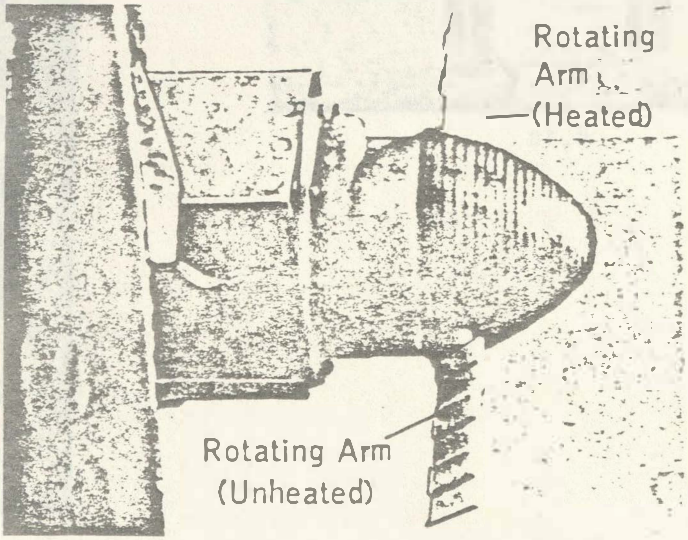
4.1b


Probes
Airflow
Control
Box

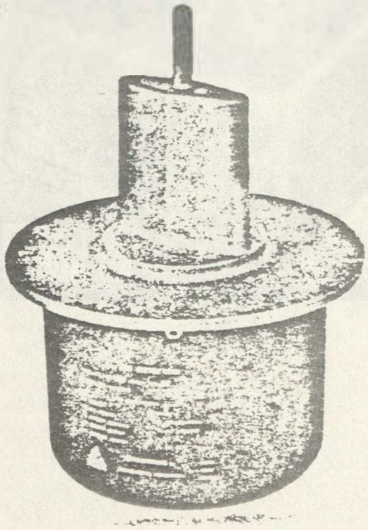
4.1c


Rotating Cylinder
Scraper
Airflow

4.1d


Rotating Arm (Heated)
Rotating Arm (Unheated)

4.1e



4.1f

A mass balanced-type ice detector shown in Figure 4.1e has similar practical difficulties. This detector is driven by an electric motor and detects ice by heating one of the rotating arms and, in the proposed case, by cooling the alternate rotating arm. The resultant mass unbalance due to ice buildup on only one blade is sensed.

A vibrating rod-type ice detector is shown in Figure 4.1f. This vibrating rod ice detector detects a change in frequency when ice buildup occurs. Cooling of the rod while maintaining the necessary freedom of vibration, along with miniaturization, would allow this concept to be utilized.

Other concepts may become apparent during the design phase and will be included in the optimization studies.

Heat Transfer Analyses

The various types of ice detectors identified will be analyzed relative to methods of cooling the probe. Initial ideas suggest a small cylinder of refrigerant with a system to meter the coolant through channels in the probe with the coolant finally escaping to the atmosphere. Analysis of the cooling flow rate, the uniformity of probe temperature, and other factors is required. In general, these analyses call for conduction heat transfer analysis of the probe which promises no difficulty. The major effort, which can occur in this regard, is if numerical analysis of a complex geometric probe is required. Computer programs for carrying out these detailed conduction heat transfer calculations, however, are available. Additionally, those who will assist in the project are well versed on low temperature heat transfer, having conducted numerous short courses and having edited a book in this area.

Alternate techniques which will be explored include evaporating fluids, packed ice, heat pipes, etc. Also, a unique concept is a hilsh tube with cooling at one end for the ice accretion portion of the probe and heating at the other end, for the refence condition.

Ice Accretion Characteristics

The probe must be analyzed to determine the basic relationships between the rate of ice accretion and the liquid water content which is to be measured. The ice accretion rate will be interrelated with the cooling properties of the probe and the signal to be monitored. For a given atmospheric condition and the rate and extent of ice accumulation is a function of the speed of the probe through the atmosphere and the probe geometry.

The form of ice accreted on the probe can be controlled by the probe temperature. At low temperatures, the water droplets freeze immediately on impact, forming rime ice. At higher tempratures, the water droplets may wet the surface of the probe, resulting in glaze ice. The size, shape, and extent of ice formation depends on the cloud liquid water content, the drop size and temperature, the speed of the probe and its angle of attack (if this is important), the probe geometry, and the duration of the icing encountered. Design of the probe requires a knowledge of rate of water catch, impingement limits and -- in certain cases -- impingement distributions. Fortunately, a large body of impingement data exists, covering a wide range of geometric body shapes. However, these data have been developed mainly for airfoil sections which are large relative to the probe concept and modifications will be necessary.

The rate of water droplet impingement on a body can be expressed in mass per unit time per unit area by the general equation:

$$W_m = \text{Const.}\ U_o W_{\ell c} G(D) E_m$$

where W_m is the rate of water droplet impingement. U_o is the flight speed; $W_{\ell c}$, the liquid water content; G(D), a geometry factor which is a function of the characteristic dimension D and is usually the projected area; and, E_m, the collection efficiency. The value of W_m will be determined from the rate of ice accumulation detected by the probe. Rate of buildup can be monitored by alternately heating and cooling the probe. The geometry factor will, of course, be determined from the final probe design; the velocity will be velocity of the probe relative to the cloud of liquid water droplets; and, its value will require some analysis. For aircraft, the value is straightforward since it will be known from the speed of the aircraft. For a radiosonde package, the characteristic value of U_o must be determined. It will be related to the balloon rate of rise which can be determined from the rate of contact point printout, but it will also be a function of the pendulum action of the package relative to the balloon. An analysis to determine U_o will be made.

The collection efficiency, E_m, can be calculated theoretically from droplet trajectory theory or determined experimentally. For the Phase 1 study, it will be determined theoretically; however, during Pase 2 analysis, an experimental determination will be made.

Reference [7] provides a discussion of existing data on collection coefficients and describes the method of calculating the coefficient from trajectory analyses. These methods are straightforward and can be readily applied to the conceptual probe design geometries selected in Task 1. The trajectory calculation, however, depends upon droplet size which is an unknown. Studies have shown that a single mean droplet size gives an adequate approximation of liquid water content for most airfoils; however, for blunt bodies such as ellipsoids and cones, serious error can result from use of uniform drop size. Since it will not be possible to determine the drop size distribution from the ground-based or in-flight stations, it will be necessary to estimate drop size in backing out the liquid water content in the data reduction process. Considerable information is available relative to the distribution of droplet sizes in clouds. Therefore, it is felt that a mean drop size can be determined which will be meaningful for use in the data reduction processes to be established for the proposed probles. However, careful consideration of the influence of droplet size will be taken into account in the optimization of the conceptual designs.

4.2 Sensing Circuitry and Signal Transmission

Since it is desired to sense and transmit the liquid water content measurement with a radiosonde unit, the various instrument design concepts must be compatible with the electronics of the radiosonde set. The radiosonde set generally transmits radio signals in the 1600-to-1700 MHz level relating to the pressure, temperature, and humidity of the upper air. The unit generally consists of a radiosonde transmitter, radiosonde modulator, temperature and humidity resistance element, and a battery. A commutator composed of alternating silver contact strips and insulating segments is used to introduce the humidity and temperature resistance elements into the circuit by means of a relay. A contact arm connected to the aneroid barometer cell moves across the commutator as the pressure decreases with height, also clock-actuated switching mechanisms are available. Temperature is transmitted whenever the contact arm is on an insulating segment, and humidity is transmitted whenever the arm is in contact with certain silver contact strips. Temperature and humidity changes in the atmosphere produced variations in the resistance of the respective circuits, causing the transmitted audio frequency to vary. A reference signal (low or high) replaces the fiftieth humidity contact. Accordingly, position of the contact arm on the commutator can be determined and pressure obtained by means of a calibration chart provided with each instrument. When the sounding reaches approximately 104 contacts, the radiosonde set discontinues transmitting humidity. The remainder of the commutator bar is divided into temperature and reference contacts. The preceding descriptions describe the AN/AMT-4 radiosonde set [8]. Most all radiosonde sets have similar characteristics.

In order to utilize standard radiosonde sets as described above, certain modifications to the circuitry are required. First of all, the signal from the ice detector should preferably produce a variation in a resistance element which will integrate directly into the existing circuit. Particularly attractive in this regard is the electrical conductivity ice detector type for which the signal output is the resistance across two probes. The commutator of the standard rawinsonde set would require modifications, in order to sense tthe output of the ice detection unit in regular sequence with humidity, temperature, and pressure. The maximum weight that can be lifted by a radiosonde balloon is approximately 2,000 grams (5 lbs.). Since the standard radiosonde set averages 600-to-700 grams, the ice detection system must be maintained at a weight somewhat less than 1,400 grams. If a vibrational-type signal such as the vibrating rod ice detector were utilized, it may be possible to feed the frequency output directly to the frequency modulator, thus, bypassing the resistance element. This approach may have certain advantages which will be studies during this phase of the program.

For those detector types which require a DC voltage -- for example, to drive an electric motor -- then, standard radiosonde battery with voltage outputs between 1.5 v to 120 v are commercially available. Moreover, relative to the proposed probe cooling system, the A/AMT-12 radiosonde set, for example, carries a small thermos bottle of carbon disulfide or Freon-11 as a boiling point reference. These thermos bottles, with minor modifications, would be ideal containers for the coolant necessary to control the probe temperature below freezing.

Thus, the circuitry of a radiosonde is readily amenable to incorporating the proposed LWC detector system.

Appendix B

AIR FORCE GEOPHYSICS LABORATORY'S

AIRCRAFT ICING PROGRAM SUMMARY

Background

1. Operational Requirement (as stated in Air Weather Service Geophysical Requirement 1-79, "Aircraft Icing," submitted to AFGL in 1979 for R&D action.)

a. The development of new airframes that operate in the region from the surface to 20,000 feet without sufficient anti-icing/de-icing capabilities has reinforced the engine/aircraft icing forecast requirement. The F-16, A-10, HH-53, T-38, cruise missiles, remotely piloted vehicles, and precision guided weapons, such as the GBU-15, are examples of such engines/airframes. Accurate icing forecasts which include accretion rates are required for both wartime and peacetime operations.

b. A requirement exists to initiate research and develop new forecasting techniques for both fixed and rotary wing aircraft icing. This requirement results from two factors:

(1) Little or no research work has been accomplished on aircraft icing since the mid-to-late fifties. Since this period, the aerodynamic characteristics and design of aircraft have changed drastically. These changes effect collection efficiency and aerodynamic heating.

(2) The new generation aircraft have limited structural and rotor anti-icing equipment, while employment concepts call for flights at altitudes where icing can occur.

2. AFGL Action Indicated. AFGL's Meteorological Division began a work unit, entitled "Aircraft Icing," in response to the AWS GR 1-79 referenced above. In this document, AWIS identified the following three needs:

a. To evaluate the current AWS techniques used in forecasting aircraft icing.

b. To develop, as required, new forecast techniques, using standard meteorological data, which can be run on the AF Global Weather Central Computers.

c. To develop a procedure for obtaining a climatology of aircraft icing based on standard archived data.

Status

Because the radiosonde observations are the primary input to the current forecast techniques, the goal of the AFGL work unit is to collect objectively-measured ice accretion observations and to relate them to concurrent observation of liquid water content, drop-size distributions and air temperature. In order to improve icing forecast techniques, it is necessary to achieve a better understanding of the microphysical processes of the atmosphere containing those elements which produce icing conditions. This requires in situ measurements of these atmospheric elements. During the 1979-80 winter season, a meteorologically instrumented HC-130E research aircraft collected icing data for 16 case studies, for a total of 23 sampling hours, in which the HC-130E flew in the immediate vicinity of radiosonde ascents. A similar amount of sampling was accomplished in the 1980-81 winter season with an increased emphasis on the study of icing conditions associated with active frontal zones. From this composite of icing data, AFGL will evalute the current AWS icing forecast procedures. In a follow-on, the same data will be used to develop improved techniques for forecasting atmospheric conditions conducive to aircraft icing. The results of these work units provide the basis for the development of an aircraft icing climatology.

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- Automated Weather Information System
- Radiological, Gaseous and Particulate Transport Models
- Weather Radar Systems

OPERATIONAL ENVIRONMENTAL SATELLITES

BASIC SERVICES

Working Groups

- Agricultural Meteorological Services
- Cooperative Backup Among Operational Processing Centers
- Dissemination of NMC Products
- Hurricane Operations
- Marine Environmental Prediction
- Meteorological Codes
- Metric Implementation
- Operational Processing Centers
- Severe Local Storms Operations
- Surface Observations
- Upper Air Observations
- Weather Radar Observations
- Winter Storms Operations
- World Weather Program

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