NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SAFETY REPORT

AIRCRAFT ICING AVOIDANCE AND PROTECTION

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16. Abstract

An investigation has been made into the problems of aircraft icing from the standpoint of icing statistics, the meteorological factors which cause icing, the certification of aircraft by the FAA for the flight into known icing conditions, and the forecasting of icing conditions.

The investigation revealed that icing accidents are a problem primarily for general aviation aircraft and that in addition to the accidental losses due to icing, there are significant operational losses due to inadequacies in the weather forecasting system.

The problems revealed by the investigation can be alleviated, but in order to do so new technology will have to be developed based upon a better understanding of ice formation and improvements in the quality of icing forecasts. This work will require a coordinated effort by several government agencies.

Two recommendations are made to the Federal Coordinator for Meteorological Services and Supporting Research to develop icing instrumentation and four recommendations were made to the Federal Aviation Administration to correct the icing definitions used in certification, and to update certification tests and requirements.

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SAFETY REPORT

Adopted: September 9, 1981

AIRCRAFT ICING AVOIDANCE AND PROTECTION

INTRODUCTION

Aircraft structural icing is primarily a problem for the smaller commuter, air taxi, and general aviation aircraft. During the years 1976 through 1979, there were no icing accidents involving certificated air carriers, supplemental air carriers, or commercial operators of large aircraft in the United States. This is primarily attributable to the operating altitudes of large commercial aircraft which are generally above the prevalent icing regimes, and the relatively sophisticated deicing and anti-icing equipment on those aircraft. Additionally, part of the credit for the excellent safety record of the commercial carriers in relation to icing must be attributed to the judgment exercised by the operators.

During the 1976 through 1979 period, there were 178 aircraft accidents involving structural icing. 1/ This is about 1 percent of the 16,997 total accidents that were recorded during the period. Of the 16,997 accidents, 2,869 (17 percent) were fatal. In the 178 structural icing accidents, 100 (56 percent) were fatal. While icing is an infrequent causal factor in aircraft accidents, it is particularly a hazardous one. There may even be a higher incidence of icing-related accidents than actually recorded since investigations into suspected icing conditions sometimes are not conclusive because of lack of evidence.

An increase in the number of general aviation instrument flight rules (IFR) operations has been apparent in recent years. From 1973 through 1977, the number of instrument ratings issued to private pilots increased by 96 percent. During this same period the total number of general aviation IFR operations increased by 104 percent. As this trend continues, spurred on by improvements in engine reliability, radios, electronic nav-aids, and autopilots, an increase in general aviation icing encounters will also occur.

The purchase of today's high performance general aviation aircraft is a relatively large investment that will tend to require increased utilization. This will certainly result in a demand for aircraft capable of flying safely in adverse weather situations. Competition for this market will require that manufacturers increase the availability of general aviation aircraft certified for flight into known icing conditions.

Of the approximately 210,000 general aviation aircraft registered in the United States, only about 12,000 (6 percent) are certificated by the Federal Aviation Administration (FAA) for flight into known icing conditions, and even these are seldom equipped adequately to handle severe icing. No helicopters are certificated in the United States for flight into icing conditions. The majority of all aircraft, whether equipped with deicing/anti-icing gear or not, can safely operate in relatively light icing conditions but for only a limited time. Consequently, the principal means of preventing accidents due to icing must be the avoidance of icing conditions. The pilot can do this through analysis of

1/ The accident statistics in this report are based upon National Transportation Safety Board records as of January 1, 1981.

the weather situation, generally in the form of a weather briefing from a flight service station and the exercise of good judgment to avoid icing situations encountered in flight. By use of the forecast, the pilot can determine where icing conditions are prevalent and choose a route and altitude which will avoid the forecast icing conditions, or the pilot can postpone the flight until conditions improve. The avoidance of icing in flight is often based upon the pilot's assumption that the conditions can be visually recognized early enough to avoid the meteorological conditions in which icing is likely and that there will be an escape route or alternate airport if such conditions are actually encountered. These are not always valid or safe assumptions, however, which leaves the weather forecast as the best means presently available for icing avoidance.

A review of the icing accidents from 1976 through 1979 shows that in only 8 percent of the accidents the weather was worse to some degree than forecast. This implies that the pilot can use forecasts to avoid icing with reasonable confidence. What is not known is how often the conditions are better than forecast and the forecast icing conditions would not have been encountered. Due to present observational and descriptive limitations, it is quite difficult to categorize or forecast icing conditions accurately. Consequently, the meteorologist may elect to err on the side of safety by forecasting significant icing over an unduly large area and or an expanded time frame. Such a practice is not in itself, an unsafe procedure. It can keep pilots out of possible icing conditions. Unfortunately, it may also have just "the opposite effect." A pilot who has frequently flown into areas of forecast icing and encountered little or no icing may tend to disbelieve and ignore future icing forecasts. To overcome this problem, it will be necessary to develop a system of observations which will lead to more accurate, readily applicable forecasts.

The record indicates that pilots frequently do not exercise good judgment in avoiding icing conditions while in flight. Thirty-four percent of the icing accidents involved aircraft flying under visual flight rules (VFR). There are conditions in which an aircraft can encounter structural icing in visual meteorological conditions, but the majority of such cases involve flight into clouds. This indicates that many pilots are either insufficiently trained or, in spite of training, lack respect for potentially hazardous conditions and purposely or accidentally attempt to fly in instrument flight conditions which are conducive to icing.

An illustrative accident involving structural icing involved a flight from Logansport, Indiana, to Columbus, Ohio. At 7:30 a.m., March 14, 1979, a pilot requested a weather briefing from the Lafayette, Indiana, FAA flight service station. The briefer described low overcast skies and strong winds based upon surface observations and forecasts and noted an AIRMET 2/ warning of the possibility of moderate icing over eastern Ohio. He also relayed a pilot report from Columbus which told of cloud bases of 2,500 feet, tops at 4,800 feet, and light clear icing. There was no official forecast for moderate or severe icing in the Columbus area.

The pilot departed Logansport on an instrument flight rules (IFR) flight plan in a light twin-engine airplane at 8:33 a.m. with two passengers on board. The airplane was equipped with deicer boots on all leading edge surfaces, but was not certificated by the FAA for flight into known icing conditions.

2/ Airman's meteorological information--an advisory of weather conditions possibly hazardous to light aircraft.

At 9:10 a.m., Columbus approach control began to give the pilot radar vectors to a final approach to the Ohio State University Airport. He was not properly aligned during the first approach and was revectored for a second approach. At 9:28 a.m. the controller issued a clearance to land. At 9:29 a.m. the Columbus final approach controller observed a low-altitude alert. There was no further contact with the aircraft. It had crashed 3.2 miles east of the airport; all three persons aboard died in the accident.

After an extensive investigation, the National Transportation Safety Board determined that the probable cause of the accident was improper planning and/or in-flight decisions on the part of the pilot in that he took off for a destination where icing had been reported, in an aircraft not certificated for flight into known icing conditions; and that once icing was encountered, there was no known attempt to deviate to escape or alleviate the icing conditions. The aircraft crashed due to airframe ice.

ICING

Structural Icing

Structural icing is the accretion of ice on any exposed surface of an aircraft due to the impingement of supercooled water drops on that surface. Normally, there are only two basic elements involved in structural icing: liquid moisture and subfreezing temperatures. Frost involves the sublimating of water vapor directly onto surfaces as crystals.

The hazards to aircraft from ice are manifold. The buildup of ice distorts the shape of airfoil surfaces, thus reducing lift and increasing stall speeds. The weight decreases performance and increases fuel consumption. Rotating airfoils such as propellers and helicopter rotors suffer not only the distortion of the airfoil shape but the weight of ice, which if unbalanced can cause serious vibrations and, in extreme cases, structural failure. Structural ice can block air intakes and cause engines to overheat and lose power. In the case of turbine engines, ice that has broken loose from other parts of the aircraft can cause damage to compressor and turbine assemblies.

In addition to the loss of performance, ice can cause operational problems such as loss of visibility due to ice on windscreens, attenuation of radio and radar signals from ice on the radomes and antennas, and erroneous readings on pressure instruments such as the altimeter and airspeed indicator due to ice accretion on the pitot-static ports.

Structural icing can be subdivided into three types: rime ice, clear ice, and frost. Frost is a hazard in that any ice on an airfoil surface will reduce the performance of the airfoil, and, at times, when the maximum performance of the aircraft is required, such as at takeoff, even a small performance loss may be unacceptable. In the air, frost often forms on the cold surfaces of an aircraft when descending into more humid regimes, but this usually evaporates rapidly at lower altitudes and seldom causes difficulty.

Rime ice is a rough, milky, opaque formation of ice caused by the impingement of small supercooled droplets. The droplets retain much of their spherical shape upon impact, trapping air between them and thus creating the milky appearance. Also, because rime ice particles tend to retain part of their original shape, they build up at the point of impingement and develop shapes which tend to seriously distort the airfoil. The shape formed depends on the airflow around the airfoil and the length of time the ice accumulates. If the accumulation is heavy the induced distortion of the airfoil changes the impact points and in turn further distorts the airfoil. A common shape is the "ram's horn" in which the ice accumulates away from the leading edge of the airfoil, both above and below it, forming a shape similar to that of the horns on a ram. Because the droplets that cause rime ice freeze on contact, rime has little tendency to spread along airfoils beyond the effective area of deicing or anti-icing surfaces. Additionally, its porous quality makes it quite brittle, which allows it to be readily broken off by deicing equipment such as the inflatable boot which works to break ice by distorting the shape of the leading edge of the airfoil.

Clear ice is a glossy, clear-to-translucent accumulation formed by large droplets or raindrops which spread and freeze on contact forming a sheet of smooth ice. It is the most hazardous of icing conditions because it accumulates rapidly and is dense and heavy. It often spreads beyond the effective area of deicing or anti-icing surfaces and adheres strongly to the aircraft's surfaces.

Rime and clear icing are unique conditions, each with a particular set of circumstances for development. In nature, the circumstances causing each type of icing often coexist and actual icing is a combination of rime and clear ice, referred to as "mixed icing." The characteristics of the mixture depend upon the weather conditions present.

Engine Icing

Aircraft engine icing is generally considered in two categories: induction icing or intake icing. Induction icing refers to the ice that is developed by the condensation of moisture inside of a carburetor due to the cooling effect of the venturi and the evaporation of fuel. This type of icing occurs most commonly in clear air, and is not associated with liquid moisture in the atmosphere. Hence, it will not be discussed in this report. Intake icing is a type of structural icing where the air intake to an engine, either jet or piston, is partially blocked or distorted by ice. It differs from airfoil icing in that, rather than affecting the aerodynamic characteristics of the aircraft, it reduces the available power. In this report, intake icing and airfoil icing will be considered as structural icing.

Icing Parameters

There are four principal factors affecting the formation of ice on aircraft. These are: temperature, liquid water content, drop size, and exposure time. The temperature must be below freezing (0° C) and above -40° C. At -40° C, for all practical purposes, all liquid moisture in the atmosphere has become ice. Most icing occurs at temperatures between 0° C and -14° C. The lower temperature which aircraft must be tested under 14 CFR 25 3/ is -22° C. In the United States Standard Atmosphere, -22° C is encountered just below 19,000 feet. Title 14 CFR 25 establishes the upper limit of aircraft icing for certification purposes to be 22,000 feet.

Liquid water content is the measure of liquid or visible moisture in the air in grams of water per cubic meter of air. Water vapor or humidity is not considered in this measure. The approximate ranges of values of liquid water content established in 14 CFR 25 are 0.04 to 0.8 grams per cubic meter in layered or stratiform clouds and from 0.2 to 2.7 grams per cubic meter in cumulus clouds. There is evidence that liquid water contents may occasionally be significantly larger, particularly in cumulonimbus clouds or thunderstorms.

3/ Aircraft certificated with ice protection under 14 CFR 23 must be capable of operating safely in the same icing conditions specified in appendix C, 14 CFR 25.

Drop size distributions are generally given in volume median diameters, which means that half the volume of water is contained in drops larger than the stated diameter and half is contained in smaller drops. The range used in 14 CFR 25 is from 15 to 50 microns (1 micron = 0.001 millimeter); this range only considers cloud droplets. If raindrops are considered, the range will go to greater than 1,000 microns (1 millimeter).

Exposure time can range from a few seconds to many hours depending upon the weather system, the aircraft's path through the system, and the aircraft's speed. Other conditions remaining normal, the longer an aircraft remains in icing conditions the more ice it will accumulate on surfaces with neither deicing nor anti-icing equipment. Based upon statistical probabilities, 14 CFR 25 has established 2.6 miles in a cumulus cloud or 17.4 miles in a stratus cloud as sufficient exposure to demonstrate the aircraft's ability to operate in icing conditions.

Water also is found in the atmosphere in ice crystals which include snow and ice pellets (sleet). Frozen particles do not normally adhere to aircraft surfaces and are not considered a hazard. They may become hazardous when mixed with water drops, but there is insufficient data available to document this.

The icing criteria for aircraft certification as defined in 14 CFR 25 are based upon research done by the National Aeronautics and Space Administration in the late 1950's with the transport aircraft of that period. Although the results of this research and the ensuing practices and regulations that came out of it are still basically valid, there have been changes in aircraft, deicing/anti-icing equipment, and improvements in the instruments used to measure atmospheric icing parameters.

OPERATIONAL ASPECTS OF AIRCRAFT ICING

The Avoidance and Prevention of Icing

Since only 6 percent of the 210,000 general aviation aircraft, air taxis, and commuters are certificated for flight into known icing conditions, 198,000 aircraft, including approximately 8,500 helicopters, must avoid icing conditions. Helicopter pilots, like others, are highly dependent upon weather forecasts. Helicopter pilots should avoid forecast icing conditions, and it appears from accident statistics that this is what they generally do. In spite of their vulnerability to icing and the requisite operational utilization of helicopters, only one helicopter accident during the 1976 through 1979 period was attributed to structural icing. The relatively good safety record of fixed-wing aircraft in icing conditions and the excellent record of helicopters shows that where icing exists, it has generally been forecast and the operators are using the weather forecasts to avoid icing conditions.

Icing forecasts generally cover a significantly larger volume of the atmosphere than that which probably contains icing conditions because of the present state of the art of icing forecasts. The numbers and kinds of observations are not sufficient to describe adequately the icing envelope, and the weather forecaster must work with what is available, keeping in mind that one is obligated to warn pilots of any suspected icing. The present definitions of icing intensity that are used in the forecasts were established in 1968 by the Subcommittee for Aviation Meteorological Services of the Federal Coordinator for Meteorological Services and Supporting Research. They are:

> Trace of icing. Icing becomes perceptible. The rate of accumulation is slightly greater than the rate of sublimation. It is not hazardous even though deicing/anti-icing equipment is not utilized, unless encountered for an extended period of time--over one hour.

Light icing. The rate of accumulation may create a problem if flight is prolonged in this environment over one hour. Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.

Moderate icing. The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or diversion is necessary.

Severe icing. The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

A problem with these definitions is that a particular liquid water content and drop size distribution may be light with respect to one aircraft and moderate to another. However, the forecaster cannot differentiate between aircraft. A forecasting system is needed which will allow the pilot to determine the icing effects on his or her particular aircraft at any of the various stages of his or her flight and to prepare from this a safe flight plan. This would allow the most effective use of airspace within the constraints dictated by the weather and the aircraft.

An immediate safety problem associated with the definitions of icing severity appeared in a review of the Federal regulations governing the operation of aircraft. In both 14 CFR 91 and 135, aircraft are restricted from flying into known or forecast severe icing conditions unless the aircraft has met the conditions of section 34 of Federal Air Regulation No. 23 or those for transport aircraft and by implication are allowed to fly in these conditions if they meet these criteria. Yet, by the definition in the Airman's Information Manual, severe icing describes a rate of accumulation that deicing/anti-icing equipment cannot effectively overcome.

There appears to be a potentially dangerous contradiction here. An aircraft could legally fly into an area of severe icing under 14 CFR 91 and 135, yet by definition the aircraft cannot control the hazard. The regulations should be reviewed to bring them into line with the definitions of icing severity.

Icing Forecasts

Icing forecasts are based upon observations of the atmosphere by several sensing devices and geographic grids of observation stations. The primary device is the rawinsonde, a balloon-carried device which measures pressure (altitude); temperature; relative humidity; and, by tracking the device from ground, wind direction and speed. There are 71 rawinsonde stations in the upper air network in the contiguous 48 states.

Although surface observations do not provide a direct measure of icing conditions aloft, they do provide an implication of conditions above a station and are the basis for the surface synoptic analysis.

Weather radar observes precipitation patterns. It is primarily used to identify areas of convective activity, but in certain circumstances it will identify rain, freezing rain, and snow. In some cases, it will show the freezing level as a "bright band," an altitude of strong return where frozen precipitation turns to rain. Satellite photographs show cloud patterns from which storm and precipitation areas may be analyzed and infrared pictures, which indicate temperature, measure the height of the cloud tops using temperature as an altitude indicator.

One of the best observations of icing conditions is the pilot report (PIREP), a direct report of icing conditions which includes altitude, geographic location, the type of aircraft and the type and intensity of the icing. The problems with PIREP's are that they are made after the icing conditions have been encountered, they are not inclusive of all the pertinent airspace, and they are not made on a regular basis in terms of time. Conversely, although spotty, the reports are most numerous in areas of heaviest traffic where they are most needed.

These observations are used directly by the forecaster in preparing icing forecasts and indirectly in other products which give such information as surface and upper air pressure and height patterns, precipitable water, atmospheric vertical motion, temperature patterns, and cloud and precipitation patterns. The forecaster analyzes these to determine known and probable geographic areas and altitude ranges of icing in terms of "trace," "light," "moderate," or "severe."

General icing forecasts are issued twice a day as part of the Aviation Area Forecasts currently issued by nine National Weather Service Forecast Offices throughout the contiguous 48 States, and in locations serving Alaska, Hawaii, and Puerto Rico. (In the near future, Aviation Area Forecasts for the contiguous 48 States will be issued by the National Severe Storms Forecast Center at Kansas City, Missouri. The format and the times of issue have not been determined.) Amendments to the forecast and warnings of situations that develop between forecast times are issued by in-flight advisories in the form of SIGMET's, 4/ convective SIGMET's, and AIRMET's which are issued at any time a situation that meets the definition of hazardous criteria exists or is forecast. In the case of SIGMET's or AIRMET's, the issuance of a warning is based upon observed weather patterns derived extensively on the information from PIREP's. Convective SIGMET's are based upon radar observations.

Since aircraft icing results from the meteorological parameters of liquid water content, drop size distribution, and temperature and from the aerodynamic parameters of airfoil shape, airspeed, and configuration, a pilot must consider all of these parameters either directly or indirectly to properly evaluate the hazard. This would require in-flight weather forecasts in terms of the meteorological parameters. To use this information, the pilot has to determine the effect of the icing conditions on his or her particular aircraft. To enable the pilot to make this determination, aircraft manufacturers would have to test the aircraft under a wide range of these parameters and varying aircraft configurations and append this information to the aircraft's flight handbook, in the form of tables or nomograms, for the pilot's use.

To forecast any meteorological parameter, observations of the parameter must be made on a grid scale equal to or smaller than the grid scale of the forecasts. This is required both for the research to develop the forecasting techniques and to verify the forecasts once made. Currently, synoptic observations of liquid water content and drop size distribution are not made, and observations of temperature by rawinsonde are on a grid spacing that is marginal for a detailed analysis of many weather systems.

The few instruments currently available to measure liquid water content and drop size distribution are primarily used for research. Generally, they all have limitations; some will measure liquid water content but not drop size distribution, a limitation that could be tolerated, others are limited in the range of values measured, and in almost

4/ Significant meteorological information. An advisory of weather conditions possibly hazardous to all aircraft.

all cases are too complex and expensive for the number of observations which would be required for synoptic use. The development of an inexpensive instrument to measure the meteorological icing parameters over a sufficiently wide range of values to describe most hazardous conditions and a means to expose the instruments on grid and time intervals which will allow a reasonably detailed synoptic analysis is needed. Several suggested means to accomplish this include the addition of instruments to rawinsondes, the mounting of telemetering instruments on commercial aircraft, and the development of laser or microwave sensors which could probe cloud and precipitation areas from the ground.

The measurement and forecasting of the meteorological parameters associated with icing would be only the first of two parts of an improved icing forecasting system. The second and equally important part would be the evaluation of aircraft performance throughout a reasonable range of the meteorological parameters. This is being done currently to the extent necessary to meet the specifications of 14 CFR 25 for those aircraft certificated to fly into known icing conditions, but considerably more data would be required to specify performance under specific icing conditions. The range of weather parameters would have to be expanded to include mixed ice crystals and water droplets and the large drop sizes encountered in freezing rain.

Icing Tests

Icing tests are made under natural or simulated icing conditions. Actual conditions undoubtedly provide the best tests and, given sufficient exposure, the whole spectrum of icing conditions can be evaluated. However, this type of testing presents several major difficulties, such as safety and cost. When extreme conditions are encountered, there is always the possibility of exceeding the aircraft's capability and an accident resulting. The costs may be acceptable for long-range aircraft which have the endurance to seek out and fly in particular weather systems, but they may be prohibitive for slow-speed, short-range aircraft such as helicopters where it could take years to encounter the full spectrum of icing conditions at the cost of many hours of flight time. The costs incurred would involve not only those of operating the aircraft but also those connected with the possible delay of the introduction of an aircraft model while awaiting certification. Consequently, there is widespread use of simulated conditions.

There are three primary methods of simulating icing conditions: the icing wind tunnel, the airborne spray rig, and the ground spray rig. Icing wind tunnels have the advantage of being controllable within the limits of their simulation capability. The primary disadvantage is that they presently are limited to testing models or small sections of aircraft. Models are limited to no smaller than one-fifth scale because of the minimum drop size that can be produced in tunnels.

The largest tunnel is the Icing Research Tunnel at the Lewis Research Center of the National Aeronautics and Space Administration (NASA) in Cleveland, Ohio. It has a test section of 6 by 9 feet which can accommodate relatively large airfoil sections and some whole sections of an aircraft. Work is underway at the Lewis Research Center to convert its Altitude Wind Tunnel into an icing tunnel. This will accommodate a full-scale small airplane or rotorcraft. It is expected to be operational in the mid-1980's.

Airborne tanker spray rigs are accepted devices for icing tests. They have the advantage of testing an aircraft in flight and are only dependent upon nature to provide the required temperature ranges. There are disadvantages to this system. The exposure time at high liquid water contents is limited due to spray rig tank capacity; the generated cloud often is not large enough to cover a whole aircraft, thus limiting the icing coverage to certain parts of the aircraft at any one time; and because the established parameters for the cloud are found at a fixed distance from the tanker, the liquid water content and drop size rapidly decreases as the distance between the tanker and the test aircraft increases.

Ground spray rigs are of three primary types. Outdoor spray rigs using natural wind, outdoor rigs with blower-driven spray, and cold rooms with blower-driven spray. These rigs appear to be most effective in helicopter testing where flight conditions in a hover may be simulated. Outdoor rigs have the advantage of low cost but use is limited to times when the required natural weather conditions are available. The cold rooms are not limited by nature but are expensive to operate. In all types of ground sprays, there still has not been adequate verification that the simulation accurately represents nature and is indicative of actual in-flight conditions.

As can be seen there are pros and cons to each of the icing testing methods and, at present, no one of them offers a complete range of the icing parameters: temperature, liquid water content, drop size distribution, and exposure time. The widest range of conditions can be found by flight testing, but here it is highly impractical, not to mention unsafe, to carry a test to the point where an aircraft becomes unable to fly.

An evaluation of each of the test methods is needed to determine the range of the parameters covered and the accuracy of parameter measurement. In the case of in-flight testing, this would require instrumentation to accurately evaluate the conditions encountered during the test.

Once the atmosphere has been adequately described as to the range of icing parameters an aircraft may be expected to encounter and the several methods of aircraft icing tests evaluated, it will be possible to prescribe testing procedures that will assure a complete evaluation of an aircraft's performance through the range of icing conditions it will meet in operation.

CONCLUSIONS

1. Aircraft structural icing is primarily a problem for the smaller commuter, air taxi, and general aviation aircraft. The principal means of preventing icing accidents must be the avoidance of icing conditions which exceed the aircraft's capabilities to carry or remove the accumulated ice.

2. While icing is an infrequent causal factor in aircraft accidents, it is a particularly hazardous one.

3. Of the approximately 210,000 general aviation aircraft registered in the United States, only about 12,000 (6 percent) are certificated by the FAA for flight into known icing conditions, and their equipment is seldom adequate to handle severe icing.

4. In the case of pilot judgment in avoiding icing conditions while in flight, the record is poor.

5. Many pilots are either insufficiently trained or, in spite of training, they demonstrate a lack of respect for potentially hazardous conditions.

6. Currently, there are no helicopters certificated for flight into icing in the United States. Helicopter pilots are highly dependent upon weather forecasts.

7. Currently, the only verification of icing conditions is pilot reports.

8. Icing forecasts generally cover a significantly larger volume of the atmosphere than probably contains icing because of the present state of the art of icing forecasts.

9. The numbers and kinds of observations are not sufficient to adequately describe the icing envelope, and the weather forecaster must work with what is available keeping in mind that one is obligated to warn pilots of any suspected icing.

10. A forecasting system is needed which will allow the pilot to determine the icing effects on a particular aircraft at any of the various stages of flight and to prepare from this a safe flight plan.

11. An aircraft could legally fly into an area of severe icing under 14 CFR 91 and 135, yet by definition the aircraft cannot control the hazard. There is a need to reconcile the contradiction between the definitions of icing severity in the Airman's Information Manual and the associated regulations.

12. To forecast any meteorological parameter, observations of the parameter must be made on a grid equal to or smaller than the grid scale of the forecasts.

13. The development of an inexpensive instrument to measure the meteorological icing parameters over a sufficiently wide range of values to describe most hazardous conditions and a means to expose the instruments on grid and time intervals which will allow a reasonably detailed synoptic analysis are needed.

14. The measurement and forecasting of the meteorological parameters associated with icing would be only the first of two parts of improved icing avoidance.

15. The second and equally important part would be the evaluation of aircraft performance throughout a reasonable range of the meteorological parameters.

RECOMMENDATIONS

The Safety Board believes that many of the problems associated with aircraft structural icing can be solved, thereby increasing both the safety of operation and the operational utility of general aviation aircraft. It also recognizes that such an effort will involve manpower and financial resources of several Federal agencies, and the contributions of scientists and technicians from varied disciplines. For example, the development of instrumentation to economically measure the meteorological parameters would probably be a NASA project. The National Oceanic and Atmospheric Administration (NOAA) would probably be tasked to oversee the collection of icing data and the development of forecasting techniques. The FAA would be the appropriate agency to review the icing criteria published in 14 CFR 25, update procedures for aircraft certification, and oversee the manufacturers' evaluations of aircraft performance in various icing conditions.

As a result of this safety report and the considerations just discussed, the National Transportation Safety Board recommends that the Federal Coordinator for Meteorological Services and Supporting Research:

> Develop instruments to measure temperature, liquid water content, drop size distribution, and altitude in the atmosphere on a real-time basis that are sufficiently economical to use on a synoptic time and grid scale. (Class III, Longer-Term Action) (A-81-113)
>
> Use the developed instrumentation to collect icing data on a real-time basis on a synoptic grid and, in turn, develop techniques to forecast icing conditions in terms of liquid water content, drop size distribution, and temperature. (Class III, Longer-Term Action) (A-81-114)

The Safety Board further recommends that the Administrator, Federal Aviation Administration:

> Evaluate individual aircraft performance in icing conditions in terms of liquid water content, drop size distribution, and temperature, and establish operational limits and publish this information for pilot use. (Class III, Longer-Term Action) (A-81-115)
>
> Review the icing criteria published in 14 CFR 25 in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and recent developments in both the design and use of aircraft; and expand the certification envelope to include freezing rain and mixed water droplet/ice crystal conditions, as necessary. (Class III, Longer-Term Action) (A-81-116)
>
> Establish standardized procedures for the certification of aircraft which will approximate as closely as possible the magnitudes of liquid water content, drop size distribution, and temperature found in actual conditions, and be feasible for manufacturers to conduct within a reasonable length of time and at a reasonable cost. (Class III, Longer-Term Action) (A-81-117)
>
> Reevaluate and clarify 14 CFR 91.209(c) and 135.227(c) to insure that the regulations are compatible with the definition of severe icing established by the Federal Coordinator for Meteorological Services and Supporting Research as published in the Airman's Information Manual. (Class II, Priority Action) (A-81-118)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ ELWOOD T. DRIVER
Vice Chairman

/s/ PATRICIA A. GOLDMAN
Member

/s/ G. H. PATRICK BURSLEY
Member

FRANCIS H. McADAMS, Member, did not participate.

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